UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
BETHESDA, MD 20814

The contents of this document will be discussed at the Commission Meeting (Briefing) scheduled for Wednesday, October 19, 2016.

This document has been electronically approved and signed.

DATE: October 5, 2016

THIS MATTER IS NOT SCHEDULED FOR A BALLOT VOTE.
A DECISIONAL MEETING FOR THIS MATTER IS SCHEDULED ON: November 2, 2016

TO: The Commission
Todd A. Stevenson, Secretary

THROUGH: Mary T. Boyle, General Counsel
Patricia H. Adkins, Executive Director

FROM: Patricia M. Pollitzer, Assistant General Counsel
Barbara E. Little, Attorney, OGC

SUBJECT: Proposed Rule: Portable Generators

Staff is forwarding to the Commission a briefing package recommending that the Commission issue a notice of proposed rulemaking (NPR), pursuant to the Consumer Product Safety Act ("CPSA"), to address the risk of injury associated with carbon monoxide poisoning from portable generators. The Office of the General Counsel is providing for the Commission's consideration a draft NPR that would establish requirements for portable generators.

Please indicate your vote on the following options:

I. Approve publication of the attached document in the *Federal Register,* as drafted.

________________________________ _______________
(Signature) (Date)

II. Approve publication of the attached document in the *Federal Register,* with changes. (Please specify.)

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__________________________________ _______________

(Signature) (Date)

III. Do not approve publication of the attached document in the *Federal Register*.

_______________________________ _______________

(Signature) (Date)

IV. Take other action. (Please specify.)

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__________________________________ _______________

(Signature) (Date)

Attachment: Draft *Federal Register* Notice: Proposed Rule to Establish a Safety Standard for Portable Generators.

Billing Code 6355-01-P

CONSUMER PRODUCT SAFETY COMMISSION

16 CFR Part 1241

[RIN 3041-AC36]

Docket No. CPSC-2006-0057

Safety Standard for Portable Generators

AGENCY: Consumer Product Safety Commission.

ACTION: Notice of proposed rulemaking.

SUMMARY: The U.S. Consumer Product Safety Commission has determined preliminarily that there may be an unreasonable risk of injury and death associated with portable generators. To address this risk, the Commission proposes a rule that limits CO emissions from operating portable generators. Specifically, the proposed rule would require that portable generators powered by handheld spark-ignition (SI) engines and Class I SI engines not exceed a weighted CO emission rate of 75 grams per hour (g/hr); generators powered by one-cylinder, Class II SI engines must not exceed a weighted CO emission rate of 150 g/h; and generators powered by Class II SI engines with two cylinders must not exceed a weighted emission rate of 300 g/h.

DATES: Submit comments by [INSERT DATE 75 DAYS AFTER DATE OF PUBLICATION IN THE FEDERAL REGISTER**]**.

ADDRESSES: You may submit comments, identified by Docket No. CPSC-2006-0057, by any of the following methods:

Electronic Submissions: Submit electronic comments to the Federal eRulemaking Portal at: http://www.regulations.gov. Follow the instructions for submitting comments. The Commission does not accept comments submitted by electronic mail (e-mail), except through www.regulations.gov. The Commission encourages you to submit electronic comments by using the Federal eRulemaking Portal, as described above.

Written Submissions: Submit written submissions by mail/hand delivery/courier to: Office of the Secretary, Consumer Product Safety Commission, Room 820, 4330 East West Highway, Bethesda, MD 20814; telephone (301) 504-7923.

Instructions: All submissions received must include the agency name and docket number for this notice. All comments received may be posted without change, including any personal identifiers, contact information, or other personal information provided, to: http://www.regulations.gov. Do not submit confidential business information, trade secret information, or other sensitive or protected information that you do not want to be available to the public. If furnished at all, such information should be submitted in writing.

Docket: For access to the docket to read background documents or comments received, go to: http://www.regulations.gov, and insert the docket number CPSC-2006-0057, into the "Search" box, and follow the prompts.

FOR FURTHER INFORMATION CONTACT: Janet Buyer, Project Manager, Directorate for Engineering Sciences, Consumer Product Safety Commission, 5 Research Place, Rockville, MD 20850; telephone: 301-987-2293; e-mail: jbuyer@cpsc.gov.

SUPPLEMENTARY INFORMATION:

I. Background

A portable generator is an engine-driven machine that converts chemical energy from the fuel powering the engine into rotational energy, which, in turn, is converted to electrical power. Reports of portable generator-related fatalities and injuries prompted the U.S. Consumer Product

Safety Commission (Commission or CPSC) to publish an advance notice of proposed rulemaking (ANPR) in December 2006 to consider whether there may be an unreasonable risk of injury and death associated with portable generators (71 FR 74472 (December 12, 2006)). The ANPR began a rulemaking proceeding under the Consumer Product Safety Act (CPSA). The Commission received 10 comments in response to the ANPR. Subsequently, in a two-part technology demonstration program, CPSC contracted with the University of Alabama (UA) to conduct a low CO emission prototype generator technology development and durability demonstration and contracted with NIST to conduct comparative testing of an unmodified carbureted generator and prototype generators in an attached garage of a test house facility. CPSC staff published a report regarding the results of the UA technology demonstration and received 12 comments in response to this report. NIST published a report concerning its comparative testing of generators and received four comments in response to its report. The Commission is now issuing a notice of proposed rulemaking (NPR) that would establish requirements for carbon monoxide emission rates. The information discussed in this preamble is derived from CPSC staff's briefing package for the NPR, which is available on CPSC's website at: [INSERT LINK].

II. **Statutory Authority**

Portable generators are "consumer products" that can be regulated by the Commission under the authority of the CPSA. *See* 15 U.S.C. 2052(a). Section 7 of the CPSA authorizes the Commission to promulgate a mandatory consumer product safety standard that sets forth certain performance requirements for a consumer product or that sets forth certain requirements that a product be marked or accompanied by clear and adequate warnings or instructions. A performance, warning, or instruction standard must be reasonably necessary to prevent or reduce an unreasonable risk or injury. *Id.*

Section 9 of the CPSA specifies the procedure that the Commission must follow to issue a consumer product safety standard under section 7. In accordance with section 9, the Commission may commence rulemaking by issuing an ANPR; as noted previously, the Commission issued an ANPR on portable generators in December 2006. (71 FR 74472 (December 12, 2006)). Section 9 authorizes the Commission to issue an NPR including the proposed rule and a preliminary regulatory analysis, in accordance with section 9(c) of the CPSA and request comments regarding the risk of injury identified by the Commission, the regulatory alternatives being considered, and other possible alternatives for addressing the risk. *Id*. 2058(c). Next, the Commission will consider the comments received in response to the proposed rule and decide whether to issue a final rule, along with a final regulatory analysis. *Id.* 2058(c)-(f). The Commission also will provide an opportunity for interested persons to make oral presentations of the data, views, or arguments, in accordance with section 9(d)(2) of the CPSA. *Id.* 2058(d)(2).

According to section 9(f)(1) of the CPSA, before promulgating a consumer product safety rule, the Commission must consider, and make appropriate findings to be included in the rule, on the following issues:

- the degree and nature of the risk of injury that the rule is designed to eliminate or reduce;
- the approximate number of consumer products subject to the rule;
- the need of the public for the products subject to the rule and the probable effect the rule will have on utility, cost, or availability of such products; and

- the means to achieve the objective of the rule while minimizing adverse effects on competition, manufacturing, and commercial practices.

Id. 2058(f)(1). Under section 9(f)(3) of the CPSA, to issue a final rule, the Commission must find that the rule is "reasonably necessary to eliminate or reduce an unreasonable risk of injury associated with such product" and that issuing the rule is in the public interest. *Id.* 2058(f)(3)(A)&(B). Additionally, if a voluntary standard addressing the risk of injury has been adopted and implemented, the Commission must find that:

- the voluntary standard is not likely to eliminate or adequately reduce the risk of injury, or that
- substantial compliance with the voluntary standard is unlikely. *Id.* 2058(f)(3(D). The Commission also must find that expected benefits of the rule bear a reasonable relationship to its costs and that the rule imposes the least burdensome requirements that would adequately reduce the risk of injury.

Id. 2058(f)(3)(E)&(F).

III. The Product

A portable generator is an engine-driven machine that converts chemical energy from the fuel powering the engine to mechanical energy, which, in turn, is converted to electrical power. The engine can be fueled by gasoline, liquid propane, or diesel fuel.[1] A portable

[1] Engines that operate on gasoline or liquid propane are called spark ignition (SI) engines and engines that operate on diesel fuel are called compression ignition (CI) engines.

generator has a receptacle panel for connecting appliances or other electrical loads[2] via a cord with a plug connection. Portable generators are designed to be carried, pulled, or pushed by a person.

Portable generators that are the subject of the proposed standard commonly are purchased by household consumers to provide electrical power during emergencies (*e.g.*, power outages caused by storms), during other times when electrical power to the home has been shut off, when power is needed at locations around the home without access to electricity, and for recreational activities (*e.g.*, camping or recreational vehicle trips). Built-in wheels or optional wheel kits are often available for heavier, more powerful units (*e.g.*, units with 3 kW power ratings and more).

One of the primary features of a generator is the amount of electrical power the generator can provide on a continuous basis. This power, commonly referred to in the industry as "rated power," is advertised in units of watts or kilowatts (kW), and can range anywhere from under 1 kW for the smallest portable generators, to nominally 15 kW for the largest portable generators.[3] Knowing the generator's rated power is useful in choosing the appropriate size generator for a particular electrical load, such as providing power to power tools, household appliances, or recreational equipment.

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[2] An electrical load is an electrical component or portion of a circuit that consumes electric power. This is opposed to a power source, which produces power, such as a battery or generator. Examples of loads include: appliances, lights, and power tools.

[3] As we will discuss further herein, the generator's rated power is generally a function of the size of the engine. However, there is no industry standard for relating the generator's rated power to the size of the engine; nor is there any uniform way in which electrical output capacity is advertised as "rated."

IV. Risk of Injury

A. Description of Hazard

Carbon monoxide is a colorless, odorless, poisonous gas formed during incomplete combustion of fossil fuels, such as the fuels used in engines that power portable generators. The initial effects of CO poisoning result primarily from oxygen deprivation (hypoxia) due to compromised uptake, transport, and delivery of oxygen to cells. Carbon monoxide has a 250-fold higher affinity for hemoglobin than does oxygen. Thus, inhaled CO rapidly enters the bloodstream and effectively displaces oxygen from red blood cells, resulting in the formation of carboxyhemoglobin (COHb).[4] The heart, brain, and exercising muscle are the tissues with the highest oxygen requirements; consequently, they are most sensitive to CO-induced hypoxia. The CO-induced hypoxia is reflected in the non-specific, flu-like symptoms of mild CO poisoning and early symptoms of severe poisoning, *e.g.*, headache, lightheadedness, nausea, and fatigue. More severe CO poisoning can result in progressively worsening symptoms of vomiting, confusion, loss of consciousness, coma, and ultimately, death. The high CO emission rate of current portable generators can result in situations where the COHb levels of exposed individuals rise suddenly and steeply, causing people to experience rapid onset of confusion, loss of muscular coordination, and loss of consciousness. This can occur without people first experiencing milder CO poisoning symptoms associated with a low, or slowly rising, CO level.

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[4] COHb, expressed as a percentage, reflects the percentage share of the body's total hemoglobin pool occupied by CO. Although the relationship is not absolute, percent COHb levels can provide a useful index of CO poisoning severity. It is measured with a blood sample from the exposed person.

B. Incident Data

1. Portable Generator Carbon Monoxide Fatalities

The Commission publishes an annual report that summarizes CO incidents associated with engine-driven generators and other engine-driven tools. [5] The Commission is using this report to provide the base number of incidents for the rulemaking. CPSC staff set a date of May 21, 2015, as a cut-off for the incident data used in the briefing package. As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents that occurred from 2004 through 2014.[6] Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete because data collection is ongoing. Therefore, the numbers for these years will likely increase.[7] Figure 1 shows the count of deaths involving a generator derived from CPSC databases for each of these years. Note that reporting of generator-related deaths is not a statistical sample or a complete count of incidents.

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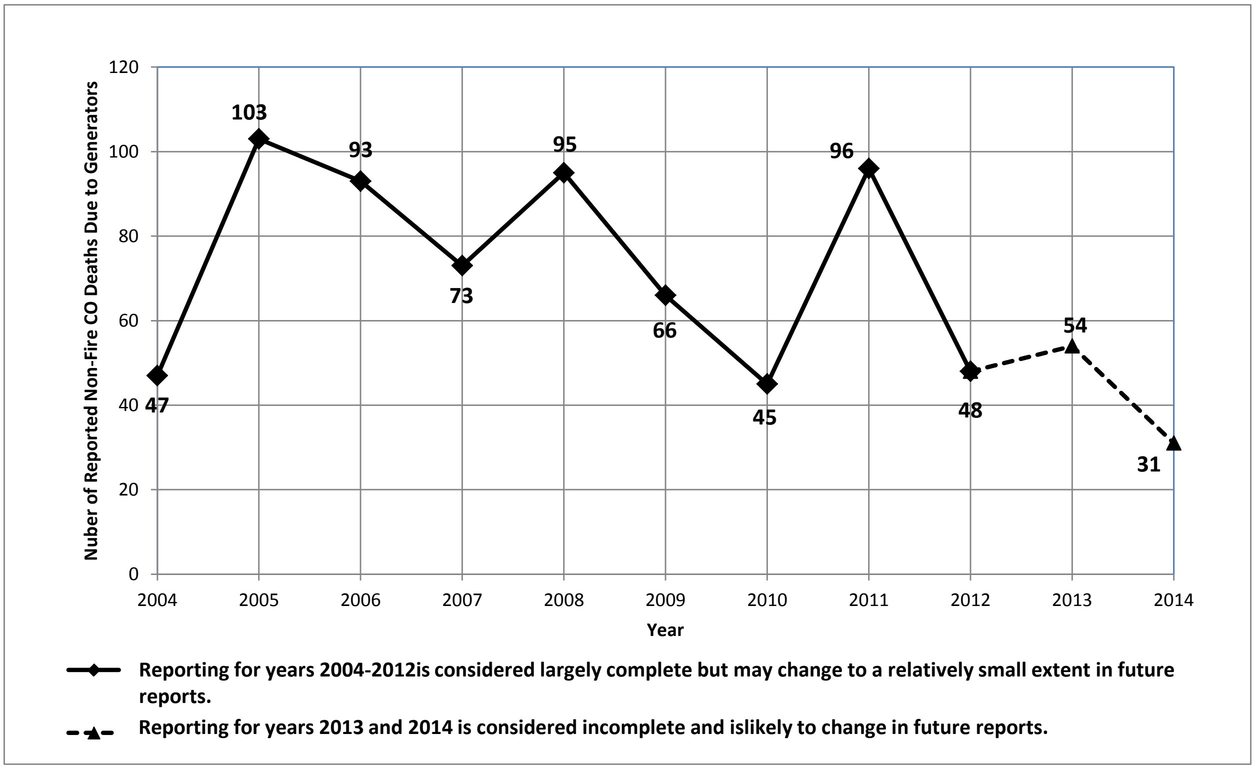
[5] These numbers are taken from a June 2015 reported by the CPSC, Hnatov, Matthew, *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014*, U.S. Consumer Product Safety Commission, Bethesda, MD, June 2015. (Docket Identification CPSC-2006-0057-0026, available online at: www.regulations.gov).

[6] Id.

[7] Note that the epidemiological benefits analysis and preliminary regulatory analysis, discussed in Sections IV and X, do not include the 85 deaths reported to CPSC as of May 21, 2015, for the years 2013 and 2014 because reporting for these years is considered incomplete. The epidemiological benefits analysis and preliminary regulatory analysis also exclude incidents involving generators that are out of the scope of the proposed rule (7 deaths in 5 incidents). Therefore, the Commission's epidemiological and regulatory analyses are based on 659 deaths in 493 incidents that occurred from 2004 through 2012.

Figure 1. Number of Reported Non-Fire Carbon Monoxide Poisoning Deaths Involving Generators Entered in CPSC Databases by Year, 2004-2014



Note: Out of the 751 deaths shown in Figure 1, sole use of a generator was responsible for 702 of these deaths, and the remaining 49 deaths involved concomitant use of a generator and another combustion product.

2. Portable Generator Carbon Monoxide Injuries

Based on CPSC's National Electronic Injury Surveillance System (NEISS) database,[8] CPSC estimates that for the 9-year period of 2004 through 2012, there were 8,703 CO injuries associated with generators seen in emergency departments (ED). This estimate should not be considered definitive because physicians have noted difficulty in correctly diagnosing these injuries. Carbon monoxide poisoning may mimic many nonfatal conditions, including alcohol or

[8] The NEISS database is a national probability sample of hospitals in the United States and its territories. Patient information is collected from each NEISS hospital for every emergency visit involving an injury associated with consumer products. From this sample, the total number of product-related injuries treated in hospital emergency rooms nationwide can be estimated.

drug intoxication, psychiatric disorders, flulike illnesses, and other conditions that can lead to misdiagnosis. Measurement of COHb levels in the victim's blood, which could confirm CO poisoning, can also be confounded based on the time elapsed and any supplemental oxygen treatment administered, which can lower COHb counts prior to measurement. In addition, in some incidents, first responders transported severely poisoned victims found at the scene directly to a medical facility with a hyperbaric oxygen (HBO) chamber[9] for treatment rather than to a hospital ED. These incidents would not have been captured in NEISS. For these reasons, the Commission believes that the injury estimate for this proposed rule may be low.

In addition to using the NEISS database to estimate CO poisoning injuries for the years 2004 through 2012, the Commission examined the narratives of the 292 records of CO-related ED visits to NEISS-member hospitals associated with generators for the years 2004 through 2014. The narratives helped illustrate the range of treatments received, the symptoms, and the reasons why victims went to a hospital ED.[10]

The Commission used the Injury Cost Model (ICM) to estimate the number of injuries treated in locations other than hospital EDs. The ICM uses empirical relationships between the characteristics of injuries and victims in cases initially treated in hospital EDs and those initially

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[9] An HBO chamber is a facility used for exposing patients to 100 percent oxygen under supra-atmospheric conditions, to shorten the time it would otherwise normally take for the CO to leave the bloodstream and to increase the amount of oxygen dissolved in the blood. A broad set of recommendations has been established for HBO treatment for CO poisoning, which includes a COHb level above 25 percent, loss of consciousness, severe metabolic acidosis, victims with symptoms such as persistent chest pain or altered mental status, and pregnant women. Treatment is not recommended for mild-to-moderate CO poisoning victims, other than those at risk for adverse outcomes.

[10] Hnatov, Matthew, *Summary of NEISS Records Associated with Carbon Monoxide Exposure Cases Related to Engine-Driven Generators in 2004 through 2014*, U.S. Consumer Product Safety Commission, Bethesda, MD, November 2015. (Docket Identification CPSC-2006-0057-0028, available online at: www.regulations.gov).

treated in other medical settings (*e.g*., physicians' offices, ambulatory care centers, emergency medical clinics), based primarily on data from the Medical Expenditure Panel Survey,[11] to estimate the number of medically attended injuries treated outside of hospital EDs. The ICM also analyzes data from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project[12] to project the number of direct hospital admissions bypassing the hospital EDs. According to the ICM estimates, there were an additional 16,660 medically attended CO injuries involving generators during 2004–2012. Consequently, based on NEISS and ICM estimates, there was a minimum of about 25,400 medically attended CO injuries treated during the 9-year period. This is a ratio of almost 39 generator-related CO injuries to every CO death that occurred in that period.

Table 1 presents a list of the most commonly identified symptoms given in the NEISS case narratives of 292 cases involving generator-related CO injuries that occurred in the 11-year period from 2004 through 2014. In many cases, multiple symptoms were reported, but in 29 percent of the cases (85 of 292), symptoms were not described in the NEISS narrative, although the diagnosis was reported. The weighted proportion of the total appears to account for the selection probabilities of each case.

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[11] The Medical Expenditure Panel Survey (MEPS) is a nationally representative survey of the civilian non-institutionalized population that quantifies individuals' use of health services and corresponding medical expenditures. The MEPS is administered by the Agency for Healthcare Research and Quality (U.S. Department of Health & Human Services). The MEPS has been collected continuously since 1999 and is the principal data set used to monitor medical spending in the United States.

[12] The National (Nationwide) Inpatient Sample (NIS) is part of a family of databases and software tools developed for the Healthcare Cost and Utilization Project (HCUP). The NIS is the largest publicly available all-payer inpatient health care database in the United States, yielding national estimates of hospital inpatient stays. HCUP is a family of health care databases and related software tools and products developed through a federal-state-industry partnership and sponsored by the Agency for Healthcare Research and Quality (U.S. Department of Health & Human Services).

Table 1. Most Common Symptoms Reported in NEISS CO Poisoning or CO Exposure Cases Involving Generators, 2004-2014

Common Symptoms*	Cases	Weighted Proportion
Headache	73	27%
Nausea Felt Sick	77	30%
Dizzy/Confused Disorientation Lightheaded	70	25%
Vomiting	34	16%
Passed Out Unconscious Unresponsive	18	5%

*Cases may appear multiple times in Table 1 because victims may have exhibited multiple symptoms.

Table 2 presents a summary of the reasons why the patients said they went to the emergency room for treatment or to be checked out. In the majority of cases, the medical records, from which the narratives were abstracted, provided little or no information on how the patients knew they needed to go to the emergency room or how they got there. However, in 47 of the 93 cases in which this information was available, the patient realized something was wrong and arranged to get to the emergency room.

Table 2. Reason Victim Went to ED for NEISS CO Poisoning or CO Exposure Cases Involving Generators, 2004-2014

Reason	Cases	Weighted Proportion
Victim realized something was wrong and arranged to get to ER	47	23%
Discovered in distress by family, friend, or due to a welfare check	24	6%
Carbon monoxide alarm sounded, arranged to get to ER	22	9%
Unknown why or how taken to Emergency Room	199	62%
Total	292	100%

Table 3 presents a summary of the location of the generator involved with the CO poisoning event. The three most common locations identified were “Inside the home” (33%); “Inside the garage” (25%); and “In the basement” (18%). In 11 percent of the reported cases, the generator was located outside. In half of the “Outside the home” scenarios, the narrative specifically states the location was near a window, door, or air conditioner.

Table 3. Location of Generator in Cases Reported in NEISS CO Poisoning or CO Exposure Cases Associated with Generators, 2004-2014

Generator Location	Cases	Weighted Proportion*
Inside the home	86	33%
Inside the garage	70	25%
In the basement	56	18%
Outside the home	29	11%
Other / Unknown	51	14%
Total	292	100%

* Percentages do not sum to 100% due to rounding.

The high number of estimated injuries relative to fatalities suggests that many more people leave the scene of the generator, are rescued, or seek care than fatally succumb to CO poisoning. As detailed in subsequent sections, reduced CO emissions will greatly extend the time it takes for CO exposures to result in incapacitation and subsequent death. Moreover, in some cases, reduced CO emissions will actually prevent incapacitation and death from happening, even if an individual does not leave the exposure location. In situations where a generator is operated indoors, the extended window of time will allow exposed individuals a much greater chance of terminating their CO exposure or increase the chance of being found by others before serious injury and/or death can occur. Exposure termination could occur for several reasons, including the following:

- Exposed individuals might leave the exposure location to engage in everyday activities (*e.g.*, work, school), without necessarily being aware of any developing CO hazard.

- In some cases, exposure termination might occur without the individual leaving the location, simply because the generator runs out of fuel, or power is restored and the generator is shut down in response, which allows CO levels to decay naturally without reaching lethal exposure.
- Exposed individuals might respond to a CO alarm activation.
- Exposed individuals might recognize a growing health concern and leave to seek treatment or summon help (call a friend, relative, or 9-1-1), even if they do not necessarily recognize CO emissions as the cause of early nonspecific adverse health effects of CO poisoning.
- Exposed individuals might be found in an impaired state by other, lesser affected, co-exposed individuals who had been in locations farther away from the generator.
- Exposed individuals might be found by concerned outside parties conducting welfare checks, or by outside parties simply arriving at their home for other reasons, such as, to co-commute to work, a social or official visit, or the return home of a co-occupant from work or school.

The Commission notes that all the reasons specified above for exposure termination have been reported in incidents where there are survivors of carbureted, generator-related CO poisoning. More such cases would be expected with reduced CO emissions, due to an overall downward shift in expected CO poisoning severity. The Commission recognizes that consumers cannot be relied upon to react appropriately to any indication of a CO exposure, and that even those who recognize a developing CO hazard, might decide to enter the area where a generator is located in an attempt to switch it off. This behavior is known to have resulted in lethal outcomes with carbureted generators because CO can accumulate to levels that can cause near-immediate loss of consciousness due to hypoxia/anoxia. However, with reduced CO emissions, the peak CO levels attained in an unventilated area where the generator is operated will be considerably lower than the level that would cause near-immediate loss of consciousness. This potentially could reduce the incidence of death among individuals who enter an unventilated area to turn off a generator, by allowing them time to egress the area before being overcome.

C. **Hazard Characteristics**

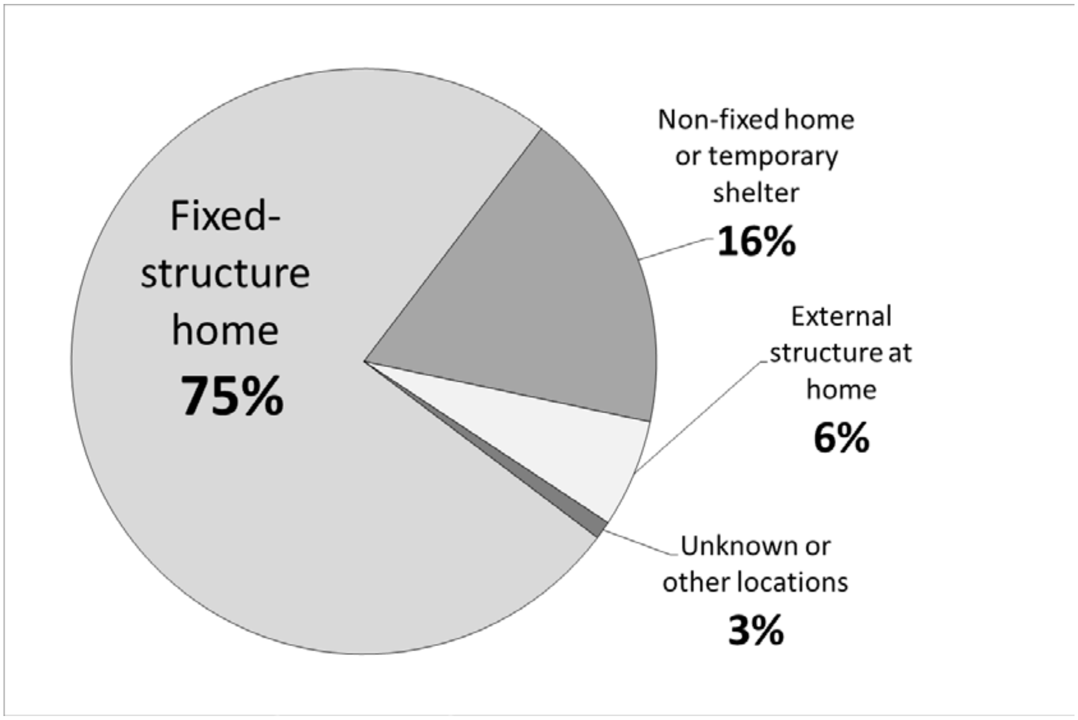
As stated in the previous section, as of May 2015, there were 562 incidents involving fatalities from portable generators reported to CPSC, which occurred between 2004 through 2014. CPSC assigned In-Depth Investigations (IDI) for 535 of these 562 incidents (95 percent), to gather more detailed information about the incident and the product(s) in use. CPSC categorized the incident data in the IDI reports according to the location where the incident occurred:

- 75 percent of deaths (565 deaths, 422 incidents) occurred in a fixed-structure home location, which includes detached and attached houses, apartments, fixed mobile homes, and cabins used as a permanent residence;
- 16 percent (117 deaths, 81 incidents) occurred at non-fixed-home locations or temporary structures, such as trailers, horse trailers, recreational vehicles (RV), cabins (used as a temporary shelter), tents, campers, and boats, and vehicles in which the consumer brought the generator on board or into the vehicle;
- 6 percent (48 deaths, 46 incidents) occurred in external structures at home locations, such as sheds and detached garages;

- 3 percent (21 deaths, 13 incidents) occurred at unknown or other locations.

In the same 11-year period, 42 deaths from 30 incidents[13] occurred with the generator operating outdoors, where the exhaust infiltrated into a nearby fixed-structure home, a non-fixed-structure home, or temporary shelter.[14] See Figure 2.

Figure 2. CO Deaths Associated with Generators by Location of the Incident, 2004-2014



[13] These figures exclude two deaths in 2011 caused by a stationary generator operated outdoors.

[14] Hnatov, Matthew, *Carbon Monoxide Deaths Associated with Engine-Driven Generators Located Outdoors in 2004 through 2014*, U.S. Consumer Product Safety Commission, Bethesda, MD, November 2015. (Docket Identification CPSC-2006-0057-0028, available online at www.regulations.gov).

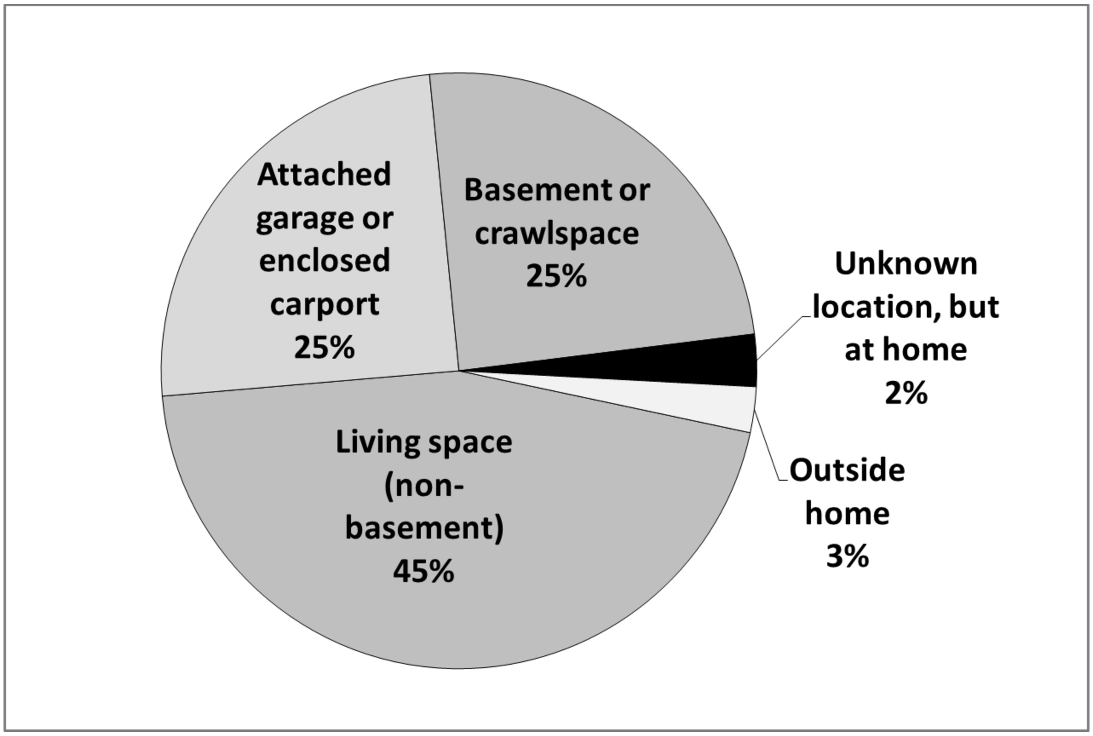
Of the 565 deaths (422 incidents) that occurred at a fixed structure home:

- 45 percent (256 deaths, 191 incidents) occurred when the generator was operated in the living space[15] of the house;
- 25 percent (140 deaths, 108 incidents) occurred when the generator was in the attached garage or enclosed carport;
- 25 percent (139 deaths, 98 incidents) occurred when the generator was in the basement or crawlspace;
- 3 percent (16 deaths, 12 incidents) occurred when the generator was operated outside;[16]
- 2 percent occurred when the generator was at the fixed-structure home site, but exact location was unknown.

See Figure 3.

[15] Used here, living space includes all rooms, closets, doorways and unidentified areas inside a home, but does not include basements, which are treated as a separate category.
[16] Another 28 deaths from 19 incidents occurred with generators operating outside structures other than fixed-structure home sites, such as RV, camper or trailer, vehicle, boat, or cabin used other than as a permanent residence.

Figure 3. CO Incidents Involving Generators that Occurred in a Fixed Structure Home Location, by Specific Location of the Generator, 2004-2014



The reason the generator was needed was identified in more than 80 percent of the 562 incidents. Following are the three biggest causes:

- 27 percent (152 incidents) were associated with the use of generators during a temporary power outage stemming from a weather problem or a problem with power distribution;
- 21 percent of the fatal incidents (116 incidents) were associated with the use of generators after a power shutoff by the utility company for nonpayment of a bill, a bill dispute, or other reason.
- 19 percent of the fatal incidents (109 incidents) did not indicate why the generator was in use, or why there was no electricity at the location of the incident.

Of the 152 fatal incidents associated with a power outage due to weather or a problem with power distribution, 93 percent were due to specific weather conditions. Ice or snow storms are associated with the largest percentage of weather-related CO fatal incidents, accounting for nearly half (49%) of the power outage-related incidents. Hurricanes and tropical storms were associated with 28 percent of CO fatal incidents. More than half (31 of 61) of the generator-related CO fatalities that were hurricane- or tropical storm-related (20 of 42 fatal incidents) occurred in 2005, a year of above-average hurricane activity.

The size of the generator involved in a CO fatality was identified in 45 percent of the 562 incidents. Because most of the generators that were associated with fatal CO poisoning were gasoline-fueled,[17] staff categorized the size of the generator by using the U.S. Environmental Protection Agency's (EPA) classification of the small SI engine powering it: a handheld engine[18]; a non-handheld, Class I engine; or a non-handheld, Class II engine.[19] The incidents involving generators powered by non-handheld, Class II engines were then divided by whether

[17] In 52 of the 562 incidents, the fuel type could not be ascertained. Of the 510 cases where the fuel type used in the generator was known, 99 percent (506 of 510) were gasoline-fueled generators. Of the remaining incidents, three involved propane-fueled generators, and the other incident involved a diesel-fueled generator.

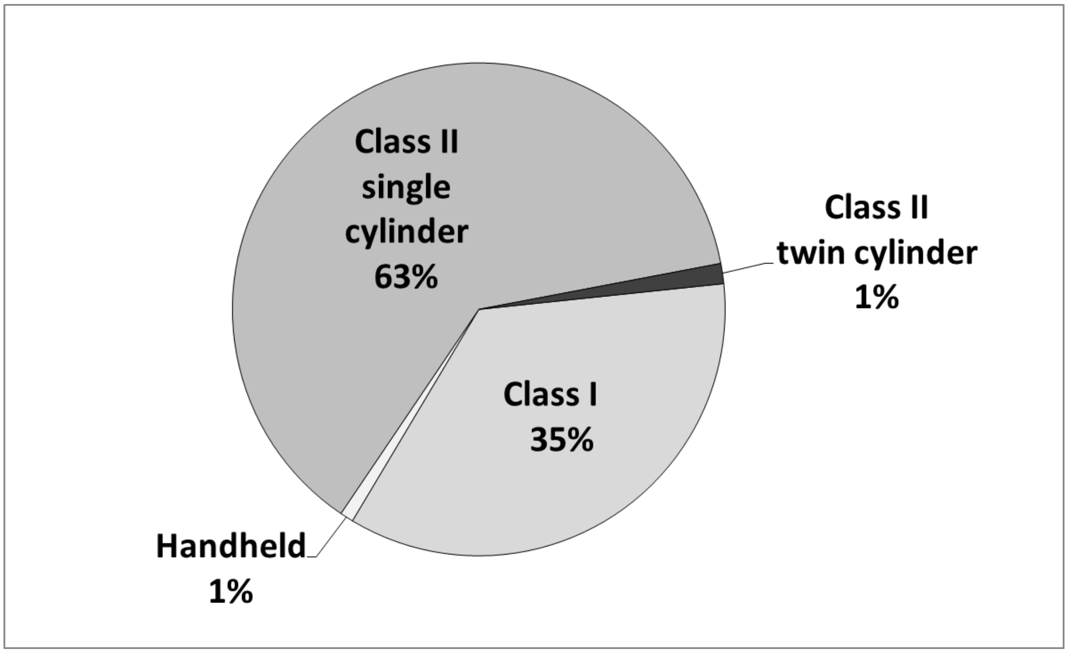
[18] Although handheld engines generally are used in equipment that is held or supported by an operator during use (such as trimmers), handheld engines may also be used to power non-handheld equipment, such as smaller portable generators.

[19] The EPA broadly categorizes small SI engines as either non-handheld or handheld, and within each of those categories, further distinguishes them into different classes, which are based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cc up to 225 cc, and Class II engines having displacement at or above 225 cc, but with maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc.

the engine had a single cylinder or twin cylinders.[20] In the majority of cases (55%), CPSC staff was unable to obtain sufficient information to be able to categorize the generator into one of these classifications. In the incidents where engine classification could be determined, slightly more than one-third (35 percent) involved Class I engine powered generators, and slightly less than two-thirds (63 percent) involved single-cylinder, Class II engine-powered generators. See Figure 4. There were two incidents involving generators powered by handheld engines that caused one death in each incident. There were three incidents involving generators powered by twin-cylinder, Class II engines that caused seven deaths. Two of the incidents were single-death incidents, and the third incident, with the generator operating outside an RV, caused five deaths inside the RV.

[20] When the IDI did not report the generator's engine displacement, or it was not obtainable from other information in the IDI, staff considered the power rating of the generator, if the IDI contained information regarding the power rating of the generator. Staff classified generators with a reported wattage of 3.5 kW and larger as powered by a Class II engine and those less than 3.5 kW as powered by either a handheld or a Class I engine. To distinguish the handheld powered generators from the Class I powered generators when there was no information to ascertain the engine displacement, generators with wattage of 2 kW to 3.5 kW were considered to have a Class I engine. To distinguish the single-cylinder Class II engines from the twin-cylinder Class II engines, staff determined from a search of EPA's exhaust emission certification database (www3.epa.gov/otaq/certdata.htm#smallsi) that twin-cylinder, class II engines generally have a maximum engine power of nominally 12 kW and higher. Based on manufacturers' generator specifications available online, generators with engines with power equal to or greater 12 kW, typically have a rated power of 9kW and higher. Therefore, staff considered generators with rated power of 3.5 kW up to 9 kW to be powered by a single-cylinder, Class II engine, and those 9 kW and greater to be powered by a twin-cylinder, Class II engine when there was no information to ascertain the engine displacement and number of cylinders.

Figure 4. Size of Generator Engine Involved In CO Incidents, When Engine Size Was Identified, 2004-2014



V. **Overview of Proposed Requirements**

The proposed standard would apply to portable generators powered by small handheld and non-handheld SI engines. The Commission categorized the size of the generator using the EPA's classification of the small SI engine powering it: a handheld engine, a non-handheld Class I engine, or a non-handheld Class II engine. The Commission further categorized the generators powered by non-handheld Class II engines by whether the engine had a single cylinder or twin cylinders. The Commission defines the *generator* categories (as distinguished from the *engine* categories) as follows:

- A *handheld generator* is a generator powered by an SI engine with displacement of 80 cc or less;

- A *class 1 generator* is a generator powered by an SI engine with displacement greater than 80 cc but less than 225 cc;
- A *class 2 single cylinder generator* is a generator powered by an SI engine with one cylinder having displacement of 225 cc or greater, up to a maximum engine power of 25 kW; and
- A *class 2 twin cylinder generator* is a generator powered by an SI engine with two cylinders having a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW.

Although the Commission categorized generators based on the EPA classification of the engines powering them, it is important to distinguish these engines from the portable generators that they are used in because the engines are also used in other products. To provide a clear distinction, the Commission refers to *engines* according to EPA's classification: handheld engines, non-handheld Class I engines, and non-handheld Class II engines, while referring to *portable generators* according to the Commission's definitions, handheld generators, class 1 generators, class 2 single-cylinder generators and class 2 twin-cylinder generators.

Generators within the scope of the proposed rule provide receptacle outlets for AC output circuits and are intended to be moved, although not necessarily with wheels. Products that would not be covered by the proposed rule include permanently installed stationary generators, 50 hertz generators, marine generators, generators permanently installed in recreational vehicles, generators intended to be pulled by vehicles, generators intended to be mounted in truck beds, and generators that are part of welding machines. Generators powered by compression-ignition (CI) engines (engines fueled by diesel) are also excluded from the scope of the proposed rule. These inclusions and exclusions are largely consistent with the scope of the two U.S. voluntary standards for portable generators, UL 2201 - *Safety Standard for Portable Generator Assemblies* and PGMA G300 - *Safety and Performance of Portable Generators*.

The great majority of the units that fall within the scope of the proposed standard are gasoline-fueled, but portable generators powered by engines fueled by liquid propane (LP) present similar risks of CO poisoning, and these units also would be covered by the proposed rule. Some portable generators can operate fueled by gasoline, LP and natural gas, and these would also be covered by the scope of the proposed rule.

The proposed rule specifies different limits on weighted carbon monoxide emission rates for different classes of generators in recognition of the effects of factors such as engine size and other engine characteristics on CO emissions, generator size, weight, and hazard patterns and the different challenges that may be faced in meeting CO emission rates expressed in grams per hour. The performance requirements for the different classes of generators also have a scaling factor of 1.5 applied to the technically feasible rates to account for production variation. Specifically, the proposed rule would require that handheld generators and class 1 generators not exceed a weighted CO rate of 75 grams per hour (g/hr); class 2 single-cylinder generators not exceed a weighted CO emission rate of 150 g/hr; and class 2 twin-cylinder generators not exceed a weighted CO emission rate of 300 g/h. The weighted emission rates are based on weighting of six modes of generator operation, ranging from maximum generator load capability (mode 1) to no load (mode 6), similar to a procedure used by EPA to certify compliance with its emission standards for small SI engines. More detail about this procedure can be found in CPSC's staff briefing package. The performance requirements apply when generators operate at normal oxygen content; however, the Commission remains interested in CO emissions when generators operate at reduced oxygen content of 17 percent. The

Commission welcomes comments on the advantages and disadvantages of setting performance requirements at 17 percent oxygen instead of normal oxygen as well as comments on the technically feasible CO emission rates for generators operating at 17 percent oxygen, for each of the generator categories. Furthermore, the Commission welcomes comments on the test methods for CO emissions in both normal oxygen and 17 percent oxygen in Tab J, Appendices A2 and A3 of the staff's briefing package.

The proposed rule does not dictate how generators would meet the CO emission limits. Rather, under the proposed rule, firms have the flexibility to determine the appropriate technology to meet the specified performance requirements. To determine feasibility and to estimate likely costs of the proposed rule, staff's briefing package, and this preamble, discuss ways that staff believes companies might modify generators to meet the CO emission limits. However, companies could use other approaches.

The proposed rule describes the test procedure and equipment that the Commission would use to assess compliance with the standard. Manufacturers, however, need not use this particular test, so long as the test they use effectively assesses compliance with the standard. The Commission believes this approach provides added flexibility to manufacturers to reduce testing burdens. The Commission welcomes comments on the benefits and costs of this approach versus requiring a specifc test method for manufacturers to demonstrate compliance.

In accordance with Section 9 of CPSA, the proposed rule contains a provision that prohibits a manufacturer from "stockpiling," or substantially increasing the manufacture or importation of noncomplying generators between the date that the proposed rule may be promulgated as a final rule, and the final rule's effective date. The rule would prohibit the manufacture or importation of noncomplying portable generators by engine class in any period of 12 consecutive months between the date of promulgation of the final rule and the effective date, at a rate that is greater than 125% of the rate at which they manufactured or imported portable generators with engines of the same class during the base period for the manufacturer. The base period is any period of 365 consecutive days, chosen by the manufacturer or importer, in the 5-year period immediately preceding promulgation of the rule.

Generator sales can vary substantially from year to year, depending upon factors such as widespread power outages caused by hurricanes and winter storms. Annual unit shipment and import data obtained by CPSC staff show that it has not been uncommon for shipments to have varied by 40 percent or more from year to year at least once in recent years. The anti-stockpiling provision is intended to allow manufacturers and importers sufficient flexibility to meet normal changes in demand that may occur in the period between promulgation of a rule and its effective date, while limiting their ability to stockpile noncomplying generators for sale after the effective date. The Commission seeks comments on the proposed product manufacture or import limits and the base period for the stockpiling provision.

VI. CPSC Technical Analysis and Basis for Proposed Requirements

A. CPSC's Two-Part Prototype Low CO Emission Generator Technology Demonstration Program

CPSC staff developed a two-part technology demonstration program to demonstrate that the small SI engine powering a commercially available portable generator could be modified with existing emission control technology to reduce its CO emission rate to levels expected to reduce the risk of fatal and severe CO poisoning. The objective of the first part of the program was to develop, from a current carbureted engine-driven generator, a prototype with a CO emission rate reduced to the lowest technically feasible level: (1) without negatively impacting the engine's power output, durability, maintainability, fuel economy, and risk of fire and burn; and (2) while also ensuring that the engine continued to meet EPA's small SI engine exhaust emission standard for hydrocarbons and oxides of nitrogen (HC+NOx), to which the unmodified OEM version of the engine was originally labeled as being certified. For this, CPSC staff sought a target CO emission rate reduction of 90 percent. The objective of the second part of the program was to assess the efficacy of the prototype generator in reducing occupant exposure profiles created by its operation in a fatal scenario commonly reported in CPSC's incident data compared to the exposure profiles created by the unmodified carbureted generator.[21]

Part One: Prototype Development and Durability Testing at University of Alabama

The Commission contracted with the University of Alabama (UA) to conduct the prototype development and durability phase of the program. The prototype development started with a commercially available generator with an advertised continuous electrical power output rating of 5.0 kW that was powered by a small, air-cooled, single-cylinder non-handheld Class II carbureted engine with a 389 cubic centimeter (cc) displacement and overhead valve (OHV) configuration. The prototype was a modification of that engine. To develop the prototype, UA replaced the engine's carburetor with a closed-loop electronic fuel-injection (EFI) system, used an oxygen sensor in the exhaust for closed-loop fuel-control feedback, tuned the fuel control to

[21] Complete documentation on the prototype generator and both parts of the demonstration program is provided in Buyer, Janet, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*, September 2012. (available online at: http://www.cpsc.gov/PageFiles/129846/portgen.pdf and in www.regulations.gov in docket identification CPSC-2006-0057-0002.).

stoichiometry[22] and replaced the muffler with a muffler that had a small three-way catalyst (TWC) integrated into it. UA subjected the prototype generator to a durability program for a total of 500 hours, which was the manufacturer's rated useful life of the engine at the time of the program. Simultaneous to the durability program on the prototype generator, UA subjected a baseline unmodified carbureted generator, the identical model to the prototype generator before modification, to the same durability program. UA made periodic emission measurements on both the prototype and the unmodified carbureted generator during the 500 hours of operation to compare the performance of the prototype to the baseline unmodified carbureted generator. After the 500-hour durability program concluded on both the baseline carbureted generator and the prototype generator, an independent laboratory, Intertek Carnot Emission Services (CES), conducted end-of-life emission testing, both with the engine installed in the generator as well as on a dynamometer,[23] in accordance with the EPA small SI engine test procedures. The purpose of this testing was to ascertain whether, at the end of the engine's rated useful life, the prototype engine's emissions would meet: (1) the EPA's Phase 2 requirements for HC+NOx, and (2) CPSC staff's target reduction for the exhaust CO emission rate.

CES's testing in accordance with EPA test procedures showed that the prototype engine, while mounted on a dynamometer and equipped with the muffler that had a catalyst installed, had a 6.0 g/kW-hr CO emission rate. This CO emission rate is 99 percent below the EPA's

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[22] Stoichiometry is the theoretical air-fuel ratio (AFR) for complete combustion and is the theoretical point for nearly the lowest amount of CO production. AFR associated with stoichiometry for typical gasoline formulations is nominally 14.6.

[23] A dynamometer is an instrument that measures the power output of an engine.

Phase 2 and Phase 3 CO standard of 610 g/kW-hr.[24] The prototype engine had an HC+NOx exhaust emission rate of 6.7 g/kW-hr. This rate is 45 percent below the EPA's Phase 2 HC+NOx standard for a Class II engine, to which the engine was originally certified, and 16 percent below the Phase 3 HC+NOx standard that came into effect shortly after CPSC's development program with UA began. CES's dynamometer testing also showed that the prototype engine delivered a maximum power of 7.9 kW, which is within 0.3 kW of the advertised rated power for the unmodified OEM carbureted engine. CES's emission testing of the prototype generator (with the engine still installed in the generator, as opposed to mounted on the dynamometer) measured a weighted CO emission rate of 26.10 g/hr.[25] Thus, at the end of the engine's rated useful life, the prototype engine's emissions met both EPA's Phase 2 requirements for HC+NOx and CPSC staff's target reduction for the exhaust CO emission rate. Staff's prototype findings have since been repeated by others who patterned their reduced CO emissions prototype generators on the design concept developed for CPSC by the University of Alabama.[26] Moreover, new generator products with reduced CO emissions, achieved by similar engine design modifications and use of catalysts, are beginning to enter the retail market.[27]

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[24] The EPA sets emission standards for all small SI engines. These engines provide power for a wide range of products typically owned by consumers, including portable generators. The EPA's primary emphasis is on regulating emissions that contribute significantly to nonattainment of the National Ambient Air Quality Standards (NAAQS) for ozone, of which hydrocarbons and oxides of nitrogen (HC+NOx) are precursors. For non-handheld engines, the EPA adopted emission standards referred to as Phase1 in 1995, Phase 2 in 1999, and Phase 3 in 2008.

[25] The highest of three tests was 26.10 g/hr. The other two tests yielded weighted CO rates of 23.47 and 19.38 g/hr.

[26] See Techtronic Industries (TTi) presentation on 3/17/16, at PGMA's Technical Summit on Carbon Monoxide Hazard Mitigation for Portable Generators – pages 85-105 of 178 page pdf file at: http://www.cpsc.gov//Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf.

[27] See Tab I staff's briefing package.

Part Two: Comparative Testing of Unmodified Carbureted (Baseline) and Prototype Generators at National Institute for Standards and Technology

The Commission entered into an interagency agreement with NIST to conduct the second part of the program. In this part of the demonstration program, NIST operated one generator in its unmodified carbureted configuration and another generator in the prototype configuration in the attached garage of a test house on NIST's campus. The test house is used for conducting indoor air quality (IAQ) studies. NIST measured the CO accumulation in the garage and transport into the house. The results provide a sense of how quickly a commonly fatal consumer scenario develops with an existing carbureted generator, and what the comparative results are from the same tests with the fuel-injected catalyzed prototype.[28]

NIST compared the garage CO concentrations from the prototype and the unmodified carbureted generator, after equal periods of generator run-time in the tests, with the garage bay door fully closed. NIST found that the prototype showed 97 percent reduction in the amount of CO released into the garage, compared to the unmodified carbureted generator. This reduction is consistent with UA's findings and translated to much lower levels of CO transporting throughout the house. Taking into consideration the CO time course profile (which is the CO concentration over time) of each room of the house and of the garage, the Commission performed health effects modeling and estimated that the prototype generator resulted in a significantly extended time interval for hypothetical occupants to escape or to be rescued before being incapacitated.

[28] Another objective of the IAG was to determine each generator's mass CO emission rates at each of the six loads used in the load profile. This work also supported NIST's validation of NIST's multizone airflow and contaminant transport model CONTAM, which is used to predict contaminant concentrations throughout a modeled structure resulting from a source mass emission rate located somewhere within the structure. NIST used CONTAM in predicting the health effects of the CO rates associated with the proposed performance requirements.

For example, in one test in which the garage bay door and connecting door to the house were both closed, the time interval increased by a factor of 12 with the prototype, compared to the unmodified carbureted generator (from 8 minutes to 96 minutes) for the deadly scenario of a consumer in the garage with the generator. The time interval increased even more for occupants inside the house.

The Commission believes that this increased time interval could give occupants an opportunity to remove themselves from the exposure before being incapacitated (perhaps due to their symptoms or other reasons such as an unrelated need to leave the house) or to be found alive by others. In contrast, the Commission predicts that the high CO emission rate of the unmodified carbureted generator would cause some of the occupants, depending on where they are located, to experience relatively quick onset of confusion, loss of muscular coordination, loss of consciousness, and death, without having first experienced milder CO poisoning symptoms associated with low or slowly rising CO-induced hypoxia.

B. Staff Assessment of Feasible CO Rates Based Upon EPA's Technology Demonstration Program and Staff Testing of Fuel-Injected Generators

A technology demonstration conducted by EPA further demonstrates the feasibility of significantly lowering CO emission generators using EFI.[29] In 2006, EPA examined the

[29] McDonald, Joseph, Olson B, and Murawski M, *Demonstration of Advanced Emission Controls for Nonroad SI Class II Engines*, SAE paper 2009-01-1899; McDonald, Joseph, Memorandum, Re: Supplemental Engine Dynamometer Data, May 5, 2006. (available online in: www.regulations.gov in docket identification EPA-HQ-OAR-2004-0008-0372.).

feasibility of reducing HC+NOx emissions beyond their Phase 2 standards.[30] EPA applied EFI and high-efficiency catalysts on two single-cylinder, air-cooled engines, both nominally 500 cubic centimeters (cc) in displacement with overhead valve (OHV) configurations. Because CO and NOx emissions have an inverse relationship, in focusing on reducing HC + NOx emissions, EPA specifically chose to test with catalysts formulations designed to *minimize* CO oxidation.[31]

EPA used low-cost engine management and fuel injection systems that were similar to that which UA used for the CPSC prototype generator. While the UA generator prototype used a closed-loop system and tuned the fuel to stoichiometry at the high loads, in interest of cost-savings, the EPA engines did not use an oxygen sensor necessary to make it a closed-loop fuel system. For its engines, EPA replaced the carburetor with open-loop EFI that was calibrated rich of stoichiometry, *i.e.*, a lower air-to-fuel ratio, at moderate-to-high loads and near stoichiometry at light load conditions to achieve the desired emission control of HC + NOx. EPA developed integrated catalyst-muffler systems for its engines, all selected to prioritize NOx reduction and HC oxidation over CO oxidation. Even though EPA was intentionally trying to select catalysts that would *minimize* CO oxidation, both engines achieved an average 68 percent reduction in the weighted CO emission rate. The average of the weighted CO emission rate of the two carbureted OEM configurations was 1,760 g/hr, and the average of the two EFI configurations with the catalyst providing the most reduction in CO emissions was 565 g/hr.

[30] U.S. EPA, *Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment - Final Regulatory Impact Analysis*, EPA420-R-08-014, September 2008 (available online in www.regulations.gov in docket identification EPA-HQ-OAR-2004-0008-0929); U.S. EPA, *EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines < 50 Horsepower*, EPA420-R-06-006, March 2006, Docket Identification EPA-HQ-OAR-2004-0008-0333. (available online at: (http://www.epa.gov/nonroad/equip-ld/phase3/420r06006-rpt-2appdx.pdf).

[31] Oxidation of CO to carbon dioxide (CO_2) is the means by which CO emissions are reduced in a catalyst.

Although the EPA noted that some engines may need improvements to accommodate stoichiometric fuel control (such as redesign of cooling fins, fan design, combustion chamber design, and a pressurized oil lube system), EPA concluded that closed-loop EFI with fuel control at or near stoichiometry *is* technically feasible and *is not* cost prohibitive on all Class II engines.[32]

CPSC staff believes that with a focus on reducing CO emissions, a lower weighted CO emission rate could have been achieved by using an oxygen sensor for closed-loop feedback, operation closer to stoichiometric at the higher loads, and a different catalyst formulated for higher conversion efficiency of CO.[33]

CPSC staff tested three fuel-injected generators created by three different manufacturers.[34] Two of these generators, neither of which was designed for low CO emissions, are available in the marketplace, and the third is a manufacturer's prototype generator that was designed for low CO emissions. The first of the three generators is a 10.5 kW rated generator powered by a twin-cylinder Class II engine with nominal 700 cc displacement and overhead valve (OHV) configuration. The generator does not have a catalyst for aftertreatment and the generator's engine is calibrated rich of stoichiometry at higher loads and at stoichiometry with closed-loop fuel control at moderate-to-light load conditions. Based on CPSC staff's testing of this generator in normal atmospheric oxygen, which found a 670 g/hr weighted CO emission

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[32] U.S. EPA, *EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines < 50 Horsepower*, EPA420-R-06-006, March 2006, Docket Identification EPA-HQ-OAR-2004-0008-0333. (available online at: (http://www.epa.gov/nonroad/equip-ld/phase3/420r06006-rpt-2appdx.pdf).
[33] See CPSC staff's briefing memorandum and Tab I of the briefing package for a more detailed explanation.
[34] See Tab I of the staff's briefing package.

rate, as well as on staff's engineering assessment of its physical and operational characteristics, staff believes that it is reasonable to expect that this engine could operate closer to stoichiometric at the higher loads and that a catalyst formulated for some CO conversion efficiency could be used for aftertreatment to further reduce its CO emission rate to nominally 200 g/hr.

The second generator is a 5.5 kW rated power generator powered by a single-cylinder Class II engine with nominal 400 cc displacement and OHV configuration, equipped with an oxygen sensor for some form of partial closed-loop operation and a catalyst. The engine is calibrated rich of stoichiometry at all loads. Based on staff's testing in normal atmospheric oxygen that found a nominal weighted CO rate of 560 g/hr, staff believes a CO emission rate of nominally 100 g/hr is possible, if the generator were operated closer to stoichiometric for at least some of the loads and used a catalyst formulated for higher CO conversion efficiency.

The third generator is a 5.5 kW rated power generator powered by a closed-loop fuel-injected single-cylinder Class II engine with nominal 400 cc displacement and OHV configuration. It has a catalyst for aftertreatment and the engine is calibrated to stoichiometric AFR with closed-loop operation at all loads. Staff's testing of this generator in normal atmospheric oxygen found a weighted CO rate of 81 g/hr.

C. Assessment of Epidemiological Benefits of Reduced CO Emission Portable Generators--NIST CO and COHb Modeling Study

1. Background

To assess the epidemiological benefits of reduced CO emission generators, CPSC contracted NIST to perform a series of CO exposure simulations that would model the operation of a portable generator in various locations within various house configurations and other structures, and at various CO emission rates.[35] CPSC used these results to determine the possible deaths averted if reduced CO emission generators had been used, as described below.

2. CO Emission Modeling

NIST modeled 40 different structures, including houses with basements and others with crawlspaces, as well as ones with slab-on-ground construction, with and without attached garages, and including older construction and newer construction homes. Three different external residential structures designed to represent detached garages and sheds were included in the 40 structures. The 37 different house models included detached home, attached home, and manufactured home designs. House models and other structures used in the modeling study were matched to 503 out of the 659 actual generator-related CO fatalities reported to CPSC over the period 2004 to 2012. One hundred fifty-six fatalities (659 minus 503) were not included in the modeling analysis because the generator was either outdoors or in a structure such as a camper, RV, tent, church, boat, or apartment complex that was not similar to any of the structure models used by NIST. The Commission believes that reduced emission generator use in these scenarios would most likely have produced fewer CO fatalities than the number observed in the incident data. This would be especially true in scenarios with the generator running outdoors, or in a large-volume space, such as a church.

CPSC staff chose the modeled CO emission rates based on: (1) CPSC's estimates of elevated CO emission rates expected for the four categories of current carbureted generator

[35] Emmerich, Steven J., B. Polidoro, W. Dols, Simulation of Residential CO Exposure Due to Portable Generator Operation in Enclosed Spaces (NIST Technical Note 1925), 2016.

products when operating in a reduced oxygen environment, and (2) a series of reduced CO generation rates that allowed CPSC to assess benefits and costs of various levels of reduced emissions within technically feasible rates for each generator category.

The first part of the modeling study used the NIST multizone airflow and contaminant transport model CONTAM, which predicted CO levels in different areas of each structure, over a 24-hour period.

Determination of CO Emission Rates, Run Times, and Heat-Release Rates for Carbureted Generators

Staff determined CO emission rates, run times, and heat release rates for NIST to model for current, carbureted generators (baseline carbureted generators) based on data from EPA's non-road small spark-ignition engine (NRSI) certification data website and advertised power ratings and engine specifications for representative products. These baseline parameters are shown in Table 4, and an explanation of the basis for the parameters follows.

Table 4. Modeled CO Emission Rates, Run times, and Heat-Release Rates for Baseline Carbureted Generators

Generator Category	Average Weighted CO rate at 17% O_2 (g/hr)	Average Run Time (hrs)	Average Heat Release Rate (kW)
Handheld	**900**	**8**	**2**
Class 1	**1800**	**9**	**6**
Class 2 Single Cylinder	**4700**	**10**	**13**
Class 2 Twin Cylinder	**9100**	**9**	**25**

To determine values for CO emission rates, run times, and heat-release rates representative of current generators involved in the fatal incidents, staff considered the generators produced by six large generator manufacturers. All of these manufacturers are members of the Portable Generator Manufacturers Association (PGMA), and, as documented on PGMA's website, are the major manufacturers of portable generators sold in North America and a significant majority of the industry."[36] Staff used the manufacturers' reported product specifications for 31 generators ranging from 900 to 15,000 watts rated power and developed the

[36] www.pgmaonline.com.

representative parameters for each of these inputs based on the range of generators in each of the four categories in Table 4.

Staff used the engine specifications provided by the generator manufacturer to search the EPA's NRSI engine certification data website to find the published CO emission rate corresponding to each generator's engine. Staff then calculated the weighted CO emission rate (in g/hr) for each generator's engine, by multiplying the g/kW-hr rate by 46.7 percent of the maximum engine power (46.7 percent of the maximum engine power is the weighted average based on the EPA six-mode calculations).[37] Staff assumes that the typical load profile of a portable generator used by a consumer is that of the weighted profile. In addition, staff assumes the engine's weighted CO rate is that of the generator.

Considering that 95 percent of the generator-related CO fatalities in CPSC's databases occurred when the generator was operated in an enclosed space, it is important for modeling studies to consider the CO emission rate when a carbureted generator is operating in such enclosed space scenarios. Evidence supporting this view is seen in results of findings from generator tests conducted by NIST under a prior interagency agreement with CPSC.[38] NIST's tests, as well as subsequent staff testing, showed that the CO emission rate of current carbureted generators increases threefold as the oxygen drops from normal levels (approximately 20.9

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[37] The engine manufacturer's CO emission rate reported in the EPA's exhaust emission certification website, in terms of grams per kilowatt-hour (g/kW-hr), is the sum of six weighted CO rates in grams per hour (g/hr) that the engine emits while installed on a dynamometer test platform and operating with each of six steady-state loads applied (also referred to as modes) divided by the sum of the weighted power for those six modes. The EPA's six-mode test cycle was developed with industry to replicate typical in-use operation of small utility engines when used in all types of engine-driven products.

[38] Emmerich, S. J., A. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline-Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), Feb 2013.

percent oxygen) to approximately 17 to 18 percent oxygen when a generator is operated in an enclosed space, such as those reported in the incident data. Consequently, to reflect more accurately current carbureted generator operation under oxygen depletion conditions, staff's calculated weighted CO emission rate, when each generator is operated outdoors at normal oxygen, was multiplied by a factor of 3.

The generators' run time on a full tank of gas that was associated with 50 percent of the advertised rated load was used to determine the full-tank run time used in the modeling. Fifty percent load was used because, as stated above, 46.7 percent of the engine's maximum power represents the weighted load profile, which is nominally 50 percent. Staff generally used manufacturer's product specifications for run time at 50 percent load, and in a few cases, used engineering estimates to determine the run times. Staff chose to model run times based on a full tank of fuel as a conservative assumption, despite knowledge of scenarios where a generator was used to allow completion of a specific short-duration task, in temporary power outage situations where power was restored within a few hours before a full tank of fuel could be consumed, or in scenarios where the generator was still running when victims were found, had summoned help, and/or had removed themselves from the area.

Staff estimated heat-release rates for these generators based on the fuel-consumption rate at 50 percent load, the manufacturer's specification for the generator's tank capacity, a heat of combustion of gasoline of 42.5 MJ/kg, and an assumed conservative 35 percent thermal efficiency of the engine.

Determination of CO Emission Rates, Run Times, and Heat Release Rates, for Reduced Emission Rate Portable Generators

NIST used the same values for run times and heat-release rates for the reduced CO emission rates of each generator category as those used for current generators.[39] NIST modeled the rates of 50, 125, 250, 500, 1,000 and 2,000g/hr. The three lowest of these approximates the range of CO emission rates that staff believes are technically feasible for both the handheld and class 1 generator categories (50 g/hr), class 2 single-cylinder category (100 g/hr), and class 2 twin-cylinder category (200 g/hr) in ambient air with normal atmospheric oxygen.

Weather, Temperature and CO Rate Parameters for Carbureted and Reduced CO Emission Generators

Simulations were run for each model structure and model generator location for 28 representative weather days to determine the CO time course profiles, which are the minute-by-minute CO concentration levels in each of the various rooms of the house. The 28 weather days were chosen to include 14 cold weather days (Detroit, MI), seven weather days from warm months (Miami, FL) and seven transition months weather days (Columbus, OH) to represent the distribution of fatalities, which has been seen to skew towards cold-weather days in a similar manner.[40] Starting indoor temperatures were assumed to be 23°C in all rooms, and temperatures were modeled to change within the rooms, based on heat transfer related to the heat release from the generator. Thus, generators of various sizes were modeled to be running on 28 different

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[39] CPSC staff reasons that an additional weight and volume of the emission control components needed to reduce the CO emission rate, could be offset by a smaller fuel tank and due to the improved fuel efficiency of reduced emission engines, the smaller tank would still be able to maintain similar run times to carbureted units with larger fuel tanks.

[40] The 28 individual days were selected using historic weather data recorded at three different geographic locations and three different temperature ranges to approximate the distribution of incidents observed in the CPSC incident data at a generalized level. Although the weather days may be consecutive (*e.g.*, 14 consecutive cold weather days), there was no carry-over effect from one day to the next. Each day modeled was reset to zero CO. Therefore, each day, from a CO standpoint, was an independent event.

weather days for a full-tank run time[41] in various rooms within each of the structures, with run times and heat-release rates appropriate to that size of generator, and emissions based on current carbureted generators, or based on possible reduced-emission generators for comparison. In the modeling of baseline carbureted generators, to simulate the increasing CO emission rate as the oxygen level drops in the space the generator is operating (and thus, a lower CO emission rate at the beginning of operation than later), NIST modeled CO rates for the first 2 hours of operation that were only two-thirds of the rates shown in Table 4. After 2 hours, the CO rates were increased to the rates in Table 4 for the duration of the run time. In contrast, as another conservative assumption, NIST modeled *reduced* CO emission rates as constant rates for the entire respective generator run time. The results of the models provided CO time-course profiles for each room of each structure on each weather day for each generator type and location and emission rate.

3. Application of COHb Modeling

The second part of the modeling study used the CONTAM-generated CO time course profiles as input values to predict corresponding COHb levels expected in healthy adults, as a

[41] NIST also modeled half-tank run times to simulate scenarios where shorter duration were considered more appropriate (*e.g.*, in scenarios in which the generator was being used to allow completion of a specific short-duration task at an unpowered location, in temporary power outage situations, where power was restored within a few hours before a full tank of fuel could be consumed, or in scenarios where the generator was still running when victims were found, had summoned help, and/or had removed themselves from the area). While staff has these modeling results, staff only analyzed the modeling results for the full-tank run times to estimate those benefits so as to be consistent with a conservative estimate of benefits.

function of time, using Coburn Forster Kane (CFK) modeling.[42] Conservative assumptions were made about respiratory rates, given expected activity rates over the 24-hours of modeled exposure. The respiratory minute volume (RMV), expressed in liters per minute (L/min), is the specific inhalation rate input value used in the CFK, and for the epidemiological benefits calculated in this analysis, staff used an RMV of 10 L/min. Staff's use of a constant 10 L/min RMV for light activity likely overestimates the breathing rate (and CO uptake rate) of a significant number of victims. In the majority of fatal incidents, victims were at home during an unplanned power outage, or an outage due to utility shut off, and there was no indication that they had engaged in more than sedentary-to-light activity levels for most of the time. For example, in several of these cases, a generator was first started in an enclosed space late in the evening/night at a time where victims were clearly preparing for/or retired to bed; in these instances, a sedentary/resting activity level of 6 L/min RMV would be more appropriate. Thus, use of an RMV of 10 L/min is another conservative assumption in the analysis. This is explained in more detail in Tab K of staff's briefing package and its appendix.

To assess the impact of low-emission generators on potential reductions in CO fatalities, the number of observed fatalities from the incident data were assigned to one of the model structures. The initial step was to assign the fatalities that occurred in an "exact match" structure type. "Exact match" structures are defined as those that match all of the NIST structure characteristic parameters used in the analysis to describe the structure, such as floor area, number

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[42] The CFK modeling is a nonlinear differential equation that is a physiologically based mechanistic model for predicting CO uptake and COHb formation and elimination in humans; it has been validated by empirical data from human studies and is widely regarded by authoritative sources as a reasonably reliable and broadly applicable COHb model for acute exposures.

of floors, existence of a garage and/or basement. Where exact matches could not be assigned, fatalities were apportioned among best matching structure types (those matching the most number of NIST parameters).

These simulations included various generator location scenarios, dependent on house/structure model designs (*i.e.*, only models that had a basement included the generator-in-basement scenario; and only models that had an attached garage included the generator-in-the-attached garage scenario). To match, as closely as possible, actual usage patterns, the simulation results of the generator locations within the house/structure were proportionately equal to those observed in the incident data.

The victim's location in the modeled house is assumed to have equal probability of occurring in any living space room. This assumption was made for three reasons. In multi-fatality incidents, victims were often found in different locations within a house. In many cases, the victim's location could not be determined from available reports. Moreover, it was frequently unclear whether victims were located in a single area in which they were found for the entire time or if the individual moved around through various parts of the structure. An example of the latter case could be that an individual felt sick and moved, perhaps, to a bedroom to lie down before expiring.

Next, CPSC staff incorporated criteria that staff developed to evaluate modeled COHb profiles considered indicative of fatal versus nonfatal outcomes. CPSC's Health Sciences (HS) staff developed four "COHb Analysis Criteria" to assess whether predicted COHb profiles from modeled residential scenarios were likely indicative of fatal or nonfatal CO exposures in average adults.[43] Where a fatal outcome is predicted, the criteria can be used to assess the predicted time to reach fatal exposure during a 24 hour modeling period for each simulated CO exposure. The criteria are intended to reflect the fact that lethal CO health effects are not simply a function of acute hypoxia resulting from a critical reduction in blood levels of oxygen delivered to tissues, as indicated by attainment of a specific peak COHb level.[44] The criteria include some consideration of the level and duration of the predicted COHb elevation, which recognizes that, in addition to reducing oxygen delivery to tissues, CO can enter the non-vascular body compartment and adversely impact important cellular functions by displacing oxygen from various intracellular heme proteins (particularly myoglobin proteins found predominantly in cardiac and skeletal muscles, and certain cytochrome P-450 enzymes involved is cellular respiration). In some prolonged CO elevations, the additional nonvascular adverse effects of CO can result in death at COHb levels that are not typically lethal.

Although the relationship is not absolute, physiological, epidemiological, and clinical studies provide evidence that acute CO poisoning effects in healthy adults tend to follow toxicological dose-response principles, and that risk of more serious adverse CO poisoning effects worsen progressively as blood levels of COHb increase.[45] However, it is clear that lethal CO exposures cannot be defined simply by attainment of a single COHb level. Staff used

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[43] See Tab K and Tab K appendices of staff's briefing memorandum.

[44] Oxygen binding sites of hemoglobin molecules have more than 200-fold higher affinity for CO than for oxygen.

[45] For example, loss of consciousness is not generally expected in average adults if peak COHb levels remain below 20 percent, but becomes increasingly more likely as levels approach, and exceed, 40 percent COHb. (Note: staff is referring to the acute COHb blood levels actually reached, or predicted by modeling, which is not necessarily the same as the highest measured COHb levels reported in clinical cases, where initial COHb measurements are typically reduced from peak levels attained, primarily due to the time lag between the end of CO exposure and blood sampling, plus use of supplemental oxygen during this interval).

several information sources to develop COHb assessment criteria to facilitate calculation of benefits estimates predicted for generators with reduced CO emissions. A recent authoritative review of CO toxicity by the Agency for Toxic Substances and Disease Registry indicates that there is a high risk of lethal outcome once COHb levels have reached a critical window, which, for healthy individuals, is generally considered to lie between 40 percent and 60 percent COHb.[46] HS staff reviewed information on COHb levels of victims who experienced acute, generator-related CO poisoning; COHb levels documented in fatal CO poisoning cases reported to CPSC were compared with COHb levels reported for a select group of survivors who received hyperbaric oxygen treatment (HBO-T) for generator-related CO poisoning injuries considered to be of high severity. Staff also considered information on fatal and nonfatal COHb levels reported in non-fire-related CO poisoning cases that did not specifically involve generator -related CO exposures. Based on review of available data on COHb levels in fatal and nonfatal generator-related CO exposures, and other non-generator, non-fire related CO deaths and injuries, staff developed the following criteria to distinguish between modeled COHb levels indicative of lethal versus nonlethal outcome:

1) If peak level is ≥60% COHb, assume death.
2) If peak level is ≥50% COHb but<60%, assume death unless average duration of elevation > 50% COHb is less than 2 hours, and average duration of elevation between ≥40% and <50% COHb is less than 4 hours.

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[46] Agency for Toxic Substances and Disease Registry (ATSDR), (June 2012) Toxicological Profile for carbon monoxide (web link: http://www.atsdr.cdc.gov/toxprofiles/tp201.pdf.

3) If peak level is ≥40% COHb, but <50% COHb, assume death if duration of the average in this range exceeds 6 hours.
4) If peak level is ≤40% COHb, assume survival.

4. Determination of Deaths Averted

The final part of the modeling study used patterns evident in fatal incident data (such as the known percentages of deaths related to various generator locations for various generator sizes and structure types) to modulate the modeled COHb data to estimate the number of fatal CO exposures reported for each generator category that could have been averted at each reduced emission rate. The modeling included exposure duration of up to 24 hours, estimated on a minute-by-minute resolution, and determined the status of living versus dead for modeled occupants at each minute in time. The model assumed equal probabilities of intervention over a 24-hour period. This assumption was used because frequently, one could not determine from the incident data how long of an interval between when the generator was started and when the victim died or some other type of intervention occurred.

Although CPSC incident data reflect primarily fatal CO incidents, the assumption that surviving people eventually depart the exposure is supported by staff's estimates of at least 25,400 medically attended CO injuries involving generators over the period of the deaths modeled and the fact that in some fatal incidents, there were surviving victims. For each scenario (CO emission rate, structure model, generator location, occupied zone, weather day), the model produced estimated COHb levels. From these COHb levels, staff determined at each minute interval, whether the victim was dead or alive, based on the criteria outlined above. The average per-minute interval over the 28 days produced a probability of fatality at the given time.

Under the assumption of equal probability of intervention over the 24-hour period, the average probability of fatality over the 24-hour period is the overall fatality rate for the given scenario. For the current carbureted generator model simulation, the probability was normalized (scaled up) to 100 percent of the allocated deaths because this is based on the actual incident data. The reduced emission rate simulation results were scaled up by the same factor to normalize the data. The difference between the allocated deaths per scenario and the number estimated for the reduced emission levels is the estimate of the deaths averted for the specified scenario. The summation of all the modeled scenarios (at a given emission level) represents an estimate of the potential deaths averted, if a reduced emission level generator had been in use in place of the current carbureted types. Thus, the same scenarios and assumptions were used for each generator size, generator location, structure, and weather day combination for current and reduced emissions generators so that the comparison was consistent and the assumptions would apply in the same way to current and reduced emissions.

Table 5 presents a summary of the number of deaths that potentially could have been averted over the 2004 to 2012 time span, if low-emission generators were used in place of the high CO output generators that were in use during this period. CPSC staff estimates that a total of 208 out of 503 deaths could have been averted. CPSC staff realizes there is uncertainty associated with this estimate given the assumptions and estimations staff used in developing this estimate. However, CPSC staff used conservative values and believes the uncertainty in the estimate is within the range of the sensitivity analysis that staff performed on the effectiveness of the emission rates, as described in the preliminary regulatory analysis.

Table 5: Summary of Potential Deaths Averted at Technically Feasible CO Emission Rates in Reduced Oxygen, 2004-2012

Generator Category	CO Emission Rate* Simulating Generator Operation in an Enclosed Space	Actual Fatalities Allocated by Class	Potential Deaths Averted	Potential Lives Saved Rate
Handheld	150	3.7	1.7	46.6%
Class 1	150	176.2	87.7	49.7%
Class 2 Single Cylinder	300	321.3	117.9	36.7%
Class 2 Twin Cylinder	600	1.8	0.3	17.2%
Total	**- -**	**503.0**	**207.6 = ~208**	**41.3%**

*- These rates are 3 times the technically feasible rates at normal ambient oxygen (~20.9%) to account for CO emission rate increase in reduced oxygen. To account for production variation the CO emission rates in the proposed requirements are 1.5 times the technically feasible rate in normal oxygen.

The numbers are based on the conservative assumption of CO emission rates tripling from technically feasible rates in normal oxygen for each generator category when operating in theorized oxygen depletion. Staff tripled the rates because staff determined that in reduced oxygen levels, the emission rates of generators that meet the technically feasible rates in ambient air may increase. This factor of 3 is based on testing of carbureted generators conducted by

NIST[47] and CPSC staff.[48] However, test results from NIST[49] indicate that the EFI generator depleted the oxygen significantly less than the carbureted generator when tested in each matched pair identical test scenario. Furthermore, based on staff's testing of three generators with fuel-injected engines having different degrees of closed-loop operation, staff believes the factor of increase when the oxygen is 17 percent may be less than 3 for some generators that use closed-loop EFI.[50] Therefore, based on both of these issues, the factor of 3 could likely overstate the weighted CO emission rates for some EFI generators when operated indoors, and understate the reduction in deaths and injuries resulting from the proposed standard. Consequently, staff believes that the assumption of a threefold increase in the technically feasible rates in ambient oxygen is an appropriate assumption to model, conservatively, for generators operating in enclosed space. Thus, staff ultimately determined epidemiological benefits overall, based on emission rates of 150, 300, and 600 g/hr technically feasible rates, as shown in Table 5.

Staff expects that some additional, but unquantified deaths, could be averted in the remaining 24 percent of fatalities that were not modeled, especially in fatal incidents where a generator was operated outdoors, and/or, that had co-exposed survivors. Staff's epidemiological benefits analysis is contained in TAB K of the staff's briefing package.

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[47] Emmerich SJ, Polidoro, B, Dols WS, *Simulation of Residential CO Exposure Due to Indoor Portable Generator Operation*, NIST Technical Note 1925, 2016.

[48] See Tab J in the staff's briefing package.

[49] Buyer J. *Technology demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*. U.S. Consumer Product Safety Commission, Bethesda, MD, September 2012.

[50] Tab J of staff's briefing package.

VII. Relevant Existing Standards

A. Portable Generator Label

On January 4, 2007, the CPSC voted unanimously (2-0) to require manufacturers of portable generators to warn consumers of carbon monoxide (CO) hazards through a mandatory label containing performance and technical data related to the performance and safety of portable generators. The required warning label informs purchasers: "Using a generator indoors CAN KILL YOU IN MINUTES"; "Generator exhaust contains carbon monoxide. This is a poison you cannot see or smell"; "NEVER use inside a home or garage, EVEN IF doors and windows are open"; "Only use OUTSIDE and far away from windows, doors, and vents." The label also includes pictograms. The label requirement went into effect on May 14, 2007, and is required for any portable generator manufactured or imported after that date.[51] Although the Commission believes that the mandatory label for portable generators might prevent some incidents of CO poisoning and death, as discussed in more detail in Section VIII of this preamble, evidence suggests that labeling alone is not sufficient to address the CO poisoning hazard, and that performance requirements for portable generators are needed.

B. Voluntary Standards

Underwriters' Laboratories Inc. (UL) and the PGMA have each been accredited by the American National Standards Institute (ANSI) to develop a U.S. safety standard for portable generators. However, only PGMA has developed an ANSI standard for portable generators, ANSI/PMGA G300-2015. UL has also developed a standard, UL 2201, which has not become

[51] 16 CFR part 1407.

an ANSI standard, due to lack of consensus. International Organization for Standardization (ISO) 8528-13:2016, *Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets – Part 13: Safety,* is a standard applicable to portable generators sold overseas.

1. UL 2201

In 2002, UL formed a standards technical panel (STP) to develop the first voluntary standard in the United States, dedicated solely to portable generators, UL 2201 *Safety Standard for Portable Generator Assemblies*. CPSC technical staff joined the STP for UL 2201 at its inception and has been an active participant with a long record of advocating that the standard address CO poisonings.

The requirements in UL 2201 cover internal combustion engine-driven generators rated 15 kW or less, 250 V or less, which are provided only with receptacle outlets for the AC output circuits. The scope section of UL 2201 states that the standard addresses: "the electric shock, fire, and casualty aspects associated with the mechanical performance and the electrical features of portable engine-driven generator assemblies." The standard restates the mandatory CPSC label requirement, but the standard does not otherwise address the risks related to CO poisoning. UL 2201 includes construction requirements to define minimum acceptability of components of the fuel system, engine, alternator, output wiring and devices, frame/enclosures and others, to ensure their suitability in this application to mitigate the risk of shock, fire and physical injury to users. The standard includes tests applicable to electrical, fire or mechanical hazards, as well as manufacturing tests.

UL has been unable to achieve consensus within the STP for UL 2201 to be recognized as an ANSI standard. Therefore UL 2201, first published in 2009, currently exists as a UL standard without ANSI recognition.

In January 2014, CPSC staff sent a letter to the UL 2201 STP Chair to request that a task group be formed to work on proposals to address the CO hazard that would eventually be balloted by the STP.[52] The letter outlined a framework of requirements based on work done by and for CPSC staff, which could be used as a starting point for discussions. This letter is described in more detail in the staff's briefing package. Accordingly, UL formed a task group with a roster of 37 members representing a broad range of stakeholder interests, including manufacturers of engines, generators, fuel-control systems and emission control components; public health officials; first responders; medical experts; indoor air quality experts; and government representatives from National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), NIST, and CPSC staff. The task group chair is a representative from NIOSH. The first meeting of the task group was held in May 2014. As of August 2016, there have been 26 meetings, all held as teleconference meetings, and there has been active participation and constructive input from a number of the members, but the task group has not yet sent a proposal to the STP to consider for adoption into UL 2201. A more detailed description of this effort is provided in TAB I of the staff's briefing package.

The Commission is unaware of any portable generator that is, or has been, certified to UL 2201; as such, it is unlikely that there would be substantial compliance with the standard it if CO emissions requirements were incorporated.

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[52] Buyer, Janet, letter to Diana Pappas-Jordan, RE: CPSC Staff Request for Formation of a Working Group and Staff's Recommendations for Requirements to Address the Carbon Monoxide Poisoning Hazard Associated with Portable Generators, January 14, 2014. http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/CPSCstafflettertoULdatedJan142014.pdf.

2. ANSI/PGMA G300-2015

In 2011, PGMA was accredited by ANSI to be a standards development organization, allowing PGMA, in addition to UL, to develop a standard for portable generators. PGMA is the accredited standards development organization for ANSI PGMA G300 – *Safety and Performance of Portable Generators*. CPSC staff served on PGMA's canvass committee. CPSC staff submitted comments to the standard, including comments regarding the lack of requirements in the standard to address the CO hazard.[53] PGMA published the first edition PGMA G300 as an American National Standard in June 2015.

PGMA G300 provides a method for testing the safety and performance of portable generators "rated 15 kW or smaller; single phase; 300 V or lower; 60 hertz; gasoline, liquefied petroleum gas (LPG) and diesel engine driven portable generators intended for multiple use and intended to be moved, though not necessarily with wheels." PGMA G300 includes construction requirements for engines, fuel systems, frame/enclosures, alternators, and output wiring and devices. The standard includes safety tests intended to address electrical, fire or mechanical hazards during intended generator operation. It also includes a section on testing for determination of output power rating that it delineates as non-safety based. PGMA G300 also includes manufacturing tests to ensure minimum levels of safety for production units. Although

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[53] Buyer, Janet, letter to Joseph Harding, Subj: CPSC Staff Comments on BSR/PGMA G300-201x, *Safety and Performance of Portable Generators*, January 2, 2015. http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/CPSCstafflettertoPGMAregardingG300draftstandarddated122015.pdf; Buyer, Janet, letter to Joseph Harding, Subj: CPSC Staff Comments on BSR/PGMA G300-201x, *Safety and Performance of Portable Generators* dated January 30, 2015, March 6, 2015. http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/CPSC-staff-letter-to-PGMA-with-comments-on-draft-G300-standard.pdf.

the standard restates the mandatory CPSC label requirement for portable generators, it does not otherwise address the risks related to CO poisoning.

CPSC staff continues to work with PGMA and urge them to address the CO hazard.[54] CPSC staff participated in a PGMA technical summit on March 17, 2016, and reaffirmed this commitment.[55] In April 2016, PGMA informed staff that "the PGMA Technical Committee will create a performance based standard that addresses the CO hazard created when portable generators are misused by operating them in or near occupied spaces as its top priority. The performance standard, once developed, will be proposed to the canvass group for addition to ANSI/PGMA G300 in the next revision cycle."[56] CPSC staff responded to PGMA[57] and met with PGMA again at PGMA's request in August[58] and September 2016.[59]

On September 19, 2016, PGMA emailed a letter to Chairman Kaye indicating that PGMA is in the process of re-opening G300 and announcing its intent to develop a "performance strategy

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[54] Letter from PGMA to Joel Recht, dated April 20, 2016, available online at: http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Voluntary-Standards-Reports/PGMALettertoRechtCPSCCooperationFinal.pdf.

[55] CPSC staff presentation, *CPSC Staff Technical Research to Address the Carbon Monoxide Hazard for Portable Generators*, March 17, 2016.

[56] The Commission's understanding is that PGMA's revision cycle is every 5 years.

[57] Recht, Joel, Letter to Susan Orenga, Response to PGMA Letter to Joel Recht dated April 20, 2016, May 13, 2016. http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/CPSCRechtLettertoPGMAMay132016inresponsetoPGMAletterdatedApril202016.pdf.

[58] Smith, Timothy, Log of Meeting, CPSC Staff, PGMA, and Exponent, August 12, 2016, available online at: https://www.cpsc.gov/s3fs-public/Meeting%20Log%20for%20meeting%20with%20PGMA%202016-08-12_0.pdf.

[59] Recht, Joel, Log of Meeting, CPSC Staff and PGMA, September 6, 2016, available online at: https://www.cpsc.gov/s3fs-public/09%2006%2016%20Meeting%20with%20PGMA%20Follow%20up%20on%20Technical%20Summit%20on%20Carbon%20Monoxide%20Hazard%20Mitigation%20for%20Portable%20Generators.pdf.

focused on CO concentrations."[60] In the letter to Chairman Kaye and in CPSC staff's September meeting with PGMA, PGMA described only broad generalities of a framework for modifying G300 that involves testing a generator in an enclosed space (test chamber).[61] The Commission looks forward to working with PGMA on developing a performance requirement addressing the CO poisoning hazard associated with portable generators. Given that PGMA described only broad generalities to CPSC regarding PGMA's intent to modify G300, the Commission does not have an adequate basis to determine if modifications to the voluntary standard would likely eliminate or reduce the risk of injury or death. In addition, because the Commission is unaware of any portable generator that is or has been certified to G300, it is unlikely there would be substantial compliance if CO emissions requirements were incorporated.

3. ISO 8528-13:2016

ISO 8528-13:2016 *Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets - Part 13: Safety,* is a standard applicable to portable generators sold overseas. Its requirements regarding the CO poisoning hazard are limited to labels and markings. It requires that the generating set must have a visible, legible, and indelible label that instructs the user: "exhaust gas is poisonous, do not operate in an unventilated area." The standard also requires that the general safety information section of the instruction manual mention: "Engine

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[60] Letter from PGMA to Chairman Elliot Kaye, dated September 16, 2016, available online at: https://www.cpsc.gov/s3fs-public/PGMALtrChairKayeVoluntaryStandardFinal.pdf.

[61] Product Safety Letter, *PGMA Talks Broad Strokes on Standards Work with CPSC*, Volume 45, Issue 34, September 12, 2016.

exhaust gases are toxic. Do not operate in unventilated rooms. When installed in ventilated rooms, additional requirements for fire and explosion shall be observed."

C. Adequacy of the Voluntary Standards for Portable Generators in Addressing CO Deaths and Injuries

The Commission does not believe that any of the standards discussed in the previous section are adequate because they fail to address the risk of CO hazard beyond restating the CPSC mandatory labeling requirement and the Commission does not believe that the mandatory labeling requirements, alone, are sufficient to address the hazard. Additionally, the Commission is not aware of any firms certifying products to these standards. Thus, the Commission does not believe there is substantial compliance with the standards. Therefore, the Commission concludes that the voluntary standards are not adequate in addressing CO deaths and injuries.

VIII. Response to Comments

In this section, we describe and respond to comments to the ANPR for portable generators. We present a summary of each of the commenter's topics, followed by the Commission's response. The Commission received 10 comments in response to the ANPR. Subsequently, in a two-part technology demonstration, CPSC contracted with UA to conduct a generator prototype development and durability demonstration program and contracted with NIST to conduct comparative testing of an unmodified carbureted generator and prototype generators in an attached garage of a test house facility. CPSC staff published a report regarding the results of the two-part technology demonstration program that included both the UA development and durability program and the NIST comparative testing program [62] and received 12 comments in response to this report. NIST published a report concerning its comparative testing of generators,[63] and staff received four comments in response to its report. The Commission responds to these comments, as well. The comments can be viewed on: *www.regulations.gov*, by searching under the docket number of the ANPR, CPSC-2006-0057.

A. Mandatory Carbon Monoxide Label

Comment: One commenter claimed that the CO hazard will continue to exist even if the Commission's demonstrated technology of the prototype were applied to commercially available generators and that "educating owners about the proper use of their generators will therefore remain the first line of defense." The commenter claimed that, for this reason, the CPSC should "conduct a study that includes a human factors analysis to determine the effectiveness of the CPSC mandated CO warning adopted in 2007." The commenter also encouraged CPSC to revise the mandated warning "to incorporate the standards and format" in ANSI Z535.3-2011, *American National Standard Criteria for Safety Symbols*, and Z535.4 – 2011, *American National Standard Product Safety Signs and Labels.*

Response: Although the Commission concurs with the commenter that the CO hazard associated with portable generators will continue to exist to some degree, even if CPSC's demonstrated technology were applied to commercially available generators, it does not necessarily follow that

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[62]Buyer, Janet, *Technology Demonstration Of A Prototype Low Carbon Monoxide Emission Portable Generator*, September 2012. (available online at: http://www.cpsc.gov/PageFiles/129846/portgen.pdf and in www.regulations.gov in docket identification CPSC-2006-0057-0002.).

[63] Emmerich, S. J., A. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), National Institute of Standards and Technology, Gaithersburg, MD, February 2013. (available online at: http://www.cpsc.gov/Global/Research-and-Statistics/Technical-Reports/Home/Portable-Generators/PortableGenerators041213.pdf.

educating owners about the proper use of generators is, should be, or would remain, the first line of defense. Human factors and safety literature identify a classic hierarchy of approaches to control hazards, based primarily on the effectiveness of each approach in eliminating or reducing exposure to the hazard. The use of hazard communications such as warning labels is universally recognized as less effective than designing-out the hazard of the product or guarding the consumer from the hazard. Thus, hazard communications are lower in this "hazard control hierarchy" than these other two approaches.[64] Hazard communications are less effective because they do not prevent consumer exposure to the hazard; instead, they must persuade consumers, who see and understand the communication, to alter their behavior in some way to avoid the hazard. Thus, hazard communications should be thought of as "last resort" measures that supplement, rather than replace, product redesign or guarding efforts to address residual risks, unless these higher level hazard-control efforts are unfeasible.

The commenter recommends that CPSC conduct a study to determine the effectiveness of the CPSC-mandated CO warning. The commenter states that testing is needed because of the importance of "educating owners about the proper use of their generators." Based on this assertion, the Commission infers that the commenter's measure of effectiveness is the extent to which the warning is understood by consumers, assuming the warning had initially captured and

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[64] Laughery, K. R., & Wogalter, M. S. (2011). The Hazard Control Hierarchy and its Utility in Safety Decisions about Consumer Products. In W. Karwowski, M. M. Soares, & N. A. Stanton (Eds.), *Human Factors and Ergonomics in Consumer Product Design: Uses and Applications* (pp. 33–39). Boca Raton, FL: CRC Press; Vredenburgh, A. G., & Zackowitz, I. B. (2005). Human Factors Issues to Be Considered by Product Liability Experts. In Y.I. Noy & W. Karwowski (Eds.), *Handbook of Human Factors in Litigation* (Chapter 26). Boca Raton, FL: CRC Press; Williams, D. J., & Noyes, J. M. (2011). Reducing the Risk to Consumers: Implications for Designing Safe Consumer Products. In W. Karwowski, M. M. Soares, & N. A. Stanton (Eds.), *Human Factors and Ergonomics in Consumer Product Design: Uses and Applications* (pp. 3–21). Boca Raton, FL: CRC Press.

maintained the consumers' attention. CPSC's mandatory labeling requirements for portable generators states that the product label shall be located on a part of the generator that is "prominent and conspicuous to the operator," while performing at least two of the following operations: filling the fuel tank, accessing the receptacle panel, and starting the engine.[65] The rule also requires that the label remain permanently affixed, intact, legible, and largely unfaded over the life of the product.[66] These requirements, as well as the minimum type size requirements,[67] were developed purposefully to address issues related to capturing and maintaining consumer attention and should address most concerns of this type, except for cases in which the user of the generator is not literate in English. However, the question of whether the label also should be provided in languages other than English was raised and addressed in detail in the final rule.[68] In summary: (1) available generator-related incident data have revealed no pattern of incidents involving people who could not read English; (2) the overall positive impact of adding another language to a label is likely to be very small; and (3) the regulation does not prohibit the addition of another language version of the warning message to the mandatory label.

The Commission supports the testing of warnings and other hazard communications. However, as discussed in the preamble to the mandatory labeling final rule, an independent contractor already performed focus-group testing with low-literacy individuals on the product label initially proposed in the notice of proposed rulemaking (NPR), and the Commission revised

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[65] 16 CFR 1407.3(a)(iii)(B).

[66] 16 CFR 1407.3(a)(iv).

[67] The signal word "DANGER" must be in letters not less than 0.15 inches and the remaining text must be in type whose uppercase letters are not less than 0.10 inches, or about 10-point type size.

[68] 72 FR 1443 (January 12, 2007).

the final label to address the message text comprehension problems identified during testing.[69] The Commission acknowledges that incremental improvements to the language of the label might be possible by conducting additional comprehension testing. However, the Commission also believes that the most significant label comprehension problems have already been addressed and that additional testing of this sort is unlikely to detect problems that would substantially impact comprehension among those at risk.[70] In terms of the formatting of the mandatory label, the Commission notes that the formatting and requirements of the mandatory generator label are virtually identical to the requirements of ANSI Z535.4 – 2011 and Z535.3 – 2011. Although the Commission acknowledges that the formatting of the mandatory label technically does not match the panel format requirements of ANSI Z535.4, these differences were deliberate and intended to improve warning comprehension. In addition, the Z535 series of standards includes exceptions and examples that are consistent with the formatting of the mandatory label. Revising the mandatory label to strictly meet the panel format requirements of Z535.4 is unlikely to improve the effectiveness of the label, and the Commission believes such changes actually could have a negative impact because it would separate the graphics from the relevant safety messages. Thus, the Commission believes that such revisions are neither appropriate, nor desirable.

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[69] Id.

[70] Virzi, R. A. (1992). Refining the test phase of usability evaluation: How many subjects is enough? *Human Factors*, *34*(4), 457–468, has found that about 80 percent of all usability problems tend to be detected with only four or five subjects; about 95 percent of all problems are detected with nine subjects; and each additional subject was less likely to detect new usability problems. The Commission believes that these general principles are likely to apply to comprehension testing as well, particularly in tests that oversample low-literacy individuals.

B. Technical Requirements/Specifications

1. *Comment*: Two commenters state that significant engine design changes would be required to incorporate and adapt emission technologies for use into any prototype portable generators. The commenters assert that engine designs that incorporate the prototype design changes are possible, but may not be suitable for all engines, especially when considering price and reliability considerations.

Response: To reduce the CO exhaust levels in portable generator units, staff developed the prototype generator with commercially available parts for better fuel delivery controls and exhaust emission controls. The prototype generator did not require extensive design changes. The prototype generator engine was derived from a readily available unit with a carburetor-equipped engine, which was retrofitted with sensors and components for electronic microprocessor controls of the intake manifold fuel injection and combustion spark timing. The prototype engine with electronic fuel controls required no disassembly between the engine cover, engine block, or cylinder head. Therefore, the head gasket and cylinder compression rings were left in their original condition. Considering price, staff agrees that there is an added cost to EFI engines, as discussed in the preliminary regulatory analysis. As to reliability, staff notes that the prototype generator was successfully tested for its longevity in service (durability) for 500 hours, which was the rated useful life, as established by the manufacturer.

Staff notes that the CPSC prototype generator was meant to be a durability program demonstration to support substantially reduced CO emission rates and encourage research on an approach to mitigate the risk of fatal and severe CO poisoning. The prototype portable generator was not intended to be a production unit, as manufacturers would need to consider appropriate suitable designs for their engine families in portable generators. Staff's prototype findings have since been repeated by others who patterned their reduced CO emissions prototype generators on the design concept developed for CPSC by the University of Alabama.[71]

2. *Comment:* The Truck and Engine Manufacturers Association (EMA) asserts that similar engine designs, including basic fuel-injection and ignition design are uniform across several manufacturers' product lines of gasoline-fueled engines, where possible. Products like lawn mowers and portable generators may use a similar engine design and components, and EMA states that this uniformity across many products provides manufacturing flexibility and economy of scale. EMA states the implementation of a different engine design in portable generators, such as described in the prototype program, may impact cost and availability of the product.

Response: The prototype design was specifically originated and developed through available off-the-shelf electronic fuel controller and components adapted onto an existing marketed portable generator engine. The prototype generator was successfully tested for its longevity in service (durability) for 500 hours, which were the longevity and emission outcomes of the new EFI engine through the rated useful life, as established by the manufacturer.

CPSC staff acknowledges the EMA concern that adoption of a portable generator engine, specifically designed to reduce CO emissions, may have different engine components pricing compared to the current portable generator engine without the emission reduction. CPSC staff

[71] See Techtronic Industries (TTi) presentation 3/17/16 at PGMA's Technical Summit on Carbon Monoxide Hazard Mitigation for Portable Generators – pages 85 -105 of 178 page pdf file at: http://www.cpsc.gov//Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf.

notes that portable generators with EFI (though not specifically designed for low CO emissions) have been increasing in availability in the market as new models have been introduced.

3. *Comment:* Honda states that the photos of the prototype unit cylinder head in the University of Alabama report, *Prototype Low Carbon Monoxide Emission Portable Generator Build Description and Performance Evaluation,*[72] may indicate that combustion gases had been leaking to the outside because the head gasket was in the early stages of failure prior to the time that the engine was disassembled. Honda indicates that they made these findings based on the carbon deposits on the prototype cylinder head fin and head gasket seating surface, shown in the photos in Figure 22 of UA's report.

Response: The cylinder heads, pistons and several other components are photographed and compared in the post durability wear analysis section of Contractor University of Alabama's report, *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation.* Figure 22 in UA's report shows a side-by-side comparison of the cylinder heads from the baseline generator (an unmodified unit) to the prototype generator unit after completion of the 500 hours of durability testing. CPSC staff partly agrees with the Honda photo assessment because more carbon deposits are visible on the prototype cylinder head gasket surface, compared to the same component in the baseline. However, the prototype's head gasket endured approximately 585 engine hours of the durability program and subsequent emission testing. According to UA's report, the head gasket with the baseline unit leaked after 175 engine

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[72] UA's report (Puzinauskas, P, Dantuluri, R, Haskew, T, Smelser, J, . Prototype *Low Carbon Monoxide Emission Portable Generator Build Description and Performance Evaluation*, , The University of Alabama, Tuscaloosa, AL, July 2011) is available as TAB G in the staff report referenced previously (Buyer, Janet, *Technology Demonstration Of A Prototype Low Carbon Monoxide Emission Portable Generator*, September 2012.)

hours into the durability test and was replaced. The cylinder head photos, which compared the generator units after completion of the durability test, showing less carbon deposit on the baseline engine's cylinder head gasket seating surface may be explained by fewer accumulated engine hours on the newer head gasket. Furthermore, staff notes that the prototype engine had been run for 585 hours by the time the photograph was taken, which was 85 hours beyond the manufacturer's rated useful life of the engine.

4. *Comment:* Honda states that that the increased combustion temperature due to the prototype's stoichiometric air-to-fuel mixture and reliance on radiant cooling is insufficient, as evident in the condition of photographed engine components, such as the pistons, after completion of the durability test.

Response: CPSC staff agrees with Honda that leaner fuel ratios generally result in increases in combustion temperatures. Increasing the air-to-fuel ratio available for combustion was intentional in the prototype engine, to influence and reduce the CO mass flow in the exhaust emission. Cylinder head temperatures were measured in generator units at all various load profiles for each occurrence of emission testing. These emission tests occurred before modifications to engine or durability testing, during the durability testing, in which hours of engine operation were accumulated, and after the durability tests.

Emission and engine test data were collected on the as-received, carburetor-fueled generators units. According to the University of Alabama report, *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation*, the as-received generator unit selected to become the prototype, but not yet modified, measured a 13.98 AFR at full generator loading (mode 1), with an associated 227º C cylinder head temperature. In addition, the range of AFR values for this pre-modified prototype generator measured 13.98 -

11.26, with progressively richer AFRs toward idle or no-load. The maximum cylinder head temperatures with the stoichiometric EFI after prototype engine modification were no hotter than the original unit. Staff believes that the 14.0 AFR carburetor design offered no cylinder head cooling capacity over the stoichiometric EFI design. Throughout the prototype generator program, including independent laboratory dynamometer emission testing after 500-cyclic engine hours of operation, the engine demonstrated a cylinder head temperature less than 227°C at full load. The mid-to-no load operating temperatures were cooler. All of these recorded measurements of the prototype cylinder head temperatures, including full load, were well below the manufacturer-recommended temperature limits.

Another comparison of cylinder head temperatures involves the baseline generator, which remained unmodified as the original unit, and the prototype generator. According to the *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation* report, the carburetor fuel system of the baseline generator delivered 13.4 to 10.5 AFR values for the range of generator loads throughout the durability program. Similar to the pre-modified prototype generator, progressively richer AFRs occurred in the baseline generator towards idle or no-load. Alternatively, the prototype generator fuel strategy sought to maintain the same stoichiometric AFR across all loads. These differences in AFR values created an average elevated temperature of 28°C in the prototype unit to the baseline unit. Staff believes the 28°C average hotter temperatures across all loads created more discoloration in the prototype piston. There appears to be more blackened areas of the piston ring, and more coloring below the seated position of the piston ring indicate hotter operating temperatures in the prototype cylinder compared to the baseline unit. However, as mentioned, the recorded measurements of the prototype cylinder head temperatures, including full load, were well below the manufacturer recommended temperature limits. For the technology demonstration program, the prototype's leaner AFR to minimize CO exhaust production was believed to be balanced with higher, but acceptable, cylinder temperatures.

5. *Comment:* EMA states that greater CO emission levels occurred with the prototype portable generator at 500 hour end-of-life compared to zero hour, suggesting that some deterioration of the prototype engine occurred with accumulation of engine hours.

Response: The UA report contains an appendix with prototype and baseline generator engine-hour durability emission test results for low-, high- and mid-life engine hours. This appendix shows prototype portable generator post-catalyst CO emission results at 2 g/kW-hr near 0 engine-hours and 17.5 g/kW-hr at 500 engine-hours. Staff does not believe that these results reflect deterioration, but rather, a mid-load controller calibration performance issue, which surfaced primarily in the post-durability emission tests.

This 500-hour prototype emission test performance was due to portions of the fuel look-up tables[73] that were not calibrated in the initiation of the engine build. Initially, it was not known that rated engine speeds supporting an alternator would involve extensive variation. Therefore, only certain areas of the controller look-up tables were mapped. Retrospectively, it is known that the mode 4 or mid-load solution was simply to expand the same parameters throughout the ECU look-up tables and all engine speeds. In the final emission tests, larger AFR excursions and higher CO emissions occurred when the engine operated in the unmapped

[73] The fuel look-up tables are part of the electronic programming of the Engine Control Unit (ECU) of the EFI system. The tables are used to associate engine operating parameters measured by the system's sensors with how much fuel the injectors need to deliver to the combustion chamber in order for the EFI system to maintain the desired air/fuel mixture.

portions of the controller. While the post durability prototype generator CO emissions results show more than 90 percent reduction over the baseline unit, the emission reduction with the prototype could likely be reduced further with more comprehensive calibration of the controller.

6. *Comment:* Honda states that the CPSC testing did not evaluate engine and generator performance in transient load conditions of performance.

Response: The empirical testing in the NIST test house included transient loads. NIST Technical Note 1781,[i] *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level,* describes how NIST evaluated the performance of both the prototype and baseline unmodified generators in the garage, with several electrical loading variations, including the generator cyclic load profile in the durability program and emission testing.[74] The measuring test equipment at the NIST test house continuously collects CO measurements as the electrical and engine load profile was altered. The proposed performance requirement is based on measuring emissions while the generator is operating with a steady load applied, as opposed to a transient load.

7. *Comment:* Two commenters asserted that CPSC's prototype components may cause exacerbated reliability issues after long-term storage.

Response: Staff disagrees because fuel-injection improves reliability. A fuel-injected system is sealed, so the fuel is not exposed to air like the vented system associated with a carburetor.

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[74] Emmerich, S. J., A. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), National Institute of Standards and Technology, Gaithersburg, MD, February 2013 (available online at: http://www.cpsc.gov/Global/Research-and-Statistics/Technical-Reports/Home/Portable-Generators/PortableGenerators041213.pdf and in: www.regultations.gov in docket identification CPSC-2006-0057-0005.)

Exposure to air significantly contributes to degrading gasoline during long-term storage and, in turn, causes problems with starting and running the engine. Manufacturers advertise improved reliability as one of the benefits associated with fuel injection.

Comment: One commenter asserted that it is harder to apply EFI and catalyst on the smaller engines used in 1 kW - 3 kW units and that they are sold in higher numbers than 5 kW units. In a similar comment, another commenter noted that CPSC's prototype used a commercial-grade engine in open frame, yet closed-frame units are more popular.

Response: CPSC has observed that there are fuel-injected handheld Class I engines, with and without catalysts, in the marketplace. CPSC acknowledges, however, that there may be more challenges associated with implementing the emission control technology on these smaller engines and the generators that these engines power. Thus, there is a later compliance date in the proposed rule for these models, relative to the larger generators powered by Class II engines. Based on CPSC staff's analysis of the market data, CPSC concurs that smaller generators are becoming more popular, relative to larger generators. CPSC staff used a larger generator, powered by a class II, single-cylinder engine, in the technology demonstration program because the Commission's incident data show that generators with these engines were associated with almost two-thirds of the CO deaths involving generators that have been reported to CPSC, when the size of the generator was identified, for the years from 2004 through 2012. The lower proposed performance requirements for smaller generators are expected to reduce deaths that could otherwise be expected to occur with increasing popularity of these smaller units.

8. *Comment:* One commenter stated that stable engine operation under transient loads requires richer-than-stoichiometric AFR. Without it, the commenter asserted, there is unreliable operation, which can result in damaged electrical loads and warranty claims.

Response: The Commission acknowledges this operating challenge, and for this reason, the proposed performance requirement is based on measuring emissions while the generator is operating with a steady load applied, as opposed to a transient load.

9. *Comment:* One commenter noted that their company uses more severe modes and requirements to test product durability, which they are doubtful the prototype would have survived. In a related comment, a commenter asserted that significantly reduced CO emissions at the highest loads resulting from operation near stoichiometric fuel control will negatively impact engine durability.

Response: The Commission notes that the proposed performance requirement for generators powered by class II single-cylinder engines is nominally six times higher (less stringent) than the CO rate that the prototype generator achieved. The Commission believes that the proposed CO emission requirements can be achieved on many existing engines by replacing the carburetor with closed-loop EFI and integrating a catalyst without engine design modification and without negatively impacting engine durability. The Commission notes, however, that for some engines, modifications might be needed to enable operation closer to stoichiometry. For other engines that cannot be improved through design modifications, those could still be used in generator applications by using a product integration strategy that precludes installed engine operation at loads where fuel enrichment is needed.

10. *Comment:* One commenter stated that the performance standard for CO emission rates must take into account deterioration of emissions to achieve the target exposure over the life of the engine.

Response: The Commission took deterioration into account in developing the performance requirements. The Commission believes deterioration of CO emissions to be minimal. This is based on both the performance of CPSC's durability-tested prototype at end of life as measured by CES, as well as by observation of published deterioration factors for CO, which are measures of the increase in CO emissions for an aged engine, relative to its emissions when new. The Commission observed in the EPA's exhaust emission database for model year 2015 that a vast majority of the engines have a deterioration factor below 1.1 (thus indicating the emissions worsen by less than 10 percent above initial emissions).

11. *Comment:* One commenter stated that the target CO emission rate in terms of g/kW-hr should be based on engine displacement, with lower rates (in terms of g/kW-hr) for larger engines to achieve the same target exposure.

Response: The Commission believes lower CO emission rates are technically feasible for smaller engines, compared to larger engines. Consequently, the Commission is proposing performance requirements for four different size categories of generators that are each based on technical feasibility and analysis of benefits and costs as a function of engine displacement, and, for the largest category, also whether the engine has one or two cylinders. The epidemiological benefits considered exposure differences for different generator types, by allocating known incidents based on location of generator and location of victims in various house types.

12. *Comment:* One commenter asserted that reducing CO emissions will increase other pollutant emissions and risk of fire and burn hazard.

Response: The Commission does not agree that reducing CO emissions will increase other pollutant emissions. Based on the emission results from CPSC's prototype generator, as well as those from the EPA's demonstration program, reducing CO emission rates also results in reduced HC+NOx emissions. CPSC staff acknowledges that for CPSC's prototype, the leaner air fuel ratio resulted in elevated exhaust temperatures compared to the carbureted configuration. Staff notes, however, that the muffler that was used was chosen to easily accommodate integration of the small catalyst into it. This muffler had less internal baffling, which resulted in average muffler surface temperatures of approximately 70°C hotter than the OEM design. As a result, UA shrouded this muffler and that resulted in shroud surface temperatures that were lower than the OEM muffler that was not shrouded. Staff notes that use of better designed mufflers, and, if needed, improved flow of cooling air over the exhaust, could mitigate the effect of elevated exhaust temperatures.

13. *Comment:* One commenter stated that EFI systems are becoming more low cost and noted that an oxygen sensor of one particular design can serve as a safety switch if the engine starts operating rich of stoichiometric.

Response: The Commission has observed that small SI engines with EFI have entered the marketplace in recent years, and expects this would mean that they have become less expensive. The Commission is interested in combining reduced CO emissions with a mechanism that will shut off a generator when operated in an enclosed or semi-enclosed space.

14. *Comment:* One commenter stated that the results from testing the generators in NIST's garage should not be relied upon for any rulemaking related to portable generator safety because, the commenter asserted, the attached garage on NIST's test house is not sufficiently representative of how garages are conventionally constructed.

Response: The Commission used the results from NIST's test house to provide an example of the reduction in the house's hypothetical occupants' exposure that the reduced CO emission rate from a portable generator can yield when compared to a current carbureted generator when operated in the same garage. The Commission is basing the proposed performance requirements for the rule on technically feasible CO emission rates, along with an assessment of the impact of those rates through indoor air quality modeling of 40 structures, representative of the U.S. housing stock, where generators were operated in 503 of the deaths in CPSC's databases that occurred from 2004 through 2012.

15. *Comment:* Several commenters expressed concern about CO deaths caused by generators and expressed support for reducing generators' CO emission rates and their belief in the technical feasibility to do so.

Response: The Commission agrees with the commenters.

C. CO Poisoning Effects

1. *Comment*: The commenter considers that CPSC staff assumes COHb levels below 10 percent are not harmful. The commenter notes that there is no scientific basis for such an assumption and also notes that, in many studies, COHb levels do not correlate consistently with symptoms.

Response: The Commission does not assume that a CO exposure resulting in less than 10 percent COHb is incapable of causing adverse health effects. The Commission has long recognized the existence of populations especially sensitive to CO health effects (fetuses, asthmatics, and individuals with cardiovascular diseases). Most authorities, including CPSC, consider individuals with coronary artery disease [CAD] to be the population most sensitive to potential adverse health effects of CO at the lowest exposure levels. Some studies report individuals with CAD might perceive adverse health effects, and/or, tests show that they may experience adverse health effects that they are unaware of, at about 2 percent to 5 percent COHb. The Commission understands that the pathophysiological effects of CO are complex and strongly influenced by multiple factors, particularly CO level, exposure duration, and exposed individual's inhalation rate and health status. In the ANPR on portable generators, and in the prototype report documents, CPSC focused on extremely high-level, acutely lethal, CO exposures caused by generator exhaust. Therefore, rather than provide an exhaustive review of all studies, including equivocal findings in some low-level exposure studies, CPSC is providing an overview of the complex interactions between multiple variables that influence the end effects of acute, high-severity CO exposures in humans. CPSC emphasizes that CO poisoning effects should be understood to be a continuum of effects of the exposure, rather than be viewed as discrete health effects tightly tied to specific CO levels or COHb levels.

2. *Comment:* One commenter stated that although a low CO emissions generator would undoubtedly save lives if widely applied, “prediction of confusion and incapacitation from COHb levels is not possible.” The commenter cited his recent publication reporting that “symptoms of CO poisoning do not correlate well with COHb levels.” Based on his findings and other clinical reports, the commenter questions the validity and/or concept of a table relating COHb levels to particular symptoms, as used by the Commission. The commenter believes that it is incorrect to use COHb levels to calculate egress times from a CO-containing environment and notes that there are no data to support the method. Another commenter also questioned the validity of an approximate relationship between COHb levels and severity of CO poisoning symptoms and health effects.

Response: The Commission’s use of predicted COHb levels was not intended to calculate an actual egress time from a CO exposure, and the Commission noted that reduced emission generators would not guarantee egress by exposed individuals. Rather, the Commission considers that reduced generator CO emissions, as achieved with its prototype unit, will substantially delay the rate at which CO levels rise in poorly ventilated spaces, and will thus delay the rate at which COHb levels of exposed individuals rise (in some cases reducing the peak COHb level attained). This will provide significantly increased time available for individuals to remove themselves from the exposure environment or to be rescued by an outside party. Supporting evidence that some individuals will react appropriately to slower onset of CO poisoning effects has been reported (*e.g.*, 111 of 167 patients with CO poisoning presented to Florida hospital emergency departments (ED) between 5 a.m. and 10 a.m., after waking and feeling ill consequent to overnight use of a generator during hurricane-related power outages). CPSC data indicate that in 69 of 93 cases where it was known how and why a patient with generator-related CO exposure presented to an ED, the patient had either transported themselves or contacted others (9-1-1, family, friends) to arrange for their transport to the ED. In the remaining cases, individuals were found in distress by others (either a lesser affected co-exposed individual or an outside party).

The Commission recognizes that even healthy individuals can exhibit variability in individual susceptibility to CO health effects under identical exposure scenarios. The Commission understands that, in clinical situations, CO poisoning symptoms and health effects do not necessarily correlate well with a patient’s initial COHb measurement, which is often confounded (generally reduced by factors such as time interval relative to cessation of CO exposure and provision of supplemental oxygen). Clearly, COHb measurements can be of limited value to physicians when determining appropriate treatment plans for individual patients. Rather than make clinical decisions, the Commission needed to provide controlled, systematic comparisons of how CPSC’s reduced CO emissions prototype generator could be expected to reduce the lethal CO hazard presented by the unmodified original generator. Therefore, CPSC used identical physiological input parameters for a healthy adult to model COHb formation and elimination from empirical generator CO time course exposure data. CPSC used predicted times taken to rise to, and progress through, three convenience benchmark percentile COHb values to compare the relative CO poisoning hazard presented by a generator before and after design modifications to reduce its CO emission rate. The Commission considered these benchmark values to approximate relatively mild (20% COHb), potentially incapacitating (40% COHb), and likely lethal (60% COHb) exposure levels. Although indicating health effects generally first reported at these benchmark COHb levels, CPSC did not intend to convey that they represented precise measures when appearance of symptoms and adverse health effects would be expected in

all individuals. CPSC noted that rapidly rising, high-level CO exposures of several thousand ppm (as can occur with current carbureted generators) would result in extreme oxygen deprivation and fast-rising COHb levels, causing rapid incapacitation, loss of consciousness and death, without individuals necessarily experiencing milder, progressively worsening CO poisoning symptoms typically manifested in slowly rising or lower-level CO exposures.
As further detailed in the staff's briefing package, the available physiological research data and clinical findings in the scientific literature support the use of "COHb benchmarks," for approximate estimation and comparison of CO-related health effects expected during generator-related exposures.[75] The Commission welcomes suggestions on alternative health-based approaches to compare the reduced CO emissions generators with current products in terms of improved safety benefits.

D. Jurisdiction

Comment: One commenter asserted that pursuant to § 31 of the CPSA, the CPSC lacks authority to regulate the risk of injury associated with CO emissions from portable generators because that risk could be addressed under the Clean Air Act (CAA). Specifically, the commenters rely on Section 213 of the CAA, which directs the EPA to conduct a study of emissions from non-road engines to determine if they cause or contribute to air pollution, "which may reasonably be anticipated to endanger public health or welfare." 42 U.S.C. 7547(a)(1)(2006). Under this provision of the CAA, the EPA has promulgated regulations governing CO emissions from portable generators. In particular, 40 CFR part 90 imposes requirements to control emissions

[75] Tab K, Appendices, of staff's briefing package.

from non-road spark-ignition engines, which includes portable generators, at or below 19 kilowatts.

Response: Section 31 of the CPSA does not establish an absolute prohibition to CPSC action whenever the CAA is implicated. Rather, the Commission lacks authority to regulate a risk of injury associated with a consumer product if that risk "could be eliminated or reduced to a sufficient extent through actions" taken under the CAA. 15 USC § 2080(a). Case law and the legislative history of § 31 confirm this. See *ASG Industries, Inc. v. Consumer Product Safety Comm'n*, 593 F.2d 1323 (D.C. Cir. 1979)(under section 31, CPSC is to consider all aspects of the risk and make a judgment whether the alternate statute can sufficiently reduce the risk of injury).

The legislative history indicates that Congress contemplated a stricter ban on the CPSC's jurisdiction and rejected it. Specifically, the Senate version of the bill for § 31 would have precluded CPSC's jurisdiction if the product was "subject to safety regulations" under one of the statutes listed in section 31 of the CPSA. S.Rep.No.92-749, 92d Cong., 2d Sess. 12-13 (1972). In contrast, under the House version of the bill, which was eventually enacted, "the Commission has authority if there has not been sufficient reduction or elimination of the risk of injury." H.R.Rep.No.92-1593, 92d Cong., 2d Sess. 38 (1972).

The CAA and the EPA regulations promulgated under it that address CO emissions from portable generators have not sufficiently reduced or eliminated the risk of CO poisoning associated with portable generators that the CPSC seeks to address. Deaths and injuries associated with CO emissions from portable generators have increased since the EPA adopted its regulations limiting CO emissions from the type of engines used in portable generators.

The CAA and the EPA's regulations create national standards intended to address large-scale ambient air pollution, not acute CO exposure from portable generators. The CAA and the

EPA's regulations, created under 42 U.S.C. § 7407, are designed to reduce CO emissions in regional areas that exceed National Ambient Air Quality Standards. These requirements are not designed to reduce the localized risk to consumers from acute CO poisoning when portable generators are used in the home.

Additionally, EPA's 2008 adoption of an averaging program for CO emissions from marine engines further demonstrates that its regulations are not concerned with the risk of acute CO poisoning, but only large-scale overall emission levels. This averaging program allows a manufacturer to exceed the EPA's CO emission limits for a group of similar engines, as long as the manufacturer offsets that increase with another "engine family" with emission levels below the EPA's limit. 73 Fed. Reg. 59,034 (Oct. 8, 2008). It is noteworthy that this averaging program applies to CO emissions from marine engines, which the EPA explicitly acknowledges are associated with "a substantial number of CO poisonings and deaths." 73 Fed. Reg. 59,034, 59,048 (Oct. 8, 2008). Under this program, emissions from an individual engine are inconsequential to EPA's rule, and so is the individual consumer's exposure level. Rather, the EPA's determination of CO emission limits focuses on ambient air pollution on a large scale.

Finally, the structure of the CAA and its delegations of authority make the EPA unable to adequately address the risk of injury associated with CO poisoning to consumers from portable generators. Under the CAA, the EPA sets National Ambient Air Quality Standards (NAAQS) and has oversight and enforcement authority, but the states retain primary responsibility for ensuring air quality. Section 107 of the CAA sets out states' responsibilities for ensuring air quality, including determining how the state will meet NAAQS, and identifying attainment and non-attainment areas. 42 U.S.C. 7407. The U.S. Supreme Court has emphasized that the EPA is "relegated by the [CAA] to a secondary role," as long as states adopt plans that meet the general requirements. *Train v. Natural Resources Defense Council, Inc.*, 421 U.S. 60 (1975). This broad leeway provided to states indicates that the CAA and the EPA's regulations are not intended to and cannot provide sufficient specificity to mitigate the risk of CO poisoning.

E. CO Sensor Systems and Exhaust Pipe Extension

1. Generator-Mounted CO Sensing Shutoff Systems

Comment: Four comments were submitted on the concept of a generator-mounted safety shutoff system using CO sensing technologies that could be used to limit consumer exposure to CO present in portable generator exhaust. Three of the four commenters advocated for such a system, and one advocated against it.

One comment in support of the use of residential CO alarm technology noted that a CO sensor that is used to activate ventilation systems in parking garages can be used for turning off the generator when it senses 35 ppm CO. The Commenter also recommended that the system be interlocked to prevent generator operation every 2 to 3 years, when the sensor's useful life is expended, and to prevent operation, if the user disables the system.

The commenter who did not recommend the use of residential CO alarm technology expressed the belief that COS sensing technology near a generator may impair its operation, causing users to disconnect the sensors to ensure a steady source of electricity. The Commenter also noted that CO sensors require routine maintenance, and their capabilities can degrade with time and during extended periods of inactivity, adding that it may be unreasonable to expect consumers to regularly check and maintain the CO sensing equipment, particularly when the generator is not even being used.

Response: The Commission shares the concern that using CO sensing technology in the vicinity of a portable generator may impair the generator's operation, causing users to disconnect the sensors. The Commission agrees that it is unreasonable to expect consumers to regularly check and maintain CO sensing equipment, particularly when a generator is not being used. Early in the portable generator project, the Commission investigated one version of the concept of an on-board CO sensing shutoff system; the investigation and its findings are documented in the staff report, *Phase 2 Test Report: Portable Generator Equipped with a Safety Shutoff Device* (Brown, 2013). Its goals were to: (1) determine if a CO sensor/alarm output signal from commercially available residential CO alarms (meeting the requirements in UL 2034 *Single and Multiple Carbon Monoxide Alarms*), when retrofitted with circuitry connected to the generator, could trigger a shutoff device installed on a portable generator when the CO alarm activated; and (2) measure CO concentrations around the generator when operated in multiple environments to assess CO migration and levels that might occur under several scenarios. Test environments examined included outdoors, in a two-sided structure, as well as inside and under a temporary modular storage (TMS) building.

In that investigation, the Commission found that when the generator was operated inside the TMS building, the CO migrated and accumulated on the far side of the room more quickly than near the generator. The CO alarms on the generator never activated before those located elsewhere in the space activated, with the time difference generally ranging from 5 to 10 minutes. In some tests, CO levels in some parts of the room reached up to 1,000 ppm before the CO alarm on the generator activated and shut off the generator. When the generator was operated in wide-open outdoors in a light breeze condition, CO concentrations ranging up to 350 ppm were measured in the immediate vicinity of the generator. Although this did not activate the CO alarms mounted on the generator to shut it off, the Commission believes this could occur in some circumstances. This would detrimentally affect the utility of the generator when used in a proper location.

In addition to these performance deficiencies, the Commission is concerned about the ability of CO sensors to survive the environments produced by an operating generator. Currently available electrochemical and semiconductor CO sensors, which dominate the CO sensing market, have numerous vulnerabilities that will compromise their ability to maintain accuracy if they are used in an atmosphere containing high concentrations of hydrocarbons, as is present in a generator's exhaust, particularly when used in a confined space.

Regarding one commenter's recommendation to use CO sensors that turn on ventilation fans in parking garages, a recent energy efficiency study examining the performance of parking garages that have CO-sensing activated ventilation indicates that this type of system is subject to failure if not maintained on the manufacturer's recommended schedule (California Utilities Statewide Codes and Standards Team, 2011). Systems employing both electrochemical and solid state technology that were five and 12 years old, respectively, failed likely because they had not been calibrated. A properly maintained 2-year-old electrochemical sensor-equipped system performed well. The commenter suggested that to account for the referenced 2 to 3 year expected sensor life, the consumer replace the sensor at the end of the sensor's useful life. The Commission believes that it is not appropriate for consumers to be required to replace a primary safety device, let alone replace it every 2 to 3 years, when the life of the overall product is much longer. Furthermore, making the sensor replaceable makes it vulnerable to tampering. Notwithstanding the previously mentioned CO concentrations that CPSC measured around a generator operating in a proper location, the conflict between making the sensor consumer-replaceable and tamper-proof leads the Commission to conclude that currently available sensors are not likely to be effective, given the long service life of portable generators. With respect to the recommendation for a 35 ppm CO set point for an on-board sensor, CPSC measured CO concentrations in excess of 35 ppm in the immediate vicinity of the generator, while operating outdoors within 11 minutes after starting the generator (Fig C2 in Brown, 2013). A 35 ppm limit for shutoff would greatly limit the utility of portable generators when used properly.

2. Remotely Located CO-Sensing Shutoff Systems

Comment: Two commenters raised concerns about the concept of a remotely located CO-sensing shutoff system, such as that investigated and documented in the staff report, "*Demonstration of a Remote Carbon Monoxide Sensing Automatic Shut-Off Device for Portable Generators"* (Lee, 2006). Conceptually, a remotely located CO-sensing shutoff system would use a CO sensor located indoors to monitor for CO infiltration at that location and when it detects an unsafe CO concentration there, the sensing shut-off device would communicate with the generator to shut it off. The report presents CPSC staff's investigation of one version of such a concept, consisting of a CO alarm retrofitted with a wireless transmitter, placed by the user in an indoor location, which communicated with a wireless receiver mounted onto a portable generator operating in an attached garage. When the CO alarm activated, it energized a circuit on the generator and shut off the generator.

One commenter raised a number of behavioral and technical issues on the utility of such a system. This commenter noted that the same technical comments he made on the generator-mounted safety shutoff concept, discussed above, apply to the remote-sensing concept as well. This commenter also noted that remote-sensing technologies require consumers to take affirmative actions to properly locate sensors inside buildings and to monitor them to make sure that they continue to be operational. The commenter stated that the risk of the CO poisoning hazard would not be mitigated when consumers fail to locate or use the sensing technology properly or the detector malfunctions due to infrequent use or lack of maintenance.

Another commenter enumerated a number of concerns about the concept of a remote CO-shutoff system that included:

- sensor performance affected by ambient conditions
- battery life
- the ability of consumers to install
- nuisance trips causing consumers to disable system
- the need to maintain proper battery charge
- ability of consumer to start generator, then remove the remote sensor to an area without CO, to allow the generator to operate.

Regarding the staff report, the commenter objected that only one model generator was included in the tests and that only a limited number of hazard scenarios were tested. The commenter provided a list of options that would need to be investigated to document remote CO-sensing device acceptability. The options include: (1) effectiveness of the mandatory warning label; (2) effects of environmental conditions on CO dispersion in a building; (3) effect of generator load profile on CO dispersion; (4) effect of walls and building materials on the sensor's radio frequency (RF) signal to the generator; and (5) maximum distance between sensor/transmitter and the generator. Additional areas the commenter listed include: (6) consumer's ability to reset the system in adverse conditions (darkness, storms); (7) timing of product sales (pre- or post-storm); (8) minimum component performance requirements; and (9) minimum battery requirements.

Response: The Commission agrees that there are multiple challenges with a remote CO-shutoff concept for portable generators, including many of the challenges identified by the commenters and notes that the staff report concluded with the following:

The study was limited to proof-of-concept and did not consider issues such as life expectancy, reliability, usability, and environmental conditions. All of these factors would need to be considered in developing a remote CO detection/shut-off system for portable generators for consumer use.

In addition to having the same sensor-related concerns as those stated above in CPSC's response to the on-board CO sensing shutoff concept, CPSC has additional concerns, a primary one being that a system of this sort would need to be provided with the generator and would require the consumer to properly install the sensing devices. The consumer could easily defeat the features by operating the generator in an enclosed location and intentionally placing the sensor outdoors or other locations away from where the CO is infiltrating in order to keep the generator running. Another scenario of concern involves the user placing the CO sensor in a room where he/she thinks the CO will infiltrate, but the CO infiltrates faster in another room that the system is not monitoring. Transmitter range is another concern; if a consumer properly locates the generator outdoors at a distance far enough from the dwelling to prevent CO infiltration, the distance may render the generator inoperable if it is not within range of the sensor signal. Based on the concerns mentioned above, the Commission is not pursuing this concept as a means of reducing the CO hazard associated with portable generators.

3. Flexible Exhaust Pipe Extension

Comment: One commenter recommended using an exhaust hose that has one end that fits over the tailpipe and a laterally expandable window fitting on the other end to direct exhaust out through a window. The commenter recommended that the hose should have an electrical circuit wired through its entire length, which plugs into the generator to prevent operation if the hose is not properly attached**.**

Response: There are several drawbacks to this approach. First, if the hose must be attached for the generator to operate, then it must be attached even if the generator is correctly located away from the house. CPSC believes this is not practical. Second, the CPSC database includes fatal CO incidents where the generator was located outside the dwelling, but not so far away to prevent exhaust from entering the home through leaks or openings (Hnatov, 2015). Third, CPSC staff believes that it is unlikely that an expandable window insert can be installed in such a way as to be leak tight. Last, this system's successful use depends on the consumer's ability to properly install both the hose and the window fitting. Given these concerns, the hose extension is not a technically feasible approach to address the carbon monoxide poisoning hazard associated with engine-driven portable generators.

F. Economic Considerations.

On February 12, 2007, counsel for American Honda Motor Co., Inc., Briggs & Stratton Company, and Yamaha Motor Corporation, USA (the companies), submitted comments jointly on the December 12, 2006 advance notice of proposed rulemaking (ANPR), concerning portable generators. The companies made the following comments on economic issues:

1. *Comment:* The vast majority of consumers use their portable generators properly and safely. CPSC should give proper weight to the benefits and widespread uses of portable generators, as well as the affordability of current models.

Response: Although the great majority of consumers might exercise proper safety precautions, improper use of the product can and does have disastrous consequences. The Commission evaluated different technologies to address the risk and has concluded that a performance standard that sets requirements that reduce CO emissions from generators is the most reliable regulatory alternative to address the risks of CO poisoning associated with portable generators. Manufacturing cost increases under the proposed rule would generally have a relatively greater impact on percentage price increases (and consumer demand) for low-price units, such as units lacking inverter technology (as discussed in the preliminary regulatory analysis section). However, the analysis finds that the estimated benefits outweigh the costs to comply with the proposed rule.

2. *Comment:* Staff has not provided consumer exposure data to support risk analysis of CO deaths associated with consumer use of generators.

Response: Since the comment was filed, additional information and analysis has greatly improved the analysis of risks associated with consumer use of portable generators. The Commission's preliminary regulatory analysis has analyzed historical shipment information acquired from market research firms (Power Systems Research and Synovate), from federal data sources (the International Trade Commission and Bureau of the Census), and from individual manufacturers to estimate the numbers of portable generators in use, by engine class and other characteristics, during the period covered by CPSC staff's epidemiological benefits analysis (Hnatov, Inkster & Buyer, 2016). The new information and analysis has enabled CPSC to estimate CO poisoning risks (and societal costs) per generator in use. Additional information on product sales and use, which the industry is encouraged to provide in comments to this NPR, could further refine these estimates.

3. *Comment:* In response to the technology demonstration report, one commenter stated that although engine designs that incorporate the report's design changes[76] are possible, they may not be suitable for all engines, including many used to power portable generators. This is especially true when considering the price point and reliability considerations associated with portable generators designed and sold to consumers for emergency or infrequent use.

Response: As noted, we agree that some types of generators (and engines) will be more severely affected by a proposed rule that is performance based, but is likely to be addressed by manufacturers through the use of EFI and catalysts (although some generators with handheld engines might not require catalysts) in terms of relative price increases that would result from incorporation of the technologies. The impact on demand for these products could affect their future availability to consumers.

IX. Description of the Proposed Rule

A. Scope, Purpose, and Compliance Dates - § 1241.1

The proposed standard would apply to "portable generators" powered by small handheld and non-handheld SI engines, and would include requirements intended to limit carbon monoxide emission rates from these portable generators. The requirements are intended to reduce an unreasonable risk of injury associated with portable generators.

Generators within the scope of the proposed rule provide receptacle outlets for AC output circuits and are intended to be moved, although not necessarily with wheels. Products that would

[76] Mr. Gault is referring to the incorporation of an electronic control unit, manifold air pressure sensor, fuel pump, fuel injector . . . exhaust oxygen sensor, catalyst aftertreatment and other components used on the prototype generator.

not be covered by the proposed rule include permanently installed stationary generators, 50 hertz generators, marine generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, generators intended to be mounted in truck beds, and generators that are part of welding machines.[77] Generators powered by compression-ignition (CI) engines fueled by diesel also are excluded from the scope of the proposed rule.[78]

The requirements would apply to four categories of portable generators: (1) handheld generators; (2) class 1 generators; (3) class 2 single-cylinder generators; and (4) class 2 twin-cylinder generators. Handheld engines have total engine displacement of 80 cubic centimeters (cc) or less; non-handheld engines include EPA Class I engines, which have total engine displacement of less than 225cc, and Class II engines, which have displacement of 225cc and more. Class II engines have an upper limit determined by rated engine power, 19 kilowatts (kW), which is equivalent to 25 horsepower. Although the Commission categorized generators by the EPA classification of the engines powering them, it is important to distinguish these engines from the portable generators in which they are used because the engines are used in other products as well. To provide a clear distinction, the Commission refers to engines according to EPA's classification: handheld engines, non-handheld Class I engines and non-handheld Class II engines, while referring to portable generators according to the Commission's definitions,

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[77] Stationary generators, marine generators, and generators installed in recreational vehicles are excluded because they are not portable. Generators intended to be pulled by vehicles, intended to be mounted in truck beds, generators that are part of welding machines, and 50-hertz generators are excluded because they are not typically used by consumers.
[78] CI engines are not typically used by consumers. In addition, CI engines have relatively low CO emission rates. The current EPA standard for CO emissions from CI engines rated below 8 kW is 8.0 g.kW-hr, which is significantly lower than the EPA standard of 610 g/kW-hr applicable to small SI engine classes used in portable generators.

handheld generators, class 1 generators, class 2 single-cylinder generators and class 2 twin-cylinder generators.

Under the CPSA, the effective date for a consumer product safety standard must not exceed 180 days from the date the final rule is published, unless the Commission finds, for good cause, that a later effective date is in the public interest. To meet the proposed performance requirements, it is likely that engines will need closed-loop fuel-injection, and with the exception of some handheld engines, the addition of a catalyst. Implementing closed-loop EFI and catalyst integration on all class II (single- and twin-cylinder) engines powering generators may require design modifications, such as redesign of cooling fins and a fan, to accommodate fuel control closer to stoichiometry. The Commission believes 180 days may not be adequate time to allow for such design modifications, and is instead proposing an effective date of 1 year following publication of the final rule, at which time portable generators with Class II single- and twin-cylinder engines, or class 2 single- and twin-cylinder portable generators, would be required to comply with the applicable requirements of the rule. The Commission proposes a compliance date of 3 years after publication of the final rule for generators powered by Class I engines and handheld generators, or class 1 and handheld generators. This later compliance date is to address manufacturers' concerns that, while industry has gained some limited experience with incorporating fuel injection on handheld and Class I engines, there may be different challenges associated with accommodating the necessary emission control technologies on these smaller engines. In addition, later compliance dates potentially could reduce the impact on manufacturers of generators, including small manufacturers, by providing them with more time to develop engines that would meet the requirements of the proposed rule, or, in the case of small manufacturers that do not manufacture the engines used in their generators, by providing them with additional time to find a supplier for compliant engines so that their generator production would not be interrupted.

B. Definitions - § 1241.2

The proposed standard would provide that the definitions in section 3 of the Consumer Product Safety Act (15 U.S.C. 2051) apply. In addition, the proposed standard would include the following definitions:

(a) *handheld generator* means a generator powered by a spark-ignited (SI) engine with displacement of 80 cc or less.

(b) *class 1 generator* means a generator powered by an SI engine with displacement greater than 80 cc but less than 225 cc.

(c) *class 2 single-cylinder generator* means a generator powered by an SI engine with one cylinder having displacement of 225 cc or greater, up to a maximum engine power of 25 kW.

(d) *class 2 two-cylinder generator* means a generator powered by an SI engine with two cylinders having a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW.

C. Requirements - § 1241.3

1. Description of Requirements

The proposed rule would require that portable generators powered by handheld engines and Class I engines, or handheld and class 1 generators, not exceed a weighted CO at a weighted rate more than 75 grams per hour (g/h); generators powered by one-cylinder Class II engines, or class 2 generators, must not exceed a weighted CO emission rate of 150 g/h; and generators powered by Class II engines with two cylinders, or class 2 twin-cylinder generators, not exceed a weighted CO emission rate of 300 g/h. The weighted emission rates are based on weighting of six modes of generator operation, ranging from maximum generator load capability (mode 1) to no load (mode 6), similar to a procedure used by EPA to certify compliance with its emission standards for small SI engines.

2. Rationale

The proposed rule would impose different limits on weighted CO emission rates for different categories of generators in recognition of the effects of factors such as engine size and other engine characteristics on CO emissions, in addition to the different challenges that may be faced in meeting CO emission rates expressed in grams per hour. The proposed rule would apply different criteria to generators, based on EPA's classification of engines (and on the number of engine cylinders), rather than on power ratings of either the generators or the engines. This determination was based mainly on the absence of standard methods for defining the rated power, maximum power, or surge power of generators. Furthermore, staff determined that the technically feasible emission rates were different for different categories of generators. Staff also found differences in hazard patterns for different categories; this is reflected in the determination of epidemiological benefits (for example more fatalities associated with large generators involved their use in garages as opposed to basements, while for small generators the reverse was true, as described in detail in staff's briefing package in Tab K).

The requirements of the proposed rule are based on technically feasible emission rates and an analysis of the benefits and costs associated with these technically feasible emission rates. The benefits analysis and cost analysis are explained in detail in Section VI and Section X, respectively, of this preamble.

D. **Test Procedures –** § 1241.4

The proposed rule details the test procedure that the Commission would use to determine compliance with the standard, but also provides that any test procedure that will accurately determine the emission level of the portable generator may be used.

The procedure the Commission would use is largely based on a test method that was developed in a collaborative effort with industry stakeholders and is explained in greater detail in Tab J of the briefing package. In brief, the Commission intends to perform the tests in ambient temperature in the range of 10 - 38 ^{0}C (50-100 ^{0}F) using E10 gasoline. The six loads that will be applied to the generator for determining the weighted CO emission rate are based on the generator's maximum load capability. Maximum load capability is determined by increasing the load applied to the generator to the maximum observed power output, without causing the voltage or frequency to deviate by more than 10 percent of the nameplate rated voltage and 5 percent of the nameplate rated frequency and can be maintained for 45 minutes with stable oil temperature. The loads will be applied using a resistive load bank capable of achieving each specified load condition to within 5 percent and will be measured using a power meter with an accuracy of ± 5 percent. The Commission will use constant volume sampling (CVS) emissions measurement equipment, as described in the EPA's regulations 40 CFR part 1054 and 40 CFR part 1065 as of 2016. If the generator is equipped with an economy mode or similar feature that has the engine operating in low speed when not loaded, the setting that produces the highest weighted CO emission rate will be used to verify whether the applicable carbon monoxide emissions rate is met.

E. Prohibited Stockpiling. - § 1241.5

In accordance with Section 9 of the CPSA, the proposed rule contains a provision that prohibits a manufacturer from "stockpiling" or substantially increasing the manufacture or importation of noncomplying generators between the date of the final rule and its effective date (or compliance date, in the case of generators with handheld and Class I engines). The rule would prohibit the manufacture or importation of noncomplying portable generators by engine class in any period of 12 consecutive months between the date of the promulgation of the rule and the effective/compliance date at a rate that is greater than 125 percent of the rate at which they manufactured or imported portable generators with engines of the same class during the base period for the manufacturer. The base period is any period of 365 consecutive days, chosen by the manufacturer or importer, in the 5-year period immediately preceding the promulgation of the final rule.

Generator sales can vary substantially from year to year, depending upon factors such as widespread power outages caused by hurricanes and winter storms. Annual unit shipment and import data obtained by CPSC staff show that it has not been uncommon for shipments to have varied by 40 percent or more from year to year at least once in recent years. The 5 year period in the anti-stockpiling provision is intended to allow manufacturers and importers sufficient flexibility to meet normal changes in demand that may occur in the period between the promulgation of a rule and its effective/compliance date while limiting their ability to stockpile noncomplying generators for sale after that date. Allowing manufacturers to produce noncomplying generators in amounts that total 125 percent of their peak 365-day period over the prior 5 years could give manufacturers enough flexibility to respond to demand if there is a year of major power outages that create a demand for consumers to purchase portable generators. The Commission is aware of some large manufacturers that have seen year-to-year shipments increase by 50 percent and 70%, so the Commission believes that the allowable stockpiling percentage over a base period should be greater for generators than most other consumer products. The Commission seeks comments on the proposed product manufacture or import limits and the base period.

F. **Findings. - §** 1241.6

In accordance with the requirements of the CPSA, we are proposing to make the findings stated in section 9 of the CPSA. The proposed findings are discussed in section XVI of this preamble.

X. Preliminary Regulatory Analysis

The Commission is proposing to issue a rule under sections 7 and 9 of the CPSA. The CPSA requires that the Commission prepare a preliminary regulatory analysis and that the preliminary regulatory analysis be published with the text of the proposed rule. 15 U.S.C. 2058(c). The following discussion is extracted from staff's memorandum, "Draft Proposed Rule Establishing Safety Standard for Portable Generators: Preliminary Regulatory Analysis."

A. Introduction

The CPSC is issuing a proposed rule for portable generators. This rulemaking proceeding was initiated by an ANPR published in the *Federal Register* on December 12, 2006. The proposed rule includes weighted carbon monoxide emission limits from four different categories of portable generators.

Following is a preliminary regulatory analysis of the proposed rule, including a description of the potential costs and potential benefits.

B. CPSC Staff Assessment of the Adequacy of Voluntary Standards for Portable Generators in Addressing CO Deaths and Injuries

As indicated in Section VII.B of this preamble, two organizations, Underwriters' Laboratories, Inc. (UL), and the Portable Generator Manufacturers Association (PGMA), have been accredited by the American National Standards Institute (ANSI) to develop U.S. safety standards for portable generators. Although each organization has developed a standard (designated as UL 2201 and PGMA G300, respectively), only PGMA's standard has achieved the consensus needed to be recognized by ANSI (as ANSI/PGMA G300-2015). A UL 2201 task group has been working on developing proposals to address CO hazards of portable generators; however, the task group has not yet sent a proposal to the standards technical panel established by UL to consider for adoption into UL 2201. The current version of UL 2201 includes the mandatory CPSC label, but does not otherwise address the risks related to CO poisoning. In the Commission's view, the label alone is insufficient to address the risk of injury from CO poisoning. CPSC is unaware of any portable generator that has been certified to UL 2201. Therefore, it is unlikely whether there would be substantial compliance with UL 2201 if the standard were to incorporate CO emissions requirements (Buyer, 2016b).

PGMA G300 also includes the mandatory CPSC label for portable generators, but it does not otherwise address the risks related to CO poisoning. In a letter emailed to Chairman Kaye on September 19, 2016, PGMA announced its intention to reopen G300 to develop a "performance strategy focused on CO concentrations." As discussed in Section VII.B of this preamble, the Commission does not have an adequate basis to determine that PGMA's modification to G300 would likely eliminate or reduce the risk of injury or that there likely will be substantial compliance with the voluntary standard, once modified. In addition, based on the complex nature of setting CO limits and the fact that G300 is just now being re-opened, the Commission is not convinced that a modification to the voluntary standard adequately addressing the risk of injury identified in the rulemaking would be accomplished within a reasonable period of time. CPSC believes that significant technical work, requiring significant time, would be required to develop appropriate requirements and test methods within the broad framework identified in the PGMA letter[79] and at a September 6, 2016, public meeting between PGMA and staff.[80] Specifically, as discussed at the meeting and in the NPR briefing memorandum, there are several technical concerns about shutoff criteria and testing that would need to be investigated (Buyer, 2016a). The Commission is concerned whether the test methodologies would be accurate, dependable and practicable and sufficient to ensure that the generators would shut off quickly enough in a sufficient number of common scenarios seen in portable generator incidents to result in an adequate reduction in the risk of injury and death. The Commission expects that significant periods of time will be needed to evaluate each of these factors. For example, determining the expected epidemiological benefits for the proposed rule required nearly a year for NIST to conduct a modeling study and for staff to evaluate the study. For the PGMA to develop an effective voluntary standard, similar efforts will be required to assess the standard after the technical details have been established.

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[79] https://www.cpsc.gov/s3fs-public/PGMALtrChairKayeVoluntaryStandardFinal.pdf.

[80]. https://www.cpsc.gov/s3fs-public/09%2006%2016%20Meeting%20with%20PGMA%20Follow%20up%20on%20Technical%20Summit%20on%20Carbon%20Monoxide%20Hazard%20Mitigation%20for%20Portable%20Generators.pdf

C. Market Information

1. Manufacturers

Based on data obtained from Power Systems Research, Inc. ("PSR"), a total of 78 domestic or foreign manufacturers produced or exported gasoline-powered portable generators for the U.S. market in recent years. However, most of these manufacturers were based in other countries. The Commission has identified 20 domestic manufacturers of gasoline-powered portable generators, 13 of which would be considered small businesses based on the Small Business Administration ("SBA") size guidelines for North American Industry Classification System ("NAICS") category 335312 (Motor and Generator Manufacturing), which categorizes manufacturers as small if they have fewer than 1,250 employees.

Few of the 78 firms involved in production for the U.S. market in recent years have held significant market shares: less than half of these firms have reportedly had annual shipments of 1,000 units of more, and only six firms have had annual shipments of 50,000 units or more. From 2009 through 2013, the top five manufacturers combined for an estimated 62 percent of the U.S. market for portable generators with power ranges more likely to be in consumer use and the top 10 manufacturers combined for about 84 percent of unit sales during that period. Under the CPSA, firms that import generators from foreign producers would be considered manufacturers of the products. A review of import records for portable generators found that the annual number of individual importers of record has ranged from about 25 to 30 in recent years. These firms would be responsible for certifying that the products they import comply with the rule, should it be finalized by the Commission.

2. Annual Shipments/Sales of Portable Generators

CPSC Directorate for Economic Analysis staff acquired information on annual unit sales of portable generators through contract purchases from market research firms, from federal data sources (*e.g.*, the International Trade Commission [ITC] and Bureau of the Census), and other sources.[81] Chart 1 presents information on sales of portable generators for 1995 through 2014. Sales estimates are based on estimated portable generator shipments and projected shipments to U.S. retailers for the years 1998─2002 and 2007─2013 (RTI International, 2006[82;] Power Systems Research, 2012, 2013) [83;] and estimated U.S. consumer purchases of portable generators for 1995─1997 and 2004─2008 (Synovate, 1999, 2006, 2009).[84]

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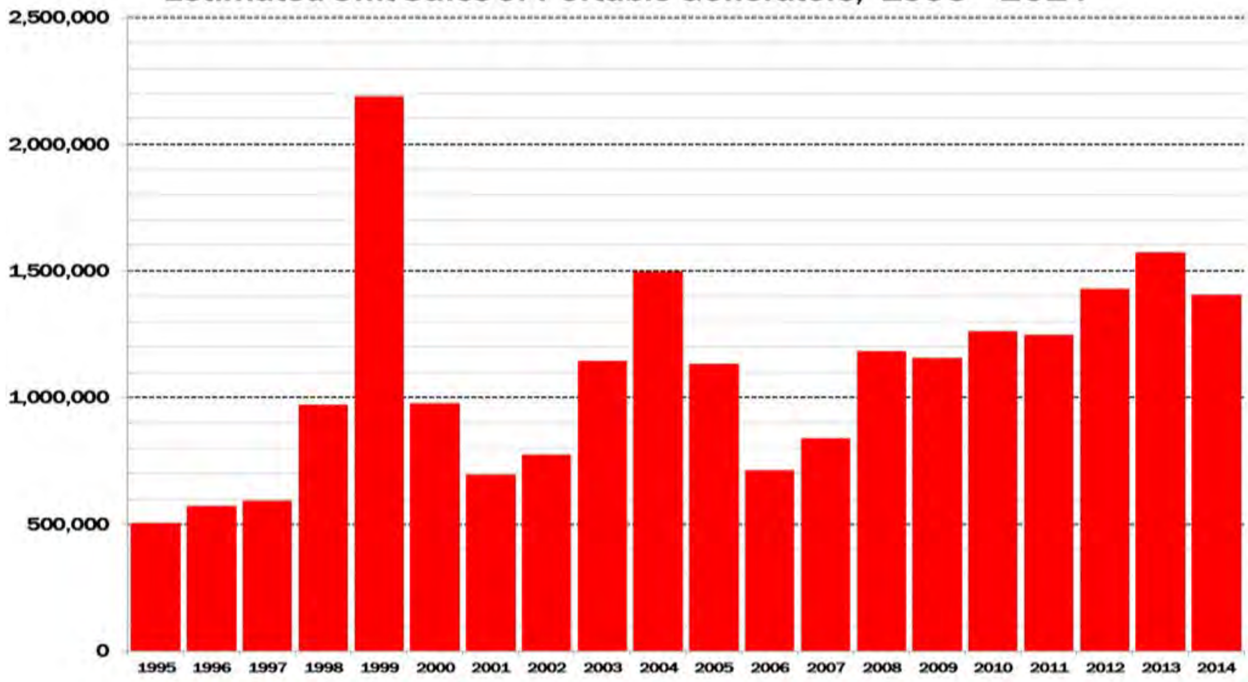
[81] Power Systems Research, compiled information on domestic production and imports of portable generators from its OE Link™ market intelligence database of original equipment and original equipment manufacturer (OEM) production & forecast data. Synovate (which was purchased by another market research firm, Ipsos, in 2011), based on analysis of surveys of the firm's Continuing Consumer Survey panel and the firm's Multi-Client Research Group (SMRG) sample.

[82] RTI International (2006, October). Industry Profile for Small Nonroad Spark-Ignition Engines and Equipment - revised draft report. Authored by Alex Rogozhin, William White & Brooks Depro.

[83] Power Systems Research, Inc. (2012, 2013). Excel data file: OE Link™ original equipment database, portable generator sets produced and sold in the United States. Attached to email from Marilyn Tarbet, PSR, to Charles Smith, Directorate for Economic Analysis, CPSC. October 3, 2012. Excel data file: OE Link™ original equipment production - forecast database with sales data, portable generators produced outside of the United States, sold in the United States. Attached to email from Marilyn Tarbet, PSR, to Charles Smith, Directorate for Economic Analysis, CPSC. October 4, 2013.

[84]

Chart 1.
Estimated Unit Sales of Portable Generators, 1995 – 2014



As shown by the chart, consumer demand for portable generators from year to year fluctuates with power outages, such as those caused by hurricanes and other storms along the Gulf and Atlantic coasts and by winter storms in other areas. Periods of increased demand for portable generators may be followed by reduced demand because a larger percentage of households had made recent purchases. Evidence of the importance of weather-related power outages in driving demand for portable generators was highlighted in the fiscal 2007 annual report issued by Briggs & Stratton, a leading manufacturer of engines used in the production of generators (its own and others). The report, noted that for 2007, the company had “a 66% reduction of engine shipments for portable generators caused by a lack of events, such as hurricanes, that cause power outages” (Briggs & Stratton, 2007). Additionally, spurred by widespread concerns over the possible impact of Y2K in disrupting power supplies, estimated portable generator shipments rose to about 2.2 million in 1999, still the highest year for estimated sales (RTI, 2006).

3. Product Characteristics of Portable Generators Shipped in Recent Years

Power Ratings

Data obtained by the Commission in recent years show that portable generators purchased by consumers and in household use generally range from under 1 kW of rated power up to perhaps 15 kW of rated power. The Commission believes that the most powerful portable generators are mainly purchased for construction or commercial use, although some also end up in household use.[85] In Table 6, we present information on generator power ratings for shipments of portable generators powered by Class I or Class II engines for the U.S. market for the years 2010 through 2014, based on Commission analysis of data obtained from PSR, import data from the U.S. International Trade Commission, and information provided by individual firms. The generators are separated into six power-rating categories. Over this 5-year period for shipments, about 6.9 million gasoline-powered portable generators were shipped for consumer use, or an average of about 1.4 million units per year. Shipments of nearly 1.6 million units in 2013, made 2013 the peak year for sales during this period.

Data on recent portable generator shipments, as shown in Table 6, compared to information on consumer purchases before 2010, indicate that the U.S. market has shifted toward smaller, less powerful units. Synovate surveys on generators purchased by consumers from 2004

[85] Although generator power ratings are only known for about 48 percent of the units involved in death reports as of May 21, 2015, for the period of 2004 through 2012, fewer than 3 percent of these units had power ratings of 8 kW or greater, and the most powerful unit involved was 10 kW (Hnatov. 2014).

to 2006, found that about 9 percent of units likely purchased for consumer use (< 15kW) had continuous electrical outputs of under 2 kW and about 12 percent had ratings of 2 ─ 3.49 kW (Synovate, 2008). Data acquired from PSR and individual manufacturers on portable generator shipments in more recent years show that units with power ratings of under 2 kW comprised an estimated 21 percent of the market, and units with power ratings of 2 ─ 3.49 kW have held an estimated market share of about 36 percent over 2010 to 2014 (as shown in Table 6). The market share of larger units, with outputs of 6.5 kW or more, fell from about 22 percent of the market in 2004 to 2006, to about 9 percent over 2010 to 2014.[86]

Table 6.
Shipments of Portable Generators, 2004—2006 & 2010—2014, by Rated Generator Power, in Kilowatts (kW)

Generator kW Range	2004 — 2006 Annual Average	2010 — 2014 Annual Average
Under 2 kW	100,900	283,923
percent	9.1%	20.5%
2 to 3.49 kW	136,245	496,684
percent	12.2%	35.9%
3.5 to 4.99 kW	196,552	184,874
percent	17.6%	13.4%
5 to 6.49 kW	437,669	289,669
percent	39.3%	20.9%
6.5 to 7.99 kW	142,277	46,938
percent	12.8%	3.4%
8 kW & Greater*	100,893	81,808
percent	9.1%	5.9%
All Portable Generators	1,114,536	1,383,896

Source: Power Systems Research, Inc. data; market estimates for individual firms; analysis by Directorate for Economic Analysis, CPSC.
* Limited to generators powered by Class II engines (*i.e.*, under 19 kW).

[86] It is possible that some of the demand for generators with greater power in recent years has been increasingly met by sales and installation of stationary stand-by generators.

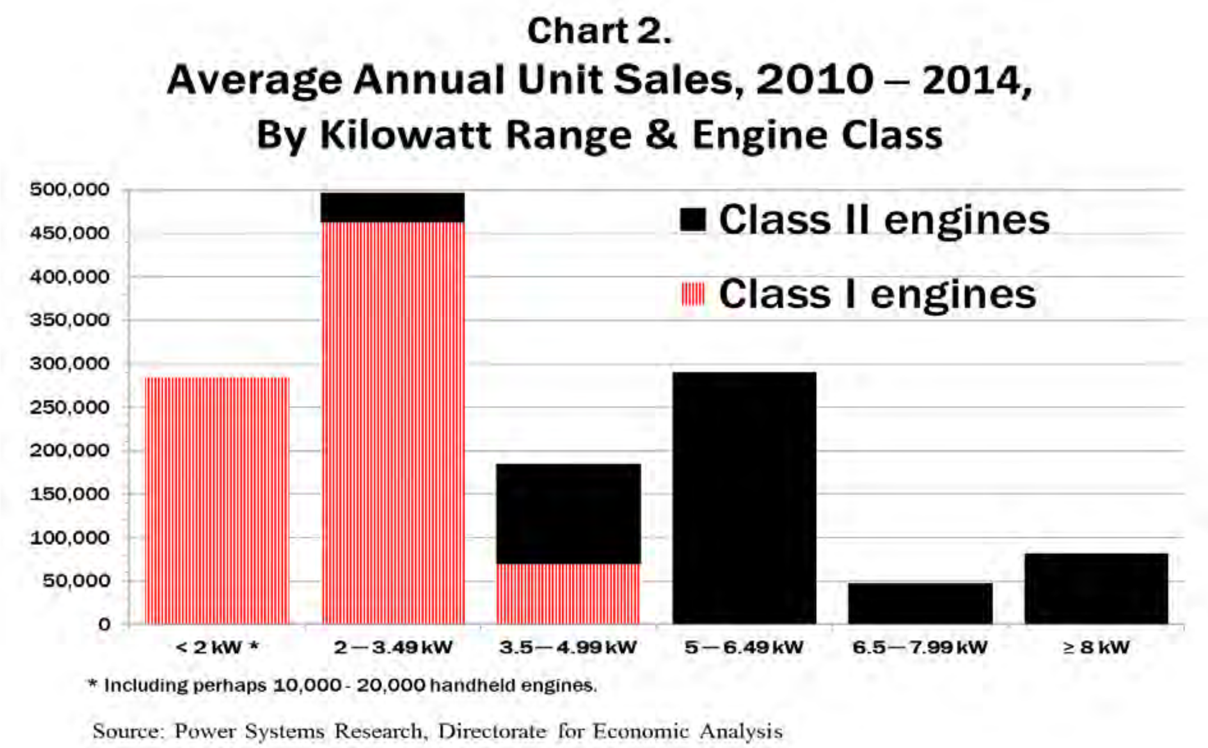
Engine Classes

Small spark-ignition engines used in the manufacture of portable generators are classified (by EPA and for the CPSC proposed rule) according to their total cylinder displacement in cubic centimeters (cc). Data on this engine characteristic were obtained from PSR and individual firms for recent shipments of portable generators, which enabled CPSC to estimate engine classes for the kilowatt ranges discussed above. Data on shipments of portable generators for 2010 through 2014 show that portable generators with Class I engines (those with a total cylinder displacement of < 225 cc) comprised about 59 percent of units shipped, and those with Class II engines (those with total displacement ≥ 225 cc) comprised about 41 percent. We estimate that total annual shipments of portable generators over 2010 to 2014 averaged almost 1.4 million units; about 816,000 of these generators had Class I engines and about 568,000 had Class II engines.

Although sometimes used in non-handheld equipment (such as portable generators), engines are classified as handheld by EPA if they have total displacement of less than or equal to 80 cc. Based on information provided by PSR and individual firms, we estimate that generators with handheld engines account for an average of about 10,000 to 20,000 units sold annually; about 1 percent of the overall consumer market for portable generators; and perhaps 2 percent of the units with smaller (< 225 cc) engines.

Chart 2 shows the relationship between rated kilowatt power of portable generators and their engine classes for 2010 through 2014. As can be seen, generators with rated power of under 2 kW were made with Class I engines; and virtually all of those with rated power of 5 kW or greater were made with Class II engines. For units with 2 to 3.49 kW (which was the largest single kW category, accounting for 36 percent of units in 2010 to 2014), the great majority

(93%) were made with Class I engines, while a majority (63%) of units with rated power in the range of 3.5 to 5 kW were made with Class II engines.



Engine Cylinders

Engines used in the manufacture of portable generators intended for consumer use have either one or two cylinders for combustion of fuel. Based on information on engine characteristics gathered and reported by PSR, virtually all of the portable generators with sustained power ratings below 6.5 kW that were sold from 2010 to 2014 were powered with one-cylinder engines. These power categories comprised about 91 percent of all units purchased by consumers during that period, as shown in Table 1. PSR data reveal that one-cylinder engines powered about 91 percent of the generators with 6.5 to 7.99 kW and about 58 percent of units with power ratings from 8 to 9.99 kW. It is in more powerful generators, with sustained power ratings of 10 kW and greater, that two-cylinder engines are more common, accounting for about 93 percent of units sold from 2010 to 2014. Overall, the data indicate that one-cylinder engines were used in the manufacture of at least 95 percent of total unit sales of portable generators to consumers, and in about 89 percent of the Class II engines used to produce portable generators.

Fuel Distribution Systems

The Commission believes that compliance with the CO emission requirements of the proposed rule likely would lead OEM manufacturers of portable generators to select engines that have fuel distribution systems that are more capable of controlling air-to-fuel ratios than traditional carbureted systems.[87] Specifically, manufacturers are expected to switch to use of electronic fuel injection (EFI) instead of conventional carburetors to control the delivery of gasoline to the pistons of generator engines. The Commission is aware of at least five portable generator manufacturers that have either developed models with EFI for evaluation or actually marketed such models within the last 2 years; and some of these models have been evaluated by the Commission at the National Product Test and Evaluation Center.[88] However, virtually all generators currently in consumer use have carbureted fuel distribution systems.

Engine Cycles

Spark-ignition engines used in portable generators have either two or four piston strokes per combustion cycle. Two-stroke engines have simpler designs with fewer moving parts, making them easier to maintain and lighter in weight at a given displacement than four-stroke engines. They also reportedly can produce up to 40 percent more power than four-stroke engines with the same displacement (MECA, 2009). These characteristics, and the ability to operate in

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[87] Tab I of staff's briefing package.

[88] See Tab J of staff's briefing package.

many directions without flooding, make two-stroke engines attractive for use in handheld equipment, such as chainsaws, trimmers and leaf-blowers. Portable generators and other larger non-handheld equipment, such as lawn and garden equipment and pressure-washers, typically have 4-stroke engines. Although all of the portable generators reported in PSR's database of recent shipments had 4-stroke engines, the Commission found portable units with small (< 80 cc) 2-stroke engines advertised for sale on internet websites. These units likely comprise an extremely small share of the market for portable generators.

Retail Prices

With the wide range of engine power and other features available on portable generators shipped in recent years, these products also have been offered to consumers at a wide range of retail prices. The most recent survey data on retail prices was provided to the Commission by Synovate and covered the years 2004 through 2006. Consumer survey data developed by Synovate found that the average retail price paid by consumers for portable generators intended primarily for backup power in the event of electric power outages (the primary stated purpose for the purchase by about 75% of consumers) was about $1,040 in 2006.

More recent pricing information was gained through an informal survey of advertised prices for portable generators by CPSC staff in October 2015 (which included units available in stores and via the Internet). This survey found that that retail prices generally vary by kW rating of the units, engine class and number of cylinders. For rated generator power, average prices were $393 for units under 2 kW; $606 for 2 to 3.49 kW generators; $640 for 3.5 to 4.99 kW units; $936 for those with 5 to 6.49 kW ratings; $1,002 for units with 6.5 to 7.99 kW ratings; and $1,745 for units with kW ratings of 8 or more. Generator characteristics other than power ratings also affect price. For example, "inverter generators" have electronic and magnetic components that convert the AC power to DC power, which is then "inverted" back to clean AC power that maintains a single phase, pure sine wave at the required voltage and frequency suitable for powering sensitive equipment, such as computers. These additional components add to the manufacturing cost, resulting in significantly higher retail prices than units with similar power outputs. For example, our limited retail price survey found that the average retail prices of generators with power ratings of under 2 kW were $242 for units not identified as inverters and $710 for those identified as inverters.

Regarding retail price information by engine class and number of cylinders, staff's informal survey found that generators with handheld engines ranged in price from $133 to $799, with an average price of about $324. Generators with non-handheld Class I engines had a wide price range, from $190 to more than $2,000, with an average price of $534. Generators with one-cylinder Class II engines ranged in price from $329 to $3,999, with an average price of $1,009. Generators with two-cylinder Class II engines ranged in price from $1,600 to $4,999, and the average price of these units was $2,550.

Table 7 shows selected characteristics (displacement, power rating, price and weight) for generators found in an informal retail market survey of generators, by engine class and type.

Table 7.
Sample Characteristics of Portable Generators Recently Marketed, by Engine Class/Type

Product Characteristic		Handheld	Class I	One-Cylinder, Class II	Two-Cylinder, Class II
	Sample size (n)[1]	(43)	(261)	(412)	(35)
Engine Displacement (cc)	Range	31 to 80	87 to 224	250 to 459	530 to 992
	Average	67.7	185.6	389.2	703.9
	Median	79	206	389	680
Power Ratings (watts)	Range	450 to 1,700	1000 to 4,375	3,500 to 9,200	9,000 to 17,500
	Average	1,094	2,968	6,230	11,771
	Median	1,050	3,250	6,200	10,500
Retail Prices	Range	$133 to $799	$190 to $2,324	$329 to $3,999	$1,600 to $4,999
	Average	$324 (24)	$534 (151)	$1,009 (226)	$2,550 (20)
	Median	$225 (24)	$439 (151)	$899 (226)	$2,439 (20)
Weight (lbs.)	Range	19 to 62	45.6 to 140	115 to 320	278 to 471
	Average	44.6 (22)	101.8 (124)	204.3 (174)	333.8 (14)
	Median	46.0 (22)	105.5 (124)	204.0 (174)	330.0 (14)

Source: Directorate for Economic Analysis, CPSC, informal market survey of portable generators offered for sale by selected major retailers in 2015 and 2016 (price information limited to 2015).

[1] Sample size pertains to engine displacement and power rating. Smaller sample sizes for retail prices and weights are reported with the averages and medians for those product characteristics.

D. Portable Generators in Use

In this section, we estimate the population of portable generators in use, averaged over the period 2004 to 2012, analyzed by the Directorate for Epidemiology, Division of Hazard Analysis.[89] Estimates of the number of generators in use represent a measure of risk exposure and is the necessary first step in calculating product-related risks (*e.g.*, generator-related deaths and injuries divided by the population of generators in use), determining the per-unit societal

[89] Tab A of staff's briefing package.

costs of deaths and injuries that would be addressed by the proposed standard, and finally, estimating the possible benefits of the proposed rule.

We estimated the population of portable generators in use with the CPSC's Product Population Model (PPM), a computer model that projects the number of products in use, given estimates of annual product sales and their expected product life.[90] The expected useful life of generators, in years, is largely a function of engine size, loads placed upon the unit and hours of use. Portable generators primarily purchased for household backup power that are mainly used during occasional or rare power outages could have useful lives much longer than 10 years if they are maintained properly. An evaluation of data on historical sales in relation to surveys of product ownership suggests an expected useful product life of about 11 years. An assumption of a considerably shorter expected useful life using data on historical annual unit shipments would yield estimated numbers of units in use and saturation rates that are well below those indicated by Synovate survey data from 2005, as well as industry estimates of ownership in recent years.[91]

Table 8 presents the product population estimates for the years 2004 through 2012; estimated totals have increased from about 9.9 million in 2004, to about 12.5 million in 2012. The average for the years 2004 to 2012 was about 11.1 million units in use. Table 8 also presents estimates of the numbers of portable generators in use by ranges of kW ratings. These estimates were based on (1) portable generator shipment and purchase data provided by PSR and Synovate for the years 2004 through 2013, augmented by estimates of annual sales developed for some individual manufacturers; and (2) estimates of aggregate annual sales for prior years, in

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[90] Lahr, M.L. & Gordon, B.B. (1980). Product life model feasibility and development study. Contract CPSC-C-79-009, Task 6, Subtasks 6.01-6.06). Columbus, OH: Battelle Columbus Laboratories.
[91] For example, portable and stationary generator manufacturer, Generac, reportedly estimated that about 12 percent of households had portable generators in 2013, up from 10 percent in 2010 (Hill, 2013).

combination with Synovate estimates of market shares for the various power categories for previous years. The PPM was then used to estimate the product population for each power category, assuming an 11-year average product life. According to the population estimates, the largest power category was generators 5 to 6.49 kW, accounting for an average of 3.6 million units in use, or about 33 percent of the total, followed by generators 3.5 to 4.99 kW (averaging about 2 million units and 18.2% of the total).

Table 8. Estimated Units of Portable Generators in Use, by Generator kW Ratings, 2004 - 2012

Year	< 2 kW	%	2—3.49 kW	%	3.5—4.99 kW	%	5—6.49 kW	%	6.5—7.99 kW	%	8 kW +	%	Total
2004	1,164,937	11.8%	1,514,418	15.3%	2,003,691	20.2%	3,307,573	33.4%	1,125,797	11.4%	785,440	7.9%	9,901,855
2005	1,169,828	11.2%	1,507,610	14.5%	2,052,923	19.7%	3,620,229	34.8%	1,218,983	11.7%	843,880	8.1%	10,413,454
2006	1,138,111	10.9%	1,494,780	14.3%	2,026,543	19.4%	3,684,521	35.3%	1,234,027	11.8%	865,844	8.3%	10,443,826
2007	1,138,122	10.8%	1,507,516	14.3%	2,019,291	19.2%	3,721,225	35.3%	1,246,975	11.8%	908,152	8.6%	10,541,281
2008	1,225,495	11.2%	1,657,508	15.2%	2,029,573	18.6%	3,804,931	34.8%	1,246,355	11.4%	965,614	8.8%	10,929,475
2009	1,382,555	12.3%	1,945,110	17.3%	2,006,405	17.8%	3,755,195	33.4%	1,189,234	10.6%	966,810	8.6%	11,245,308
2010	1,565,789	13.5%	2,278,780	19.6%	2,001,427	17.2%	3,686,827	31.7%	1,133,894	9.8%	962,137	8.3%	11,628,854
2011	1,724,038	14.4%	2,579,743	21.6%	1,988,252	16.6%	3,641,605	30.4%	1,071,810	9.0%	961,550	8.0%	11,966,999
2012	1,906,637	15.3%	2,943,773	23.6%	2,001,557	16.1%	3,626,361	29.1%	1,012,496	8.1%	968,748	7.8%	12,459,571
9-Year Average	1,379,501	12.5%	1,936,582	17.5%	2,014,407	18.2%	3,649,830	33.0%	1,164,397	10.5%	914,242	8.3%	11,058,958

Source: CPSC Directorate for Economic Analysis, based on Product Population Model evaluation of estimated historical sales.

Note that the estimates provided in Table 8 assume uniform expected product lives across engine sizes and power ratings; that is, the generators with smaller engine sizes are assumed to last as long as the larger engine sizes. Larger engines usually are rated for more hours of operation than smaller engines. Assuming the hour ratings reflect the relative differences in total hours of actual use, our estimates imply fewer hours of use per year for smaller generators versus larger units over their useful lives. This issue is addressed in the sensitivity analysis, and information regarding product lives of units and average annual hours of operation would be welcome from industry and the public.

The proposed rule specifies different requirements for CO emission rates depending on generator engine class and other objective characteristics, rather than engine or generator power ratings. The Directorate for Economic Analysis has estimated historical sales of generators by engine class from estimated sales by kW ratings using data from PSR reporting both generator power and engine displacement. Table 9 presents estimated units in use for 2004 to 2012, by engine class. Based on our analysis, the proportion of generators with smaller engines (handheld and Class I) has increased over the 9-year period. This is consistent with estimates of the increasing share of generators in use with power ratings of under 3.5 kW, shown in Table 8, which follows from the information presented regarding the apparent shift in the U.S. market towards smaller, less powerful units.

Table 9.

Estimated Units of Portable Generators in Use, by Generator Engine Class, 2004 – 2012

Year	Handheld Engines		Class I Engines		Class II Engines				All Units
					1-Cylinder		2-Cylinders		
	Units	Percent	Units	Percent	Units	Percent	Units	Percent	
2004	67,418	0.7%	3,317,468	33.5%	5,826,761	58.8%	690,209	7.0%	9,901,855
2005	67,701	0.7%	3,335,886	32.0%	6,266,611	60.2%	743,256	7.1%	10,413,454
2006	65,866	0.6%	3,283,911	31.4%	6,333,338	60.6%	760,711	7.3%	10,443,826
2007	65,866	0.6%	3,293,317	31.2%	6,390,317	60.6%	791,781	7.5%	10,541,281
2008	70,923	0.6%	3,521,657	32.2%	6,504,141	59.5%	832,755	7.6%	10,929,475
2009	80,012	0.7%	3,932,257	35.0%	6,405,261	57.0%	827,778	7.4%	11,245,308
2010	90,616	0.8%	4,418,072	38.0%	6,301,520	54.2%	818,646	7.0%	11,628,854
2011	99,775	0.8%	4,846,279	40.5%	6,208,911	51.9%	812,035	6.8%	11,966,999
2012	110,342	0.9%	5,367,384	43.1%	6,170,376	49.5%	811,468	6.5%	12,459,571
9-Year Average	79,835	0.7%	3,924,026	35.5%	6,267,471	56.7%	787,626	7.1%	11,058,958

Source: CPSC Directorate for Economic Analysis, based on Product Population Model evaluation of estimated historical sales.

E. Benefit –Cost Analysis

This section of the analysis consists of a comparison of the benefits and costs of the proposed rule. The analysis is conducted from a societal perspective, considering all of the significant costs and health outcomes. Benefits and costs are calculated on a per-product-in-use basis. The benefits are based on the reduced risk of fatal and nonfatal injury due to CO poisoning involving portable generators. The costs are defined as the added costs of making the portable generators comply with the proposed rule.

Our primary outcome measure is the expected net benefits (*i.e.*, benefits minus costs) of the proposed rule. As noted above, our primary analysis calculates the benefits and costs of the rule on a per-product-in-use basis. However, aggregated estimates of the benefits and cost on an annual basis can be readily calculated, given projections of annual generator sales.

1. Societal Costs of Portable Generator Deaths and Injuries

As discussed in Section III, the Directorate for Epidemiology, Division of Hazard Analysis (EPHA) reports that there were 659 deaths involving portable generators from 2004 to 2012, an average of about 73 annually.[92] The average annual societal costs of these CO deaths are estimated to be about $637 million in 2014 dollars, based on a value of a statistical life (VSL) of $8.7 million.[93]

EPHA also provided an estimate of CO-related injuries involving portable generators, based on estimates from the National Electronic Injury Surveillance System (NEISS) during the years 2004 through 2012.[94] According to EP, there was a minimum of 8,703 nonfatal CO poisonings involving portable generators that were treated in hospital emergency departments from 2004 through 2012, or a minimum of about 967 annually.[95] This NEISS estimate is considered a

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[92] Tab A of staff's briefing package.

[93] The estimated value of a statistical life (VSL) of $8.7 million (in 2014 dollars) is a revision of the VSL estimated by the U.S. Environmental Protection Agency and is generally consistent with other estimates based on willingness-to-pay. Kneiser et al. (2012), suggested that a reasonable range of values for VSL was between $4 million and $10 million (in 2001 dollars), or about $5.3 million to $13.3 million in 2014 dollars (BLS 2015).

[94] Stephen Hanway, Division Director, Division of Hazard Analysis, Directorate for Epidemiology, CPSC. Memorandum to Gregory B. Rodgers, AED, Directorate for Economic Analysis, CPSC: "Injuries associated with generators seen in emergency departments with narratives indicative of CO poisoning 2004-2012 for injury cost modeling," October 6, 2015.

[95] Tab H of staff's briefing package.

minimum because the estimate only included injuries that were explicitly attributed to CO poisoning injuries in the NEISS narrative.

The NEISS injury estimates are limited to individuals initially treated in hospital emergency departments. However, the CPSC's Injury Cost Model (ICM) uses empirical relationships between the characteristics of injuries and victims in cases initially treated in hospital emergency departments and those initially treated in other medical settings (e.g., physicians' offices, ambulatory care centers, emergency medical clinics), based primarily on data from the Medical Expenditure Panel Survey,[96] to estimate the number of medically attended injuries that were treated outside of hospital emergency departments. The ICM also analyzes data from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project[97] to project the number of direct hospital admissions bypassing the hospital emergency departments. According to the ICM estimates, there were an additional 16,660 medically attended injuries during 2004 to 2012, or about 1,851 annually. Consequently, based on NEISS and ICM estimates, there was a minimum of about 2,818 medically attended injuries (967 ED + 1,851 non-ED) treated annually during the 9-year period.

The ICM is fully integrated with NEISS and provides estimates of the societal costs of injuries reported through NEISS, as well as the costs associated with the estimated medically

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[96] The Medical Expenditure Panel Survey (MEPS) is a nationally representative survey of the civilian non-institutionalized population that quantifies individuals' use of health services and corresponding medical expenditures. The MEPS is administered by the Agency for Healthcare Research and Quality (AHRQ). The MEPS has been collected continuously since 1999 and is the principal data set used to monitor medical spending in the U.S.

[97] The National (Nationwide) Inpatient Sample (NIS) is part of a family of databases and software tools developed for the Healthcare Cost and Utilization Project (HCUP). The NIS is the largest publicly available all-payer inpatient health care database in the United States, yielding national estimates of hospital inpatient stays. HCUP is a family of health care databases and related software tools and products developed through a Federal-State-Industry partnership and sponsored by the Agency for Healthcare Research and Quality (U.S. Department of Health & Human Services).

attended injuries treated outside of hospital emergency departments. The major aggregated societal cost components provided by the ICM include medical costs, work losses, and the intangible costs associated with lost quality of life or pain and suffering.

Medical costs include three categories of expenditures: (1) medical and hospital costs associated with treating the injury victim during the initial recovery period and in the long run; the costs associated with corrective surgery; the treatment of chronic injuries, and rehabilitation services; (2) ancillary costs, such as costs for prescriptions, medical equipment, and ambulance transport; and (3) costs of health insurance claims processing. Cost estimates for these expenditure categories were derived from a number of national and state databases, including the Medical Expenditure Panel Survey, the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project, the Nationwide Emergency Department Sample,[98] the National Nursing Home Survey,[99] MarketScan®[100] claims data, and a variety of other federal, state, and private data.

Work loss estimates are based on information from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project, the Nationwide Emergency Department Sample, Detailed Claims Information (a workers' compensation database), the National Health Interview Survey, the U.S. Bureau of Labor Statistics and other sources. These estimates include: (1)

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[98] The Nationwide Emergency Department Sample (NEDS) is part of a family of databases and software tools developed for the Healthcare Cost and Utilization Project (HCUP). The NEDS is the largest all-payer emergency department (ED) database in the United States, yielding national estimates of hospital-based ED visits.

[99] The National Nursing Home Survey (NNHS) is a series of nationally representative sample surveys of United States nursing homes, their services, their staff, and their residents. The NNHS was first conducted in 1973-1974 and repeated in 1977, 1985, 1995, 1997, 1999, and most recently in 2004.

[100] The MarketScan® Commercial Claims and Encounters (MarketScan) Database from Truven Health Analytics contains de-identified, person-specific health data of reimbursed healthcare claims for employees, retirees, and their dependents of more than 250 medium and large employers and health plans.

forgone earnings of the victim, including lost wage work and household work; (2) forgone earnings of parents and visitors, including lost wage work and household work; (3) imputed long-term work losses of the victim that would be associated with permanent impairment; and (4) employer productivity losses, such as the costs incurred when employers spend time juggling schedules or training replacement workers.

Intangible, or noneconomic, costs of injury reflect the physical and emotional trauma of injury, as well as the mental anguish of victims and caregivers. Intangible costs are difficult to quantify because they do not represent products or resources traded in the marketplace. Nevertheless, they typically represent the largest component of injury cost and need to be accounted for in any benefit-cost analysis involving health outcomes.[101] The ICM develops a monetary estimate of these intangible costs from jury awards for pain and suffering. Although these awards can vary widely on a case-by-case basis, studies have shown them to be systematically related to a number of factors, including economic losses, the type and severity of injury, and the age of the victim (Viscusi, 1988; Rodgers, 1993).[102] Estimates for the ICM were derived from regression analysis of jury awards compiled by Jury Verdicts Research, Inc., for nonfatal product liability cases involving consumer products.

[101] Rice, D., MacKenzie, E. & Associates (1989). Cost of injury in the United States: A report to Congress. San Francisco, CA: Institute for Health & Aging, University of California and Injury Prevention Center, The Johns Hopkins University.

[102] Viscusi, W.K. (1988). The determinants of the disposition of product liability cases: Systematic compensation or capricious awards? *International Review of Law and Economics*, 8, 203-220; Rodgers, G. (1993). Estimating jury compensation for pain and suffering in product liability cases involving nonfatal personal injury. *Journal of Forensic Economics* 6€, 251-262.

According to the ICM, the estimated injury costs of the approximately 2,817 medically attended portable generator CO injuries annually amounted to about $184 million (in 2014 dollars), an estimated average of $65,400 per injury. Medical costs and work losses accounted for about 53 percent of the total, while the non-economic losses associated with pain and suffering accounted for about 47 percent. The societal costs of both fatal and nonfatal CO poisoning injuries involving portable generators amounted to about $821 million ($637 million for fatal injuries + $184 million for nonfatal injuries) annually.

The average annual societal cost estimates for generators in use in 2004 through 2012, by engine class, are presented in more detail in Table 10. Row 1 provides the annual estimates of fatal CO poisoning injuries by engine class, and the estimated percent of all deaths involving each category. Note that information on engine class for generators involved in the deaths was available on only about 48 percent of the cases. The cases in which the engine classes were not known were distributed proportionally to the cases in which the classes were known.

Row 2 shows estimated annual nonfatal injuries by engine class; the nonfatal CO injuries were distributed proportionally to the deaths because very little information is available on the displacement of engines of generators involved in these injuries. Row 3 provides estimates of the aggregate annual societal costs of the deaths and injuries. Societal costs were based on a VSL of $8.7 million per death, and the nonfatal injury costs are from the ICM modeling. Row 4 provides the annual estimates of portable generators in use by engine class, as well as the estimated percent of all units in use for each category. Row 5 provides annual per-unit societal costs of deaths and injuries, which is based on the Row 3 estimates divided by the estimated numbers of portable generators in use (shown in Row 4).

Table 10.
Estimated Units of Portable Generators in Use and Expected Societal Costs of CO Poisoning, by Generator Engine Class, 2004 – 2012

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinder	
Estimated Deaths / Year (Percent)	0.5 0.7%	25.6 35.0%	46.2 63.0%	0.9 1.2%	73.2 100.0%
Estimated Nonfatal Injuries / Year	21	986	1,776	34	2,818
Aggregate Annual Societal Costs of Deaths and Injuries (million $)	$6.0	$287.6	$517.8	$10.0	$821.3
Estimated Number of Units in Use (Average, 2004 – 2012) (Percent)	79,835 0.7%	3,924,026 35.5%	6,267,471 56.7%	787,626 7.1%	11,058,958 100.0%
Annual Societal Costs of CO Poisonings / Unit	$74.90	$73.29	$82.62	$12.66	$74.27
Total Present Value of Expected Societal Costs of Deaths and Injuries / Unit	$687	$672	$758	$116	$682

Finally, Row 6 provides per-unit estimates of the present value of the expected societal costs (at a 3% discount rate) over the expected product life of a generator. This figure is useful in benefit-cost analysis because it represents the maximum per-unit benefits that might be derived from a product safety standard, if the standard prevented all deaths and injuries. The present value of expected societal costs is $687 per unit for portable generators with handheld engines (which are estimated to have accounted for less than 1% of units in use during the period 2004 through 2012); $672 per unit for generators with Class I engines (35.5% of units in use); $758 per unit for generators with one-cylinder Class II engines (56.7% of units in use); and $116 per unit for generators with two-cylinder Class II engines (7.1% of units in use). The societal costs associated with the two-cylinder Class II generators are substantially lower than for the other generator categories because of the small relative risk for the two-cylinder models. Because the two-cylinder models accounted for about 7.1 percent of generators in use, but only about 1.2 percent of the deaths, the risk of death with two-cylinder generators was only about 16 percent of the risk associated with generators with one-cylinder engines (*i.e.*, handheld, Class I, and one-cylinder Class II generators). The average expected present value of societal costs of CO poisoning deaths and injuries for all portable generators is $682 per unit. These calculations also represent baseline estimates of the societal costs associated with portable generators, by engine class and other characteristics: estimates of what per-unit societal costs would be in the absence of regulatory action. Benefits of the proposed rule can, therefore, be estimated as the expected reduction in the baseline societal costs.

2. Estimated Benefits of the Proposed Rule

As described in Section IX, the requirements of the proposed performance standard require portable generators powered by handheld engines and Class I engines to emit CO at a weighted rate that is no more than 75 grams per hour (g/hr); generators powered by one-cylinder Class II engines to emit CO at a weighted rate that is no more than 150 g/hr; and generators powered by two-cylinder Class II engines to emit CO at a weighted rate that is no more than 300 g/hr. As noted in CPSC staff's analysis that provides the rationale for the performance requirements, considering expected manufacturing variability of ±50 percent, based on limited testing of pairs of generators, as described in the staff's briefing package, these emission requirements reflect a factor of 1.5 over the expected technically feasible emission rates for each engine classification: 50 g/h for those with handheld and Class I engines; 100 g/h for those with one-cylinder Class II engines; and 200 g/h for those with two-cylinder Class II engines.[103] Comments and additional

[103] Tab I of staff's briefing package.

data on expected manufacturing variability would be welcome, given the limited data available to staff to evaluate variability.

To estimate the expected reduction in societal costs, and hence, the benefits from the proposed rule for portable generators, an interdisciplinary analysis by CPSC staff provided estimates of generator-related consumer CO poisoning deaths reported in the agency's databases that could have been avoided as a result of reduced CO emission rates from generators. An important part of the analysis was indoor air quality modeling by NIST under an interagency agreement to estimate the transport of CO emitted from generators and predicted health effects for scenarios and house characteristics found in CPSC's incident data. CPSC staff then compared the health effects resulting from emission rates from current generators to a range of lower CO emission rates to estimate deaths that could have been avoided for each emission rate.[104]

The NIST modeling and CPSC staff analysis considered scenarios associated with 503 CO poisoning deaths over 2004 to 2012, or about 76 percent of the 659 CO poisoning deaths in CPSC records over the 9-year period. These deaths occurred at various fixed-structure residential settings, including traditional houses, mobile homes, townhomes, and structures attached to a home, in addition to residential sites where generators were operated in separate structures, such as sheds cabins used for temporary (non-residential) shelter and detached garages. For the purposes of this analysis, deaths and injuries occurring in these settings are considered to be those that would be which would be addressable by the proposed rule. However, we note that an

[104] See Tab K of staff's briefing package.

unquantified number of the 156 deaths not modeled by NIST might be addressed and prevented by the proposed rule.[105]

Chart 3 presents the results of CPSC staff analyses of estimated reductions in CO poisoning fatalities that would result from lower-weighted emission rates for modeled scenarios under various weighted CO emission rates. At each reduced emission rate, the estimated percentage reduction in fatalities is greater for generators powered with larger engines because of their higher average estimated base rate for CO emissions (4700 g/h for one-cylinder and 9100 g/h for two-cylinder Class II engines vs 1800 g/h for Class I non-handheld engines and 900 g/h for handheld engines).[106] In CPSC engineering staff's judgment, the technically feasible weighted CO emission rates are 50 g/h for generators powered by handheld and Class I engines, 100 g/h for generators powered by one-cylinder Class II engines, and 200 g/h for generators with two-cylinder Class II engines.[107]

Emission rates from generators meeting the proposed performance requirements are expected to be higher while operating indoors (at reduced oxygen levels of approximately 17%) than the feasible rates under conditions of approximately 20.9% oxygen: perhaps 150 g/h for generators with handheld engines and Class I engines, 300 g/h for generators with one-cylinder Class II engines and 600 g/h for generators with two-cylinder Class II engines (three times the

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[105] *IBID.*

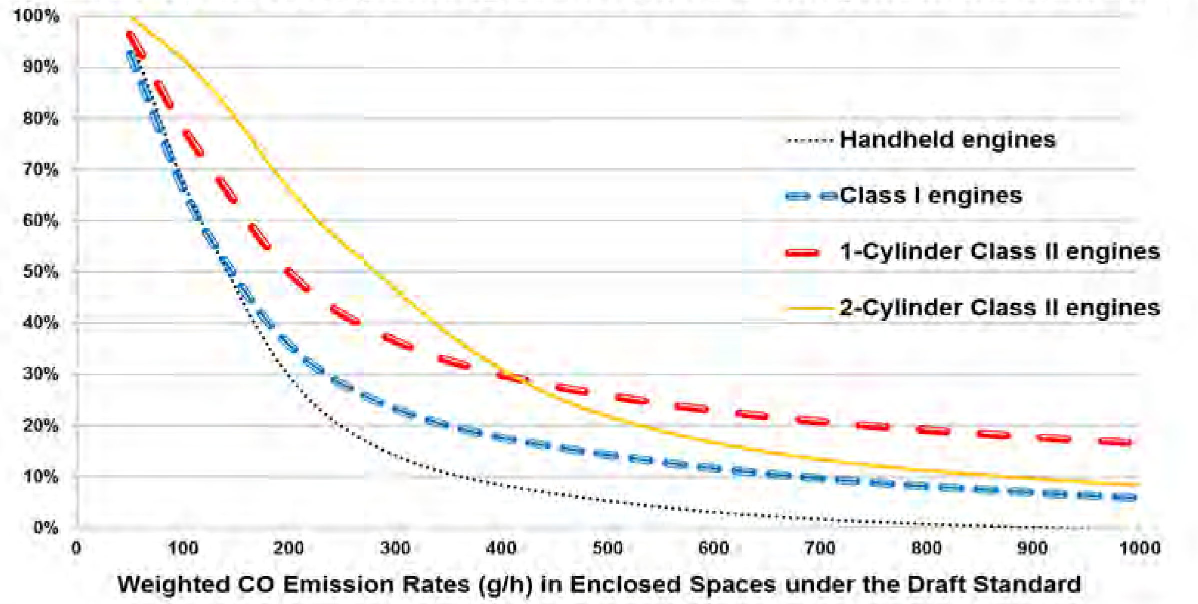
[106] These rates assume a factor of 3 in the increase in CO emission rate of a generator operating in an enclosed space compared to operation outdoors in normal oxygen. This factor of 3 is based on testing of carbureted generators conducted by NIST (Emmerich, Polidoro & Dols, *op. cit.*) and CPSC staff (Brookman, 2016, TAB J of the NPR Briefing Package).

[107] See Tab I of staff's briefing package.

technically feasible rate for each generator category).[108] Based on staff's analysis of 503 deaths (76 percent of all deaths) modeled by NIST (and generally deemed to be addressable by the proposed standard), these emission rates are expected to result in about a 47 percent reduction in (addressable) fatalities involving generators with handheld engines; about a 49 percent reduction in fatalities involving generators with Class I engines; a 37 percent reduction for those with one-cylinder Class II engines: and a reduction of about 17 percent for generators with two-cylinder Class II engines. The average expected reduction in CO poisoning fatalities across generators of all engine types is about 44 percent of the addressable deaths and injuries, or about 33 percent of all generator-related deaths and injuries (44% x 76%).

[108]Based on CPSC's testing of three generators with fuel-injected engines having different degrees of closed-loop operation (see TAB J of staff's briefing package), CPSC believes the factor of increase when the oxygen is 17 percent may be less than 3 for some generators that use closed-loop EFI. Furthermore, test results from NIST (Buyer, 2012) indicate the prototype EFI generator depleted the oxygen significantly less than the carbureted generator, when tested in each of four matched-pair identical test scenarios. Nevertheless, CPSC assumes in the benefits analysis a conservative factor of 3 for the increase in CO emissions for low-emission generators when operating at reduce oxygen levels of 17 percent. Therefore, the factor of 3 likely overstates the weighted CO emission rates for EFI generators when operated indoors, and understates the reduction in deaths and injuries resulting from the draft standard.

Chart 3.
Estimated Reduction (%) in CO Poisoning Fatalities for Scenarios Modeled by NIST, Depending on CO g/h Resulting from the Standard*



* Estimated base CO emission rates at reduced O_2 average about 900 g/h for generators with handheld engines; 1800 g/h for generators with non-handheld Class I engines; 4700 g/h for generators with one-cylinder Class II engines and 9100 g/h for generators with two-cylinder Class II engines.

Table 11 presents estimated reductions in societal costs, and hence, benefits of the reduced CO emissions predicted to result from the proposed standard. The per-unit societal costs per generator, from Table 10, are included at row 1. However, as noted above, not all of these costs would be addressed by the proposed standard or were not included among the major residential scenarios modeled by NIST.[109] The present value of expected societal costs of CO poisoning that would be addressed by an emission standard are shown in row 2 and average about $514 for generators with Class I engines and about $586 for generators with one-cylinder Class II engines─engine categories that combine for an estimated 92 percent of portable

[109] About 76 percent of all CO poisoning deaths from 2004 to 2012 involved scenarios that were modeled by NIST. Among the scenarios that were not modeled are those involving CO poisoning deaths in apartments, vehicles and trailers (non-mobile homes), and other structures, such as a church, a sea-land container, and tents.

generators in use. Generators with handheld engines, estimated to account for less than 1 percent of units in use, are estimated to average $525 in societal costs. Generators with two-cylinder Class II engines are estimated to average $26 in societal costs of CO poisoning over their useful lives. These larger generators are estimated to account for about 7 percent of all units in use.

Row 3 shows the staff's estimates of weighted CO emissions from complying generators of the different engine categories that would result from operation in conditions of reduced oxygen. Row 4 shows the estimated reduction in addressable societal costs resulting from the weighted emission rates, based on CPSC staff's estimate of the reduction in CO poisoning deaths.[110] Our estimate of reduction in societal costs of CO poisoning deaths and injuries assumes that projected injury costs from annual production of generators will fall in proportion to estimated death reduction, with a minor adjustment to account for the possibility that deaths avoided by reduced CO emissions would still occur as injuries.[111] With projected reductions in deaths and injuries under the proposed standard, the present value of benefits (shown in row 5 of Table 10) is estimated to average about $243 for generators with handheld engines; $254 per unit for generators with Class I engines; $214 per unit for generators with one-cylinder Class II engines; and $4 for generators with two-cylinder Class II engines. Average projected present value of benefits for all portable generators is about $227 per unit.

Multiplying the present value of expected benefits per unit by estimated annual unit sales (in row 6) yields the estimated aggregate present value of benefits from annual sales of portable generators that would comply with the proposed standard. The estimated present value of

[110] Tab K of the staff's briefing package.

[111] We have assumed that avoided deaths under the proposed rule would still occur as nonfatal CO injuries of average severity and cost.

benefits of reduced CO poisoning from complying portable generators sold in a year totals about $315 million. Nearly 99 percent of the total benefits are attributable to expected sales of generators with Class I engines and one-cylinder Class II engines. These two types of engines are expected to comprise about 94 percent of annual unit sales under the proposed standard.

Table 11.
Estimated Present Value of Societal Costs from CO Poisoning Involving Portable Generators and Expected Benefits Under the Proposed Standard, by Generator Engine Class & Characteristics

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinders	
Total Present Value of Expected Societal Costs of Deaths and Injuries / Unit	$687	$672	$758	$116	$682
Estimated Present Value of Societal Costs per Unit Addressed by The Draft Standard	$525	$514	$586	$26	$520
Estimated Weighted CO Emission Rate Under the Draft Standard in Conditions of Reduced Oxygen	150	150	300	600	
Estimated Reduction in Addressable Societal Costs of CO Poisoning*	47%	50%	37%	17%	44%
Expected Benefits per Unit: Present Value of Expected Reduction in Societal Costs	$243	$254	$214	$4	$227
Estimated Annual Unit Sales (Percent)	15,000 1.1%	800,502 57.8%	503,576 36.4%	64,818 4.7%	1,383,896 100.0%
Present Value of Expected Reduction in Societal Costs from Units Sold Annually (Millions $)	$3.6	$203.1	$107.5	$0.3	$314.5

* Based on estimated reduction in CO poisoning deaths by CPSC staff (Hnatov, Inkster & Buyer, 2016)

Projections of benefits of the proposed rule should account for recent changes, and reasonably expected changes, in the market that will affect societal costs and the costs of compliance by manufacturers. One consideration that would be expected to reduce the addressable societal costs of the rule from those estimated for the period of 2004 to 2012 is the relatively recent introduction of units with EFI. Increased use of EFI would also reduce the costs of compliance with a standard based on reduced CO emissions. However, portable generators with EFI have not yet gained a significant share of the consumer market for portable generators, and we have little basis for incorporating projected sales of EFI units into the analysis. Regarding the introduction of EFI on expected hazard costs, most of the EFI-equipped portable generators have reportedly not targeted reductions in CO emissions, specifically. Therefore, a relatively small share of the generator market would not be expected to contribute to substantial reduction in the overall hazard. However, costs of compliance with a mandatory standard would be greatly reduced for units with EFI systems.

In addition to reducing societal costs related to CO poisoning deaths and injuries, product modifications to achieve greatly reduced CO emissions could also result in improved fuel efficiency and other benefits, including easier starting, altitude compensation, fuel adaptability, improved power, better reliability and longer useful product life.

3. Estimated Costs of Compliance with the Proposed Rule

a. Costs of Compliance Per Unit

Based on the judgment of CPSC engineering sciences staff, the most likely technical means of compliance with the requirements of the proposed rule would be the use of closed-loop electronic fuel-injection systems to achieve and maintain the needed air-to-fuel ratios under different loads and ambient conditions.[112] Another element expected to be part of the industry's technical response to the proposed standard is the addition of 3-way catalysts in the muffler systems of portable generator engines. Besides achieving further reductions in CO emissions, these catalysts would likely serve to reduce HC and NOx emissions for continued compliance with EPA emission standards for small spark-ignition engines.

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[112] Janet L. Buyer, Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator. U.S. Consumer Product Safety Commission, Bethesda, MD. September 2012.

More detailed discussions of the expected product modifications, and other factors leading to cost increases, appear in the following discussion. All cost estimates are expressed in 2014 dollars, for comparison with estimated benefits of the proposed rule.[113]

1.) Electronic Fuel Injection (EFI)

The likely industry switch from engines with carburetors as the means of fuel delivery to closed-loop EFI is expected to be the most significant factor in determining cost increases under the proposed rule. This technology has been used for a number of years on the small spark-ignition engines in small motorcycles and scooters, as well as in more recent years in a variety of other product applications, including lawnmowers/tractors and golf carts. Although some firms have introduced portable generators with EFI for the consumer market in the last couple of years, generators with this fuel delivery system currently account for a very small fraction of sales. Associated components for closed-loop EFI could include the electronic control unit, fuel pump, injector(s), pressure regulator, throttle body, and a variety of sensors, such as manifold air pressure sensor or throttle position sensor, intake air temperature sensor, oil temperature sensor, crank position sensor, and related wiring and hardware, and an oxygen sensor for closed-loop feedback. According to the EPA, the combined costs of these elements for one-cylinder engines (which dominate the market for residential generators) are estimated to be about $90 per unit in 2014 dollars.[114] Cost savings of about $20 per unit are estimated for elimination of the carburetor, yielding estimated net costs of about $70 for the EFI components.

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[113] Cost estimates are adjusted to 2014 dollars by applying changes in the producer price index for riding lawn & garden equipment, a product group with similarities to portable generators.

[114] U.S. Environmental Protection Agency (EPA), (2006, July). Small SI engine technologies and costs, final report. Prepared by Louis Browning and Seth Hartley, ICF International, for the Assessment and Standards Division, Office of Transportation and Air Quality, EPA. Washington, DC. These cost estimates include original equipment

The effectiveness of EFI in controlling the air-fuel ratio with resulting improved engine combustion efficiency and reduced CO emissions was demonstrated by CPSC staff's technology demonstration project,[115] as well as by the EPA.[116] The EPA's demonstration work, which formed the basis of their 2008 analysis of more stringent requirements for HC and NOx emissions of small non-road spark-ignition engines, provides a basis for our evaluation of this technology, specific to portable generators. The EPA estimates are largely consistent with other confidential estimates of costs provided by manufacturers of generators, as well as by a manufacturer of fuel-control components during discussions with CPSC staff.

Most CO poisoning deaths from portable generators occur when generators are used in enclosed spaces, such as in a closed garage, basement, or room in the living space of a house, or in a partially enclosed space, such as in a garage with the garage door opened part way.[117] In such scenarios, the spark-ignition engines are likely to be operating in conditions of decreasing oxygen concentrations in the ambient air. As noted previously, these conditions can make combustion less efficient, thereby increasing CO emission rates as the generators continue to operate, unless the reduced oxygen level is taken into account. CPSC's benefits analysis takes this into consideration by noting that both carbureted and closed-loop fuel-injected generators' CO emission rates increase as the oxygen in the intake air to the generator decreases.[118] In CPSC

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manufacturer markups and warranty markups totaling an estimated 34 percent; such markups were also included in EPA's cost estimates.

[115] Janet L. Buyer, Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator. U.S. Consumer Product Safety Commission, Bethesda, MD. September 2012.

[116] McDonald, Joseph, Olson B, and Murawski M, Demonstration of Advanced Emission Controls for Nonroad SI Class II Engines, SAE paper 2009-01-1899.

[117] Tab A of the staff's briefing package.

[118] See Tabs I and K of the staff's briefing package.

staff's view, compliance with these performance requirements would likely require the use of an oxygen sensor placed in the engine's exhaust stream to provide closed-loop feedback to the fuel-control system. The oxygen sensor sends a voltage signal to the electronic control unit that varies with the amount of oxygen in the engine exhaust. The ECU uses this signal to check that the correct amount of fuel is being metered through the fuel injector to maintain the air/fuel ratio at or near stoichiometry, which is the theoretical point for near-complete combustion and minimized CO emissions. The ECU uses the other sensors to determine how much fuel to provide, and the oxygen sensor provides feedback on whether or not the fuel mixture is correct. In this closed-loop operation, the ECU would continually adjust the fuel mixture to maintain complying CO emission rates. Based on information developed for EPA when its staff considered more stringent requirements for HC and NOx emissions, engine manufacturers that incorporate oxygen sensors in the exhaust streams of portable generator engines could incur variable costs of about $10 per engine (adjusted to 2014 dollars).[119]

In its assessment of costs of this feature for small spark-ignition engines, the EPA (2006) also projected that Class I engines would also require batteries and alternators/regulators at estimated additional costs totaling about $17 (including original equipment manufacturer and warranty markups). As previously noted, data on shipments of portable generators for 2010 through 2014 show that portable generators with Class I engines comprised about 59 percent of units shipped, and those with Class II engines accounted for about 41 percent of units. Therefore, the estimated cost increase per unit for the EFI-related components identified in this section

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[119] U.S. Environmental Protection Agency (EPA) (2008, September). Control of emissions from marine SI and small SI engines, vessels, and equipment: Final regulatory impact analysis. Assessment and Standards Division, Office of Transportation and Air Quality. Washington, DC. Page 6-22; As with EFI cost estimates, this per-unit cost estimate related to oxygen sensors includes original equipment manufacturer and warranty markups totaling 34 percent.

would be about $94 for generators with Class I engines (55% of units); about $79 for generators with one-cylinder Class II engines (about 36%); and about $85 for generators with two-cylinder Class II engines.[120]

We note that it may be technically feasible, and perhaps eventually less costly for manufacturers to incorporate EFI systems that power-up the fuel pump and electronic components by magnets when starter cords are pulled. Battery-less EFI systems have been available in consumer products for several years, including snowmobiles, outboard motors, and motorcycles. However, we are not aware of the current use of this technology in applications with Class I engines. Comments on prospective use (*e.g.*, costs, applicability and challenges) of battery-less EFI for portable generators would be welcome.

2.) Catalysts in Mufflers

Generator manufacturers also are likely to include three-way catalysts[121] in the mufflers of generator engines to achieve the low CO emission rates that would be required by the proposed standard, and still allow compliance with EPA Phase 3 emissions standards for other pollutants in ES staff's judgment.[122] Catalysts assist in chemical reactions to convert harmful components of the engine's exhaust stream (Hydrocarbons [HC] and oxides of nitrogen [NOx] in addition to CO) to harmless gases. According to the Manufacturers of Emission Controls Association (MECA), the catalysts perform this function without being changed or consumed by the reactions that take place. In particular, when installed in the exhaust stream, the catalyst

[120] Two-cylinder engines would require two fuel injectors, which increases costs versus one-cylinder Class II engines.
[121] Three-way catalysts are designed to simultaneously convert three pollutants to harmless emissions: Carbon Monoxide → Carbon Dioxide; Hydrocarbons → Water, and; Oxides of Nitrogen → Nitrogen.
[122] Tab I of staff's briefing package.

promotes the reaction of HC and CO with oxygen to form carbon dioxide and water, and the chemical reduction of NOx to nitrogen is caused by reaction with CO over a suitable catalyst.[123]

In its assessment of the costs of the Phase 3 emission standards for small SI engines, EPA estimated that 3-way catalysts in mufflers of one-cylinder engines of portable generators could add about $10 to $20 in additional hardware costs to the manufacturing costs per engine, depending on capacity, power, and useful life.[124] These estimates were based on assumptions regarding use of precious metals (principally platinum and rhodium), which were not formulated to oxidize CO, and their prices in 2005. Based on our analysis of costs, including heat shields or double-walled mufflers that could be necessary, catalytic mufflers could add about $14 to the manufacturing cost of a Class I engine and about $19 to the cost of a Class II engine. These costs could vary, depending on choices and assumed loadings of precious metals. Recent evaluations of nonprecious metal catalysts by MECA have found that these less-costly catalysts perform well in the oxidization of CO.[125] Application of this technology could lead to a reduction in costs of compliance related to catalytic after-treatment.

Although EPA assumed that Class I and Class II engines would include catalytic mufflers under Phase 3 emission requirements, a majority of small SI engines submitted for EPA certification in recent years has not included after-treatment devices, such as catalysts. Current engines produced with catalytic after-treatment would incur smaller costs for this feature. In the

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[123] Manufacturers of Emission Controls Association (MECA) (2009, January). White Paper: Emission control of small spark-ignited off-road engines and equipment. Washington, DC. Retrieved from: http://www.meca.org/galleries/files/sore_white_paper_0109_final.pdf.

[124] EPA, *op. cit.*

[125] Kevin Hallstrom. “Catalyst control of CO from portable generators.” Presentation on behalf of Manufacturers of Emission Controls Association (MECA) at the PGMA Technical Summit, March 17, 2016. Available online (pp. 125-141) at: http://www.cpsc.gov//Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf.

view of CPSC engineering staff, portable generators powered by 4-stroke handheld engines might not require catalysts to comply with the proposed rule since the catalyst in both CPSC's and EPA's demonstration programs was primarily for NOx reduction, and handheld engines have less stringent NOx emission requirements under EPA emission standards.[126] For purposes of estimating costs, we assume that catalyst-related costs for generators with handheld engines would average 50 percent of estimated costs for units with Class I engines, or about $7 per generator.

3.) Design & Development/Other Reengineering

In an analysis of small SI engine technologies and costs, ICF International estimated that costs of conversion to EFI from carburetors would require 4 months of design time (engineers) and 6 months for development (by engineers and technicians) for Class I engines and 2 months for design and 2 months for development for Class II engines).[127] Based on estimated labor costs for engineering/technical staff, EPA estimated that these design and development costs totaled about $175,000 for Class I engines and about $64,000 for Class II engines, for each engine family. Design and development costs for three-way catalysts in mufflers were estimated by EPA to be about $135,000 per engine line for 2 months of design time (engineers) and 5 months of development time (engineers and technicians). Adjusting for changes in an appropriate producer price index, the total design and development costs for engines to incorporate EFI and catalysts are estimated to be about $316,000 for a Class I engine family and $203,000 for a Class II engine family. We assume (as EPA did) that these costs are recovered over 5 years. If average annual

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[126] Tab I of staff's briefing package.

[127] EPA (2006), *op. cit.*

production per-engine family ranges from 10,000 to 50,000 units, per-unit design and development costs could range from about $1 to $6 for Class I engines and under $1 to about $4 for Class II engines.

These estimated costs could be applicable for portable generator manufacturers that supply their own engines. Engine manufacturers that supply engines to independent generator manufacturers might successfully pass along research and development costs with markups. EPA estimated that manufacturing and warranty markups by suppliers of EFI and catalytic components total 34 percent. Similar markups of design and development costs by suppliers of complying engines could increase generator manufacturing costs by about $2 to $8 for generators with Class I engines and by about $3 to $5 for generators with Class II engines. Manufacturers of approximately 80 percent of generators supply their own engines. Therefore, average generator manufacturing costs for design and development could be about $4.05 for generators with Class I engines and $2.60 for generators with Class II engines.[128]

Costs of design and development for generators powered by handheld engines were not specifically addressed by EPA. For the purposes of this preliminary analysis, we assume that these costs will be similar to those estimated for units with Class I engines. However, we assume that costs per engine family would be apportioned over perhaps 5,000 to 10,000 units annually. This assumption leads to average generator manufacturing costs for design and development of about $10 per unit for generators with handheld engines. We also acknowledge that models with handheld engines often are valued and promoted for their compactness and light weight. Accommodating new features that might be necessary for compliance with the proposed rule and

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[128] Midpoint estimates for annual engine family production ranging from 10,000 to 50,000 units.

still provide these desired product characteristics could present greater challenges and costs for product engineers and firms. The Commission welcomes comments on this issue, as well as on components and technologies that might be available to meet these challenges and moderate the impacts of the proposed rule on these models.

Costs of new designs and tooling may also be required for generator frames and housings to accommodate additional components, such as batteries for generators with Class I engines, and to address reported concerns with heat dissipation. Modifications could be minimal for many larger generators with open-frame designs; but some smaller units with housings that enclose engines and other components could require larger, redesigned housings, at greater cost. We have assumed that per-unit tooling costs for generators with handheld engines would be twice that of other generators, but costs may be underestimated for small generators. The Commission welcomes comments on this issue from firms that would be affected by the rule.

The modifications to small SI engines to comply with the CO emission requirements of the CPSC standard would likely require engine manufacturers to seek certifications (as new engine families) under EPA requirements for HC+NOx and CO, with the attendant costs for fees and testing, which could be passed on to generator manufacturers that purchase the engines to power their products. Some of the larger manufacturers of portable generators are vertically integrated firms that also manufacture the engines that power their products. It is possible that engine modifications by engine manufacturers (including firms that also manufacture generators) to comply with the CPSC emission standards for CO could result in emissions of HC+NOx that are consistently lower than the EPA emission requirements. This potential effect of the use of EFI and catalysts was shown by demonstration programs sponsored by CPSC (conducted by the University of Alabama) and EPA, as detailed in the CPSC staff's technical rationale for the proposed standard.[129] Consistently lower emission rates for HC+NOx could result in "engine credits" for engine families under EPA's program for averaging, banking and trading (ABT) of emission credits. If manufacturers of engines participate in the ABT program, they could partially offset increased manufacturing costs of compliance with the proposed CPSC standard, and some of these savings could moderate the engine cost increases incurred by generator manufacturers that do not make their own engines.

4.) Testing and Certification

The proposed rule does not prescribe a particular test that manufacturers must use to assess compliance with the performance requirements. Instead, the proposed rule includes the test procedure and equipment that CPSC would use to assess compliance with the applicable performance requirements of the standard.[130] Manufacturers need not use the particular test referenced by the proposed rule, although whatever test is used must effectively assess compliance with the standard. We have assigned minor costs per unit for this element in Table 12, but we welcome comments on this issue.

b. Other Potential Costs

Evaluation of more stringent emission standards by the EPA found that pressurized oil lubrication systems for engines would be among the engine design changes. EPA's assessment of this engine feature is that it results in "enhanced performance and decreased emissions" because

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[129] Tab I of the staff's briefing package.

[130] *i.e.*, Weighted CO emission rates emitted from the generator when operating in normal oxygen: 75 g/h for generators with handheld and Class I engines; 150 g/h for generators powered by one-cylinder Class II engines; and 300 g/h for generators powered by two-cylinder Class II engines.

it allows better calibrations and improved cooling potential.[131] Based on estimates made for EPA, variable costs for a pressurized oil system would be about $19 for small spark-ignition engines that now lack this feature. In the view of the Directorate for Engineering Sciences, pressurized lubrication systems would not be necessary to comply with the draft standard. We welcome comments on this issue.

c. Total Costs, Per Unit

Aggregate estimated compliance costs to manufacturers of portable generators average approximately $113 per unit for engine and muffler modifications necessary to comply with the CO emission requirements of the proposed standard. Cost elements by engine class and characteristics are shown in Table 12.

[131] EPA (2006), *op. cit.*

Table 12.
Net Estimated Manufacturing Costs[1] per Unit to Comply with the Proposed Standard CO Emission Requirements[2]

Cost Elements	Handheld Engines	Class I Engines	Class II Engines	
			1-Cylinder	2-Cylinder
EFI-Related Costs[3]	$67	$67	$69	$75
Oxygen Sensor for Closed-Loop	$10	$10	$10	$10
Battery and Alternator/Regulator[4]	$17	$17	n/a	n/a
Catalyst-Related Costs	$7	$14	$27	$49
Research and Development	$10	$4	$3	$3
Tooling Costs	$4	$2	$2	$2
Testing and Certification	< $1	< $1	< $1	< $1
Combined Compliance Costs	$114	$113	$110	$138

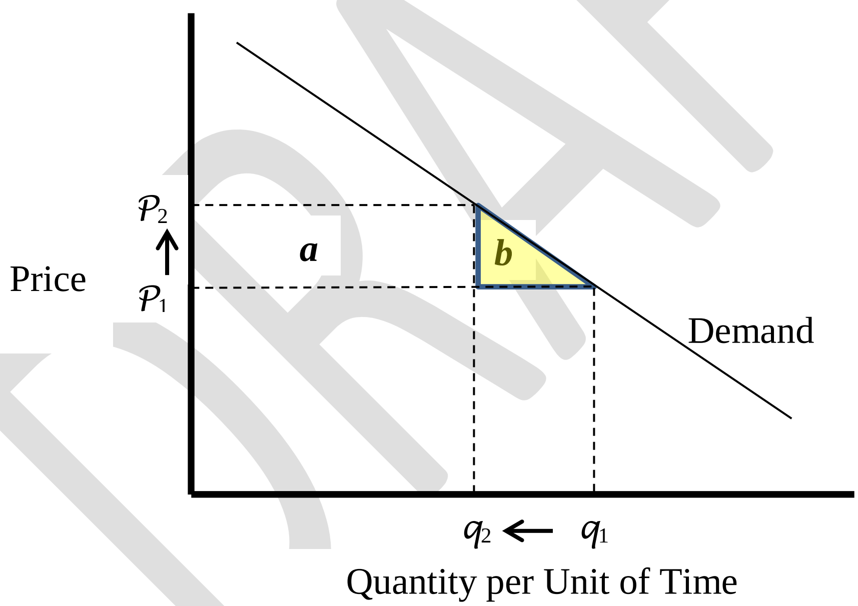
[1] Costs expressed in 2014 dollars, rouonded to the nearest dollar.
[2] Estimates are for overhead valve (OHV) engines, which comprise nearly all engines used in the manufacture of portable generators
[3] Net, less costs related to carburetors.
[4] For those generators with handheld and Class I engines which currently do not have batteries.

1.) Implications for Retail Prices and Consumer Demand

In addition to the direct costs of the rule, increases in the retail price of portable generators (as costs are passed forward to consumers) are likely to reduce sales. Additionally, consumers who no longer purchase portable generators because of the higher prices will experience a loss in utility that is referred to as consumer surplus, but is not included in the direct cost estimates described in the last section. These impacts are illustrated conceptually in Chart 4 below. For purposes of this analysis, we assume that cost increases are pushed forward to consumers.

The downward sloping curve in Chart 4 represents the demand for generators; p_1 and q_1 represent the preregulatory price and quantity of generators demanded. After the regulation becomes effective, generator prices rise to p_2, and the quantity of generators demanded declines to q_2. The value of $p_2 – p_1$ represents the direct costs of the rule per generator (*e.g.*, $113 for those with Class I engines and $138 for two-cylinder Class II generators). The area given by the rectangle ***a*** represents the aggregate annual direct costs of the rule, which is equal to the product of the increase in portable generator price ($p_2 – p_1$) and the post-regulatory quantity demanded (*i.e.*, q_2). The triangle ***b*** represents additional costs of the rule in the form of a loss in consumer surplus: a value over and above what consumers paid for the product prior to the regulation, but that is lost to the consumers who do not purchase a generator at the higher price, p_2.

Chart 4.
Demand for Portable Generators



Given information on the pre-regulatory price (p_1) and quantity demanded (q_1), the impact of the rule on product prices, and information on the elasticity of demand for portable generators (*i.e.*, the percentage change in quantity demanded given a percentage change in price), we can make an estimate of the expected reduction in sales ($q_1 – q_2$), and the lost consumer surplus represented by triangle ***b*** in Chart 4. Based on information presented earlier, estimated preregulatory (current) sales (*i.e.*, q_1) consist of about 15,000 generators with handheld engines; about 801,000 generators with non-handheld Class I engines; about 504,000 generators with one-cylinder Class II engines; and about 65,000 generators with two-cylinder Class II engines. Preregulatory retail prices of portable generators (p_1) average about $324 for generators with handheld engines; $534 for generators with non-handheld Class I engines; $1,009 for generators with one-cylinder Class II engines; and $2,550 for generators with two-cylinder Class II engines.[132]

We are not aware of precise estimates of the price elasticity of demand for portable generators; however, the nature of the product could argue for a relatively inelastic demand: sales of the product often peak when consumers need or anticipate the need for backup power for small and major appliances (*e.g.,* during weather-related outages, anticipated Y2K outages). In these circumstances price may not be a significant determinant for many purchasing decisions. Based on available estimates of the price elasticity of demand for household appliances (for example: – 0.23, by Houthakker & Taylor, [133] and – 0.35, for refrigerators, clothes washers and dishwashers, by Dale & Fujita, 2008[134]), the price elasticity for portable generators could be approximately – 0.3. If this relationship between price increase and consumer demand holds true for complying portable generators marketed under the proposed rule, a 1.0 percent increase in price for generators would result in a 0.3 percent reduction in unit demand.

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[132] Based on an October 2015 survey of retail prices of more than 350 portable generators as reported on Internet sites of six retailers.
[133] Houthakker, H.S. and Taylor, L. (2010). Consumer demand in the United States: Analyses and projections, 2nd edition. Cambridge, MA: Harvard University Press.

[134] Dale, L. and Fugita, K.S. (2008, February). An analysis of the price elasticity of demand for household appliances. Energy Analysis Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, University of California. Berkeley, CA

Given these parameters, the quantity demanded might decline by about 11 percent ($114/$324 × – 0.3), on average, for generators with handheld engines (reducing sales from about 15,000 to about 13,400 annually); by an average of about 6 percent ($113/$534 × – 0.3) for generators with non-handheld Class I engines (projected to reduce sales from about 801,000 to about 750,000 annually); by about 3 percent ($110/$1,009 × – 0.3) for generators with one-cylinder Class II engines (projected to reduce sales from about 504,000 to about 487,000); and by about 1 percent ($138/$2,550 × – 0.3) for generators with two-cylinder Class II engines (projected to reduce sales from about 65,000 to 64,000). As noted in our discussion of retail price information, factors other than engine capacity or generator power affect retail prices; and lower-priced generators with each engine class/category would be expected to face a relatively greater price increase under the proposed rule, and correspondingly, a greater decrease in consumer demand. In general, we would anticipate that generators without features that increase price, such as inverter technology, would realize a more significant percentage impact on manufacturing costs, retail prices and consumer demand, at least initially. Price increases for new generators that would comply with the standard could lead more consumers to repair their older units or to purchase used units on the secondary market. Additionally, price increases for larger portable generators could lead more consumers to purchase stationary, standby generators for use during power outages.

The value of lost consumer surplus resulting from increased prices under the proposed rule (represented by the area of triangle ***b*** in Chart 4) could be about $4 million annually; comprised of about $90,000 for generators with handheld engines; $2.9 million for generators with Class I engines; about $910,000 for generators with one-cylinder Class II engines; and about $70,000 for generators with two-cylinder Class II engines.

2.) Combined Direct Costs and Lost Consumer Surplus Per Unit

If the estimate of lost consumer surplus is spread over the remaining units sold, the estimated costs, per product sold, might average about $6.78 for generators with handheld engines ($91,000 ÷ 13,400 units); $3.85 for generators with Class I engines ($2,889,000 ÷ 750,000 units); $1.88 for generators with one-cylinder Class II engines ($914,000 ÷ 487,000 units); and $1.14 for generators with two-cylinder Class II engines ($73,000 ÷ 64,000 units). If these per-unit costs of lost consumer surplus are combined with the direct manufacturing costs estimated previously in this section, the total estimated per-unit costs would amount to about $121 for generators with handheld engines; $117 for generators with Class I engines; $112 for generators with one-cylinder Class II engines; and about $139 for generators with two-cylinder Class II engines. These are the cost figures that will be compared to the expected benefits of the rule.

It is possible, however, that some consumers might perceive greater value for complying generators, in terms of fuel efficiency, greater ease of starting, product quality and safety. These perceptions could moderate the adverse impact on demand (*i.e.*, reduced sales) resulting from price increases.

1. Comparison of Benefits and Costs

Table 13 presents both the estimated benefits (Row 1) and the estimated costs (Row 2) of the proposed rule. The expected per-unit benefits were derived in Table 5; they average about $243 for generators with handheld engines; $254 for generators with Class I engines; $214 per unit for generators with one-cylinder Class II engines, and; $4 for generators with two-cylinder Class II engines. The estimated $4 in benefits for the two-cylinder Class II engines reflects the fact that very few consumer deaths have involved these generators in the scenarios modeled by NIST and analyzed by CPSC staff, perhaps because they are less likely to be brought indoors because of their size and weight or loudness during operation. Additionally, given the limits on CO emissions for those generators, only about 17 percent of the addressable societal costs are projected to be prevented by the proposed rule.

The costs, including both manufacturing compliance costs (from Table 12), and the costs associated with lost consumer surplus (from the previous section), amount to $121 for generators with handheld engines; $117 for generators with Class I engines; $112 for generators with one-cylinder Class II engines; and about $139 for generators with two-cylinder Class II engines.

As shown in Row 3, the proposed CO emission standard is estimated to result in net benefits (*i.e.*, benefits minus costs) of about $122 per unit for generators with handheld engines ($243 - $121); $137 per unit for generators with Class I engines ($254 - $117); about $101 for generators with one-cylinder Class II engines ($214 - $112); and approximately −$135 for generators with two-cylinder Class II engines ($4 - $139).

Projected annual unit sales under the proposed standard are shown in Row 4. Finally, Row 5 shows aggregate net benefits based on the product of net benefits per unit (Row 3) and product unit sales (Row 4).

An examination of Row 5 indicates that aggregate net benefits would be maximized at about $153 million annually, if only handheld engines, Class I engines, and one-cylinder Class II engines are covered by the proposed rule. Including the two-cylinder Class II engines under the standard would reduce aggregate net benefits to about $145 million. Rather, under the CPSA, the benefits of the rule must bear a reasonable relationship to its costs, and the rule must impose the least burdensome requirement that prevents or adequately reduces the risk of injury. 15 U.S.C. 2058(f)(3)(E) and (F).

Hence, the preliminary regulatory economic analysis suggests that excluding the portable generators with two-cylinder Class II engines from the rule would maximize net benefits, an outcome that would be consistent with OMB direction but not required under the CPSA. Generators with these larger and more powerful engines accounted for just 0.4 percent of the 503 consumer CO poisoning deaths addressed by the simulation analysis performed by NIST and the benefits analysis performed by CPSC staff (Hnatov, Inkster & Buyer, 2016). Portable generators with two-cylinder engines are estimated to have comprised about 7 percent of units in use over 2004 to 2012 (as shown in Tables 9 & 10) and about 5 percent of unit sales in recent years (Table 11).

Table 13.
Aggregate Estimated Present Value of Benefits and Expected Costs Resulting from the Proposed Standard, for Annual Unit Shipments, by Generator Engine Class

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinders	
Present Value of Expected Benefits / Unit	$243	$254	$214	$4	$227
Costs to Manufacturers + Lost Consumer Surplus / Unit	$121	$117	$112	$139	$116
Net Benefits / Unit	$122	$137	$101	-$135	$110
Projected Annual Unit Sales Under the Standard	13,410	749,504	487,026	63,765	1,313,705
Aggregate Net Benefits from Annual Sales (Million $)	$1.6	$102.3	$49.3	-$8.6	$144.6

As discussed previously, the analysis was limited to the 503 out of 659 CO poisoning deaths during the period 2004 through 2012. Commission staff reports that there could be some unquantified benefits associated with 156 deaths not modeled by NIST.[135] However, this would

[135] See Tab K of the staff's briefing package.

not change the main findings of our analysis. If there were some additional deaths involving generators with handheld, Class I, or one-cylinder Class II engines that would have been prevented, our estimated net benefits for these generator classes would increase somewhat. On the other hand, even if all of the deaths involving generators with two-cylinder Class II engines would have been prevented, the costs for this class of generators would have exceeded the benefits.

Additionally, one underlying assumption for the benefits estimate is that there would be no behavioral adaptations by consumers in response to the reduced rate of CO emissions from portable generators. Knowledge about reduced CO emissions from generators produced under the proposed rule could reduce consumers' perceptions of injury likelihood and susceptibility, which, in turn, could affect consumer behavior.[136] In economic terms, the proposed rule could reduce what we might call the cost or risk-price of unsafe behavior, and implicitly provide an incentive for consumers to increase that behavior. If consumers are aware of the reduced CO poisoning risk, and the rule does not make it more difficult to operate generators indoors, it seems likely that there would be some increase in warned-against practices. For example, some consumers might reduce the distance between their house and the generator because they think closer proximity of the generator to the house will reduce the likelihood that the generator will be stolen. Similarly, to keep the generator out of the elements, some consumers who had run their generator outside might decide to bring it into the garage. Additionally, some consumers might even decide to run the generator inside their home. Behavioral adaptation as a potential effect of

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[136] This potential effect of knowledge about improvements in safety has been addressed in human factors literature, such as the article by Leonard Evans in "Human Behavior Feedback and Traffic Safety," published in Human Factors: The Journal of the Human Factors and Ergonomics Society, 27(5), 555–576. January 1985.

the rule is discussed by CPSC's Division of Human Factors (HF) (Smith, T., 2016). We cannot quantify this impact, and for reasons cited by HF, it could be small. However, while the proposed rule will significantly increase the safety of generators from an engineering standpoint, it seems likely that the increased technical safety predicted by modeling under the assumption of no behavioral adaptation will be partially be offset by the behavioral adaptations of some users.

F. Sensitivity Analysis

The benefit-cost analysis presented above compares benefits and costs of our base-case analysis. In this section, we present a sensitivity analysis to evaluate the impact of variations in some of the important parameters and assumptions used in the base-case analysis. Alternative inputs for the sensitivity analysis included:

- Shorter (8 years) and longer (15 years) expected product-life estimates than the 11 years used in the base analysis;
- A discount rate of 7 percent, rather than 3 percent, to express societal costs and benefits in their present value;
- Compliance costs and lost consumer surplus per-unit that are 25 percent higher than the base analysis;
- Lower ($5.3 million) and higher ($13.3 million) values of a statistical life (VSL) than the $8.7 million value for the base analysis; and
- Lower (by 25%) and higher (by 25%) effectiveness for each engine class and characteristic at reducing societal costs of CO poisoning.

The results of the sensitivity analysis are presented in Table 14, with Part A showing estimated net benefits per unit for generators in our base-case analysis (from Table 13) for each engine class and type, and Part B presenting the estimated net benefits per unit, using the alternative input values.

Variations in the expected product life had a relatively small impact on net benefits; a reduced expected product life decreased expected net benefits slightly, while an increased expected product life increased net benefits (rows a and b).

OMB (2003) recommends conducting a regulatory analysis using a 3 percent and 7 percent discount rate.[137] Because of the relatively long product life of generators, using a 7 percent discount rate substantially reduced estimates of net benefits for the first three generator categories, but they remained positive (row c). However, because benefits were so small for the units with 2-cylinder Class II engines, the impact of the 7 percent discount rate on this category was negligible.

Variations in cost estimates would directly impact our estimates of net benefits. Discussions with generator and engine manufacturers suggest that the EPA cost estimates, upon which our analysis was based, may have led to underestimates of the incremental costs of EFI and other components that would be needed for the proposed rule. However, the results of this sensitivity analysis show that even if we had systematically underestimated the costs of the proposed rule by 50 percent, the findings of the analysis would have remained unaltered: Generators with handheld, Class I, and one-cylinder Class II engines would continue to exhibit positive net benefits.

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[137] Our base analysis discount rate is consistent with research suggesting that a real rate of 3 percent is an appropriate discount rate for interventions involving public health (see Gold, M., Siegel, J., Russell, L. and Weinstein, M., eds. (1996). *Cost-effectiveness in health and medicine*. New York: Oxford University Press); a 3 percent discount rate (along with a 7 percent discount rate) is also recommended for regulatory analyses by the Office of Management and Budget (OMB, 2003).

Finally, we considered the impact of variations in the value of statistical life (VSL) on the results of the analysis. Kniesner, Viscusi, Wook and Ziliak (2012) suggested that a reasonable range of values for VSL was between $4 and $10 million (in 2001 dollars),[138] or about $5.3 million to $13.3 million in 2014 dollars. Consequently, we evaluated the sensitivity of our results to variations in the VSL by applying these alternative VSLs (rows e and f). This variation had a substantial impact on the estimated net benefits (as would be expected given deaths account for the great majority of generator-related societal costs). Nevertheless, the variations in VSL did not affect the results of the analysis.

In summary, for each variation analyzed, the overall estimated net benefits of the proposed standard were found to remain positive for the first three categories of generators. However, as with the base-case analysis, the sensitivity analysis showed that generators with two-cylinder Class II engines had estimated costs that remained substantially greater than the present value of projected benefits.

Table 14. Sensitivity Analysis: Expected Net Benefits Associated with Variations in Inputs

Part A: Base-Case Results.*

Row	Input Value	Net Benefits per Generator, by Portable Generator Engine Class/Type			
		Handheld	**Class I**	**1-cylinder Class II**	**2-cylinder class II**
A	**Base Case Analysis**	**$122**	**$137**	**$101**	**−$135**

[138] Kneiser, Viscusi, Wook & Ziliak (2012). The value of a statistical life: evidence from panel data. *The Review of Economics and Statistics, 94*(1), 74-87.

* Base-Case Inputs:

- 3% discount rate;
- Portable Generators in Use: 10.3 million.
- VSL = $8.7 million per statistical life
- Expected product life: (years), 11 years
- Compliance Costs & Lost Consumer Surplus per unit ranging from $112 – $139
- Estimated reduction in addressable deaths (and injuries) ranging from ≈ 17% for 2-cylinder Class II engines to ≈ 49% for Class I engines

Table 14. Part B: Alternative Inputs for Sensitivity Analysis

Row	Input Variable and Value(s) Used in Sensitivity Analysis	Net Benefits per Generator, by Portable Generator Engine Class/Type			
		Handheld	**Class I**	**1-cylinder Class II**	**2-cylinder Class II**
Base Case Analysis:		**$122**	**$137**	**$101**	**−$135**
Expected Product Life					
A	Shorter Expected Product Life: 8 years	$107	$121	$88	−$135
B	Longer Expected Product Life: 15 years	$144	$161	$124	−$134
Discount Rate					
C	7% discount rate	$66	$78	$52	−$136
Costs Estimates					
D	50% higher than base-case for each engine class/type	$61	$78	$45	−$204
Value of a Statistical Life					
E	Lower VSL: $5.3 million	$48	$60	$36	−$136
F	Higher VSL: $13.3 million	$221	$241	$189	−$133
Effectiveness at Reducing Deaths & Injuries					
G	Lower Effectiveness: 25% lower than estimated	$62	$75	$49	−$136
H	Higher Effectiveness: 25% higher than estimated	$185	$202	$157	−$134

G. Regulatory Alternatives

In accordance with OMB (2003) guidelines to federal agencies on preparation of regulatory impact analyses, the Commission considered several regulatory alternatives available to the Commission that could address the risks of CO poisoning from consumer use of portable generators. The alternatives considered included: (1) establishing less-stringent (higher allowable) CO emission rates; (2) excluding generators with Class II, two-cylinder engines from the scope of the rule; (3) an option for reducing consumer exposure to CO by using an automatic shutoff; (4) establishing later compliance dates; (5) relying upon informational measures only; and (6) taking no action.

1. Less Stringent (Higher Allowable) CO Emission Rates

Cost savings from higher allowable CO emission rates might result from lower costs associated with catalysts (if they would not be required, or if less costly materials could suffice), less extensive engine modifications (other than EFI-related costs) and less extensive generator-housing modifications (if housing enlargement and other retooling would be minimized). For example, CPSC staff's report presenting the technical rationale for the proposed standard speculates that 4-stroke handheld engines might not need a catalyst[139], and in our base-case estimate of catalyst-related costs for generators with handheld engines, we assumed an average of 50 percent of the estimated costs for units with Class I engines, or about $7 per unit. A less stringent emission standard could allow more units with handheld engines, and perhaps some with smaller Class I engines, to comply without catalytic after-treatment.

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[139] See Tab I of the staff's briefing package.

Expected reductions in societal costs from CO poisoning in scenarios analyzed by the Commission could be about 30 percent for units with handheld engines; about 36 percent for units with Class I engines; about 30 percent for generators with 1-cylinder Class II engines; and about 11 percent for generators with 2-cylinder Class II engines. We estimate that these reductions in societal costs would be reflected in decreased present value of benefits per unit of nearly $90 for generators with handheld engines (a decrease of 36%); about $70 for generators with Class I engines (– 28%); and about $40 for units with 1-cylinder Class II engines (– 18%). It seems likely that cost savings from less stringent CO emission requirements would be less than expected reductions in benefits. Therefore, net benefits of the rule would probably decrease under this regulatory alternative.

The Commission did not consider a more stringent alternative because CPSC engineering staff believes that the rates in the proposed rule are based on the lowest rates that are technically feasible. Comments providing information on the benefits and costs that would be associated with different CO emission rates would be welcome.

2. Alternative Scope: Limiting Coverage to One-Cylinder Engines, Exempting Portable Generators with Two-Cylinder, Class II Engines from the Proposed Rule

The Commission could exempt portable generators with two-cylinder Class II engines from the requirements of the proposed rule. As shown in the base-case analysis, the gross benefits that would be derived from including this class of portable generators within the requirements of the standard would only amount to about $4 per unit. There are two reasons for the small per-unit benefit estimate. First, while generators with two-cylinder Class II engines accounted for 7.1 percent of generators in use during the 2004 through 2012 study period, they accounted for only about 1.2 percent of deaths. Consequently, the relative risk for generators with two-cylinder Class II engines was only about 16 percent of the risk for the handheld and one-cylinder models. Second, the analysis of benefits of the proposed emission limits for generators with two-cylinder Class II engines (300 g/hr at unreduced ambient oxygen levels) suggests that the proposed rule would only prevent about 17 percent of the addressable deaths for this class of generators (Hnatov, Inkster & Buyer, 2016).[140]

The costs of the proposed rule are estimated to amount to $139 per two-cylinder, Class II generator, yielding *negative* net benefits of about $135 ($4 in benefits – $139 in costs) per unit. Given annual sales of about 64,000 units, the aggregate net benefits associated with this class of generators would amount to about −$8.6 million (64,000 generators × $135 per generator) annually. In other words, excluding this class of generators from the requirements of the proposed rule would increase the net benefits of the rule by about $8.6 million annually, to approximately $153 million. We also note that the total estimated value of expected societal costs of CO poisoning deaths and injuries per unit, including those <u>not</u> addressed by the staff's epidemiological benefits analysis, is $116 per unit (as shown in Tables 5 & 6); hence, even if all of the deaths attributed to generators with two-cylinder Class II engines were to be prevented by the proposed rule standard, the costs would exceed the benefits for these generators.

Exclusion of generators with two-cylinder engines from the scope of the rule could create an economic incentive for manufacturers of generators with larger one-cylinder engines to either switch to two-cylinder engines for those models, or if they already have two-cylinder models in their product lines, they could be more likely to drop larger one-cylinder models from their

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[140] See Tab K of the staff's briefing package.

product lines. The precise impacts of such business decisions on aggregate net benefits of the rule are not known at this time, but it would likely be of marginal significance. We have no evidence that such substitution would occur or, even if it did, that the impact would be significant. Moreover, the higher cost of manufacturing the two-cylinder generators could offset any cost advantage that would result by avoiding the requirements of the proposed rule.

If it would be technologically feasible and cost-effective for manufacturers to use smaller two-cylinder engines for generators in lower power ratings that are associated with greater per-unit societal costs, the reduction in scope of the rule might also specify a minimum engine displacement. For example, if this issue were a concern to the Commission, it could exempt generators with two-cylinder engines, but only if the two-cylinder models had a displacement above a specified value of total engine displacement.

The Commission is including class 2 twin-cylinder generators in the scope of the proposed rule and seeks comments and input on whether class 2 twin-cylinder generators should be excluded from the scope and input on possible shifts in the market of generators powered by two-cylinder engines, such as those discussed above, that might result if two-cylinder generators were excluded from the scope of the rule. The Commission seeks comments on what an appropriate limit on displacement would be if generators with two-cylinder engines above a certain displacement were excluded from the scope, to avoid creating a market incentive for small twin-cylinder generators that avoid the scope of the proposed rule.

3. Alternate Means of Limiting Consumer Exposure: Automatic Shutoff Systems

CPSC staff considered options for reducing the risk of CO poisoning that would require portable generators to shut off automatically if they sensed that a potentially hazardous situation was developing, or if they were used in locations that are more likely to result in elevated COHb levels in users. CPSC engineering staff evaluated four shutoff strategies/technologies: (1) a generator-mounted CO-sensing system, which would (ideally) sense higher CO levels during operation indoors and shut off the engine before dangerous levels build up; (2) a CO-sensing system located away from the generator (*e.g.*, inside the dwelling) that relies on the user to properly place the sensing unit in a location where it can communicate with the generator and send a signal remotely, causing the engine to shut down; (3) a generator-mounted global-positioning (GPS) system intended to infer operation of the generator indoors (from detection of reduced satellite signal strength) and automatically shut down the engine; and (4) applicable to generators equipped with EFI, an algorithm programmed into the engine control unit (ECU) that relies on system sensors to infer indoor operation, signaling the ECU to shut down the engine. The findings of the CPSC engineering evaluation reports on each of the shutoff strategies are summarized in detail in the briefing memorandum for the proposed rule.

As alternative means of limiting exposure to CO, automatic shutoff systems could be incorporated into a standard that limits CO production per hour (such as the draft proposed standard), or they could enable compliance with an alternative standard that requires generators to shut off automatically if they are used in conditions that could lead to accumulation of hazardous levels of CO. Allowing the use of automatic shutoff systems, as either a supplement to limits on CO production per hour or under an alternative shutoff standard could potentially be less costly for manufacturers, and result in greater reductions in CO poisoning for consumers.

However, CPSC staff does not believe that an automatic shutoff standard or option is sufficiently proven to be feasible at this time. As noted, CPSC engineering staff investigated four different approaches for an automatic shutoff system, and was not able to demonstrate how any of the shutoff systems could be implemented satisfactorily. Unresolved concerns with the automatic shutoff technologies studied by CPSC staff include: (1) possibly creating a false sense of safety, which could lead to increased use of portable generators indoors; (2) alternatives that require CO sensors falsely could identify hazards, which would detrimentally affect the utility of the generator when used in proper locations, and could lead to consumers overriding the mechanism; (3) the system would have to be shown to be durable and capable of functioning after being stored for long periods and being used under widely different conditions; and (4) use of algorithms to shut off engines with ECUs would have to be engine-specific and tailored to each engine function, requiring a significant amount of additional testing on this system. These concerns would have to be resolved before a standard incorporating an automatic shutoff option could be developed.

4. Different (Longer) Compliance Dates

As noted in the technical rationale for the proposed rule, staff believes that 1 year is sufficient lead time for manufacturers to implement the necessary modifications on both one-cylinder and two-cylinder Class II engines powering generators.[141] This assessment is partly based on greater industry experience in manufacturing small engines with closed-loop EFI for a variety of applications, including portable generators, since 2006, when the EPA estimated that manufacturers would need 3 years to 5 years to implement closed-loop EFI and make necessary engine improvements, if EPA were to adopt more stringent requirements for its HC+NOx emission standard for small SI engines. Because of the experience gained by engine

[141] Briefing memorandum for staff's briefing package.

manufacturers in recent years, the Commission thinks 1 year from the date of publication of the final rule would provide an appropriate lead-time for generators powered by Class II engines. The Commission is proposing a later compliance date that would take effect 3 years from the date of publication of the final rule for generators powered by smaller engines (handheld and Class I engines). This longer period addresses manufacturers' concerns that there may be different challenges associated with accommodating the necessary emission control technologies on these smaller engines (even though industry has also gained some limited experience with incorporating fuel-injection on handheld and Class I engines).

The Commission could decide that the recent industry experience in manufacturing small engines with EFI, cited in the staff's technical rationale (Buyer, 2016), while facilitating compliance for some manufacturers of engines and generators, might not shorten the time needed by other manufacturers that have not gained relevant experience in application of EFI technology to their products. Based on recent discussions with generator manufacturers, a longer time frame before compliance is required would allow firms more time to design and build parts in-house, which could be more cost-effective than outsourcing. Lack of relevant recent experience with incorporating EFI in engine manufacturing could be more common for small manufacturers of generators. As noted in the staff's initial regulatory flexibility analysis, a longer period before the rule becomes effective (or before compliance is required for generators with smaller engines) would provide small engine manufacturers more time to develop engines that would meet the requirements of the proposed rule, and in the case of small manufacturers of generators that do not also manufacture their own engines, "it would provide them with additional time to find a supplier for compliant engines so that their production of generators would not be interrupted [and . . .] for small importers, a later effective date would provide them with additional time to locate a supplier of compliant generators."[142]

5. Informational Measures

OMB (2003) notes that informational measures often will be preferable when agencies are considering regulatory action to address a market failure arising from inadequate information. As discussed previously, although labels for generators were improved in 2007, with the introduction of mandatory labels, deaths and injuries from the improper placement of newly purchased generators suggest that at least some consumers poorly understand and process the information contained in the operating instructions and warning labels and consequently, these consumers continue to put themselves and others at risk through the improper placement of generators in enclosed areas. Additionally, a review of injury and market data since improved warning labels have been required finds that there is not sufficient evidence to conclude that the label required in the current labeling standard has reduced the CO fatality risks associated with portable generators. Moreover, findings of other general studies on the effectiveness of labels "make it seem unlikely that any major reductions in fatalities should be anticipated due to the introduction of these labels."[143]

Other informational measures that the Commission could take include increased provision of information through means such as government publications, telephone hotlines, or public interest broadcast announcements. CPSC has previously taken actions to alert consumers to the

[142] Tab M of the staff's briefing package.

[143] Tab H of the staff's briefing package.

dangers of CO poisoning by portable generators, and the Commission believes that continued involvement in these activities is warranted. However, evidence of problems in processing information, and continued occurrence of deaths and injuries from improper use of portable generators, indicate that informational measures do not adequately address the risks presented by these products.

6. Taking No Action to Establish a Mandatory Standard

The Commission could take no further regulatory action to establish a mandatory standard on portable generators. Given that some generator manufacturers have demonstrated that it is technologically feasible to produce generators that emit significantly lower levels of CO, taking no regulatory action to establish a mandatory standard would allow manufacturers to market low CO-emitting generators if they believe that there would be a market for such products. In addition, it would allow fully informed consumers to purchase low CO-emitting generators if they value the reduced risk. However, the Commission does not expect that a significant number of generators with CO emission rates proposed by the standard would be marketed voluntarily, at least in the short run.

H. Conclusions from Preliminary Regulatory Analysis

During 2004 to 2012, there was an average of about 73 portable generator-related deaths and at least 2,800 generator-related nonfatal injuries annually. The societal costs of these injuries, as described above, totaled about $820 million annually. During the same period, there was an average of about 11.1 million portable generators in use, suggesting about 0.66 deaths and at least 25.2 nonfatal CO poisonings per 100,000 portable generators in use. Based on indoor air quality modeling by NIST, and a staff technical evaluation of the predicted health effects for scenarios and housing characteristics found in the CPSC incident data, CPSC estimated that the proposed rule would prevent about one-third of these deaths and injuries.[144]

The preliminary regulatory analysis evaluated the benefits and costs of the proposed rule. It distinguished between four categories of portable generators by engine class and type: (1) those with handheld engines with displacement of 80 cc or less; (2) generators with Class I engines with engine displacement of less than 225 cc; (3) generators with one-cylinder Class II engines with engine displacement of 225 cc or more; and (4) two-cylinder class II generators with engine displacement of 225 cc or more.

Generators with Class I and one-cylinder Class II engines accounted for about 92.2 percent of portable generators in use over the period 2004 through 2012. Generators with handheld engines (with engine displacement of 80 cc or less) and two-cylinder Class II engines (with displacement of 225 cc or more) accounted for 0.7 percent and 7.1 percent of portable generators in use, respectively, over 2004 ─ 2012.

The preliminary regulatory analysis suggests that the proposed rule could have substantial benefits for most generators. The estimated gross benefits per generator (over its expected product life) ranged from about $215 to $255 for models with hand-held, Class I, and one-cylinder Class II engines. However, gross benefits for the units with two-cylinder Class II engines amounted to only about $4 per unit.

The estimated costs of the proposed rule were generally similar across generator types, ranging from about $110 to $120 per generator for the models with handheld, Class I, and one-cylinder Class II engines, to about $140 for the models with two-cylinder Class I engines. The

[144] See Tab K of the staff's briefing package.

retail price increases likely to result from these higher costs could reduce portable generator sales by roughly 50,000 units annually, an overall sales reduction of about 3 to 4 percent. The relative impact on handheld generator sales could be greater because of the lower base price of these models.

Given these benefit and cost estimates, net benefits (*i.e*., benefits minus costs) ranged from about $100 to about $140 per generator for the models with *handheld, Class I, and one-cylinder Class II engines*. However, net benefits were a *negative $135 for the models with two-cylinder Class II engines* (*i.e*., benefits of $4 per generator minus costs of $139 per generator). Consequently, net benefits for portable generators as a group would be maximized by excluding the models with two-cylinder Class II engines from the rule.

Estimated net benefits can be converted to aggregate annual estimates, given estimates of the annual sales of portable generators. The estimated aggregate net benefits, based on 1 year's sales of the generators with handheld, Class I, and one-cylinder Class II engines amounted to $153 million. Including the models with two-cylinder Class II engines (which account for only about 5 percent of portable generators sold in recent years) under the requirements of the standard would reduce aggregate net benefits to about $145 million annually.

The sensitivity analysis supported the findings of the base analysis. None of the inputs used in the sensitivity analysis altered the main findings that there would be positive net benefits for the generators with handheld, Class I, and one-cylinder Class II engines, but negative net benefits for the generators with two-cylinder Class II engines.

Additionally, we note that benefits of the proposed rule were estimated based on an assumption that consumer behavior would not change in response to knowledge of the reductions in CO emissions from generators. However, a perceived reduction in the risk associated with using the generators in unsafe environments may increase the likelihood that some consumers will use their generators in the house, in the garage, or in outside locations that are near openings to the house–behaviors the CPSC recommends against. Although such a response could offset the expected benefits from the proposed rule, staff anticipates that any impact would be minimal. On the other hand, the benefits estimates were based on 503 of the 659 CO-related deaths during 2004 through 2012. These were the deaths occurring in fixed-residential or similar structures (*e.g.*, detached and attached houses, and fixed mobile homes) that could be modeled by NIST. CPSC staff believes that some unquantified proportion of the remaining 156 deaths that were not modeled by NIST, because they occurred at non-fixed home locations (*e.g.*, temporary structures such as trailers, horse trailers, recreational vehicles, or tents), and some that occurred when portable carbureted generators were operated outdoors, would have been prevented.[145] If so, the benefits estimates would have been somewhat higher than presented in this analysis.

XI. Initial Regulatory Flexibility Analysis

This section provides an analysis of the impact on small businesses of a proposed rule that would establish a mandatory safety standard for portable generators. Whenever an agency is required to publish a proposed rule, section 603 of the Regulatory Flexibility Act (5 U.S.C. 601–612) requires that the agency prepare an initial regulatory flexibility analysis (IRFA) that describes the impact that the rule would have on small businesses and other entities. An IRFA is not required if the head of an agency certifies that the proposed rule will not have a significant

[145] Tab K of the staff's briefing package.

economic impact on a substantial number of small entities. 5 U.S.C. 605. The IRFA must contain:

(1) a description of why action by the agency is being considered;

(2) a succinct statement of the objectives of, and legal basis for, the proposed rule;

(3) a description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;

(4) a description of the projected reporting, recordkeeping and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record; and

(5) identification to the extent practicable, of all relevant Federal rules which may duplicate, overlap or conflict with the proposed rule.

An IRFA must also contain a description of any significant alternatives that would accomplish the stated objectives of the applicable statutes and that would minimize any significant economic impact of the proposed rule on small entities. Alternatives could include: (1) establishment of differing compliance or reporting requirements that take into account the resources available to small businesses; (2) clarification, consolidation, or simplification of compliance and reporting requirements for small entities; (3) use of performance rather than design standards; and (4) an exemption from coverage of the rule, or any part of the rule thereof, for small entities.

A. Reason for Agency Action

The proposed rule would limit the rate of CO emitted by portable generators and is intended to reduce the risk of death or injury resulting from the use of a portable generator in or near an enclosed space. The Directorate for Epidemiology, Division of Hazard Analysis (EPHA) reports that there were 659 deaths involving portable generators from 2004 to 2012, an average of about 73 annually.[146] Furthermore, there was a minimum of 8,703 nonfatal CO poisonings involving portable generators that were treated in hospital emergency departments from 2004 through 2012, or a minimum of about 967 annually (Hanway, 2015); and, as discussed in the preliminary regulatory analysis, there were an additional 16,600 medically attended injuries treated in other settings, or an estimated 1,851 per year. The societal costs of both fatal and nonfatal CO poisoning injuries involving portable generators amounted to about $821 million ($637 million for fatal injuries + $184 million for nonfatal injuries) on an annual basis. The proposed standard is expected to significantly reduce generator-related injuries and deaths and the associated societal costs.

B. Objectives of and Legal Basis for the Rule

The objective of the proposed rule is to reduce deaths and injuries resulting from exposure to CO associated with portable electric generators being used in or near confined spaces. The Commission published an ANPR in December 2006, which initiated this proceeding to evaluate regulatory options and potentially develop a mandatory standard to address the risks of CO poisoning associated with the use of portable generators. The proposed rule is being promulgated under the authority of the Consumer Product Safety Act (CPSA).

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[146] Tab A of the staff's briefing package.

C. Small Entities to Which the Rule Will Apply

The proposed rule would apply to small entities that manufacture or import SI portable generators. Based on data collected by Power Systems Research, Trade IQ, and general market research, the Commission has identified more than 70 manufacturers of generators that have at some time supplied portable generators to the U.S. market. However, most of these manufacturers were based in other countries. The Commission has identified 20 domestic manufacturers of gasoline-powered portable generators, of which 13 would be considered small based on the Small Business Administration (SBA) size guidelines for North American Industry Classification System (NAICS) category 335312 (Motor and Generator Manufacturing), which categorizes manufacturers as small if they have fewer than 1,250 employees. Four of the small manufacturers are engaged primarily in the manufacture or supply of larger, commercial, industrial, or backup generators, or other products, such as electric motors, which would not be subject to the draft standard. For the other nine small manufacturers, portable generators could account for a significant portion of the firms' total sales. Of these nine small, domestic manufacturers, six have fewer than 99 employees; one has between 100 and 199 employees; another firm has between 200 and 299 employees; and one has between 300 and 399 employees, based on firm size data from Hoovers, Inc., and interviews with several manufacturers.

In some cases, a small manufacturer may be responsible for designing its own brand of generators but outsource the actual production of the generators to other manufacturers, which are often based in China. Other small manufacturers may assemble using components (including engines) purchased from other suppliers. There may be some small manufacturers that manufacture or fabricate some components of the generators, in addition to assembling them.

Using the same sources of data described above, the Commission identified more than 50 firms that have imported gasoline-powered portable generators. However, in some cases, the firms have not imported generators regularly, and generators appear to account for an insignificant portion of these firm's sales. Of these firms, the Commission believes that 20 may be small importers of gasoline-powered portable generators that could be affected by the proposed rule. Importers were considered to be a small business if they had fewer than 200 employees, based on the SBA guidelines for NAICS category 423610 (Electrical Apparatus and Equipment, Wiring Supplies, and Related Equipment Merchant Wholesalers) or $11.0 million in average annual receipts, based on the SBA guidelines for NAICS category 443141 (Household Appliance Stores). Of the 20 small, potential importers staff identified, all have 50 or fewer employees, based on firm size data from Hoovers, Inc.

D. Compliance, Reporting, and Record Keeping Requirements of Proposed Rule

The proposed rule would establish a performance standard that would limit the rate of CO that could be produced by portable generators that are typically used by consumers for electrical power in emergencies or other circumstances in which the electrical power has been shut off or is not available. The performance standard would be based on the generator's weighted CO emissions rate, and stated in terms of grams/hour (g/hr), depending upon the class[147] of the

[147] Because most of the generators that were associated with fatal CO poisoning incidents reported to CPSC were gasoline-fueled, staff has chosen to set the performance standard based on the U.S. Environmental Protection Agency's (EPA) classification of the small SI engine powering the generator and the number of cylinders the engine has. The EPA broadly categorizes small SI engines as either non-handheld or handheld, and within each of those categories, further distinguishes them into different classes, which are based upon engine displacement. Nonhandheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cc up to 225 cc and Class II having displacement at or above 225 cc but maximum power of 19 kilowatts (kW). Handheld

engine powering the generator. Generators powered by handheld engines and Class I engines would be required to emit CO at a weighted rate that is no more than 75 grams per hour (g/hr). Generators powered by Class II engines with a single cylinder would be required to emit CO at a weighted rate that is no more than 150 g/hr. Generators powered by Class II engines with two (or twin) cylinders, which are generally larger than others in the class, and are believed to comprise a very small share of the consumer market, would be required to emit CO at a weighted rate of no more than 300 g/hr.

Section 14 of the CPSA requires that manufacturers, importers, or private labelers of a consumer product subject to a consumer product safety rule to certify, based on a test of each product or a reasonable testing program that the product complies with all rules, bans or standards applicable to the product. The proposed rule details the test procedure that the Commission would use to determine compliance with the standard, but also provides that any test procedure may be used that will accurately determine the emission level of the portable generator. However, for certification purposes, manufacturers must certify that the product conforms to the standard, based on either a test of each product, or any reasonable alternative method to demonstrate compliance with the requirements of the standard. For products that manufacturers certify, manufacturers would issue a general certificate of conformity (GCC).

The requirements for GCCs are in Section 14 of the CPSA. Among other requirements, each certificate must identify the manufacturer or private labeler issuing the certificate and any third party conformity assessment body, on whose testing the certificate depends, the place of manufacture, the date and place where the product was tested, each party's name, full mailing

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engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Staff chose to divide non-handheld Class II engines based on whether the engine had a single cylinder or twin cylinders.

address, telephone number, and contact information for the individual responsible for maintaining records of test results. The certificates must be in English. The certificates must be furnished to each distributor or retailer of the product and to the CPSC, if requested.

1. Costs of Proposed Rule that Would Be Incurred by Small Manufacturers

The most likely method for manufacturers of portable generators to comply with the proposed CO emissions requirement is converting to the use of closed-loop electronic fuel-injection (EFI) systems instead of conventional carburetors, to control the delivery of gasoline to the pistons of generator engines. Manufacturers also are likely to use catalytic converters in the mufflers of the generator engines. As discussed in the preliminary regulatory analysis in Section XX, the cost to manufacturers for complying with the proposed rule is expected to be, on average, about $114 per unit for generators with handheld engines (1.1% of unit sales between 2010 and 2014), $113 per unit for generators with Class I engines (57.8% of unit sales between 2010 and 2014); $110 for those with single cylinder Class II engines (36.4% of unit sales between 2010 and 2014); and $138 for those with twin cylinder Class II engines (4.7% of unit sales between 2010 and 2014).

These estimates include the variable costs related to EFI, including an oxygen sensor for a closed-loop system, a battery and alternator or regulator; and 3-way catalysts. The estimates also include the fixed costs associated with the research and development required to redesign the generators, tooling costs, and the costs associated with testing and certification that the redesigned engines comply with the EPA requirements for exhaust constituents they regulate, HC + NOx and CO emissions.[148]

Manufacturers likely would incur some additional costs to certify that their portable generators meet the requirements of the proposed rule, as required by Section 14 of the CPSA. The certification must be based on a test of each product or a reasonable testing program. Manufacturers may use any testing method that they believe is reasonable and are not required to use the same test method that would be used by CPSC to test for compliance. Based on information from a testing laboratory, the cost of the testing might be more than $6,000 per generator model, although it may be possible to use the results from other tests that manufacturers already may be conducting, such as testing to ensure that the engines comply with EPA requirements, per 40 CFR part 1054, for HC + NOx and CO emissions to certify that the generator meets the requirements of the proposed rule. Manufacturers and importers also may rely upon testing completed by other parties, such as their foreign suppliers, in the case of importers, or the engine suppliers in the case of manufacturers, if those tests provide sufficient information for the manufacturers or importers to certify that the generators comply with the proposed rule.

The Commission welcomes comments from the public regarding the cost or other impacts of the certification requirements under Section 14 of the CPSA and whether it would be

[148] The modifications to small SI engines to comply with the CO emission requirements would likely require engine manufacturers to seek certifications (as new engine families) under EPA requirements for HC + NOx and CO, with the attendant costs for fees and testing, which could be passed on to generator manufacturers that purchase the engines to power their products. Some of the larger manufacturers of portable generators are vertically-integrated firms that also manufacture the engines that power their products. These testing and certification requirements are to meet EPA requirements and are in addition to the testing and certification requirements of Section 14 of the CPSA.

feasible to use the results of tests conducted for certifying compliance with EPA requirements to certify compliance with the proposed rule.

2. Impacts on Small Businesses

Manufacturers

To comply with the proposed rule, small manufacturers would incur the costs described above to redesign and manufacture generators that comply with the CO emissions requirements and to certify that they comply. However, to the extent that the volume of generators produced by small manufacturers is lower than that of the larger manufacturers, the costs incurred by smaller manufacturers may be higher than the average costs reported above. One reason to expect that costs for lower-volume manufacturers could be higher than average is that some of the costs are fixed. For example, research and development costs were estimated to be about $203,000, on average, for Class II engines and about $316,000 for Class I engines. On a per-unit basis, the preliminary regulatory analysis estimated that these costs would average about $4 for Class I engines and $3 for Class II engines, but for manufacturers with a production volume only one-half the average production volume, the per-unit costs would be twice the average.

For lower-volume producers, the per-unit costs of the components necessary to modify their engines might also be higher than those for higher-volume producers. As discussed in the preliminary regulatory analysis, generators that meet the requirements of the proposed rule would probably use closed-loop electronic fuel-injection instead of conventional carburetors. Therefore, manufacturers would incur the costs of adding components associated with EFI to the generator, including injectors, pressure regulators, sensors, fuel pumps, and batteries. Based on information obtained from a generator manufacturer, the cost of these components might be as much as 35 percent higher for a manufacturer that purchased only a few thousand units at a time, as opposed to more than 100,000 units.

While the cost for small, low-volume manufacturers that manufacture their own engines might be higher than for high-volume manufacturers, small portable generator manufacturers often do not manufacture the engines used in their generators, but obtain them from engine manufacturers such as Honda, Briggs and Stratton, and Kohler, as well as several engine manufacturers based in China. These engine manufacturers often supply the same engines to other generator or engine-driven tool manufacturers. Because these engine manufacturers would be expected to have higher production volumes and can spread the fixed research and development and tooling costs over a higher volume of production, the potential disproportionate impact on lower-volume generator producers might be mitigated to some extent.

As discussed in the preliminary regulatory analysis, the retail prices CPSC observed for portable generators from manufacturers and importers of all sizes ranged from a low of $133 to $4,399, depending upon the characteristics of the generator. On a per-unit basis, the proposed rule is expected to increase the costs of generators by an average of $110 to $140. Generally, impacts that exceed 1 percent of a firm’s revenue are considered to be potentially significant. Because the estimated average cost per generator would be between about 3 percent and 80 percent of the retail prices (or average revenue) of generators, the proposed rule could have a significant impact on manufacturers and importers that receive a significant portion of their revenue from the sale of portable generators.

Based on a conversation with a small manufacturer, CPSC staff believes that the proposed rule may have a disproportionate impact on generator manufacturers that compete largely on the basis of price, rather than brand name or reputation. Currently, CPSC cannot identify how many of the nine domestic small manufacturers of engines compete on the basis of price. One reason for the disproportionate impact is that consumers of the lower priced generators are probably more price sensitive than consumers of the brand name generators and may be more likely to reduce or delay their purchases of generators in response to the cost increases that would be expected to result from the proposed rule. A second reason that manufacturers that compete largely on the basis of price could be disproportionately impacted is that brand name generator manufacturers might have more options for absorbing the cost increases that result from the proposed rule. For example a high-end generator manufacturer might be able to substitute a less expensive, but still adequate engine for a name brand engine that they currently might be using. On the other hand, manufacturers that have been competing primarily on the basis of price are more likely to have already made such substitutions and will have fewer options for absorbing any cost increases. As a result, the price differential between generators aimed at the low-end or price-conscious market segments and the name brand generators will be reduced, which could affect the ability of the manufacturers of generators aimed at the price conscious market to compete with the name-brand manufacturers.

Importers

For many small importers, the impact of the proposed rule would be expected to be similar to the impact on small manufacturers. One would expect that the foreign suppliers would pass much of the costs of redesigning and manufacturing portable generators that comply with the proposed rule to their domestic distributors. Therefore, the cost increases experienced by small importers would be similar to those experienced by small manufacturers. As with small manufacturers, the impact of the proposed rule might be greater for those importers that primarily compete on the basis of price. Currently, CPSC cannot identify how many of the 20 domestic, small importers of engines compete on the basis of price.

In some cases, the foreign suppliers might opt to withdraw from the U.S. market, rather than incur the costs of redesigning their generators to comply with the proposed rule. If this occurs, the domestic importers would have to find other suppliers of portable generators or exit the portable generator market. Exiting the portable generator market could be considered a significant impact, if portable generators accounted for a significant percentage of the firm's revenue.

Small importers will be responsible for issuing a GCC certifying that their portable generators comply with the proposed rule should it become final. However, importers may rely upon testing performed and GCCs issued by their suppliers in complying with this requirement.

E. Federal Rules that May Duplicate, Overlap, or Conflict with the Proposed Rule

The Commission has not identified any federal rules that duplicate or conflict with the proposed rule. The EPA promulgated a standard in 2008 for small spark-ignited engines that set a maximum rate for CO emissions. However, the maximum level set by the EPA is higher than the proposed CPSC standard for portable generators.

F. Alternatives Considered to Reduce the Burden on Small Entities

Under section 603(c) of the Regulatory Flexibility Act, an initial regulatory flexibility analysis should "contain a description of any significant alternatives to the proposed rule which accomplish the stated objectives of the applicable statutes and which minimize any significant impact of the proposed rule on small entities." CPSC examined several alternatives to the proposed rule that could reduce the impact on small entities. These include: (1) less stringent CO emission rates; (2) limit coverage to one-cylinder engines; (3) an option for reducing consumer exposure to CO by using an automatic shutoff; (4) establishing alternative compliance dates; (5) informational measures; or (6) taking no action. These alternatives are discussed in more detail in Section X.G.

G. Summary and Request for Comments Regarding Potential Impact on Small Business

The Commission has identified about nine small generator manufacturers and about 20 small generator importers that would be impacted by the proposed rule.

The most likely means of complying with the proposed rule would be to use closed-loop electronic fuel-injection (EFI) systems, instead of conventional carburetors, to control the delivery of gasoline to the pistons of generator engines and to use catalytic converters in the mufflers of the generator engines to be able to meet the EPA's HC+NOx emission standards. The Commission estimates that, on average, the requirements will increase the costs of generator manufacturers by about $110 and $140, depending upon engine type. The costs might be higher than average for lower-volume manufacturers.

Manufacturers and suppliers that serve the low-end of the market and compete mostly on the basis of price might be more severely impacted by the proposed rule because their customers may be more price sensitive; and compared with larger manufacturers, they may not have the same options of reducing other costs to mitigate the impact of the proposed rule on the price of generators. Suppliers of name-brand generators or ones that compete on basis other than price might be able to make other adjustments, such as using less expensive engines to mitigate the impact of the proposed rule on the price of their generators. CPSC currently cannot identify how many of the nine domestic, small manufacturers or the 20 domestic, small importers of engines compete on the basis of price.

Generator manufacturers and importers will be responsible for certifying that their products comply with the requirements of the proposed rule. Testing and certification costs can have a disproportionate impact on small manufacturers, depending upon the cost of the tests and volume of production, relative to larger manufacturers. However, some of these testing costs might be mitigated, if manufacturers could use the results of testing already being conducted (such as, for example, testing to certify compliance with EPA requirements), to offset some of the testing costs required for certification with the proposed rule.

The Commission invites comments on this IRFA and the potential impact of the proposed rule on small entities, especially small businesses. Small businesses that believe they will be affected by the proposed rule are especially encouraged to submit comments. The comments should be specific and describe the potential impact, magnitude, and alternatives that could reduce the impact of the proposed rule on small businesses.

In particular, the Commission seeks comment on:

- the types and magnitude of manufacturing costs that might disproportionately impact small businesses or that were not considered in this analysis;
- the costs of the testing and certification requirements of the proposed rule, including whether EPA testing can be used to meet the certification requirements for the proposed rule;
- whether other factors not considered in this analysis could be significant, such as EPA's Averaging, Banking and Trading (ABT) program that could allow manufacturers of engine families that do have low CO emissions to meet the proposed rule and that also

have very low HC+NOx emissions to “buy credits” in the ABT program, thus allowing their other engine families to exceed HC+NOx limits;

- differential impacts of the proposed rule on small manufacturers or suppliers that compete in different segments of the portable generator market; and finally,
- CPSC would be interested in any comments that provide alternatives that would minimize the impact on small businesses but would still reduce the risk of CO poisoning associated with generators.

XII. Environmental Considerations

The Commission’s regulations address whether CPSC is required to prepare an environmental assessment (EA) or an environmental impact statement (EIS). 16 CFR 1021.5. Those regulations state CPSC’s actions that ordinarily have “little or no potential for affecting the human environment,” and therefore, are categorically excluded from the need to prepare and EA or EIS. Among those actions are rules, such as the portable generator NPR, which provide performance standards for products. *Id*. 1021.5(c)(1).

XIV. Executive Order 12988 (Preemption)

In accordance with Executive Order 12988 (February 5, 1996), the CPSC states the preemptive effect of the proposed rule, as follows:

The regulation for portable generators is proposed under authority of the CPSA. 15 U.S.C. 2051–2089. Section 26 of the CPSA provides: “whenever a consumer product safety standard under this Act is in effect and applies to a risk of injury associated with a consumer product, no State or political subdivision of a State shall have any authority either to establish or to continue in effect any provision of a safety standard or regulation which prescribes any requirements as to the performance, composition, contents, design, finish, construction, packaging or labeling of such product which are designed to deal with the same risk of injury associated with such consumer product, unless such requirements are identical to the requirements of the Federal Standard". 15 U.S.C. 2075(a). Upon application to the Commission, a state or local standard may be excepted from this preemptive effect if the state or local standard: (1) provides a higher degree of protection from the risk of injury or illness than the CPSA standard, and (2) does not unduly burden interstate commerce. In addition, the federal government, or a state or local government, may establish or continue in effect a non-identical requirement for its own use that is designed to protect against the same risk of injury as the CPSC standard if the federal, state, or local requirement provides a higher degree of protection than the CPSA requirement. 15 U.S.C. 2075(b).

Thus, the portable generator requirements proposed in today's Federal Register would (if finalized) preempt non-identical state or local requirements for portable generators designed to protect against the same risk of injury and prescribing requirements regarding the performance, composition, contents, design, finish, construction, packaging or labeling of portable generators .

XV. Certification

Section 14(a) of the CPSA requires that products subject to a consumer product safety rule under the CPSA, or to a similar rule, ban, standard or regulation under any other act enforced by the Commission, must be certified as complying with all applicable CPSC-enforced requirements. 15 U.S.C. 2063(a). A final rule on portable generators would subject portable generators to this certification requirement.

XVI. Effective Date

The CPSA requires that consumer product safety rules take effect not later than 180 days from their promulgation unless the Commission finds there is good cause for a later date. 15

U.S.C. 2058(g)(1). The Commission proposes that the rule would take effect 1 year from the date of publication of the final rule for generators powered by Class II engines and three years from the date of publication of the final rule for generators powered by handheld and Class I engines.

Because of the experience gained by engine manufacturers in recent years in designing and building EFI small SI engines, the Commission believes one year from the date of publication of the final rule would provide an appropriate lead-time for generators powered by one and two cylinder Class II engines. The Commission is proposing an effective date of three years from the date of publication of the final rule for generators powered by handheld and Class I engines. This longer period to become compliant addresses manufacturers' concerns that there may be different challenges associated with accommodating the necessary emission control technologies on these smaller engines. In addition, later compliance dates could potentially reduce the impact on manufacturers of generators, including small manufacturers, by providing them with more time to develop engines that would meet the requirements of the proposed rule, or, in the case of small manufacturers that do not manufacture the engines used in their generators, by providing them with additional time to find a supplier for compliant engines so that their production of generators would not be interrupted.

XVII. Proposed Findings

The CPSA requires the Commission to make certain findings when issuing a consumer product safety standard. Specifically, the CPSA requires that the Commission consider and make findings about the degree and nature of the risk of injury; the number of consumer products subject to the rule; the need of the public for the product and the probable effect on utility, cost, and availability of the product; and other means to achieve the objective of the rule, while minimizing the impact on competition, manufacturing, and commercial practices. The CPSA also requires that the Commission find that the rule is reasonably necessary to eliminate or reduce an unreasonable risk of injury associated with the product and issuing the rule must be in the public interest. 15 U.S.C. 2058(f)(3).

In addition, the Commission must find that: (1) if an applicable voluntary standard has been adopted and implemented, that compliance with the voluntary standard is not likely to reduce adequately the risk of injury, or compliance with the voluntary standard is not likely to be substantial; (2) that benefits expected from the regulation bear a reasonable relationship to its costs; and (3) that the regulation imposes the least burdensome requirement that would prevent or adequately reduce the risk of injury. *Id*. These findings are discussed below.

Degree and nature of the risk of injury.

Carbon monoxide is a colorless, odorless, poisonous gas formed during incomplete combustion of fossil fuels, such as the fuels used in engines that power portable generators. Mild CO poisoning symptoms include headaches, lightheadedness, nausea, and fatigue. More severe CO poisoning can result in progressively worsening symptoms of vomiting, confusion, loss of consciousness, coma, and ultimately, death. The high CO emission rate of current generators can result in situations in which the COHb levels of exposed individuals rise suddenly and steeply, causing them to experience rapid onset of confusion, loss of muscular coordination, and loss of consciousness.

As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014. Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete, because data collection is still ongoing, and the death count most likely will increase in future reports.

Based on NEISS, the Commission estimates that for the 9-year period of 2004 through 2012, there were 8,703 CO injuries seen in emergency departments (EDs) associated with portable generators. The Commission considers this number to represent a lower bound on the true number of generator-related CO injuries treated in EDs from 2004-2012. According to Injury Cost Model (ICM) estimates, there were an additional 16,660 medically-attended CO injuries involving generators during 2004-2012.

Number of consumer products subject to the rule.

For the U.S. market for the years 2010 through 2014, about 6.9 million gasoline-powered portable generators were shipped for consumer use, or an average of about 1.4 million units per year. Shipments of nearly 1.6 million units in 2013 made it the peak year for estimated sales during this period. Consumer demand for portable generators from year-to-year fluctuates with major power outages, such as those caused by tropical or winter storms. Portable generators purchased by consumers and in household use generally range from under 1 kW of rated power up to perhaps 15 kW of rated power. In the last 10 to 15 years, the U.S. market has shifted towards smaller, less powerful units.

The need of the public for portable generators and the effects of the rule on their utility, cost, and availability.

Portable generators that are the subject of the proposed standard commonly are purchased by consumers to provide electrical power during emergencies (such as during outages caused by storms), during other times when electrical power to the home has been shut off, when power is needed at locations around the home without access to electricity, and for recreational activities (such as during camping or recreational vehicle trips).

The proposed rule is based on technically feasible CO emission rates, so that the function of portable generators is unlikely to be adversely affected by the rule. Moreover, there may be a positive change in utility in terms of fuel efficiency, greater ease of starting, product quality, and safety of portable generators. There may be a negative effect on the utility of portable generators, however, to the extent consumers are unable to purchase generators due to increased retail prices.

In terms of retail price information, the Commission's review found that generators with handheld engines ranged in price from \$133 to \$799, with an average price of about \$324. Generators with non-handheld Class I engines had a wide price range, from \$190 to over \$2,000, with an average price of \$534. Generators with one-cylinder Class II engines ranged in price from \$329 to \$3,999, with an average price of \$1,009. Generators with two-cylinder Class II engines ranged in price from \$1,600 to \$4,999, and the average price of these units was \$2,550.

Aggregate estimated compliance costs to manufacturers of portable generators average approximately \$113 per unit for engine and muffler modifications necessary to comply with the CO emission requirements of the proposed standard. The net estimated manufacturing costs per unit to comply with the proposed standard is \$114 for handheld engines, \$113 for Class I engines, \$110 for Class II, one cylinder engines, and \$138 for Class II, two cylinder engines.

The expected product modifications to produce complying generators (EFI & catalysts) are available to manufacturers, and the Commission does not have any indication that firms would exit the market because of the rule. Therefore, the availability of portable generators would not likely be affected by the rule.

Other means to achieve the objective of the rule, while minimizing the impact on competition and manufacturing.

The Commission considered alternatives to achieving the objective of the rule of reducing unreasonable risks of injury and death associated with portable generators. For example, the Commission considered less stringent CO emission rates for portable generators; however, cost savings from less-stringent CO emission requirements likely would be less than expected reductions in the benefits, so that the net benefits of the rule probably would decrease under this regulatory alternative. The Commission also considered including an option for reducing CO emissions through use of automatic shutoff systems, which could potentially reduce the impact of the proposed rule by providing an additional option for complying with the proposed rule; however, because of unresolved issues concerning an automatic shutoff, the Commission does not believe that a regulatory alternative based on automatic shutoff technology instead of reduced emissions is feasible for hazard reduction at this time.

Unreasonable risk.

As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014. Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete, because data collection is still ongoing, and the death count most likely will increase in future reports.

Based on NEISS, the Commission estimates that for the 9-year period of 2004 through 2012, there were 8,703 CO injuries seen in emergency departments (EDs) associated with portable generators. The Commission considers this number to represent a lower bound on the true number of generator-related CO injuries treated in EDs from 2004-2012. According to

Injury Cost Model (ICM) estimates, there were an additional 16,660 medically-attended CO injuries involving generators during 2004-2012.

The Commission estimates that the rule would result in aggregate net benefits of about $145 million annually. On a per-unit basis, the Commission estimates the present value of the expected benefits per unit for all units to be $227; the expected costs to manufacturers plus the lost consumer surplus per unit to be $116; and the net benefits per unit to be $110. The Commission concludes preliminarily portable generators pose an unreasonable risk of injury and finds that the proposed rule is reasonably necessary to reduce that unreasonable risk of injury.

Public interest.

This proposed rule is intended to address an unreasonable risk of injury and death posed by portable generators. The Commission believes that adherence to the requirements of the proposed rule will reduce portable generator deaths and injuries in the future; thus, the rule is in the public interest.

Voluntary standards.

The Commission is aware of two U.S. voluntary standards that are applicable to portable generators, UL 2201 - *Safety Standard for Portable Generator Assemblies,* and ANSI/PGMA G300-2015 – *Safety and Performance of Portable Generators.* These standards include the same requirements set forth in the mandatory CPSC portable generator label but do not otherwise address the risks related to CO poisoning. The Commission does not believe the standards are adequate because they fail to address the risk of CO hazard beyond the CPSC mandatory labeling requirement. The Commission is unaware of any portable generator that has been certified to either of the standards, and as such it is unlikely whether there would be substantial compliance with it if CO emissions requirements were incorporated.

Relationship of benefits to costs.

The aggregate annual benefits and costs of the rule are estimated to be about $298 million and $153 million, respectively. Aggregate net benefits from the rule, therefore, are estimated to be about $145 million annually. On a per unit basis, the Commission estimates the present value of the expected benefits per unit for all units to be $227. The Commission estimates the expected costs to manufacturers plus the lost consumer surplus per unit to be $116. Based on this analysis, the Commission preliminarily finds that the benefits expected from the rule bear a reasonable relationship to the anticipated costs of the rule.

Least burdensome requirement that would adequately reduce the risk of injury.

The Commission considered less-burdensome alternatives to the proposed rule on portable generators, but preliminarily concluded that none of these alternatives would adequately reduce the risk of injury.

(1) The Commission considered not issuing a mandatory rule, but instead relying upon voluntary standards. As discussed previously, the Commission does not believe that either voluntary standard adequately addresses the CO risk of injury and death associated with portable generators. Furthermore, in the absence of any indication that a portable generator has been certified to either standard, the Commission cannot determine that there would be substantial compliance by industry.

(2) The Commission considered excluding portable generators with two cylinder Class II engines from the scope of the rule. The Commission estimates that net benefits of the proposed rule range from about $100 to about $140 per generator for the models with handheld, Class I and one-cylinder Class II engines. However, the Commission estimates net benefits of negative $135 for the models with two-cylinder class II engines. Consequently, excluding portable

generators with two cylinder Class II engines would result in a less burdensome alternative. However, it is possible that exclusion of generators with two-cylinder Class II engines from the scope of the rule could create an economic incentive for manufacturers of generators with larger one-cylinder engines to either switch to two-cylinder engines for those models, or if they already have two-cylinder models in their product lines, they could be more likely to drop larger one-cylinder models from their product lines. Because the Commission lacks more specific information on the generators with Class II twin cylinder engines, the Commission is proposing this rule with the broader scope of including these generators. The Commission welcomes comments on inclusion of portable generators with Class II twin cylinder engines, or class 2 twin cylinder generators, in the scope of the rule.

(3) The Commission considered higher allowable CO emission rates, which might result in costs savings from lower costs associated with catalysts (if they would not be required, or if less-costly materials could suffice), less-extensive engine modifications (other than EFI-related costs) and less-extensive generator housing modifications (if housing enlargement and other retooling would be minimized). However, based on Commission estimates, it seems likely that cost savings from less-stringent CO emission requirements would be less than expected reductions in benefits. Therefore, the Commission is not proposing this alternative.

XIII. Request for Comments

We invite all interested persons to submit comments on any aspect of the proposed rule. More specifically, the Commission seeks comments on the following:

- The cost or other impacts of the certification requirements under Section 14 of the CPSA and whether it would be feasible to use the results of tests conducted for certifying compliance with EPA requirements to certify compliance with the proposed rule;

- The product manufacture or import limits and the base period in the proposed anti-stockpiling provision;
- Prospective use (*e.g.*, costs, applicability and challenges) of battery-less EFI for portable generators;
- Costs of new designs and tooling that may be required for generator frames and housings to accommodate additional components, such as batteries for generators with handheld or Class I engines, and to address reported concerns with heat dissipation.
- Information on potential challenges in accommodating new features in handheld and Class I engines to comply with the proposed rule, as well as on components and technologies that might be available to meet these challenges and moderate the impacts of the proposed rule on handheld and Class I engines.
- Costs per unit element for testing and certification, including what additional costs per unit element might be if the Commission required specific testing requirements;
- Costs firms experience with testing and certification of engines for EPA emissions testing;
- Advantages and disadvantages of setting performance requirements at 17 percent oxygen instead of normal oxygen as well as comments on the technically feasible CO emission rates for generators operating at 17 percent oxygen, for each of the generator categories.
- Based on estimates made for EPA, estimated variable costs for a pressurized oil system would be about $19 for small spark-ignition engines that that now lack this feature. In the view of the Directorate for Engineering Sciences, pressurized lubrication systems would not be necessary to comply with the draft standard. We welcome comments on this issue.

- Whether to exclude portable generators with two-cylinder Class II engines from the final rule, and if two-cylinder Class II engines were to be excluded, whether a limit on displacement should be included to avoid developing a market for small two-cylinder engines for portable generators that would be exempt from the rule;
- Information on the benefits and costs that would be associated with different CO emission rates;
- Information and data about the expected range of manufacturing variability for CO emissions from EFI equipped small spark ignited engines, including data on emissions variability from production target values and expected manufacturing tolerances.
- Information about the benefits and costs associated with altering the performance requirements for CO emissions such that an alternate performance requirement could be based on limits on those emissions when the generator is operating in air with reduced oxygen content of 17 percent oxygen (or a different reduced level) rather than normal atmospheric oxygen (approximately 20.9 percent), as proposed; if so, what that performance requirement should be and how should CPSC should test to verify compliance.
- Test methods staff use for determining CO emissions from generators in normal atmospheric oxygen levels (approximately 20.9 percent) and at reduced oxygen levels (as described in staff's briefing package), as well information on benefits and costs that could be associated with requiring those specific methods for evaluation and the benefits and costs of not requiring a specific test method.
- The appropriateness of compliance dates that are one year from the date of publication of the final rule for portable generators with Class II engines, or class 2 generators, and

three years from the date of publication of the final rule for generators with handheld and Class I engines, or class 1 generators.

- Additional information on portable generator sales and use.

Comments should be submitted in accordance with the instructions in the **ADDRESSES** section at the beginning of this document.

XIV. Conclusion

For the reasons stated in this preamble, the Commission proposes requirements for portable generators to address an unreasonable risk of injury associated with portable generators.

List of Subjects

16 CFR Part 1241

Consumer protection, Imports, Information, Safety.

For the reasons discussed in the preamble, the Commission proposes to amend Title 16 of the Code of Federal Regulations as follows:

1. Add part 1241 to read as follows:

PART 1241-SAFETY STANDARD FOR PORTABLE GENERATORS

Sec.

1241.1 Scope, purpose and compliance dates.

1241.2 Definitions.

1241.3 Requirements.

1241.4 Test procedures.

1241.5 Prohibited stockpiling.

1241.6 Findings.

Authority: 15 U.S.C. 2056, 2058 and 2076.

§ 1241.1 Scope, purpose and compliance dates.

(a) This part 1241, a consumer product safety standard, establishes requirements for portable generators, as defined in § 1241.2(b). The standard includes requirements for carbon monoxide emission rates for categories of portable generators. These requirements are intended to reduce an unreasonable risk of injury and death associated with portable generators.

(b) For purposes of this rule, portable generators include single phase; 300 V or lower; 60 hertz; portable generators driven by small handheld and non-handheld (as defined by the Environmental Protection Agency) spark-ignited utility engines intended for multiple use which are provided only with receptacle outlets for the AC output circuits and intended to be moved, though not necessarily with wheels. For purposes of this rule, portable generators do not include:

(1) Permanently installed generators;

(2) 50 hertz generators;

(3) Marine generators;

(4) Trailer mounted generators;

(5) Generators installed in recreational vehicles;

(6) Generators intended to be pulled by vehicles;

(7) Generators that are part of welding machines;

(8) Generators powered by compression-ignition engines fueled by diesel.

(c) Class 2 single cylinder and two cylinder generators, as defined in §1241.2(c) and (d) manufactured or imported on or after [date that is 365 days after publication of a final rule] shall comply with the requirements stated in § 1241.3(b)(2) and (3). Handheld generators and Class 1 generators, as defined in § 1241.2(a) and (b), manufactured or imported on or after [date that is 3 years after publication of a final rule], shall comply with the requirements stated in § 1241.3(b)(1).

§ 1241.2 Definitions.

In addition to the definitions in section 3 of the Consumer Product Safety Act (15 U.S.C. 2051), the following definitions apply for purposes of this part 1241.

(a) *Handheld generator* means a generator powered by a spark ignited (SI) engine with displacement of 80 cc or less.

(b) *Class 1 generator* means a generator powered by an SI engine with displacement greater than 80 cc but less than 225 cc.

(c) *Class 2 single cylinder generator* means a generator powered by an SI engine with one cylinder having displacement of 225 cc or greater, up to a maximum engine power of 25 kW.

(d) *Class 2 two cylinder generator* means a generator powered by an SI engine with two cylinders having a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW.

§ 1241.3 Requirements.

(a) When tested in accordance with the test procedures stated in § 1241.4 (or similar test procedures), all portable generators covered by this standard shall meet the requirements stated in paragraph (b) of this section.

(b) Emission rate requirements.

(1) Handheld generators and Class 1 generators must not exceed a weighted CO emission rate of 75 grams per hour (g/hr).

(2) Class 2 single cylinder generators must not exceed a weighted CO emission rate of 150 g/hr.

(3) Class 2 two cylinder generators must not exceed a weighted CO emission rate of 300 g/hr.

§ 1241.4 Test procedures.

(a) Any test procedure that will accurately determine the carbon monoxide emission rate of the portable generator may be used. CPSC uses the test procedure stated in this section to determine compliance with the standard.

(b) *Definitions*.

(1) *Load bank and power meter* means An AC electric resistor load bank used to simulate steady electric loads on the generator. The load bank shall be capable of adjustment to within 5 percent of each required load condition. A power meter is used to measure the actual electrical load delivered by the generator with an accuracy of ± 5 percent.

(2) *Fuel and lubricants* means fuel and lubricants that meet manufacturer's specifications for the generator being tested.

(3) Emission measurement system means the constant volume sampling (CVS) emission measurement system described in 40 CFR Part 1054 and 1065.

(4) Maximum *generator load* means the maximum output power capability of the generator assembly as determined by the maximum generator load determination procedures. The maximum generator load is used to establish the 6-mode load profile.

(c) Determining maximum generator load.

(1) *Power saturation method for conventional (non-inverter) generator assemblies*.

(i) Ensure test facility is at ambient conditions 15 - 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen.

(ii) Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

(iii) Monitoring voltage and frequency, increase the load applied to the generator to the maximum observed power output without causing the voltage or frequency to deviate from the following tolerances:

(A) Voltage Tolerance: ± 10 percent of the nameplate rated voltage.

(B) Frequency Tolerance: ± 5 percent of the nameplate rated frequency.

(iv) Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

(v) The maximum generator load is the power supplied by the generator assembly that satisfies the tolerances in paragraph (c)(1)(iii) of this section when the generator is at stable operating temperature as defined in paragraph (c)(iv) of this section. Record the maximum generator load.

(2) *Power saturation method for inverter generator assemblies*.

(i) Ensure test facility is at ambient conditions 15 - 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen.

(ii) Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

(iii) Increase the load applied to the generator to the maximum observed power output.

(iv) Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

(v) Maximum generator load is the maximum observed power output that satisfies the criteria defined in paragraph (c)(2)(iv) of this section. Record the maximum generator load.

(d) *Test method to determine the modal CO emission rates of a portable generator.* To determine the weighted CO emission rate of a portable generator assembly, determine the modal CO emission rates at six discrete generator loads based on maximum generator load using a CVS emissions tunnel described in 40 CFR 1054 and 40 CFR 1065, and calculate the weighted CO emission rate. All tests shall be performed under typical operating conditions at an ambient air temperature of 15 – 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen. Testing shall be performed on a complete generator assembly and load shall be applied through the generators receptacle panel. If a generator is equipped with a system that provides different engine operating modes such as a fuel economy mode, the generator shall be tested to this Section in all available modes. CO emission performance shall be determined by the highest weighted CO emission rate calculated in paragraph (e) of this section.

(1) Place the generator assembly in front of the CVS tunnel with the exhaust facing towards the collector. Connect the load bank and apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

(2) Adjust the load bank to apply the appropriate mode calculated from the maximum generator load. Modal testing shall be performed in order from mode 1 to mode 6. Mode points are determined by a percentage of the maximum generator load:

(i) Mode 1: 100 percent of maximum generator load

(ii) Mode 2: 75 percent of maximum generator load

(iii) Mode 3: 50 percent of maximum generator load

(iv) Mode 4: 25 percent of maximum generator load

(v) Mode 5: 10 percent of maximum generator load

(vi) Mode 6: 0 percent of maximum generator load

(3) Stabilize oil and head temperatures by operating at mode for 5 minutes. After the 5 minute stabilization period, record emissions for at least 2 minutes at a minimum rate of 0.1 Hz with the prescribed mode applied. Record the mean CO emission value for that mode during the data acquisition period.

(4) Repeat steps in paragraphs (d)(2) to (d)(4) for the successive modes listed in paragraph (d)(2).

(5) When all modal mean CO emission rates have been determined, calculate and report the weighted CO emission rate using guidance in paragraph (e).

(e) *Weighted CO emission rate calculation and reporting*.

(1) Calculate the weighted CO emission rate using the mean CO emission rates determined in paragraph (d).

$$\dot{\boldsymbol{m}}_{\boldsymbol{w}} = \mathbf{0.09} \times \dot{\boldsymbol{m}}_{\mathbf{1}} + \mathbf{0.20} \times \dot{\boldsymbol{m}}_{\mathbf{2}} + \mathbf{0.29} \times \dot{\boldsymbol{m}}_{\mathbf{3}} + \mathbf{0.30} \times \dot{\boldsymbol{m}}_{\mathbf{4}} + \mathbf{0.07} \times \dot{\boldsymbol{m}}_{\mathbf{5}} + \mathbf{0.05} \times \dot{\boldsymbol{m}}_{\mathbf{6}}$$

where,

$\dot{m}_w = Weighted\ CO\ Emission\ Rate\ (\frac{g}{hr})$

$\dot{m}_1 = Mean\ CO\ Emission\ Rate\ at\ mode\ 1\ (\frac{g}{hr})$

$\dot{m}_2 = Mean\ CO\ Emission\ Rate\ at\ mode\ 2\ (\frac{g}{hr})$

$\dot{m}_3 = Mean\ CO\ Emission\ Rate\ at\ mode\ 3\ (\frac{g}{hr})$

$\dot{m}_4 = Mean\ CO\ Emission\ Rate\ at\ mode\ 4\ (\frac{g}{hr})$

$\dot{m}_5 = Mean\ CO\ Emission\ Rate\ at\ mode\ 5\ (\frac{g}{hr})$

$\dot{m}_6 = Mean\ CO\ Emission\ Rate\ at\ mode\ 6\ (\frac{g}{hr})$

(2) Report the following results for the generator:

(i) Weighted CO emission rate in grams per hour.

(ii) Modal information including the mean CO emission, and head and oil temperature.

(iii) Maximum generator load information as determined in paragraph (c). Include maximum generator load, voltage, amperage, and frequency.

§ 1241.5 Prohibited stockpiling.

(a) *Base period.* The base period for portable generators is any period of 365 consecutive days, chosen by the manufacturer or importer, in the 5-year period immediately preceding the promulgation of the final rule.

(b) *Prohibited acts.* Manufacturers and importers of portable generators shall not manufacture or import portable generators that do not comply with the requirements of this part in any 12-month period between (date of promulgation of the rule) and (effective/compliance date of the rule) at a rate that is greater than 125% of the rate at which they manufactured or imported portable generators with engines of the same class during the base period for the manufacturer.

§ 1241.6 Findings.

(b) *General.* In order to issue a consumer product safety standard under the Consumer Product Safety Act, the Commission must make certain findings and include them in the rule. 15 U.S.C. 2058(f)(3). These findings are discussed in this section.

(c) *Degree and nature of the risk of injury.* Carbon monoxide is a colorless, odorless, poisonous gas formed during incomplete combustion of fossil fuels, such as the fuels used in engines that power portable generators. Mild CO poisoning symptoms include headaches, lightheadedness, nausea, and fatigue. More severe CO poisoning can result in progressively worsening symptoms of vomiting, confusion, loss of consciousness, coma, and ultimately, death. The high CO emission rate of current generators can result in situations in which the COHb levels of exposed individuals rise suddenly and steeply, causing them to experience rapid onset of confusion, loss of muscular coordination, and loss of consciousness.

As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014. Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete, because data collection is still ongoing, and the death count most likely will increase in future reports.

Based on NEISS, the Commission estimates that for the 9-year period of 2004 through 2012, there were 8,703 CO injuries seen in emergency departments (EDs) associated with portable generators. The Commission considers this number to represent a lower bound on the true number of generator-related CO injuries treated in EDs from 2004-2012. According to Injury Cost Model (ICM) estimates, there were an additional 16,660 medically-attended CO injuries involving generators during 2004-2012.

(d) *Number of consumer products subject to the rule.* For the U.S. market for the years 2010 through 2014, about 6.9 million gasoline-powered portable generators were shipped for consumer use, or an average of about 1.4 million units per year. Shipments of nearly 1.6 million units in 2013 made it the peak year for estimated sales during this period. Consumer demand for portable generators from year-to-year fluctuates with major power outages, such as those caused by tropical or winter storms. Portable generators purchased by consumers and in household use generally range from under 1 kW of rated power up to perhaps 15 kW of rated power. In the last 10 to 15 years, the U.S. market has shifted towards smaller, less powerful units.

(e) The *need of the public for portable generators and the effects of the rule on their utility, cost, and availability*. Portable generators that are the subject of the proposed standard commonly are purchased by household consumers to provide electrical power during emergencies (such as during outages caused by storms), during other times when electrical power to the home has been shut off, when power is needed at locations around the home without access to electricity, and for recreational activities (such as during camping or recreational vehicle trips).

The proposed rule is based on technically feasible CO emission rates, so that the function of portable generators is unlikely to be adversely affected by the rule. There may be an effect on the utility of portable generators to the extent consumers are unable to purchase generators due to increased retail prices. There may be a positive change in utility in terms of fuel efficiency, greater ease of starting, product quality, and safety of portable generators.

In terms of retail price information, the Commission's review found that generators with handheld engines ranged in price from $133 to $799, with an average price of about $324. Generators with non-handheld Class I engines had a wide price range, from $190 to over $2,000, with an average price of $534. Generators with one-cylinder Class II engines ranged in price from $329 to $3,999 with an average price of $1,009. Generators with two-cylinder Class II engines ranged in price from $1,600 to $4,999 and the average price of these units was $2,550.

Aggregate estimated compliance costs to manufacturers of portable generators average approximately $113 per unit for engine and muffler modifications necessary to comply with the CO emission requirements of the proposed standard. The net estimated manufacturing costs per unit to comply with the proposed standard is $114 for handheld engines, $113 for Class I engines, $110 for Class II, one cylinder engines, and $138 for Class II, two cylinder engines.

The expected product modifications to produce complying generators (EFI & catalysts) are available to manufacturers, and the Commission does not have any indication that firms would exit the market because of the rule. Therefore, the availability of portable generators would not likely be affected by the rule.

(f) *Other means to achieve the objective of the rule, while minimizing the impact on competition and manufacturing.* The Commission considered alternatives to achieving the objective of the rule of reducing unreasonable risks of injury and death associated with portable generators. For example, the Commission considered less stringent CO emission rates for portable generators; however, the Commission found that cost savings from less-stringent CO emission requirements likely would be less than expected reductions in the benefits, so that the net benefits of the rule probably would decrease under this regulatory alternative. The Commission also considered including an option for reducing CO emissions through use of automatic shutoff systems, which could potentially reduce the impact of the proposed rule by providing an additional option for complying with the proposed rule; however, because of unresolved issues concerning an automatic shutoff, the Commission does not believe that a regulatory alternative based on automatic shutoff technology instead of reduced emissions is feasible for hazard reduction at this time.

(g) *Unreasonable risk.*

As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014. Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete, because data collection is still ongoing, and the death count most likely will increase in future reports.

Based on NEISS, the Commission estimates that for the 9-year period of 2004 through 2012, there were 8,703 CO injuries seen in emergency departments (EDs) associated with portable generators. The Commission considers this number to represent a lower bound on the true number of generator-related CO injuries treated in EDs from 2004-2012. According to Injury Cost Model (ICM) estimates, there were an additional 16,660 medically-attended CO injuries involving generators during 2004-2012.

The Commission estimates that the rule would result in aggregate net benefits of about $145 million annually. On a per-unit basis, the Commission estimates the present value of the expected benefits per unit for all units to be $227; the expected costs to manufacturers plus the lost consumer surplus per unit to be $116; and the net benefits per unit to be $110. The Commission concludes preliminarily portable generators pose an unreasonable risk of injury and finds that the proposed rule is reasonably necessary to reduce that unreasonable risk of injury.

(g). *Public interest.* This proposed rule is intended to address an unreasonable risk of injury and death posed by portable generators. The Commission believes that adherence to the requirements of the proposed rule will reduce portable generator deaths and injuries in the future; thus, the rule is in the public interest.

(h). *Voluntary standards.* The Commission is aware of two U.S. voluntary standards that are applicable to portable generators, UL 2201 - *Safety Standard for Portable Generator Assemblies,* and ANSI/PGMA G300-2015 – *Safety and Performance of Portable Generators.* These standards include the same requirements set forth mandatory CPSC portable generator label but do not otherwise address the risks related to CO poisoning. The Commission does not believe the standards are adequate because they fail to address the risk of CO hazard beyond the CPSC mandatory labeling requirement. The Commission is unaware of any portable generator that has been certified to either of the standards, and as such it is unlikely whether there would be substantial compliance with it if CO emissions requirements were incorporated.

(i). *Relationship of benefits to costs.* The aggregate annual benefits and costs of the rule are estimated to be about $298 million and $153 million, respectively. Aggregate net benefits from the rule, therefore, are estimated to be about $145 million annually. On a per unit basis, the Commission estimates the present value of the expected benefits per unit for all units to be $227. The Commission estimates the expected costs to manufacturers plus the lost consumer surplus per unit to be $116. Based on this analysis, the Commission finds preliminary that the benefits expected from the rule bear a reasonable relationship to the anticipated costs of the rule.

(j). *Least burdensome requirement that would adequately reduce the risk of injury.*

The Commission considered less-burdensome alternatives to the proposed rule on portable generators, but concluded preliminary that none of these alternatives would adequately reduce the risk of injury.

(1) The Commission considered not issuing a mandatory rule, but instead relying upon voluntary standards. As discussed previously, the Commission does not believe that either voluntary standard adequately addresses the CO risk of injury and death associated with portable generators. Furthermore, the Commission doubts that either of the voluntary standards would have substantial compliance by industry.

(2) Excluding portable generators with two cylinder, Class II engines from the scope of the rule. The Commission estimates that net benefits of the proposed rule range from about $100 to about $140 per generator for the models with handheld, Class I and one-cylinder Class II engines. However, net benefits were negative $135 for the models with two-cylinder class II engines. Consequently, excluding portable generators with two cylinder Class II engines would

result in a less burdensome alternative. However, it is possible that exclusion of generators with two-cylinder Class II engines from the scope of the rule could create an economic incentive for manufacturers of generators with larger one-cylinder engines to either switch to two-cylinder engines for those models, or if they already have two-cylinder models in their product lines, they could be more likely to drop larger one-cylinder models from their product lines. Because the Commission lacks more specific information on the generators with Class II twin cylinder engines, the Commission is proposing this rule with the broader scope of including these generators.

(3) The Commission considered higher allowable CO emission rates, which might result in costs savings from lower costs associated with catalysts (if they would not be required, or if less-costly materials could suffice), less-extensive engine modifications (other than EFI-related costs) and less-extensive generator housing modifications (if housing enlargement and other retooling would be minimized). However, based on Commission estimates, it seems likely that cost savings from less-stringent CO emission requirements would be less than expected reductions in benefits. Therefore, the Commission is not proposing this less burdensome alternative.

Dated: ________________

____

Todd A. Stevenson,
Secretary, Consumer Product Safety Commission

____

BRIEFING PACKAGE FOR NOTICE OF PROPOSED RULEMAKING FOR SAFETY STANDARD FOR CARBON MONOXIDE HAZARD FOR PORTABLE GENERATORS

For further information, contact: Janet Buyer, Project Manager
Directorate for Engineering Sciences
(301)987-2293

ACKNOWLEDGEMENTS

CPSC Staff:
Susan Bathalon
Matthew Brookman
Steven Hanway
Matthew Hnatov
Dr. Sandra Inkster
Charu Krishnan
Han Lim
Barbara Little
Charles Smith
Timothy Smith
Robert Squibb
Andrew Trotta
Troy Whitfield
CPSC Field Investigators

National Institute of Technology and Standards:
Steven Emmerich
Dr. Andrew Persily
Dr. Leon Wang
Daniel Greb

University of Alabama:
Dr. Paulius V. Puzinauskas
Dr. Timothy Haskew
Raju Dantuluri
Jennifer Smelser
Chandon Mahato
Andrew Greff
Joshua Spiegel

Intertek Carnot Emission Services:
Steve Griffin
Timothy Griffin

EXECUTIVE SUMMARY

In 2002, the U.S. Consumer Product Safety Commission (CPSC or Commission) initiated the Portable Generator Project to look specifically at the carbon monoxide (CO) poisoning hazard associated with portable generators. In December 2006, the Commission voted to approve an advance notice of proposed rulemaking (ANPR) for staff to begin research to investigate technologies that could reduce the risk of CO poisoning associated with portable generators. This notice of proposed rulemaking (NPR) briefing package contains staff's draft proposed standard to address the hazard and staff's analyses that support the standard.

A portable generator is an engine-driven machine that converts chemical energy from the gasoline, propane, or diesel fuel powering the engine to rotational energy, which, in turn, is converted to electrical power. The engine emits CO due to incomplete combustion. Initial CO poisoning effects result primarily from oxygen deprivation (hypoxia) because inhaled CO rapidly enters the bloodstream and effectively displaces oxygen from red blood cells, resulting in formation of carboxyhemoglobin (COHb). Severe CO poisoning can result in progressively worsening symptoms of vomiting, confusion, loss of consciousness, coma, and ultimately, death. When CO levels rise steeply and suddenly, as is often believed to be the case in generator-related fatalities, given the magnitude of generator CO emission rates, it is possible for exposed individuals to rapidly experience confusion, loss of muscular coordination, and loss of consciousness. This can occur without individuals having first experienced milder CO poisoning symptoms associated with a low, or slowly rising, CO level.

As of May 2015, CPSC databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents that occurred from 2004 through 2014. Of these, 75 percent of deaths (565 deaths) occurred in a fixed structure home location, which includes detached and attached houses, apartments, fixed mobile homes, and cabins used as a permanent residence. Of the 565 deaths, 95 percent (535 deaths) occurred when the generator was used in an enclosed or semi-enclosed space, such as a living space of the house, attached garage, enclosed carport, basement, or crawlspace; and 3 percent (16 deaths) occurred when the generator was used outside a fixed structure home. Seventy-five percent of all incidents involved a single fatality (423 of 751 deaths [56 percent]) and 25 percent of the incidents involved multiple fatalities (328 of 751 deaths [44 precent]), with up to as many as six deaths reported in a single incident. Victims age 25 years or older account for about 82 percent of the deaths.

Staff's epidemiological benefits and preliminary regulatory analyses for the NPR do not include data for years 2013 and 2014 because data for those years are still incomplete. Additionally, excluded from these analyses are incidents that would not be in-scope of the proposed rule (such as those involving stationary generators and generators that are part of welding machines). Therefore, staff's analyses are based on 659 deaths in 493 incidents that occurred from 2004 through 2012. During this same period, staff estimates that there were a minimum of about 25,400 medically attended CO injuries involving generators.

Staff assessed the voluntary standards applicable to portable generators (UL 2201,ANSI/PGMA G300-2015, and ISO 8528-13:2016) and found that none addressed the CO hazard (other than labeling requirements). Staff does not believe that any of these standards are adequate because the standards do not address the risk of CO hazard and staff does not believe that labeling requirements alone are sufficient to address the hazard. Furthermore, because staff is not aware of any firms certifying products to UL 2201 and ANSI/PGMA G300-2015, staff does not believe that there is substantial compliance with these standards.

Staff investigated CO hazard mitigation strategies of reduced CO emissions, as well as concepts that would automatically shut off the generator after the generator is started in an enclosed space. Regarding automatic shutoff, staff investigated four different shutoff concepts; based on unresolved issues, including creating a false sense of safety, reliability, durability, nuisance shutoffs, among others, staff concluded that a mitigation strategy based on an automatic shutoff concept without reduced emissions is not feasible for CO hazard reduction at this time. Staff investigated the feasibility of substantially reducing a generator's CO emission rate by conducting a two-part technology demonstration program on a commercially available generator. The generator was modified with existing emission control technology, subjected to a durability test program, and tested in conditions replicating a common fatal incident scenario. Using the information staff learned from that program, as well as information learned from examination of technical feasibility data developed by the U.S. Environmental Protection Agency (EPA), along with staff's emission testing of fuel-injected portable generators manufactured by three different generator manufacturers, staff concluded that significant reductions in the CO emission rates of portable generators are technically feasible for each of four different generator categories. These four categories are defined primarily by the displacement of the engine, with a secondary categorization of the largest generators that distinguishes between engines with one or two cylinders (*i.e*., handheld; class 1; class 2 single cylinder; and class 2 twin cylinder generator).

Staff analyzed the four defined generator categories to estimate how many deaths, in a subset of 503 out of the 659 deaths that occurred from 2004 through 2012, could have been averted by generators emitting the technically feasible emission rates. The results, based on indoor air quality modeling and health effects modeling, indicate that, in many scenarios where fatalities have been documented with current carbureted generators, staff's conservative estimates of technically feasible, reduced CO emission rates could have averted an estimated 208 of 503 deaths that occurred during the 9-year period, 2004 through 2012. The additional time provided by reduced CO emission rate increases the chances for someone to find the exposed occupant(s) while still alive or for other circumstances to intervene that could interrupt the exposure, such as the consumer turning off the generator if the power is restored, or the occupants leave the home for other reasons. The reduced CO emission rate also provides the possibility that occupants, depending on where they are located relative to the generator, could survive the exposure, even if none of the above occurred and they remained exposed after the generator ran out of fuel. Staff believes such circumstances occur regularly, given that the number of victims seeking treatment for injuries is substantially higher than the number of fatalities. The modeling of the deaths averted aligns with staff's belief that slowing the extremely quick onset of incapacitation in cases of extremely high CO levels from current generators operating in enclosed spaces and increased survival time for occupants in the range of modeled scenarios will reduce CO deaths and injuries. Of the 156 deaths (659 minus 503) not included in the modeling analysis—because the generator was either outdoors or in a structure such as a camper, RV, tent, church, boat, or apartment complex that was not similar to any of the existing structure models—staff expects that an unquantified number of additional deaths would be averted, especially in incidents in which a generator was operated outdoors, or in large-volume enclosed or semi-enclosed locations, and/or in incidents in which co-exposed survivors were reported. From the staff's analyses, staff developed performance requirements for the four generator categories.

Staff recommends maximum CO emission rates for generators in each of four categories. Staff categorized the size of the generator by using the EPA's classification of the small spark ignition (SI) engine powering it: a handheld engine, a non-handheld Class I engine, or a non-handheld Class II engine.[a] The generator categories (as distinguished from the engine classes), and proposed emission rates, follow:

- A *handheld generator* is a generator powered by an SI engine with displacement of 80 cc or less; it may not exceed a weighted CO emission rate of 75 g/hr.
- A *class 1 generator* is a generator powered by an SI engine with displacement greater than 80 cc but less than 225 cc; it may not exceed a weighted CO emission rate of 75 g/hr.
- A *class 2 single cylinder generator* is a generator powered by an SI engine with one cylinder having displacement of 225 cc or greater, up to a maximum engine power of 25 kW; it may not exceed a weighted emission rate of 150 g/hr.
- A *class 2 twin cylinder generator* is a generator powered by an SI engine with two cylinders having a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW; it may not exceed a weighted emission rate of 300 g/h.

Each proposed emission rate limit is a weighted CO emission rate emitted from the generator when operating in ambient atmosphere with normal oxygen content (nominally 20.9%), calculated from the CO emission rates produced when each of six specified steady-state loads are applied to the generator.

Staff recommends that handheld and class 1 generators would have to comply within 3 years after a final rule is promulgated, and class 2 generators (both single and twin cylinder) would have to comply within 1 year after a final rule is promulgated. Additionally, staff recommends that the Commission adopt anti-stockpiling provisions as part of the draft proposed rule.

Staff conducted a regulatory analysis to evaluate the benefits and costs of the staff's draft proposed rule. The preliminary regulatory analysis found that the proposed rule could have substantial benefits for most generators. Estimated benefits ranged from about $210 to $240 for models with handheld, class 1 and class 2 single cylinder generators; however, benefits for the class 2 twin cylinder generators amounted to only about $4 per unit. The estimated costs of the

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[a] The EPA broadly categorizes small SI engines as either non-handheld or handheld and within each of those categories the EPA further distinguishes them into different classes, which are based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cc up to 225 cc and Class II having displacement at or above 225 cc but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Note that staff describes generators in this briefing package using the categories: handheld generator, class 1 generator, class 2 single cylinder generator and class 2 twin cylinder generator, as defined here. Staff describes engines as handheld, Class I and Class II, based on their EPA classifications, per 40 C.F.R. § 1054.801.

draft proposed rule were generally similar across generator types, ranging from about $110 to $120 per generator for the handheld, class 1, and class 2 single cylinder models, to about $139 for the twin cylinder models.

Given these benefit and cost estimates, net benefits (*i.e.*, benefits minus costs) ranged from about $100 to about $140 per generator for the *handheld, class 1, and class 2 single cylinder generators*. However, net benefits were a *negative $135 for the class 2 twin cylinder models* (*i.e.*, benefits of $4 per generator minus costs of $139 per generator). Consequently, net benefits for portable generators as a group would be maximized by excluding the two-cylinder models from the rule, though it should be noted that the CPSA does not require such a maximization of benefits. The CPSA requires only that benefits bear a reasonable relationship to costs.

Aggregate net benefits (*i.e.*, benefits minus costs), based on 1 year's production and sale of the handheld, class 1, and class 2 single cylinder generators amounted to $153 million. Including the class 2 twin cylinder models (which account for only about 5 percent of portable generators sold in recent years) would reduce aggregate net benefits to about $145 million annually. Staff performed a sensitivity analysis that generally supported the findings of the base analysis. For each variation analyzed (*i.e.*, expected product life; the discount rate; compliance costs; the value of statistical life applied; and the estimated effectiveness of each generator category in reducing CO emissions), staff found that the overall estimated net-benefits of the draft standard were positive; however, as with the base analysis, staff found class 2 twin cylinder generators to have estimated costs that are greater than the present value of projected benefits.

Staff identifies several regulatory alternatives that the Commission could consider to address the risks of CO poisoning from consumer use of portable generators. The alternatives include: (1) establishing less-stringent (higher allowable) CO emission rates; (2) excluding class 2 twin-cylinder generators from the scope of the rule; (3) including an option allowing compliance via automatic shutoff systems; (4) establishing a later effective date; (5) relying upon informational measures only; and (6) taking no regulatory action. Staff recommends that the Commission publish the draft NPR for portable generators provided with this briefing package. The draft NPR would establish a consumer product safety rule under the Consumer Product Safety Act (CPSA) and would specify CO emission limits for four different generator categories.

TABS

TAB A Hnatov, Matthew, *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014*, U.S. Consumer Product Safety Commission, Bethesda, MD, June 2015.

TAB B Hnatov, Matthew, *Generator Categories for Generators Involved in Fatal CO Incidents*, 2004-2014, U.S. Consumer Product Safety Commission, Bethesda, MD, September 30, 2016.

TAB C Smith, Timothy, *Consumer Responses to Reduced Carbon Monoxide Emissions from Portable-Generator Engines and to Carbon Monoxide Poisoning Symptoms*, U.S. Consumer Product Safety Commission, Bethesda, MD, August 15, 2016.

TAB D Lim, Han, *Engineering Staff Responses to CO-Sensing and Exhaust Ventilation Related Public Comments on 2006 ANPR for Portable Generators; 2012 CPSC Staff Report, "Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator"; and Related Staff and Contractor Reports*, U.S. Consumer Product Safety Commission, Bethesda, MD, May 26, 2016.

TAB E Bathalon, Susan, *Responses to comments concerning the CPSC report titled, 'Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator"* U.S. Consumer Product Safety Commission, Bethesda, MD, October 3, 2016.

TAB F Smith, Timothy, *Human Factors Staff Responses to Labeling-Related Public Comments on 2006 ANPR for Portable Generators and 2012 CPSC Staff Report, "Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator,"* U.S. Consumer Product Safety Commission, Bethesda, MD, August 15, 2016.

TAB G Whitfield, Troy, *Portable Generator Compliance Activity*, U.S. Consumer Product Safety Commission, Bethesda, MD, July 21, 2016.

TAB H Hanway, Stephen, *Assessing the Impact of the 2007 Generator Label Requirements*, U.S. Consumer Product Safety Commission, Bethesda, MD, July 21, 2016.

TAB I Buyer, Janet, *Rationale for Proposed Performance Requirements, Effective Dates, and Certification for Staff's Proposed Rule for Portable Generators*, U.S. Consumer Product Safety Commission, Bethesda, MD, October 3, 2016.

TAB J Brookman, Matthew, P.E., *Development of Test Methods for Determining the Carbon Monoxide Emission Rate of Portable Generators in Normal and Reduced*

Atmospheric Oxygen, U.S. Consumer Product Safety Commission, Bethesda, MD, October 3, 2016.

TAB K Hnatov, Matthew, S. Inkster, and J. Buyer, *Estimates Of Epidemiological Benefits Associated With Reduced Carbon Monoxide (CO) Emission Rates Compared To CO Emission Rates Of Current Portable Generators*, U.S. Consumer Product Safety Commission, Bethesda, MD, October 3, 2016.

TAB L Smith, Charles, *Draft Proposed Rule Establishing a Safety Standard for Portable Generators: Preliminary Regulatory Analysis*, U.S. Consumer Product Safety Commission, Bethesda, MD, September 2016.

TAB M Krishnan, Charu, R. Squibb, *Draft Proposed Rule Establishing a Safety Standard for Portable Electric Generators: Initial Regulatory Flexibility Analysis*, U.S. Consumer Product Safety Commission, Bethesda, MD, September 2016.

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UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

This document has been electronically approved and signed.

MEMORANDUM

DATE: October 3, 2016

TO : The Commission
Todd Stevenson, Office of Secretary

THROUGH: Mary T. Boyle, General Counsel
Patricia H. Adkins, Executive Director
DeWane Ray, Deputy Executive Director for Safety Operations

FROM : George A. Borlase, Ph.D., P.E.
Assistant Executive Director
Office of Hazard Identification and Reduction

Janet Buyer, Project Manager
Division of Mechanical and Combustion Engineering
Directorate for Engineering Sciences

SUBJECT : Notice of Proposed Rulemaking for Portable Generator Standard to Address Carbon Monoxide Poisoning Hazard

1. Introduction

This memorandum, prepared by staff of the U.S. Consumer Product Safety Commission (CPSC or Commission) as a follow up to the Commission's advance notice of proposed rulemaking (ANPR),[b,1] describes staff's draft proposed standard to address the carbon monoxide (CO) poisoning hazard associated with portable generators and summarizes staff's analyses that support the standard.

[b] Superscripted numbers refer to references listed in Section 7 of this memorandum. Superscripted letters refer to footnotes.

2. Product Description

A portable generator is an engine-driven machine that converts chemical energy from the fuel powering the engine to rotational energy, which, in turn, is converted to electrical power. The engine can be fueled by gasoline, liquid propane, or diesel fuel.[c] The generator has a receptacle panel for connecting appliances or other electrical loads to it via a plug connection. Such generators are designed for portability, to be carried, pulled, or pushed by a person. CPSC staff does not consider the following items to be portable generators:

- Generators that are permanently installed in recreational vehicles and boats;
- Stationary generators that have permanent fuel and power output connections.

Generators are advertised by their many different features, but one of the primary features is the amount of electrical power the generator can provide on a continuous basis. This power, commonly referred to in the industry as "rated power," which is advertised in units of watts or kilowatts (kW), can range from under 1 kW for the smallest portable generators, to nominally 15 kW for the largest portable generators.[d] Knowing a generator's rated power is useful to the consumer because the consumer can choose an appropriate size generator for the power tools, household appliances, recreational equipment, and any other electrical loads to which the consumer anticipates wanting to provide power.

Staff's recent informal review of advertised prices for portable generators (including units available in stores and via the Internet) found that retail prices generally vary by kW rating of the units. Average prices are $393 for units under 2 kW; $606 for 2 to 3.49 kW generators; $640 for 3.5 to 4.99 kW units; $936 for units with 5 to 6.49 kW ratings; $1,002 for units with 6.5 to 7.99 kW ratings; and $1,745 for units with kW ratings of 8 or more. Generator characteristics other than power ratings also affect price. For example, "inverter generators" have electronic and magnetic components that convert the AC power to DC power, which is then "inverted" back to clean AC power that maintains a single phase, pure sine wave at the required voltage and frequency suitable for powering sensitive equipment, such as computers. These additional components add to the manufacturing cost, resulting in significantly higher retail prices than units with similar power outputs. For instance, staff's limited retail price survey found that the average retail prices of generators with power ratings of under 2 kW are $242 for units not identified as inverters and $710 for those that were identified as inverters.[e]

Figure 1 provides photos of examples of gasoline-fueled portable generators, in order of increasing rated power, from among the smallest to among the largest.

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[c] Engines that operate on gasoline or liquid propane are called spark ignition (SI) engines and engines that operate on diesel fuel are called compression ignition (CI) engines.

[d] The generator's rated power is generally a function of the size of the engine, but there is no standard that industry follows that relates the generator's rated power to the size of the engine, nor any uniform way in which electrical output capacity is advertised as "rated." This is discussed in more detail in TAB I.

[e] This information is discussed in more detail in TAB L.

Figure 1: Examples of Gasoline-Fueled Portable Generators

3. Background

3.1. Consumer CO Poisoning Deaths Involving Generators Reported to CPSC and the Hazard Patterns Associated with Those Deaths

In 2002, the Commission initiated the Portable Generator Project to look specifically at the CO poisoning hazard associated with this product because the CPSC's estimated number of CO poisoning deaths associated with generators appeared to be increasing annually.

CO is a colorless, odorless, poisonous gas formed during incomplete combustion of fossil fuels, such as the fuels used in the engines that power portable generators. Although pure CO is colorless and odorless, when it is produced by combustion engines, pure CO may be accompanied by noxious odors of other exhaust gas constituents. Initial CO poisoning effects result primarily from oxygen deprivation (hypoxia) due to compromised uptake, transport, and delivery to cells. Compared to oxygen, CO has approximately a 250-fold higher affinity for hemoglobin. Thus, inhaled CO rapidly enters the bloodstream and effectively displaces oxygen from red blood cells, resulting in formation of carboxyhemoglobin (COHb).[f] CO can also displace oxygen in the muscle protein myoglobin, but this usually does not occur until after COHb levels have been significantly elevated. The heart, brain, and exercising muscle are the

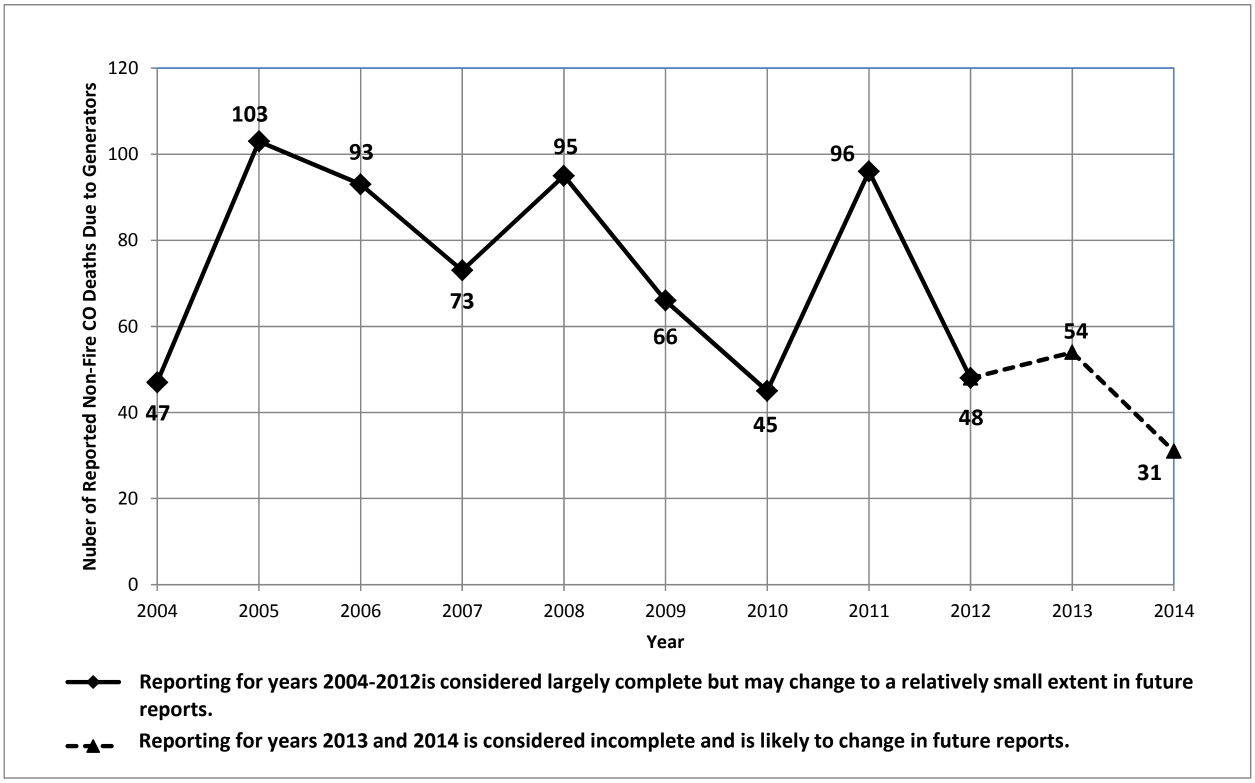
[f] COHb, expressed as a percentage, reflects the percentage share of the body's total hemoglobin pool occupied by CO. Although the relationship is not absolute, percent COHb levels can provide a useful index of CO poisoning severity. It is measured with a blood sample from the exposed person.

tissues with the highest oxygen requirements; consequently, they are most sensitive to CO-induced hypoxia. This is reflected in the non-specific flu-like symptoms of mild CO poisoning and early symptoms of severe poisoning, *e.g*., headache, lightheadedness, nausea, and fatigue. More severe CO poisoning can result in progressively worsening symptoms of vomiting, confusion, loss of consciousness, coma, and ultimately, death. The high CO emission rate of current generators can result in situations where the COHb levels of exposed individuals rise suddenly and steeply, causing them to experience rapid onset of confusion, loss of muscular coordination, and loss of consciousness. This can occur without people first experiencing milder CO poisoning symptoms associated with a low, or slowly rising, CO level.

CPSC staff publishes an annual report summarizing the in-scope[g] CO incidents associated with engine-driven generators and other engine-driven tools. Staff is using that report to provide the base number of incidents for the rulemaking. To be able to use the incident data as an input to aspects of the analysis described below, and to maintain consistency, staff set a date of May 21, 2015, as a cut-off for the incident data used in this package. As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related, consumer CO poisoning deaths resulting from 562 incidents that occurred from 2004 through 2014 (TAB A). Figure 2 shows the count of deaths involving a generator in CPSC databases for each of these years. Due to incident reporting delays, statistics for the two most recent years, 2013 and 2014, are incomplete because data collection is ongoing, and the death count most likely will increase in future reports.

[g] In-scope cases are unintentional, not work-related, non-fire CO poisoning deaths associated with a consumer product under the jurisdiction of the CPSC. Out-of-scope cases involve CO sources that are not under the jurisdiction of the CPSC (including motor vehicle exhaust cases), fire or smoke-related exposures, or intentional CO poisonings. Examples of out-of-scope cases include: poisonings due to gases other than CO (*i.e*., natural gas, ammonia, butane); poisonings from motor vehicle exhaust or generators permanently installed in boats or recreational vehicles; and work-related exposures.[4]

Figure 2. Number of Reported Non-Fire Carbon Monoxide Poisoning Deaths Involving Generators Entered in CPSC Databases by Year, 2004-2014



Note: Out of the 751 deaths shown in Figure 2, sole use of a generator was responsible for 702 of these deaths, and the remaining 49 deaths involved concomitant use of a generator and another combustion product.

Staff's analysis of expected epidemiological benefits (TAB K) and the regulatory analysis (TAB L) do not include data reported to CPSC after May 21, 2015, or any data for incidents beyond 2012 (85 deaths in 64 incidents known as of May 21, 2015) because data for these years is incomplete. These analyses also exclude incidents involving generators that are out of scope of the draft proposed rule (7 deaths in 5 incidents). Therefore, staff's analyses discussed in TABs K and L are based on 659 deaths in 493 incidents that occurred from 2004 through 2012. Staff notes that reporting of generator-related deaths is not a statistical sample or a complete count of incidents.

CPSC staff assigned IDIs on 535 of the 562 incidents (95 percent) to gather more detailed information about the incident and the product(s) in use to characterize hazard patterns. In cases where IDIs did not contain sufficient information because the information was unavailable or unknowable or when lack of participation prevented conduct of IDIs, staff used other CPSC source documents and information gathered from Internet searches of news and other sources to supplement the information.

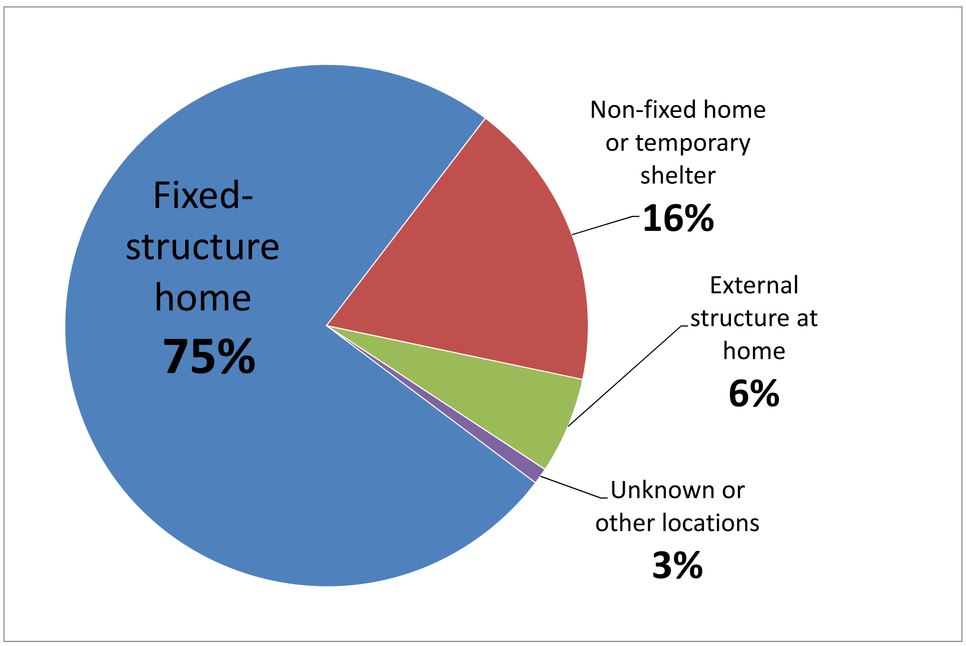
3.1.1. Locations of Incidents and Locations of Generators when Location Was Fixed Structure Home Site

From the IDI reports, staff categorized the incident data according to the location where the incident occurred:

- Seventy-five percent of deaths (565 deaths, 422 incidents) occurred in a fixed-structure home location, which includes detached and attached houses, apartments, fixed mobile homes, and cabins used as a permanent residence.
- Sixteen percent (117 deaths, 81 incidents) occurred at non-fixed home locations or temporary structures, such as trailers, horse trailers, recreational vehicles (RV), cabins (used as a temporary shelter), tents, campers, and boats and vehicles in which the consumer brought the generator on board or into the vehicle.
- Six percent (48 deaths, 46 incidents) occurred in external structures at home locations, such as sheds and detached garages.
- Three percent, (21 deaths, 13 incidents) occurred at unknown or other locations.

See Figure 3.

Figure 3. CO Deaths Associated with Generators by Location of the Incident, 2004-2014



Of the 565 deaths (422 incidents) that occurred at a fixed structure home,

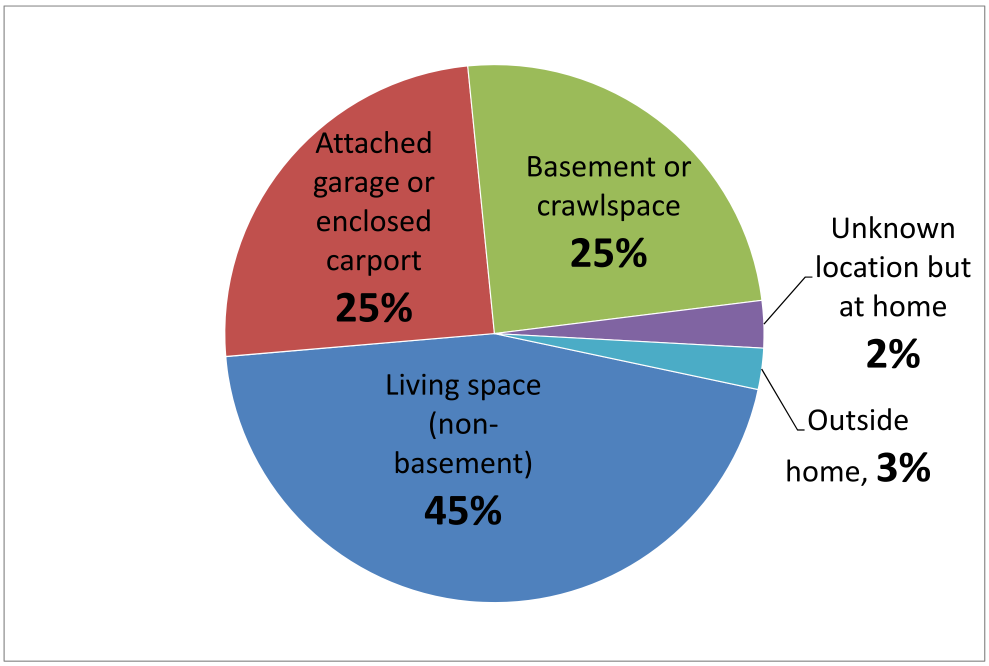
- Forty-five percent (256 deaths, 191 incidents) occurred when the generator was operated in the living space[h] of the house.
- Twenty-five percent (140 deaths, 108 incidents) occurred when the generator was in the attached garage or enclosed carport.

[h] Used here, living space includes all rooms, closets, doorways and unidentified areas inside a home, but it does not include basements, which are treated as a separate category.

- Twenty-five percent (139 deaths, 98 incidents) occurred when the generator was in the basement or crawlspace.
- Three percent (16 deaths, 12 incidents) occurred when the generator was operated outside.[i]
- Two percent (14 deaths, 13 incidents) occurred when the generator was at the fixed structure home site but exact location was unknown.

See Figure 4.

Figure 4. CO Incidents Involving Generators that Occurred in a Fixed Structure Home Location, by Specific Location of the Generator, 2004-2014



3.1.2. Sizes of Generators Involved in Incidents

The size of the generator involved in a CO fatality was identified in 45 percent of the 562 incidents (TAB B). Because most of the generators that were associated with fatal CO poisoning were gasoline-fueled[j], staff categorized the size of the generator by using the U.S. Environmental Protection Agency's (EPA) classification of the small spark ignition (SI) engine powering it: a handheld engine, a non-handheld Class I engine, or a non-handheld Class II engine. Staff further divided the incidents involving generators powered by non-handheld Class II engines by whether

[i] Another 28 deaths from 19 incidents occurred with generators operating outside structures other than fixed-structure home sites, such as RV, camper or trailer, vehicle, boat, or cabin used other than as permanent residence (see reference 72).

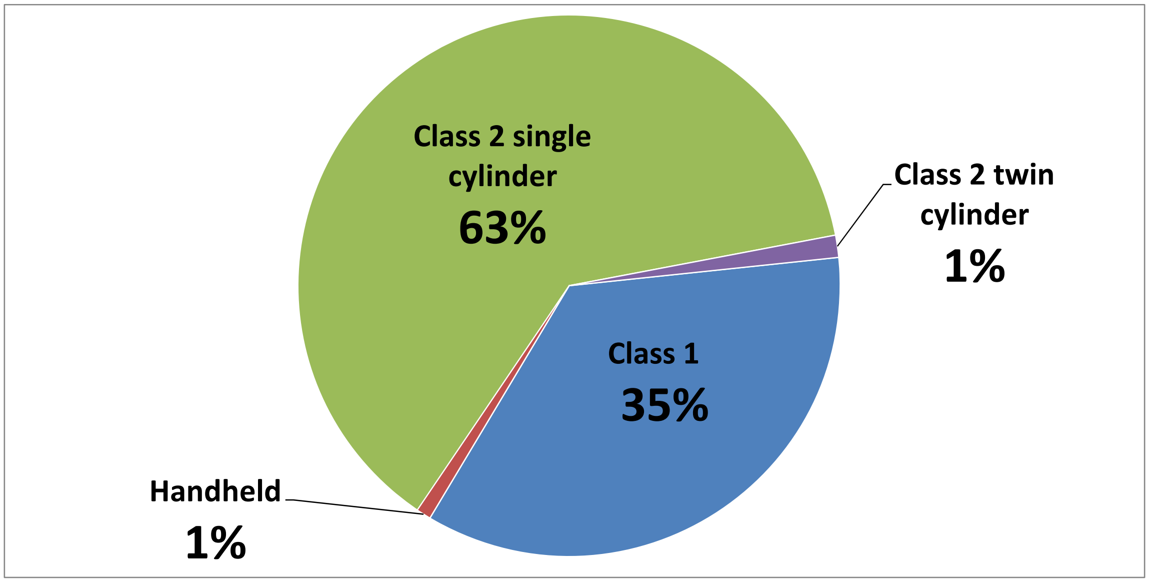
[j] In 52 of the 562 incidents, the fuel type could not be ascertained. Of the 510 cases where the fuel type used in the generator was known, 99 percent (506 of 510) were gasoline-fueled. Of the remaining incidents, three involved propane-fueled generators, and the other incident involved a diesel-fueled generator.

the engine had a single cylinder or twin cylinders. Staff refers to these four generator categories as handheld, class 1, class 2 single cylinder, and class 2 twin cylinder.

In the majority of cases (55 percent), CPSC staff could not obtain sufficient information to categorize the involved generator. In the incidents where engine classification could be determined, slightly more than one-third (35 percent) involved class 1 generators, and slightly less than two-thirds (63 percent) involved class 2 single cylinder generators. See Figure 5.

There were two incidents involving handheld generators that caused one death in each incident. There were three incidents involving class 2 twin-cylinder generators that caused seven deaths; two of the incidents were single-death incidents and the third incident, with the generator operating outside an RV, caused five deaths inside the RV.

Figure 5. Size of Generator Involved In CO Incidents, When Generator Size Was Identified, 2004-2014



To see examples of what portable generators in each of the four categories look like, refer to the generators shown in Figure 1. Generators 1 and 2 are handheld generators, generators 3 and 4 are class 1 generators, generators 5 and 6 are class 2 single-cylinder generators, and generators 7 and 8 are class 2 twin-cylinder generators.

3.1.3. Deaths per Incident and Ages of Victims Involved in Incidents

CPSC staff examined the number of deaths associated with each fatal incident. Seventy-five percent (423 out of 562) of the fatal generator-related incidents involved a single fatality. One incident involving a generator resulted in the deaths of six individuals, and two others involved five fatalities. See Figure 6.

Figure 6. Number of Reported CO Deaths per Incident Involving with Generators, 2004-2014

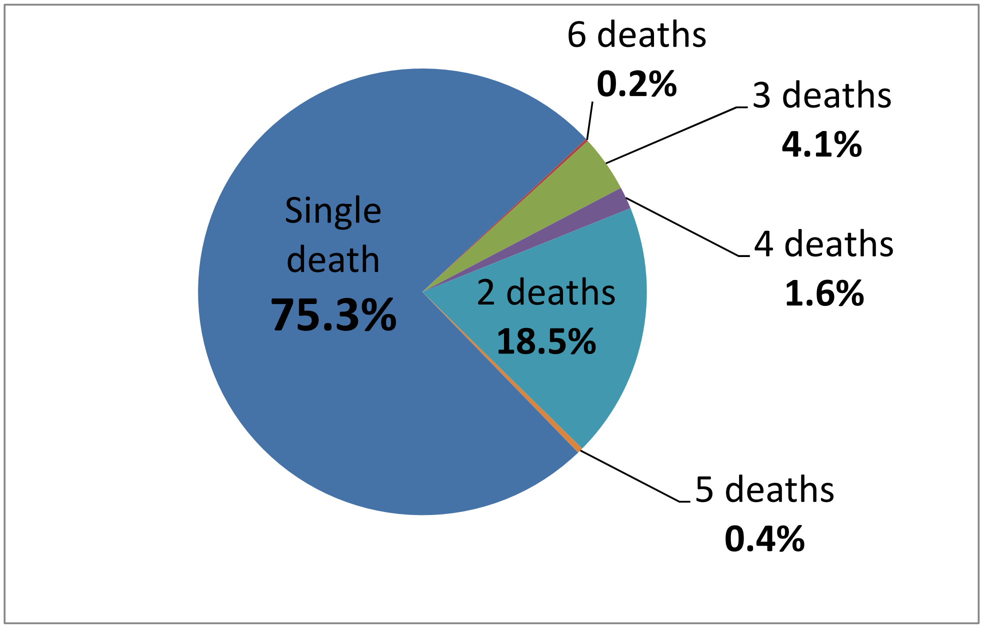
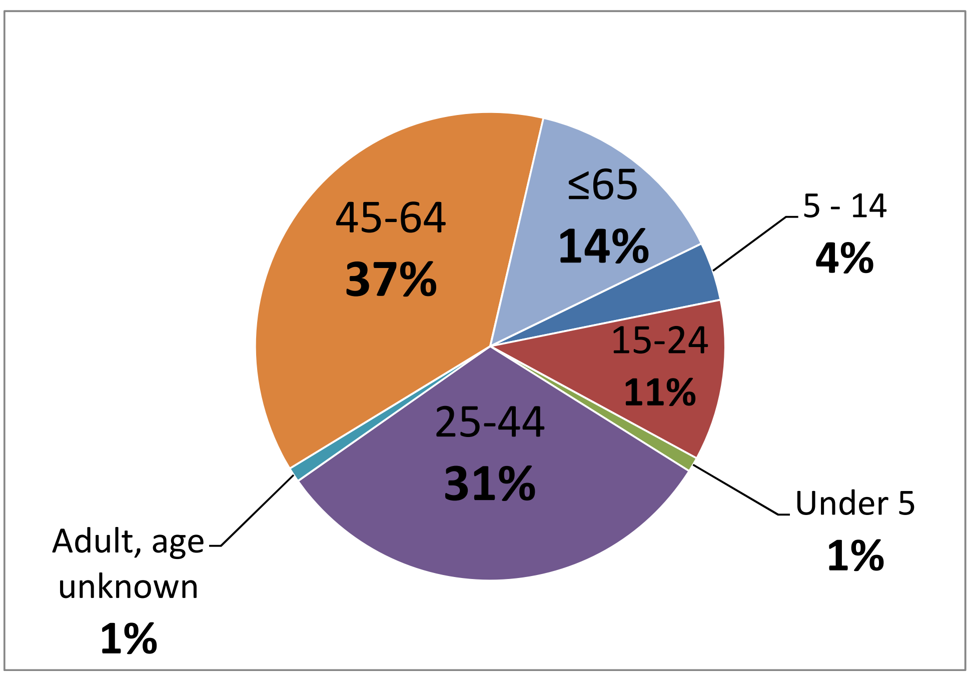


Figure 7 represents the distribution of ages of the victims. Victims age 25 years or older accounted for about 82 percent (620 of 751) of reported CO poisoning deaths associated with generators when age of the victim was reported.

Figure 7. Number of Reported CO Deaths Involving Generators by Age of Victim, 2004-2014



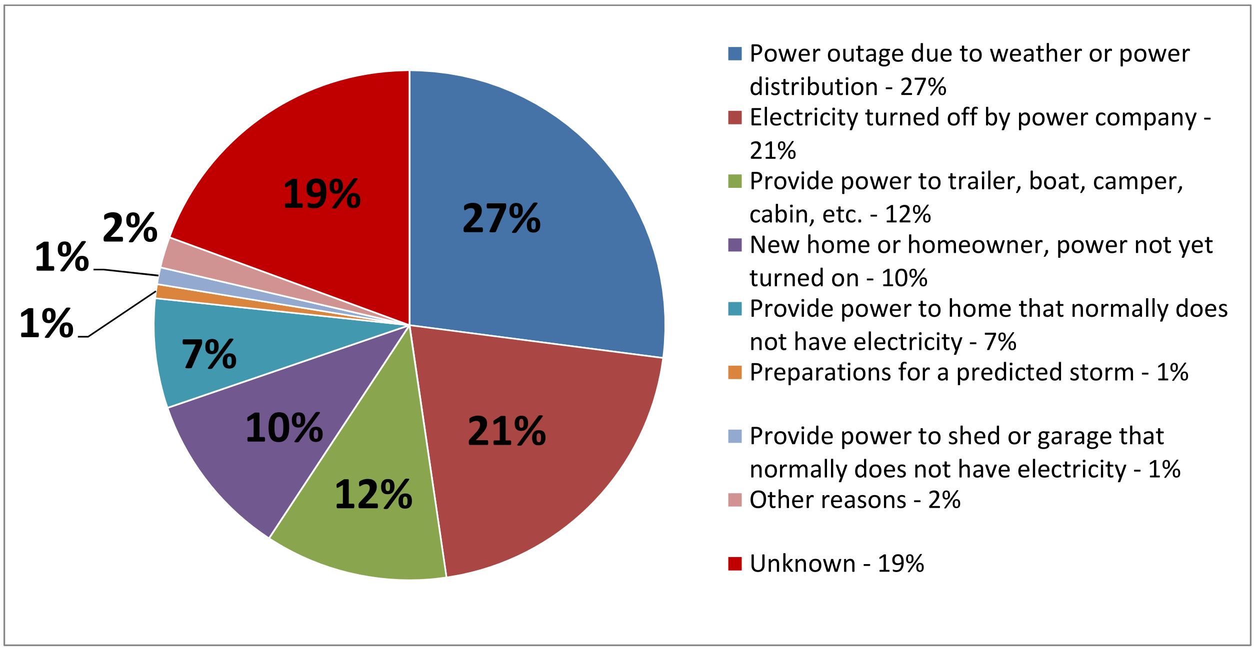
3.1.4. Reason for Generator Usage in Incidents

The reason the generator was needed was identified in more than 80 percent of the 562 incidents.

- Twenty-seven percent (152 incidents) were associated with the use of generators during a temporary power outage stemming from a weather problem or a problem with power distribution.
- Twenty-one percent (116 incidents) were associated with the use of generators after a power shutoff by the utility company for nonpayment of a bill, a bill dispute, or other reason.
- Nineteen percent (109 incidents), did not indicate why the generator was in use, or why there was no electricity at the location of the incident.

See Figure 8.

Figure 8. Reason for Generator Use, 2004-2014



Of the 152 fatal incidents associated with a power outage from weather or a problem with power distribution, 93 percent were due to specific weather conditions. Ice or snow storms are associated with the largest percentage of weather-related CO fatal incidents, accounting for nearly half (49 percent) of the power outage-related incidents. Hurricanes and tropical storms are also associated with 28 percent of CO fatal incidents. More than half (31 of 61) of the generator-related CO fatalities that were hurricane- or tropical storm-related (20 of 42 fatal incidents) occurred in 2005.

TAB A contains additional detailed information on the hazard patterns.

3.2. Other Potentially Fatal Hazards Associated with Generators

Two other potentially fatal hazards are associated with generators: electrocution and fire. For the 11-year period from 2004 through 2014, there are records of six non-work-related electrocutions[2] and 15 fire-related deaths.[3] Additionally, based on the latest available data from the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association's (NFPA) annual survey of fire losses, staff estimates that there were a total of 1,000 fires involving portable generators over the 2004 through 2012 timeframe. Associated with these fires, staff estimates that there were a total of 110 injuries and $55.9 million in property and content loss.[4] The estimates pertain to unintentional, residential structure fires, resulting in civilian (*i.e.*, not firefighter) injuries. The fire estimate above was rounded up to the nearest 100; the injury estimate was rounded to the nearest 10; and the property/content loss was rounded to the nearest tenth of a million dollars. Compared to the potentially fatal electrocution and fire hazards, the overwhelming majority of deaths associated with generators is due to nonfire CO poisonings.

3.3. CPSC's Estimate of Generator-Related Consumer CO Poisoning Injuries and Narrative Summaries of NEISS Records

In addition to CO poisoning fatalities reported to CPSC that are associated with generators, staff also investigated CO poisoning injuries from literature and from CPSC data. Staff considered numerous published articles about fatal and nonfatal CO poisonings involving generators that occurred with the generator operating indoors and outdoors.[5,6,7,8,9] In addition, based on the CPSC's National Electronic Injury Surveillance System (NEISS) database, which is a national probability sample of hospitals in the United States and its territories, staff estimates that for the 9-year period from 2004 through 2012, there were 8,703 CO injuries associated with generators and seen in emergency departments (ED).[10] Staff cautions that this estimate should not be considered definitive because physicians have noted difficulty in correctly diagnosing these injuries.[11] CO poisoning may mimic many nonfatal conditions, including alcohol or drug intoxication, psychiatric disorders, flulike illnesses, and other conditions that can lead to misdiagnosis. Measurement of COHb levels in the victim's blood, which could confirm the poisoning, can also be confounded, based on the time elapsed and any breathing treatment administered that can lower counts before measurement. In addition, staff is aware that in some incidents reported in the IDIs, first responders transported severely poisoned victims found at the scene directly to a medical facility with a hyperbaric oxygen (HBO) chamber[k] for treatment, rather than to a hospital ED. For all these reasons, staff believes that the injury estimate may be low. Staff considers this number to represent a lower bound on the true number of generator-related CO injuries treated in EDs from 2004 through 2012.

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[k] A HBO chamber is a facility used for exposing patients to 100 percent oxygen under supra-atmospheric conditions to shorten the time it otherwise normally takes for the CO to leave the bloodstream and to increase the amount of oxygen dissolved in the blood. A broad set of recommendations has been established for HBO treatment for CO poisoning, which includes a COHb level above 25 percent, loss of consciousness, severe metabolic acidosis, victims with symptoms such as persistent chest pain or altered mental status, and pregnant women. Treatment is not recommended for mild-to-moderate CO poisoning victims, other than for those at risk of adverse outcomes.[16]

In addition to the estimate of generator-related CO injuries treated in the EDs of NEISS hospitals, staff also estimated CO injuries using CPSC's Injury Cost Model (ICM) (TAB L). The ICM estimates injuries treated in locations other than hospital emergency departments. Specifically, the ICM uses empirical relationships between the characteristics of injuries and victims in cases initially treated in hospital emergency departments and those initially treated in other medical settings (*e.g.*, physicians' offices, ambulatory care centers, emergency medical clinics, etc.), based primarily on data from the Medical Expenditure Panel Survey,[1] to estimate the number of medically attended injuries that were treated outside of hospital emergency departments. The ICM also analyzes data from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project to project the number of direct hospital admissions bypassing the hospital emergency departments. According to the ICM estimates, there were an additional 16,660 medically attended CO injuries involving generators during 2004 through 2012. Consequently, based on NEISS and ICM estimates, there was a minimum of about 25,400 medically attended CO injuries treated during the 9-year time period. This is a ratio of almost 39 generator-related CO injuries to every CO death that occurred in that period.

In addition to the CO injury estimates cited above, staff examined the narratives of 292 cases of CO-related ED visits to NEISS member hospitals that were associated with generators for the years 2004 through 2014[12] . The percentages provide observed proportions based on a sampling of all EDs. These percentages are weighted to correspond to national averages. Sixty-six percent of the patients were treated and released or released without treatment. Twenty-eight percent of the patients were treated and admitted for hospitalization, treated and transferred to another facility, or held for observation. In cases where patients were treated and transferred to another hospital (35 cases), it may be because the other hospital was better equipped to treat CO poisoning. In nine of these cases, patients were known to have been transferred to a hospital and received treatment in an HBO chamber.

Table 1 presents a list of the most commonly identified symptoms given in the NEISS case narratives. In many of the cases, multiple symptoms were reported. However, in 29 percent of the cases (85), symptoms were not described in the NEISS narrative although the diagnosis was reported. The weighted proportion of the total accounts for differences in selection probabilities in the NEISS sample design.

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[1] The Medical Expenditure Panel Survey (MEPS) is a nationally representative survey of the civilian non-institutionalized population that quantifies individuals' use of health services and corresponding medical expenditures. The MEPS is administered by the Agency for Healthcare Research and Quality (AHRQ). The MEPS has been collected continuously since 1999, and it is the principal data set used to monitor medical spending in the United States.

Table 1. Most Common Symptoms Reported in NEISS CO Poisoning or CO Exposure Cases Involving Generators, 2004-2014

Common Symptoms*	Cases	Weighted Proportion
Headache	73	27%
Nausea Felt Sick	77	30%
Dizzy/Confused Disorientation Lightheaded	70	25%
Vomiting	34	16%
Passed Out Unconscious Unresponsive	18	5%

*Cases may appear multiple times in Table 1 because victims may have exhibited multiple symptoms.

Table 2 presents a summary of the reasons why the patients went to the emergency room for treatment or to be checked out. In the majority of cases, the medical records, from which the narratives were abstracted, provided little or no information on how the patients knew they needed to go to the emergency room or how they got there. However, in more than half of the cases where this information was available (47 of 93 cases, or 59 percent when selection probabilities are accounted for), the patient realized that there was a problem and arranged to get to the emergency room.

Table 2. Reason Victim Went to ED for NEISS CO Poisoning or CO Exposure Cases Involving Generators, 2004-2014

Reason	Cases	Weighted Proportion
Victim realized something was wrong and arranged to get to ER	47	23%
Discovered in distress by family, friend or due to a welfare check	24	6%
Carbon monoxide alarm sounded, arranged to get to ER	22	9%
Unknown why or how taken to Emergency Room	199	62%
Total	292	100%

Table 3 presents a summary of the location of the generator involved with the nonfatal CO poisoning incidents. The three most common locations identified were "Inside the home" (33percent), "Inside the garage" (25 percent), and "In the basement" (18 percent). In 11 percent of the reported cases, the generator was located outside. In half of the "Outside the home" scenarios, the narrative specifically states that the location was near a window, door, or air conditioner.

Table 3. Location of Generator in Cases Reported in NEISS CO Poisoning or CO Exposure Cases Associated with Generators, 2004-2014

Generator Location	Cases	Weighted Proportion*
Inside the home	86	33%
Inside the garage	70	25%
In the basement	56	18%
Outside the home	29	11%
Other/Unknown	51	14%
Total	292	100%

* Percentages don't sum to 100% due to rounding

The prognosis for CO poisoning survivors can be difficult to predict, but given the extremely high CO levels in generator exhaust, and particularly if incidents involve a fatality, survivors of generator-related CO poisoning incidents can be significantly at risk of developing the phenomenon of delayed neurological sequelae (DNS), which can manifest in a few days or weeks after apparent recovery from the initial CO poisoning incident.[13,14,15,16] Symptoms can include: emotional instability, memory loss, dementia, psychosis, Parkinsonism, incontinence, blindness, paralysis, and peripheral neuropathy. Symptoms of DNS may respond to HBO therapy and/or may resolve spontaneously over a 2-year period. However, victims exhibiting the most severe symptoms, such as Parkinsonism, blindness, and paralysis are often permanently affected. Although loss of consciousness is typically associated with more serious outcomes, it is not necessary to lose consciousness to sustain DNS from CO exposures. Although current understanding of DNS does not allow very accurate prediction of DNS occurrence in nonfatal CO poisoning cases, some authorities regard 20 percent COHb as an approximate lower threshold of concern for DNS.[17]

3.4. Voluntary Standards Pertaining to Portable Generators

Two organizations have been accredited by the American National Standards Institute (ANSI) to develop a U.S. safety standard for portable generators. One is Underwriters' Laboratories Inc. (UL) and the other is the Portable Generator Manufacturers Association (PGMA). Each organization has a standard; however, only PGMA has developed an ANSI-recognized consensus standard. In addition, staff is aware of a product standard by the International Organization for Standardization (ISO) that has requirements applicable to portable generators. Each of these is discussed below.

3.4.1. UL 2201

In 2002, UL formed a standards technical panel (STP) comprised of stakeholders to develop the first U.S. voluntary standard dedicated solely to portable generators, UL 2201 *Safety Standard for Portable Generator Assemblies*. CPSC technical staff joined the STP for UL 2201 at its inception and has been an active participant, with a long record of advocating that the standard address CO poisonings.

The requirements in UL 2201 cover internal combustion engine-driven generators rated 15 kW or less, 250 V, or less, which are provided only with receptacle outlets for the AC output circuits. The scope of UL 2201 states that it addresses: "the electric shock, fire, and casualty aspects associated with the mechanical performance and the electrical features of portable engine-driven generator assemblies." Other than incorporating requirements of the mandatory CPSC label, discussed in section 3.6, the standard does not address the risks related to CO poisoning. UL 2201 includes construction requirements to define minimum acceptability of components of the fuel system, engine, alternator, output wiring and devices, frame/enclosures and others to ensure their suitability in this application to mitigate the risk of shock, fire and physical injury to users. The UL standard also addresses hazards through normal and abnormal operation tests to ensure that the engine generator does not introduce any of the electrical, fire or mechanical hazards that are intended to be mitigated. UL 2201 also includes manufacturing tests to ensure minimum levels of safety for production units.

UL has been unable to achieve consensus within the STP for UL 2201 to be recognized as an ANSI standard. Therefore UL 2201, first published in 2009, currently exists as a UL standard without ANSI recognition.

In January 2014, CPSC staff sent a letter to the UL 2201 STP Chair[18] to request a task group be formed to work on proposals to address the CO hazard that would eventually be balloted by the STP. The letter outlined a framework of requirements, based on work done by and for CPSC staff (described in more detail in sections 3.5.1 and 4.1.1 as well as TAB I) that could be used as a starting point for discussions. Accordingly, UL formed a task group with a roster of 37 members representing a broad range of stakeholder interests, including manufacturers of engines, generators, fuel control systems, and emission control components; public health officials; first responders; medical experts; indoor air quality experts; and government representatives from National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), National Institute for Standards and Technology (NIST), and CPSC staff. The task group chair is a representative from NIOSH. The first meeting of the task group was held in May 2014. As of August 2016, there have been 27 meetings, all held as teleconference meetings; and there has been active participation and constructive input from a number of the members. However, the task group has not yet sent a proposal to the STP to consider for adoption into UL 2201. A more detailed description of this effort is provided in TAB I.

Staff is unaware of any portable generator that is, or has been, certified to UL 2201, and, as such, it is unlikely whether UL 2201 would be substantially complied with if the UL standard incorporated CO emissions requirements.

3.4.2. Portable Generator Manufacturers Association ANSI/PGMA G300-2015

In 2011, ANSI accredited PGMA to be a standards development organization allowing PGMA, in addition to UL, to develop a standard for portable generators. PGMA's technical committee developed PGMA G300 – *Safety and Performance of Portable Generators* and used a canvass committee method for balloting. CPSC staff participated on PGMA's canvass committee, submitting comments that included noting the PGMA standard's lack of requirements to address the CO hazard.[19,20] PGMA published the first edition PGMA G300 as an American National Standard in June 2015.

G300 provides a method for testing the safety and performance of portable generators "rated 15 kW or smaller; single phase; 300 V or lower; 60 hertz; gasoline, liquefied petroleum gas (LPG) and diesel engine driven portable generators intended for multiple use and intended to be moved, though not necessarily with wheels." PGMA G300 includes construction requirements for engines, fuel systems, frame/enclosures, alternators, and output wiring and devices. The standard includes safety tests intended to address electrical, fire or mechanical hazards during intended generator operation. The standard also includes a section on testing for determination of output power rating that it delineates as non-safety based. PGMA G300 also includes manufacturing tests to ensure minimum levels of safety for production units. Other than a reference to the mandatory CPSC label, the standard does not address the risks related to CO poisoning.

CPSC staff continues to work with PGMA and urges PGMA to address the CO hazard. CPSC staff participated in a PGMA technical summit on March 17, 2016, and reaffirmed this commitment.[21] In April 2016, PGMA informed staff[22] that "the PGMA Technical Committee will create a performance-based standard that addresses the CO hazard created when portable generators are misused by operating them in or near occupied spaces as its top priority. The performance standard, once developed, will be proposed to the canvass group for addition to ANSI/PGMA G300 in the next revision cycle."[m] Staff responded to PGMA[23] and met with PGMA again at PGMA's request in August[24] and September 2016.[25]

In connection with the September meeting, on September 19, 2016, PGMA sent a letter to Chairman Kaye[26] indicating that PGMA is in the process of re-opening G300 and announcing its intent to develop a "performance strategy focused on CO concentrations." In the letter to Chairman Kaye and in staff's September meeting with PGMA, PGMA described only broad generalities of a framework for modifying G300 that involves testing a generator in an enclosed space (test chamber).[n] Staff believes that significant technical work, requiring significant time, will be required to develop appropriate requirements and test methods. Specifically, as discussed at the meeting, there are several technical concerns that would need to be investigated, particularly regarding shutoff criteria and testing. For example, staff is concerned whether a shutoff mechanism within a test chamber would be sufficient to work in a wide variety of real-world scenarios, whether the shutoff would occur quickly enough and in enough common scenarios seen in portable generator incidents to adequately reduce the risk of injury and death. Staff is also concerned about whether the test methodologies would be accurate, reliable, and practical. Staff expects that significant periods of time will be needed to develop requirements that will address each of these factors and to evaluate them. Furthermore, determining the expected epidemiological benefits for the draft proposed rule recommended by staff, summarized in section 4.3 and described in full in TAB K, required nearly a year for NIST to conduct the

[m] Staff's understanding is that PGMA's revision cycle is every 5 years.

[n] Product Safety Letter, *PGMA Talks Broad Strokes on Standards Work with CPSC*, Volume 45, Issue 34, September 12, 2016.

modeling study and for staff to analyze and evaluate it. For the PGMA to develop an effective voluntary standard, similar efforts will be required after the technical details have been established. In sections 3.5.2 and 3.5.3 of this memorandum, staff discusses concerns with a variety of shutoff methods and believes that a substantial effort will be required to analyze how PGMA's as-yet undetermined requirements and methods can address those concerns. Staff will be pleased to work with PGMA on this effort, but anticipates it will take a significant period of time to attempt to develop suitable requirements and subsequently to evaluate them.

Given the above information, staff does not have an adequate basis to determine if modifications to the voluntary standard would likely eliminate or reduce the risk of injury or death. In addition, because staff is unaware of any portable generator that is or has been certified to G300, it is unlikely whether there would be substantial compliance if CO emissions requirements were incorporated.

3.4.3. International Organization for Standardization ISO 8528-13:2016

International Organization for Standards (ISO) 8528-13:2016 *Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets - Part 13: Safety* is a standard applicable to portable generators sold overseas. The standard's requirements regarding the CO poisoning hazard are limited to labels and markings. The standard requires that the generating set must have a visible, legible, and indelible label that instructs the user: "exhaust gas is poisonous, do not operate in an unventilated area." Additionally, the standard requires that the general safety information section of the instruction manual shall state: "Engine exhaust gases are toxic. Do not operate in unventilated rooms. When installed in ventilated rooms, additional requirements for fire and explosion shall be observed."

3.4.4. CPSC Staff Assessment of the Adequacy of Voluntary Standards for Portable Generators in Addressing CO Deaths and Injuries

Staff assessed the voluntary standards applicable to portable generators and found that none addressed the CO hazard (other than including labeling requirements), and that they are not adequate to address CO deaths and injuries. Furthermore, because staff is not aware of any firms certifying products to these standards, staff does not believe that there is substantial compliance with these standards.

3.5. The ANPR and CO Hazard Mitigation Strategies Investigated by CPSC Staff

After the Commission initiated the Portable Generator Project in 2002, to look specifically at the associated CO poisoning hazard, staff continued to collect incident data and analyze the hazard patterns, among other activities. In May 2004, staff hosted a forum to present hazard information to the public and seek stakeholder input on possible solutions. In October 2005, the then-Chairman directed staff to conduct a thorough review of portable generator safety. In October 2006, staff presented to the Commission staff findings from that safety review, which included the currently available fatality information and recommended that the Commission initiate rulemaking.[27] In December 2006, the Commission voted to approve an advance notice of proposed rulemaking (ANPR), and staff began research to investigate technologies that could reduce the risk of CO poisoning associated with portable generators. The ANPR was published in the *Federal Register* on December 12, 2006.[1] The ANPR discussed a broad range of regulatory approaches that could be used to reduce portable generator-related deaths and injuries, particularily related to CO poisoning; staff invited public comment on the regulatory alternatives and any other approaches that could reduce portable generator-related deaths and injuries due to CO poisoning, shock/electrocution, and fire and burns. The Commission also invited interested persons to submit an existing standard to address the risk of injury described in the ANPR. Staff subsequently investigated several approaches to mitigate the CO hazard; those efforts are discussed in sections 3.5.1 and 3.5.2. Staff's conclusions about the strategies to address the hazard are discussed in section 3.5.3. Staff's responses to public comments received on the ANPR, (contained in reference 28) are discussed in section 3.5.4.

3.5.1. CO Hazard Mitigation Strategy Based on Reduced CO Emission Rate

One of the first approaches CPSC staff investigated was to reduce CO emissions from generator engines, thereby reducing the hazard at its source. To illustrate the potential benefits of such an approach, staff cites as one example, catalytic converters put on automobile engines beginning in 1975 to meet EPA emission standards. An approximate 76 percent decrease in their CO emission rate was achieved, and this resulted in a reduction of unintentional vehicle-related CO deaths of approximately 81 percent in the years of 1975 through 1996, as compared to earlier years.[29]

In the current rulemaking, staff aims to reduce generator-related CO deaths and injuries by reducing generators' CO emission rates and minimizing negative impacts on generators. More specifically, staff intends for any standard to minimize negative impacts on the engine's power output, durability, maintainability, fuel economy, and risk of fires and burns. Staff is also aware that the engine must continue to meet the EPA's standard for hydrocarbon and oxides of nitrogen (HC+NOx) emissions.

Looking at the technical feasibility of reduced CO emission rates and the corresponding potential for reduction in the CO hazard, staff developed a two-part technology demonstration program. The program was designed to establish that a portable generator powered by an engine modified with existing emission control technology could be developed to reduce simultaneously the risk of fatal and severe CO poisoning when used in an enclosed or semi-enclosed space and at the same time meet the EPA's (non-CO) emission standards to which the engine was originally certified.[30] The first part of the program, conducted under contract with the University of Alabama (UA),[o] was to develop and durability test a prototype from a commercially available carbureted 5 kW generator, by replacing the carburetor with an electronic fuel injection (EFI) system, installing an oxygen sensor in the exhaust for closed loop fuel control, and installing a small catalyst in the muffler. The second part of the program, conducted under an interagency agreement with NIST,[p] was to operate the generator in its unmodified carbureted configuration

[o] CPSC-S-06-0079.

[p] CPSC-1-06-0012.

and operate another generator in the prototype configuration, in the attached garage of a test house on NIST's campus. The test house, designed and used for indoor air quality (IAQ) studies, was used to measure the CO accumulation in the garage and transport into the house.[31] The results provide a sense of how quickly a commonly fatal scenario develops with an existing carbureted generator, and what the comparative results are from the same tests with the fuel-injected catalyzed prototype.

NIST compared the garage CO concentrations after equal periods of generator run-time from seven pairs of tests. The prototype showed 97 percent reduction in the amount of CO released into the garage, compared to the carbureted generator. This reduction translated to much lower levels of CO transported into the house. To quantify the generator's emission rates, NIST conducted tests on the generator in both configurations in a single-zone enclosed space. The results showed that the carbureted generator's CO emission rate was, depending on the load, around 500 grams per hour (g/hr) to 1500 g/hr at and near normal oxygen (~20.9%). As the oxygen dropped nominally to 17.0 to 17.5 percent oxygen, the CO emission rates for each load increased by a nominal range of two to five times. Overall, the generator's weighted CO emission rate increased by a factor of three compared to the generator's weighted rate when operating at or near normal oxygen.

The closed loop, EFI-equipped prototype's CO emission rates at normal and reduced oxygen levels were in most cases below 50 g/hr, depending on the load. Staff believes that based on recent testing, closed-loop EFI-equipped portable generators will typically experience an increase in CO emission rates at 17 percent oxygen, compared to normal oxygen levels. More information leading to this conclusion is in TABs I and J; and more information on the design and performance of the prototype generator is in section 4.1.1 and in TAB I.

The high CO emission rate of current generators can cause exposed individuals' COHb levels to rise suddenly and steeply.[14] Without the warning provided by milder symptoms, victims have very little, if any, time to recognize that an imminent life-threatening hazard is occurring and take actions that could reduce their CO exposure. Reduced CO emission rates can decrease the levels of CO that are likely to cause rapid loss of consciousness and other forms of incapacitation to exposed victims. The additional time provided by lower CO levels from a reduced CO emission rate could lower the potential for injury or death by allowing time for someone to find the potential victim, for the power to be restored, or the generator to run out of fuel, or other intervention. Staff recognizes that consumers exposed to these lower CO levels may ignore the milder symptoms and may not take any actions to reduce their exposure but instead remain in the location of the exposure. However, the reduced CO emission rate also provides the possibility that occupants, depending on where they are located relative to the generator, could survive the exposure, even if none of the above occurred and they remained in the exposure even after the generator ran out of fuel.

In the second part of the demonstration program, staff performed health effects modeling on the CO time course profiles in each room of NIST's house from transport of CO from the garage, to estimate COHb levels of hypothetical occupants in each room. From that modeling, staff estimated that the time interval for all occupants, even occupants in the garage with the generator, to perceive and react to the developing CO hazard before becoming incapacitated, is significantly extended with the low CO emission prototype generator, compared to the unmodified carbureted generator. For example, in one test in which the garage bay door and connecting door to the house were both closed, by using benchmark COHb levels to represent onset of obvious symptoms and incapacitation, the time interval increased by a factor of 12 with the prototype, compared to the carbureted configuration, from eight minutes to 96 minutes, for the deadly scenario of a consumer in the garage with the generator; the time interval increased even more for occupants inside the house.

Staff recognizes that extending the time interval does not guarantee safety. Even with slowed progression of symptoms, safety will depend upon individual behavioral responses. However, the results of NIST's testing and CPSC staff's analysis indicate that the reduced CO emission rate achieved by the prototype has significant potential for reducing CO deaths and injuries, compared to the carbureted configuration of most generators currently on the market. Indeed, based on an analysis staff performed on modeling conducted by NIST, staff estimates that a substantial number of the deaths reported in CPSC's databases could have been avoided if generators with lower CO emission rates had been involved in those incidents. This analysis is detailed in TAB K and summarized in section 4.3.

The CO emission rate of small SI engines is higher than commonly understood. For example, the CO emission rate of the unmodified carbureted 5 kW portable generator, when operating at normal oxygen and loaded with about half of its rated capacity, has a CO emission rate that is ***200 times greater*** than that measured on an idling 1996 Oldsmobile Cutlass.[q,32] When such a generator is operating in an enclosed space, and loaded to its rated capacity, the generator can have a CO emission rate more than ***1,500 times greater*** than an idling 1996 Oldsmobile Cutlass. As another example, CPSC staff measured CO concentrations in the flues of four natural gas-fired furnaces operating under normal conditions; they ranged from 12 to 198 ppm.[r,33,34,35,36] In contrast, UA measured the CO concentration from the undiluted exhaust of a carbureted generator while operating at normal oxygen in the range of 32,182 ppm to 77,888 ppm.[s] Thus, the CO in the undiluted exhaust of this generator's carbureted engine is more than two to three ***orders of magnitude*** (100 to 1000 times) greater than the furnaces'.   A carbureted generator's CO emission rate (and thus, concentration in terms of ppm) rises more when operated in an enclosed space while the oxygen is depleted. This 100- to 1,000-fold disparity in normal oxygen could be even greater for other engine models than the one used in staff's technology demonstration program. In contrast, the standard for furnaces, ANSI Z21.47 *Gas-Fired Central Furnaces*, has a limit of 400 ppm in an air-free sample of the flue gases.[37] All of this, in conjunction with increased consumer ownership of portable generators in recent years (discussed

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[q] Per reference 31, the carbureted generator's CO emission rate at normal oxygen with partial load applied was nominally 500 g/hr. At approximately 17.5 percent oxygen with near rated load applied, the generator's CO emission rate was nominally 3,750 g/hr. In contrast, reference 32 reports the CO emission rate of the 1996 Oldsmobile Cutlass while idling was 0.66 mg/sec (2.37 g/hr).

[r] The CO present in the flue gas is specified on an air-free basis.

[s] This is the range of exhaust CO concentration, measured on the unmodified, carbureted baseline generator using the raw gas sampling method, at 0 hrs for all six applied loads.

in section 4.4), could help explain why generators have overtaken furnaces as the consumer product responsible for the largest estimated number of annual nonfire-related CO deaths.[38]

3.5.2. CO Hazard Mitigation Strategy Based on an Automatic Shutoff Concept

In addition to staff's low CO emission prototype technology demonstration program, staff also investigated ways to possibly mitigate the CO hazard through a system that would automatically shut off the engine before creating an unsafe CO exposure. CPSC staff studied four candidate systems; their descriptions and staff's findings are explained in the sections below.

3.5.2.1. On-Board CO Sensing Shutoff

In this investigation, staff tested a generator that had been modified by attaching residential CO alarms to it that were modified to cause the generator to shut off when the CO alarm activated.[39] Staff tested the generator in different scenarios, one with the generator operating just on the inside of a roll-up door of a small building, similar to a doublewide manufactured home. Another scenario tested involved the generator operating in the middle of an outdoor courtyard. With the test generator operated indoors, the CO migrated and accumulated on the far side of the building more quickly than near the generator. The CO alarms on the generator never activated before alarms that were located elsewhere inside activated. The time difference for activation generally ranged from 5 to 10 minutes. In certain tests, CO levels in some parts of the building reached up to 1,000 ppm before the CO alarm on the generator activated and shut off the generator.

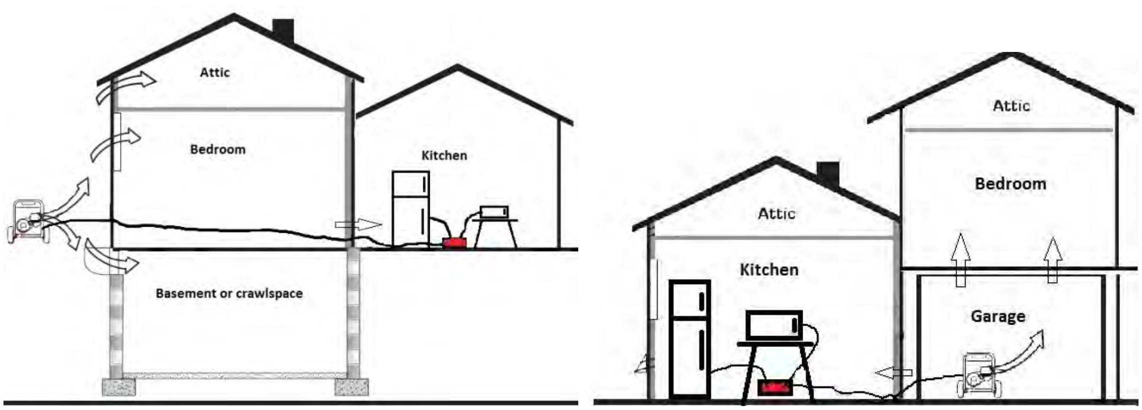
When the generator was operated outdoors in a light breeze condition, CO concentrations up to 350 ppm were measured in the immediate vicinity of the generator. Although this did not activate the CO alarms mounted on the generator to shut it off, staff believes this could occur in some circumstances. If such false-positive shut-off events occurred as nuisance shut-offs in real-world use of such a generator, that would detrimentally affect the utility of the generator when used in a proper location. Moreover, this could lead to consumers trying to override the mechanism, rendering it useless when the generator is operated indoors.

3.5.2.2. Remote CO Sensing Shutoff

In this investigation, staff used a residential CO alarm, modified with a wireless transmitter, which communicated with a receiver mounted on the generator to activate a shutoff circuit when the CO alarm activated.[40] In the scenarios tested, the system performed as intended. Staff notes, however, that the effectiveness of this type of system relies on the consumer accurately guessing which room of a house is going to have the highest CO infiltration and installing the alarm in that location. Figure 9, shown below, gives examples of why relying on the consumer to locate the CO alarm is unadvisable in staff's opinion. (In the Figure, the CO alarm is shown in red and is tethered to the generator, rather than wirelessly communicating with the generator; but the same concerns apply.) In both scenarios illustrated in the Figure, the consumer uses the generator to power kitchen appliances and both scenarios locate the CO alarm for the generator's shutoff mechanism in the kitchen. One scenario in the Figure shows the generator operating outdoors, but the exhaust infiltrates the bedroom, attic, and basement in higher concentrations than in the kitchen. The other scenario in the Figure shows the generator operating in a "tuck under" garage, with the high CO concentration in the garage infiltrating the bedroom over the garage more than into the kitchen. Both scenarios could create unsafe exposures in rooms other than where the CO alarm is located.

Although the CPSC mandatory label warning advising against use in an enclosed space, as discussed in section 3.6, would be on the generator, CPSC incident data indicate that some consumers do not comply with this warning. Furthermore, because the system's purpose is to shut off the generator but not to prevent it from starting, such a system may encourage some consumers at least to try and operate the generator in an enclosed space and rely on the system for protection. Other consumers, particularly those who think the CO alarm is activating and shutting off the generator unnecessarily, may try to bypass the shutoff feature. This could be done without tampering with the circuitry, by simply putting the CO alarm in a drawer or outside.

Figure 9. Example of Remote CO Sensing Shutoff Concept



3.5.2.3. Shutoff Using Global Positioning System Receiver

The third concept staff investigated used a global positioning system (GPS) mounted on the generator. This concept used an electromechanical circuit to shut off the generator if the GPS inferred indoor operation based on the GPS receiving poor satellite signal strength.[41] This is not an interlock system but requires the generator to be running to provide power to the GPS before it can detect indoor operation. From staff's testing using an automotive GPS, the prototype was able to detect successfully indoor operation; however, the GPS also detected indoor operation in several locations that were, in fact, outdoors under heavy tree cover. As stated above, staff believes that a shutoff mechanism should not adversely affect the generator's ability to operate outdoors. If shutdowns in proper locations were to occur, not only would this detrimentally affect the utility of the product, but it also might lead consumers to try and override or bypass the mechanism, rendering it useless for any subsequent event where the generator is operated indoors.

3.5.2.4. Programming in Engine Control Unit to Shutoff

The fouth concept staff pursued tasked UA with developing and programming into the prototype generator's EFI system's engine control unit (ECU), an algorithm that would sense when the generator was being operated in an indoor location and would signal the generator to shut off if it inferred indoor operation.[42,43] For this approach, staff specified that the algorithm not rely on any additional sensors other than those already integral to the existing engine management system for the EFI system. UA developed two algorithms. The first had shortcomings discovered later during supplementary testing conducted by CPSC staff and NIST that rendered the algorithm unacceptable: the algorithm would occasionally shut off the generator when operated outdoors; and under certain circumstances, would not shut off the generator when operated indoors. The second algorithm, based on employing data from the ECU to estimate the oxygen concentration in the intake air, showed more promise. In the limited testing that UA performed, the second algorithm for shutdown of the generator performed as intended. To prove this algorithm's robustness, however, a significant amount of additional testing on this system would be required. According to UA, more development work would be needed because the algorithm is engine-specific and would need to be tailored to how each engine on which it is installed functions.

3.5.3. Staff's Conclusions about CO Hazard Mitigation Strategies

Although staff investigated four different approaches for an automatic shutoff system, including two using CO sensors, staff was not able to demonstrate how a shutoff system could be implemented satisfactorily. The concept that staff considers might potentially be effective without negatively impacting the proper use of the generator is the use of sensors in the ECU (described in section 3.5.2.4), as demonstrated with UA's algorithm. Staff notes that the concept is *supplementary* to the low CO rate emitted by the prototoype because the shutoff algorithm only existed by virtue of the closed-loop fuel injection system. Staff considers this use of ECU sensor programming on a reduced-CO emissions generator to be the best potential shutoff strategy known because the low emissions would provide primary protection and the additional benefits of a shutoff system would come through changes to programming using existing parts. Additionally, the deaths and injuries resulting from the exhaust of outdoor operating generators infiltrating indoors would not be addressed without first reducing the CO emission rate of generators. Furthermore, the ECU programming concept would build on the recommendations of this memoramdum because staff believes that such programming could be implemented with little additional cost while providing additional benefits, compared to a performance requirement that only reduced emissions.

Staff believes that an effective automatic shutoff system must be durable, tamper-resistant, resistant to causing nuisance shutoffs, and include a supervisory circuit. Staff believes that the durability must be sufficient to function throughout the generator's operational life, without calibration or service, taking into consideration the wide variety of environmental conditions in which consumers use their generators and store them. Depending on the technology employed for the shutoff system, both the usage and storage environments can pose significant challenges to the durability and reliability of the system's components. For instance, a consumer may store a generator in a garage for years, exposing the shutoff system to extreme temperatures and humidity, as well as vapors and particulates that could contaminate a sensor. Furthermore, when the generator is in use, the shutoff system would be exposed to the engine's exhaust, heat, and vibration plus a wide range of weather conditions. CO sensors used in residential CO alarms are not designed for use in such extreme environments. CO sensors that may be more durable and used in commercial or industrial settings require periodic professional maintenance and calibration, which staff does not believe a consumer is likely to perform. Staff considers the ECU-based approach the most promising because the programming of the ECU could be accomplished to meet these challenges.

In addition, the incident data show that consumers use generators in a myriad of enclosed and semi-enclosed spaces characterized by a wide variety of room sizes and degrees of air tightness, such as a small closed closet (small volume, low air exchange rate) and an open garage (large volume, high air exchange rate). A shutoff system must demonstrate its ability to work reliably in these and multitudes of other extremely different scenarios, in addition to the extremes of environmental conditions in which consumers use their generators and store them during prolonged periods of non-use.

A supervisory circuit for the control circuit is needed to prevent the generator from being able to start, if it, or its sensor, were to fail or otherwise not be able to shut off the generator when needed. This requirement would be necessary to provide protection under certain circumstances, such as when a system's sensor fails or is not provided necessary power to operate, or the consumer attempts to override the circuitry to prevent the system from shutting off the generator. Staff recommends all of these requirements. Staff believes reliability of a shutoff system is of paramount importance, particularly if it is not supplementary to any CO emission rate reduction; this is because, if it fails to perform, there would be no protection added to current generators.

In summary, staff determined that an engine shut-off system for portable generators to prevent excessive CO accumulation is not technically feasible for a production generator at this time. Reliability to function as intended, resistance to nuisance shutoff, tamper resistance and durability are some of the development challenges for a shut-off system. Staff's preliminary investigation to use the ECU sensor programming on a reduced-CO emissions generator to shut off the engine showed potential feasibility. Staff considers this strategy to be the best potential shut-off strategy because the low emissions would provide primary protection and the additional benefits of a shutoff system would come through changes to programming using existing parts. UA demonstrated this concept; however, additional development work, best-suited to be performed by engine manufacturers, including specialized ECU programing, testing and evaluation would be required to determine if this type of shut-off system is feasible.

Staff has concluded that a reduced CO emission strategy is technically feasible, manufacturable, effective and could be implemented by manufacturers in a reasonable time frame. Therefore, while staff remains interested in a shutoff approach, for all the reasons stated above, staff's draft proposed rule, discussed in section 4.2, is based on the CO emission rate reduction strategy as the means to mitigate the CO hazard. Staff's epidemiological benefits analysis (TAB K**)** indicates that reducing the CO emission rate will translate to fewer CO deaths and injuries.

3.5.4. Public Comments and Staff Responses on the ANPR and Two Reports

Following the publication of the ANPR on December 12, 2006, the Commission received comments from a total of 10 people or entities.[28] In addition to comments on the ANPR, staff voluntarily solicited comments from the public on two reports, both pertaining to staff's prototype technology demonstration program discussed in section 3.5.1, once the reports posted on CPSC's website. One report is staff's report on the two-part technology demonstration program[30]; staff received comments from 12 people or entities.[44] The other report is NIST's final report on the generator testing that NIST performed as the second part of that two-part technology demonstration program[31]; staff received comments from a total of four people or entitities.[45]

A number of comments covered the same or similar topics. Staff's detailed responses to comments are discussed in TAB C, D, E, F, H, I, K, and L, and synopses are provided here. Several commenters discussed a shutoff strategy, in general, and CO sensing shutoff concepts, in particular, both for remote and on-board CO sensing systems. Comments favored and opposed these concepts. As noted and discussed in TAB D, staff believes that no shutoff system has been demonstrated to be technically feasible.

Comments supporting and opposing the feasibility of significantly lowering CO emission rates from portable generators of various sizes and types of construction were made. Staff believes that reduced CO emission rates recommended in the staff's draft proposed rule are technically feasible, based on the discussion in section 4.1 and TAB I**.** Staff responds directly to these comments in TABs E and I**.**. Staff summarizes the economic aspects of those comments in section 4.4 and addresses these details in TAB L.

One commenter asked CPSC staff to evaluate the effectiveness of CPSC's mandatory label for portable generators (shown in section 3.6). Staff evaluated the impact of the label and found that the label is useful but not sufficient to reduce deaths and injuries, as summarized in the findings in section 3.6. The full details of staff's analysis are provided in TAB H. TAB F also addresses this comment and others concerning the label, including comments regarding the label's simililarity to relevant ANSI standards for safety symbols, signs, and labels.

Two commenters asserted that there is no proof that a proposed rule with a low CO emission rate that causes slower onset of symptoms than current generators will result in fewer deaths. Staff believes they have demonstrated that the recommended draft proposed rule would significantly reduce CO poisoning deaths and injuries from portable generators. Section 4.3 summarizes staff's epidemiological benefits analysis performed to estimate the deaths in the incident data that could have been averted if the involved generators emitted CO rates meeting staff's suggested performance requirements in the draft proposed rule. TAB K provides full details.

One commenter suggested that consumers will adapt their behavior if they know that generators have lower CO emissions and also suggested that consumers who experience a slow onset of CO poisoning symptoms may not respond in ways that will reduce the exposure.

Although this may be the case for some consumers, staff believes that staff has demonstrated that the recommended draft proposed rule would significantly reduce CO poisoning deaths from portable generators. TAB C provides staff analysis on these comments.

Three commenters stated that CPSC should promote widespread use of CO alarms to protect consumers from all sources of CO, not just portable generators, and one commenter stated that the most effective and practical means to address the CO hazard with portable generators is already available through properly installed CO alarms with battery back-up. CPSC agrees that it is important to promote CO alarm usage to protect consumers from all sources of CO. CPSC actively encourages consumers to purchase and install battery-operated CO alarms or plug-in CO alarms with battery back-up in their homes and bi-annually reminds consumers to replace the batteries. However, while a working CO alarm provides added protection, a CO alarm is not a substitute for reducing the CO hazard at its source. Staff believes that the most important means to effectively address any hazard is to reduce the hazard at its source, in this case by reducing the CO emission rate.

One commenter asserted that CPSC lacks authority to regulate the risk of injury associated with CO emissions from portable generators. Staff believes that the CPSC has authority to regulate portable generators to address an unreasonable risk of injury and death from CO emissions. Staff's response is provided in TAB I.

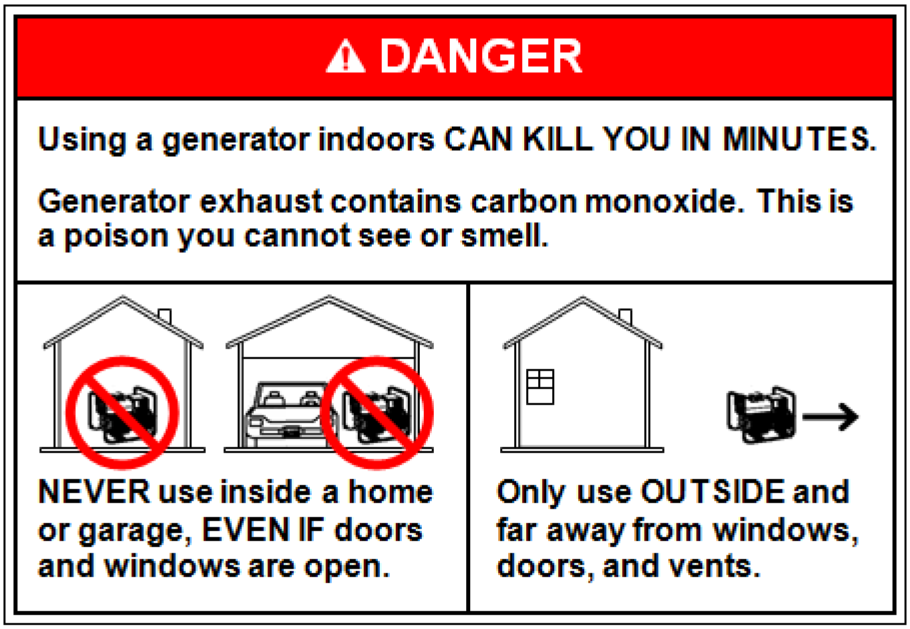
One commenter asserted that there is no scientific basis for the assumption that COHb levels below 10 percent are not harmful; another commenter asserted that CO poisoning symptoms do not correlate well with COHb levels. Staff believes that staff has demonstrated that the recommended draft proposed rule would significantly reduce CO poisoning deaths from portable generators. Staff's responses are provided in TAB K.

3.6. CPSC Mandatory Label for Portable Generators

As an initial step to help address the growing CO hazard, on January 12, 2007, the Commission published a rule specifying warning label requirements for portable generators.[46,47] As documented in reference 27, staff found that many generator manufacturers used warning labels and language in the owner's manual about the CO hazard that staff deemed were inadequate and ambiguous, such as warnings advising consumers to "provide proper ventilation." Additionally, some portable generator manufacturers recommended (and continue to recommend) using extension cords that are preferably less than 15 feet long, to prevent voltage drop and possible overheating wires. Other generator manufacturers also recommended (and continue to recommend) that portable generators be placed under cover when it is wet outside because, although these products are intended for outdoor use only, they are not weatherized for safe use in wet conditions posing a risk of shock or electrocution. Staff believes these manufacturer recommendations conflict with the need to avoid the CO poisoning hazard because the recommendations may encourage generator operation in close proximity to a residence or in an enclosed or semi-enclosed environment. Proper placement of the unit is especially significant because demand for portable generators to power home appliances increases dramatically during storms with wet or icy conditions that cause power outages. For extended outages, in particular, homeowners experience a sense of urgency for basic needs, such as heat and refrigeration. However, the power cord on many home appliances commonly is not long enough to reach windows or other openings where the consumer could connect the appliance to a 15-foot extension cord that is located entirely outdoors. Furthermore, staff believes that in many settings, consumers may not be able to place a generator more than 15 feet away from all neighboring occupied buildings.

To help address these issues, staff developed the mandatory label depicted in Figure 10. The label became effective on May 14, 2007, and is required on the generator and on the packaging in which the generator is sold.[t]

Figure 10. On-Product Carbon Monoxide Poisoning Hazard Label for Portable Generators



Since the effective date of the labeling standard, CPSC's Compliance staff has periodically inspected retailers and import shipments of generators for compliance with the labeling rule (TAB G). In most cases, the generators and their packaging met the labeling requirements. However, staff found some violations over the course of several years where: (1) labeling was not on the product; (2) labeling was not on the packaging; (3) the text size on the labeling was not the correct size; (4) pictograms were missing; and/or (5) the label was not in English. In these cases, Compliance staff told the manufacturer to stop sale and distribution and correct the labeling (attach labeling to the product and/or packaging) and correct future production of the product to ensure compliance with the requirements of the standard. There have been no recalls assocated with violations of the standard.

By examining incidents reported to CPSC before May 14, 2007, and reports received after that date, CPSC can gauge whether a change in the generator fatality rate has coincided with the introduction of the label (TAB H). Rates computed by combining the total generator fatalities

[t] The label on the package differs slightly from what is shown in Figure 10. There is an instruction included across the bottom of the label that reads: "Avoid other generator hazards. READ MANUAL BEFORE USE."

observed, with the CPSC estimates of generators in use, do not indicate declines in the rate of generator fatalities between 2007 (when an overwhelming majority of generators did not include "Danger" labels) and subsequent years (when the estimated proportion of generators in use with "Danger" labels has steadily risen). PGMA hypothesized that an increase in the frequency of power outages could be obscuring declines in generator fatality rates. In other words, despite the relatively flat usage numbers since 2007, an increase year after year in power outages might be causing these products to be used more frequently.[48, 23] However, analysis of the reasons why generators were used shows that in most years before and after the "Danger" labels were applied, most of the fatal incidents were not due to power outages, but were due to other reasons.[49] The reasons include: shutoffs by the power company for nonpayment; power to other non-building structures, such as sheds, trailers, boats, or campers; power to homes under construction; power to structures that do not typically have electricity, like garages, campers or mobile homes; and preparation for anticipated storms. The only year in which power outages exceeded other reasons reported was 2005, most likely due to the extraordinary number of hurricanes making landfall that year, including Dennis, Katrina, and Rita, as well as ice and snow storms. There is no apparent increasing trend in outages consistent with an outage increase hypothesis. The data do not provide sufficient evidence to conclude that the "Danger" label standard has reduced or eliminated the carbon monoxide fatality risks associated with portable generators. Thus, major reductions in fatalities arising from the introduction of these labels is unlikely. Staff strongly believes a technical solution is needed to effectively address the CO poisoning hazard from portable generators.

4. Discussion

4.1. Technical Feasibility of Reducing CO Emissions of Small Air-Cooled SI Engines, Fuel-Injected Engines in the Marketplace and Their Associated Benefits

4.1.1. CPSC Staff's Technology Demonstration Program

In March 2006, before initiating the contract with UA to develop the prototype low CO emission portable generator (discussed in section 3.5.1), staff issued a request for information (RFI) to solicit ideas on how to substantially reduce tailpipe exhaust CO emissions from gasoline engines used to power portable generators. Staff's interest was finding out how to reduce CO emission levels and decrease the number of CO poisoning deaths and injuries.[50] Providing a target CO emission rate reduction of 90 percent, staff sought solutions that would: (1) not negatively affect engine performance and engine life, (2) be able to meet the then-anticipated EPA Phase 3 HC+NOx standard for non-handheld small SI engines, (3) minimize any increase in the fire and burn risk associated with increased temperatures on the exterior of the exhaust system, and (4) minimize incremental cost increases associated with the CO emission-abatement equipment to be consistent with product marketability.

The nine respondents to the RFI suggested various approaches to address the hazard. Seven respondents identified catalytic exhaust aftertreatment alone, or coupled with a fuel injection system that would replace the existing carburetor fuel delivery system. Some respondents and EPA technical staff who CPSC staff consulted with suggested that using a closed-loop EFI system greatly reduces the amount of unburned fuel in the engine exhaust, which, in turn, would allow a catalyst to be used as an aftertreatment to reduce 90 to 95 percent of CO leaving the tailpipe without causing unmanageable heat buildup in the catalyst. These commenters and EPA technical staff indicated that combinations of catalytic converters and fuel injectors are used on small displacement 2-stroke and 4-stroke engines on motor-scooters in some countries, including China and India, and are also used on small displacement motorcycles in the United States.[51,52,53,54,55]

Based on these comments and with input from EPA staff, CPSC awarded a contract to UA to develop and durability test a prototype low-CO emission portable generator. In the demonstration program, a small, air-cooled, single-cylinder Class II engine, powering a portable generator with an advertised continuous electrical power output rating of 5.0 kW, was modified by replacing the carburetor with a closed-loop EFI system tuned with stoichiometric[u] fuel control, and by replacing the muffler with a muffler that had a small catalyst integrated into it. The prototype generator was subjected to a durability program for a total of 500 hours, which was the manufacturer's rated useful life of the engine at the time of the program. (TAB I has more detailed information on the prototype development and demonstration program and references 30 and 31 have full details.)

For the durability program, UA applied an automated hourly cyclic load profile consisting of six resistive loads, or modes, through the generator's 240-volt receptacle to replicate the 6-mode rated speed test cycle that the EPA uses in its emission test procedures for non-handheld small SI engines,[v] including engines used for generator applications. Staff understands that the EPA's 6-mode test cycle was developed with industry to replicate typical in-use operation of small utility engines when used in all types of engine-driven products. The test cycle defines the six modes that the engine needs to power while mounted on a dynamometer and emission rates are measured. Additionally, the test cycle defines the weighting factor associated with each mode to represent the duration that the engine operates at each of the 6 modes over its lifetime. This EPA 6-mode test cycle is based on the approach that these weighting factors represent lifetime engine load levels regardless of the application in which the engine is installed. In the absence of any data that shows how consumers typically load their generators, staff believes that EPA's information is representative of how consumers load their generators. Thus, staff assumes that the typical load profile of a portable generator used by a consumer is that of the EPA's 6-mode test cycle and it is the *weighted* CO emission rate resulting from operation at *all* 6 modes that the consumer is potentially exposed to during the generator's operation. Therefore, CPSC staff used the weighting factors to determine both the duration for each of the six modes in the hourly cyclic load profile used during the durability program, as well as to determine the generator's weighted CO emission rate.[w]

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[u] Stoichiometry is the theoretical air:fuel ratio for complete combustion, which is nominally 14.6 for typical gasoline formulations, and it is the theoretical point for nearly the lowest amount of CO production.

[v] The EPA's applicable regulation is 40 C.F.R. part 1065, *Engine-Testing Procedures*.

[w] The equation for determining the weighted CO emission rate is as follows:
weighted CO rate = $(wf_1 \text{ x } m_1) + (wf_2 \text{ x } m_2) + (wf_3 \text{ x } m_3) + (wf_4 \text{ x } m_4) + (wf_5 \text{ x } m_5) + (wf_6 \text{ x} m_6)$,
where wf is that mode's weighting factor and m is the CO emission rate measured at that mode.

UA made periodic emission measurements for each of the six modes with the engine installed in the generator at select times during the 500-hour durability program.[x] Simultaneous to the durability program on the prototype generator, UA subjected a baseline unmodified carbureted generator, the identical model to that of the prototype generator before it was modified, to the same durability program. Like the prototype, UA made periodic emission measurements on it during the 500 hours of operation to compare the performance of the prototype relative to it. After the 500-hour durability program concluded on both the baseline carbureted generator and the prototype generator, an independent laboratory, Intertek Carnot Emission Services (CES), conducted end-of-life emission testing with the engine installed in the generator and on a dynamometer, in accordance with the EPA small SI engine test procedures. Staff had this testing performed to ascertain whether, at the end of the engine's rated useful life, the prototype engine's emissions would meet the EPA's Phase 2 requirements for HC+NOx, to which the unmodified OEM version of the engine was originally labeled as certified[y]; and would meet staff's target reduction for the exhaust CO emission rate.

At the completion of the durability program, UA determined that the prototype generator's weighted CO emission rate and its fuel consumption rate were reduced by 93 percent[z] and 20 percent, respectively, from that of the unmodified baseline generator. CES's testing in accordance with EPA test procedures showed that the prototype engine, while mounted on a dynamometer and equipped with the muffler that had the catalyst installed in it, had a 6.0 g/kW-hr CO emission rate, which is 99 percent below the EPA's Phase 2 and Phase 3 CO standard of 610 g/kW-hr. The prototype engine had an HC+NOx exhaust emission rate of 6.7 g/kW-hr, which is 44 percent below the Phase 2 HC+NOx standard to which the engine was originally certified and 16 percent below the EPA's Phase 3 HC+NOx standard for a Class II engine, which the EPA adopted shortly after CPSC's development program with UA began. CES's emission

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[x] Mode 1 is full engine power, as measured on a dynamometer test platform, and the five other modes (modes 2 through 6), are percentages (75%, 50%, 25%, 10%, and no load, respectively) of mode 1 power. With the engine installed in the generator, full engine power, as determined on the dynamometer by disabling or decoupling the governor from the throttle and physically holding the throttle wide open, was not achieved; therefore, the electrical power that was applied for mode 1 was the maximum that could be sustained without tripping the generator's breakers on the 240-volt circuit. This was found to be 5.5 kW, 500 watts greater than the advertised, continuous electrical power rating of the generator. For modes 2 through 6, the engine manufacturer's advertised 8.2 kW maximum power rating of the engine was used in conjunction with the generator manufacturer's alternator efficiency curve to estimate the electrical load that needed to be applied to achieve those desired engine loads. The loads, in kW, for modes 2 through 6 were determined to be 5.50, 4.75, 3.25, 1.50, 0.625, 0.0 and the durations, in minutes, at each were were 5.5, 12, 17.5, 18, 4, and 3 minutes, respectively.

[y] The EPA's primary emphasis for environmental air pollution from small SI engines is on regulating emissions that contribute significantly to nonattainment of the National Ambient Air Quality Standards (NAAQS) for ozone, of which hydrocarbons (HC) and oxides of nitrogen (NOx) are precursors. For non-handheld engines, the EPA adopted emission standards referred to as Phase1 in 1995, Phase 2 in 1999, and Phase 3 in 2008.

[z] The 93 percent CO emission rate reduction of the prototype over the unmodified baseline unit measured by UA is nominally consistent with the 97 percent reduction determined by NIST from testing both configuratons in NIST's test house, discussed in section 3.5.1.

testing of the prototype generator (with the engine installed in the generator as opposed to the dynamometer) had a weighted CO emission rate of 26 g/hr.

4.1.2. Staff Assessment of Feasible CO Rates Based Upon EPA's Technology Demonstration Program and Staff Testing of Fuel Injected Generators

In 2006, the EPA examined the feasibility of two different levels of HC+NOx emission reduction from their Phase 2 standards. In the more stringent of the two levels, the EPA applied EFI and high-efficiency catalysts on two single-cylinder, air-cooled Class II engines, both nominally 500 cubic centimeter (cc) in displacement with overhead valve (OHV) configurations.[56,57] EPA's goal with this work was to demonstrate the safe and effective use of existing emission control systems in reducing the HC+NOx emissions by 70 percent or greater. Because CO and NOx engine emissions have an inverse relationship, the EPA specifically chose to test with catalysts formulations designed to <u>minimize</u> CO oxidation.[aa]

In this part of the EPA's demonstration program, they used low-cost engine management and fuel-injection systems, similar to what UA used for the CPSC prototype generator, which were originally developed for motor-scooter and small motorcycle applications, as discussed in section 4.1.1. However, to reduce costs as much as possible, EPA did not use an oxygen sensor (necessary to make it a closed-loop fuel-control system). For both engines, EPA replaced the carburetor with open-loop EFI that was calibrated rich (lower air to fuel ratio) of stoichiometry at moderate to high loads and near stoichiometry at light load conditions to achieve the desired emission control of HC+NOx and maintain or improve fuel consumption, engine durability, and performance. Integrated catalyst-muffler systems were developed for each, with a total of six different catalysts to investigate different metal loadings and substrate cell densities, all of which were selected to prioritize NOx reduction and HC oxidation over CO oxidation. This is largely the same fuel control and catalytic aftertreatment strategy implemented by UA, in which most CO is prevented from forming in the engine's combustion process and then the catalyst is used as aftertreatment to primarily reduce NOx. However, UA used a closed-loop system and tuned the fuel control to stoichiometry at the high loads.

The EPA's results from this program are important to staff because the results show that even though the EPA was intentionally trying to select catalysts that would minimize CO oxidation, both engines achieved an average 68 percent reduction in the weighted CO emission rate. The average of the weighted CO emission rate of the two carbureted OEM configurations was 1760 g/hr, and the average of the two EFI configurations with the catalyst that provided the most reduction in CO emissions was 565 g/hr. Although the EPA did note that some engines may need improvements (such as redesign of cooling fins, fan design, combustion chamber design, and a pressurized oil lube system) to accommodate stoichiometric fuel control, importantly the EPA concluded from this program that closed-loop EFI with fuel control at or near stoichiometry *is* technically feasible and *is not* cost prohibitive on all Class II engines.[bb]

[aa] Oxidation of CO to carbon dioxide (CO_2) is the means by which CO emissions are reduced in a catalyst.

[bb] Staff's understanding is that Class II engines are used to power generators with continuous power output ratings of nominally 3.5 kW and higher.

Staff believes that if the EPA had an additional focus on reducing CO emissions, a lower weighted CO emission rate could have been achieved. Specifically, by using an oxygen sensor for closed-loop feedback along with tuning the fuel control for operation closer to stoichiometric at the high and moderate loads, and using a different catalyst formulated for higher conversion efficiency of CO, the weighted CO emission rate could have been even lower. Staff believes that for one of the engines, if they had used an oxygen sensor for feedback fuel control, they could have tuned the engine to oscillate about 0.98 Lambda[cc] at all loads without needing any engine design improvements.[dd] As a result, staff focused on the emission data from the EFI-only configuration of the Kohler engine. The EPA had tuned Lambda for modes 1 through 3 to nominally 0.95 and tuned modes 4 through 6 to nominally 1.0. Because the emission constituents in the exhaust of a SI engine are a function of Lambda or AFR, staff referred to engineering literature[58] to estimate the engine-out (before catalytic aftertreatment) CO emission rates if Lambda had been tuned to 0.98 for modes 1 through 3. Staff estimated that as AFR moves closer to stoichiometry from 0.95 to 0.98, those modes' CO emissions are reduced by nominally 50 percent. Furthermore, staff considered information about catalyst treatments that could be applied to these emissions, based on information provided by MECA. CPSC staff used this information to estimate that the weighted CO emission rate out the tailpipe (after catalytic aftertreatment) could have been nominally 100 g/hr, by assuming there was exhaust aftertreatment using a base metal catalyst.[48] This is discussed in detail in TAB I.

Furthermore, staff tested three fuel-injected generators created by three different manufacturers (also discussed in detail in TAB I but synopsized here). Two of these generators, neither of which was designed for low CO emissions, are available in the marketplace, and the third is a manufacturer's prototype generator that was designed for low CO emissions. The first of these three is a 10.5 kW rated generator powered by a twin-cylinder Class II engine with nominal 700 cc displacement and OHV configuration. Staff observed that it does not have a catalyst for aftertreatment and that the engine is calibrated rich of stoichiometry at higher loads and at stoichiometry with closed-loop fuel control at moderate-to-light load conditions. Based on staff's testing of this generator in normal atmospheric oxygen, which found a 670 g/hr weighted CO emission rate, and based on staff's engineering assessment of its physical and operational characteristics, staff believes that it is reasonable to expect that this engine could operate closer to stoichiometric at the higher loads and that a catalyst formulated for some CO conversion efficiency could be used for aftertreatment to further reduce its CO emission rate to nominally 200 g/hr.

[cc] Lambda is ratio of actual air-fuel ratio (AFR) to stoichiometric AFR. So Lambda=1.0 means the fuel control is stoichiometric, the theoretical point of complete combustion and the theoretical point for nearly the lowest amount of CO production.

[dd] Staff believes the other engine did not have this flexibility, due to its marginal cooling system and lubricating system designs, as the EPA had to retrofit an oil cooler to the keep the oil temperature in the OEM configuration from exceeding 140^{o}C during modes 1 and 2.

The second generator is a 5.5 kW rated power generator powered by a single-cylinder Class II engine with nominal 400 cc displacement and OHV configuration, equipped with an oxygen sensor for some form of partial closed-loop operation and a catalyst. The engine is calibrated rich of stoichiometry at all loads. Based on staff's testing in normal atmospheric oxygen that found a nominal weighted CO rate of 560 g/hr, staff believes a CO emission rate of nominally 100 g/hr is possible if it were operated closer to stoichiometric for at least some of the loads and used a catalyst formulated for higher CO conversion efficiency.

The third generator is a 5.5 kW rated power generator powered by a closed-loop fuel-injected single-cylinder Class II engine with nominal 400 cc displacement and OHV configuration. It has a catalyst for aftertreatment and the engine is calibrated to stoichiometric AFR with closed-loop operation at all loads. Staff's testing of this generator in normal atmospheric oxygen found a weighted CO rate of 81 g/hr.

4.1.3. Small SI Fuel Injected Engines in the Marketplace

Because fuel injection could be a technically feasible way of reducing CO emissions for portable generators, staff investigated the availability and benefits of small SI fuel-injected engines in the marketplace. Fuel injectors in engines that use them replace carburators as a means of fuel delivery. There are a number of disadvantages associated with carburetors. These include issues associated with the venting of a carbureted fuel system because exposure to air promotes fuel deterioration during storage.[59] This will cause hard starting, and it leaves gum deposits that can clog the carburetor. The sealed fuel systems associated with fuel injection reduces fuel deterioration, which is one of the reasons the manufacturers of fuel-injected engines cite improved reliability and start capability, especially after long-term storage.

Carburetors are also prone to leaks, which can create a fire hazard, and they have been the reason for a number of CPSC's recalls associated with portable generators.[60,61,62] Staff expects the proposed rule will address these issues because staff expects manufacturers will use fuel injection as part of their emission-control strategy to meet the proposed performance requirements. Small SI air-cooled, fuel-injected engines and the products they power are in the marketplace. Table 4 lists applications and/or engines with fuel injection that staff found from an online review. Aside from the significant reductions in CO emissions that this emission-control technology can provide, there are many benefits associated with fuel injection. Manufacturers advertise their benefits by comparing their performance relative to their carbureted counterparts. Their advertised benefits include: improved performance and reliability; improved start capability, even after long storage periods and in cold weather; faster, smoother response to load transients; more power; improved fuel economy; reduced emissions; eliminating the need for a choke; and eliminating the need to adjust the carburetor to compensate for operation in less dense air in higher altitudes, among other benefits. [63,64,65,66,67,68]

Table 4. Fuel-Injected Engines in the Marketplace

Application	OEM Manufacturer	Engine Manufacturer	EPA Engine Classification (number of cylinders noted for Class II)
Portable Generator	Honda	Honda	Nonhandheld Class II (single cylinder)
Portable Generator	Kohler	Kohler	Nonhandheld Class II (twin cylinder)
Generator/Welder	Miller Electric	Kohler	Nonhandheld Class II (twin cylinder)
Cut-off Saw	Stihl	Stihl	Handheld Class V
Portable Generator	Lifan	FME	Nonhandheld Class I and Class II (single cylinder)
Portable Generator	Powerhouse		Nonhandheld Class II (single cylinder)
Snow blower	Ariens		Nonhandheld Class II (single cylinder)
RV Generator	Cummings/Onan	Cummings/Onan	Nonhandheld Class II (twin cylinder)
RV Generator	Gentron	Gentron	Nonhandheld Class II (single cylinder)
Utility vehicle	Club Car	Subaru	Nonhandheld Class II (single cylinder)
Pressure Washer	TTi (Ridgid)	Subaru	Nonhandheld Class I
Riding mower		Briggs & Stratton	Nonhandheld Class II (twin cylinder)
Riding mower		Kawasaki	Nonhandheld Class II (twin cylinder)
Riding mower		Kohler	Nonhandheld Class II (twin cylinder)
Golf Cart		Yamaha	Nonhandheld Class II (single cylinder)
		Kohler	Nonhandheld Class II (single and twin cylinders)

4.2. Draft proposed standard

4.2.1. Draft Proposed Scope

Staff recommends that this draft proposed standard apply to single phase, 300 V or lower, 60 hertz, portable generators driven by small handheld and non-handheld (as defined by the EPA at 40 C.F.R. § 1054.801) SI utility engines intended for multiple use that are provided with receptacle outlets for the AC output circuits and intended to be moved, although not necessarily, with wheels. The standard would not cover generators powered by compression-ignition (CI) engines, permanently installed stationary generators, 50 hertz generators, marine generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, generators intended to be mounted in truck beds, and generators that are part of welding machines.

The scope excludes CI engines because staff considers diesel generators atypical consumer products and also notes that CI engines have relatively low CO emission rates.[ee] Stationary generators, marine generators, and generators installed in recreational vehicles are excluded because they are not portable. Generators intended to be pulled by vehicles, intended to be mounted in truck beds, generators that are part of welding machines, and 50-hertz generators are excluded because staff considers them atypical consumer products. Staff notes that these

[ee] The current EPA standard for CO emissions is 8.0 g/kW-hr for CI engines rated below 8 kW, which is significantly lower than the EPA standard of 610 g/kW-hr applicable to small SI engine classes used in portable generators.

inclusions and exclusions, with the exception of diesel generators and generators that are intended to be pulled by vehicles and generators intended to be mounted in truck beds, are largely consistent with the scopes of the two U.S. voluntary standards for portable generators, UL 2201 and PGMA G300, which are discussed in section 3.4.1 and 3.4.2, respectively.

4.2.2. Draft Proposed Performance Requirements, Effective/Compliance Dates, and Certification

Staff recommends that portable generators within the scope of the draft proposed rule meet the applicable performance requirements in Table 5 when sold after the applicable compliance date. Staff notes that these performance requirements are emission rates and that the proposed rule is not prescriptive about how the rates are reached. Manufacturers can choose the technologies and methodologies they prefer to meet the performance requirements in Table 5, which includes four different generator categories that are defined primarily by the displacement of the engine, with a secondary categorization of the largest generators that distinguishes between engines with one or two cylinders:

- A handheld generator is a generator powered by an SI engine with displacement of 80 cc or less; it may not exceed a weighted CO emission rate of 75 g/hr.
- A class 1 generator is a generator powered by an SI engine with displacement greater than 80 cc, but less than 225 cc; it may not exceed a weighted CO emission rate of 75 g/hr.
- A class 2 single cylinder generator is a generator powered by an SI engine with one cylinder with displacement of 225 cc or greater, up to a maximum engine power of 25 kW; it may not exceed a weighted emission rate of 150 g/hr.
- A class 2 twin-cylinder generator is a generator powered by an SI engine with two cylinders with a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW; it may not exceed a weighted emission rate of 300 g/hr.

Each rate is a weighted CO emission rate emitted from the generator when operating in ambient atmosphere with normal oxygen content (nominally 20.9%), calculated from the CO emission rates produced when each of six specified steady-state loads are applied to the generator. Staff recommends that handheld and class 1 generators would have to comply within 3 years after a final rule is promulagated; and class 2 generators (both single and twin cylinder) would have to comply within 1 year after a final rule is promulgated. Information regarding certification is provided below Table 5. While staff recommends the above performance requirements when generators operate at normal oxygen content, staff remains interested in CO emissions when generators operate at reduced oxygen content of 17 percent. Staff welcomes comments on the advantages and disadvantages of setting performance requirements at 17 percent oxygen instead of normal oxygen as well as comments on the technically feasible CO emission rates for generators operating at 17 percent oxygen, for each of the generator categories. Furthermore, staff welcomes comments on the test methods for CO emissions in both normal oxygen and 17 percent oxygen in Tab J, Appendicees A2 and A3.

Staff's rationale for the technical feasibility of these performance requirements include the results described in section 4.1.1 and 4.1.2, showing, respectively, the reduced emissions in the

UA prototype generator and staff's assessment about engines tested by EPA and three fuel-injected generators tested by staff. The rationale for the categories and for the requirements for each category take into consideration the associated differences in emission rates, size, weight, hazard patterns, technically feasible reduced emission rates and costs for achieving emission reductions. The performance requirements for the different categories of generators also have a scaling factor of 1.5 applied to the technically feasible rates to account for production variation. Additional details on the technical feasibility of these performance requirements are provided in TAB I. Details on staff's assessment of the epidemiological benefits associated with these performance requirements are provided in TAB K and summarized in section 4.3 below. Details on staff's preliminary assessment of the impact of these requirements are provided in TABs L and M and are summarized in sections 4.4 and 4.5 below. Staff's analyses found that less stringent CO emission requirements that would decrease the costs would result in a greater decrease in benefits than the decrease in cost, thus decreasing the net benefits. Staff did not consider more stringent CO emission rates because staff is not confident that lower rates could be achieved without significant cost increases.

Table 5. Recommended Performance Requirements and Effective Dates for Portable Generators

Generator Category	Engine	Draft Proposed CO Standard (g/hr)	Compliance Date (years after publication of final rule)
Handheld	≤ 80 cc	75	3
Class 1	>80 cc to <225 cc	75	3
Class 2 single cylinder	≥225 cc, up to 25 kW maximum engine power and 1 cylinder	150	1
Class 2 twin cylinder	≥225 cc, up to 25 kW maximum engine power and 2 cylinders	300	1

Note: Maximum engine power for both class 2 categories is 25 kW so as to include the largest SI engines in portable generators.

Staff recommends that the rule not prescribe a particular test that manufacturers must use to assess compliance with the performance requirements. Instead, staff recommends that the Commission adopt a proposed rule that would describe the test procedure and equipment that staff would use to assess compliance with the standard (provided in Appendix A3 of TAB J). Manufacturers, however, need not use this particular test, so long as the test they use effectively assesses compliance with the standard. Staff believes this approach provides added flexibility to manufacturers to reduce testing burdens. Staff welcomes comments on the benefits and costs of this approach versus requiring a specifc test method for manufacturers to demonstrate compliance.

The procedure staff would use is based largely on a test method developed in collaboration with industry stakeholders, which was discussed in section 3.4.1 and is described in more detail in appendix A of TAB I. Briefly, staff proposes to perform the tests in ambient temperature in the range of 10 - 38 ^{0}C (50-100 ^{0}F), using E10 gasoline. The six loads that would be applied to the generator for determining the weighted CO emission rate are based on the generator's maximum load capability. Maximum load capability would be determined by increasing the load applied to the generator to the maximum observed power output without causing the voltage or frequency to deviate by more than 10 percent of the nameplate rated voltage and 5 percent of the nameplate rated frequency and that can be maintained for 45 minutes with stable oil temperature. The loads would be applied using a resistive load bank capable of achieving each specified load condition to within 5 percent and would be measured using a power meter with an accuracy of ± 5 percent. The emissions measurement equipment that staff would use is a constant-volume sampling (CVS) system, as described in the EPA's regulations at 40 C.F.R. part 1054 and 40 C.F.R. part 1065, as of 2016. If the generator is equipped with an economy mode or similar feature that has the engine operating at a low speed when not loaded, the setting that produces the highest weighted CO emission rate would be used to verify if the applicable rate in Table 5 is met.

If the Commission should finalize a portable generator rule, manufacturers, including importers, would need to certify that the product conforms to the standard, based on either a test of each product or any reasonable alternative testing method. For products that manufacturers certify, manufacturers would issue a general certificate of conformity (GCC).

Under the CPSA, the effective date for a consumer product safety standard must not exceed 180 days from the date the final rule is published, unless the Commission finds for good cause that a later effective date is in the public interest. Staff believes that 180 days after publication of the final rule may not be adequate time for manufacturers to comply, due to possible need for modifications to use closed-loop fuel injection and possible modifications to accommodate fuel control closer to stoichiometry, such as adding cooling fins and a fan. Staff believes that 1 year after the rule is promulgated is sufficient lead time for portable generators using Class II engines to comply. For portable generators using Class I and handheld engines, staff believes that an additional 2 years may be necessary due to increased challenges related to maintaining smaller sizes for these generators. Staff notes, however, that fuel injection has been successfully implemented in the marketplace on both a handheld engine used for a cut-off saw and Class I engines used in portable generators, as shown in Table 4. In 2006, when the EPA drafted the Regulatory Impact Analysis for Phase 3, EPA estimated that manufacturers needed 3 to 5 years to implement closed-loop EFI and make any necessary engine improvements if the EPA had adopted a 4.0 g/kW-hr HC+NOx standard based on their demonstration of 2.0 g/kW-hr on the two engines, as discussed in section 4.1.2. As noted in section 4.1.3, staff has observed over the subsequent decade, that Class II single and twin-cylinder, fuel-injected engines have since come into the marketplace in a variety of applications, including a number of portable generators. Accordingly, staff thinks the lead time can be 1 year.

Staff recommends that the Commission propose anti-stockpiling provisions as part of the draft proposed rule. Specifically, staff recommends that the draft proposed rule prohibit manufacturing or importing noncomplying portable generators, by generator category, in any period of 12 consecutive months, between the date of promulgation of the rule and the effective date, at a rate that is greater than 125 percent of the rate at which they manufactured or imported portable generators in the same category during the base period for the manufacturer. The base period is any period of 365 consecutive days, chosen by the manufacturer or importer, in the 5-year period immediately preceding promulgation of the rule. As discussed in staff's preliminary regulatory analysis, summarized in section 4.4 and described in detail in TAB L, generator sales can vary substantially from year to year, depending upon factors such as widespread power outages caused by hurricanes and winter storms. Annual unit shipment and import data obtained from PSR, ITC, and individual manufacturers show that it has not been uncommon for shipments to have varied by 40 percent or more from year-to-year at least once in recent years. The anti-stockpiling provision is intended to allow manufacturers and importers sufficient flexibility to meet normal changes in demand that may occur in the period between promulgation of a rule and its effective date, and at the same time limit their ability to stockpile noncomplying generators for sale after the effective date.

4.3. CPSC Staff Assessment of Epidemiological Benefits of Reduced CO Emission Portable Generators

To assess the epidemiological benefits of reduced CO emission generators, CPSC staff contracted with NIST to perform a series of CO exposure simulations that would model the operation of a portable generator in several locations within various house configurations and other structures, and at different CO emission rates.[69] Staff used these results to determine the number of possible deaths averted if reduced CO emission generators had been used, as described below and provided in detail in TAB K.

4.3.1. CO emission modeling

NIST modeled 40 different structures, including houses with basements and others with crawlspaces, as well as structures with slab-on-ground construction, with and without attached garages, and including older construction and newer construction homes.[ff] Included in the 40 structures were three different external residential structures designed to represent detached garages and sheds. The 37 different house models included detached homes, attached homes, and manufactured home designs. House models, and other structures used in the modeling study, were matched to 503 out of the 659 actual generator-related CO fatalities reported to CPSC over the period 2004 to 2012. One hundred fifty-six fatalities (659 minus 503) were not included in the modeling analysis because the generator was either outdoors or in another type of structure, such as a camper, RV, tent, church, boat, or apartment complex that was not similar to any of the structure models used by NIST. It should be noted that CPSC staff believes that some of these 156 deaths from the incident data that were not included in the modeling analysis would have been prevented by using a reduced-emission generator in these same scenarios, including ones with generators running outdoors close to structures like homes and RVs, or in a large volume space, such as a church.

Staff chose the modeled CO emission rates based on: (1) staff's estimates of elevated-CO emission rates expected for the four categories of current carbureted generator products when

[ff] Older construction homes tend to have more leakage sites than newer construction homes and, as a result, relatively higher air exchange rates, as compared with newer construction homes.

operating in a reduced oxygen environment, and (2) a series of reduced CO generation rates to reflect CPSC staff's assessment of what is technically feasible for each generator category.

Determination of CO Emission Rates, Run Times, and Heat Release Rates for Carbureted Generators

The first part of the modeling study used the NIST multizone airflow and contaminant transport model CONTAM, which predicted CO levels in different areas of each structure, over a 24-hour period. Staff determined CO emission rates, run times, and heat release rates for NIST to model for current, carbureted generators ("baseline carbureted generators"), relying on data from EPA's nonroad small spark-ignition engine (NRSI) certification data website[70] and advertised power ratings and engine specifications for representative products. These baseline parameters are shown in Table 6, and the basis for them is provided below.

Table 6. Modeled CO Emission Rates, Run Times, and Heat Release Rates for Baseline Carbureted Generators

Generator Category	Average Weighted CO rate at 17% O_2 (g/hr)	Average Run Time (hrs)	Average Heat Release Rate (kW)
Handheld	900	8	2
Class 1	1800	9	6
Class 2 Single Cylinder	4700	10	13
Class 2 Twin Cylinder	9100	9	25

To determine values for CO emission rates, run times, and heat release rates representative of current generators involved in the fatal incidents, staff considered the generators produced by six large generator manufacturers. Staff used the manufacturers' reported product specifications for 31 generators ranging from 900 to 15,000 watts rated power and developed the representative parameters for each of these inputs based on the range of generators in each of the four categories in Table 6.

Staff used the engine specifications provided by the generator manufacturer to search the EPA's NRSI engine certification data website to find the published CO emission rate corresponding to each generator's engine. The reported CO emission rate in terms of grams per kilowatt-hour (g/kW-hr) is the sum of six weighted CO rates in grams per hour (g/hr) that the engine emits while installed on a dynamometer test platform and operating with each of six steady-state loads applied (also referred to as modes) divided by the sum of the weighted power for those six modes. The EPA's six-mode test cycle was developed with industry to replicate typical in-use operation of small utility engines when used in all types of engine-driven products. Staff then calculated the weighted CO emission rate (in g/hr) for each generator's engine by multiplying the g/kW-hr rate by 46.7 percent of the maximum engine power (46.7 percent of the maximum engine power is the weighted average based on the EPA six-mode calculations). Staff assumes that the typical load profile of a portable generator used by a consumer is that of the weighted profile. In addition, staff assumes the engine's weighted CO rate is that of the generator.

Considering that 95 percent of the generator-related CO fatalities in CPSC's databases occurred when the carbureted generator was operated in an enclosed or semi-enclosed space, it is important for modeling studies to consider the CO emission rate when a carbureted generator is operating in such scenarios. Evidence supporting this view is seen in results of findings from generator tests conducted by NIST under a prior interagency agreement with CPSC.[31] NIST's tests, as well as subsequent staff testing, showed that the CO emission rate of current carbureted generators increases nominally threefold as the oxygen drops from normal levels (approximately 20.9 percent oxygen) to approximately 17 to 18 percent oxygen when a generator is operated in an enclosed space, such as those reported in the incident data.[69, TAB J] Consequently, to reflect more accurately current carbureted generator operation under oxygen depletion conditions, staff's calculated weighted CO emission rate when each generator is operated outdoors at normal oxygen was multiplied by a factor of 3.

The generators' run time on a full tank of gas that was associated with 50 percent of the advertised rated load was used to determine the full-tank run time used in the modeling. Fifty percent load was used because, as stated above, 46.7 percent of the engine's maximum power represents the weighted load profile, which is nominally 50 percent. Staff generally used manufacturer's product specifications for run time at 50 percent load, and in a few cases, engineering estimates to determine the run times. Staff chose to model run times based on a full tank of fuel as a conservative assumption, despite knowledge of scenarios where a generator was used to allow completion of a specific short-duration task, in temporary power outage situations where power was restored within a few hours before a full tank of fuel could be consumed, or in scenarios where the generator was still running when victims were found, had summoned help, and/or had removed themselves from the area.

Staff estimated heat release rates for these generators based on the fuel consumption rate at 50 percent load, the manufacturer's specification for the generator's tank capacity and an assumed conservative 35 percent thermal efficiency of the engine.[71]

Determination of CO Emission Rates, Run Times, and Heat Release Rates, for Reduced Emission Rate Portable Generators

NIST used the same values for run times and heat release rates for the reduced CO emission rates of each generator category as those used for current generators.[gg] NIST modeled the rates of 50, 125, 250, 500, 1,000 and 2,000g/hr. The three lowest of these approximates the range of

[gg] CPSC staff reasons that an additional weight and volume of the emission control components needed to reduce the CO emission rate could be offset by a smaller fuel tank, and due to the improved fuel efficiency of reduced emission engines, the smaller tank would still be able to maintain similar run times to carbureted units with larger fuel tanks.

CO emission rates that staff believes are technically feasible for both the handheld and class 1 generator categories (50 g/hr), class 2 single cylinder category (100 g/hr), and class 2 twin cylinder category (200 g/hr).

Weather, Temperature and CO Rate Parameters for Carbureted and Reduced CO Emission Generators

Simulations were run for each model structure and model generator location for 28 representative weather days to determine the CO time course profiles, which are the minute-by-minute CO concentration levels in each of the various rooms of the house. The 28 weather days were chosen to include 14 cold weather days (Detroit, MI), seven weather days from warm months (Miami, FL) and 7 transition months weather days (Columbus, OH) to represent the distribution of fatalities that has been seen, to skew towards cold-weather days in a similar manner.[hh] Starting indoor temperatures were assumed to be 23°C in all rooms, and temperatures were modeled to change within the rooms, based on heat transfer related to the heat release from the generator and the outdoor ambient temperature. Thus, generators of various sizes were modeled to be running on 28 different weather days for a full-tank run-time[ii] in various rooms within each of the structures with run times and heat release rates appropriate to that size of generator, and emissions based on current carbureted generators or based on possible reduced-emission generators for comparison. In the modeling of baseline carbureted generators, to simulate the increasing CO emission rate as the oxygen level drops in the space the generator is operating (and thus a lower CO emission rate at the beginning of operation than later), NIST modeled CO rates for the first 2 hours of operation that were only two-thirds the rates shown in Table 6. After 2 hours, the CO rates were increased to the rates in Table 6 for the duration of the run time. In contrast, as another conservative assumption, NIST modeled reduced CO emission rates as constant rates for the entire respective generator run time. The results of the models provided CO time-course profiles for each room of each structure on each weather day for each generator type and location and emission rate.

4.3.2. Application of COHb Modeling

[hh] The 28 individual days were selected using historic weather data recorded at three different geographic locations and three different temperature ranges to approximate the distribution of incidents observed in the CPSC incident data at a generalized level. Although the weather days may be consecutive (*e.g.*, 14 consecutive cold weather days), there was no carry-over effect from one day to the next. Each day modeled was reset to zero CO. Therefore, each day, from a CO stand point, was an independent event.

[ii] NIST also modeled half-tank run times to simulate scenarios where shorter durations were considered more appropriate, but only analyzed the full tank run times to get a conservative estimate of benefits: for instance, in scenarios in which the generator was being used to allow completion of a specific short-duration task at an unpowered location, in temporary power outage situations where power was restored within a few hours before a full tank of fuel could be consumed, or in scenarios where the generator was still running when victims were found, had summoned help, and/or had removed themselves from the area. Although staff has these modeling results, staff only analyzed the modeling results for the full-tank run times to estimate those benefits to be consistent with a conservative estimate of benefits.

The second part of the modeling study used the CONTAM-generated CO time course profiles as input values to predict corresponding COHb levels expected in healthy adults, as a function of time, using Coburn Forster Kane (CFK) modeling.[jj] Conservative assumptions were made about respiratory rates, given expected activity rates over the 24-hours of modeled exposure. The respiratory minute volume (RMV), expressed in liters per minute (L/min), is the specific inhalation rate input value used in the CFK; and for the epidemiological benefits calculated in this analysis, an RMV of 10 L/min was used. Staff's use of a constant 10 L/min RMV for light activity likely overestimates the breathing rate (and CO uptake rate) of a significant number of victims. In the majority of fatal incidents, victims were at home during an unplanned power outage or an outage due to utility shut off and there was no indication that they had engaged in more than sedentary to light activity levels for most of the time. For example, in several of these cases, a generator was first started in an enclosed space late in the evening/night at a time where victims were clearly preparing for/or retired to bed. In these instances, a sedentary/resting activity level of 6 L/min RMV would be more appropriate. Thus, using an RMV of 10 L/min is another conservative assumption in the analysis. This is explained in more detail in TAB K and its appendices.

To assess the impact of low-emission generators on potential reductions in CO fatalities, the observed fatalities from the incident data were assigned to one of the model structures. The initial step was to assign the fatalities that occurred in an "exact match" structure type. "Exact match" structures are defined as those that match all of the NIST structure characteristic parameters used in the analysis to describe the structure, such as floor area, number of floors, existence of a garage and/or basement. Where exact matches could not be assigned, fatalities were apportioned among best matching structure types (*i.e*., matching the most number of NIST parameters).

These simulations included various generator location scenarios, dependent on house/structure model designs (*i.e.,* only models that had a basement included the generator in basement scenario and only models that had an attached garage included the generator in the attached garage scenario). To match actual usage patterns as closely as possible, the simulation results of the generator locations within the house/structure were proportionately equal to those observed in the incident data.

The victim's location in the modeled house is assumed to have equal probability of occurring in any living space room. This assumption was made for three reasons. First, in multifatality incidents, victims often were found in different locations within a house. Second, in many cases, the victims' locations could not be determined from available reports. And, third, frequently, it was unclear whether victims were located for the entire time in a single area in which they were found, or the individual moved around through various parts of the structure. In the latter case, an individual could have felt sick and moved to, perhaps, a bedroom to lie down before they expired.

[jj] The CFK modeling is a nonlinear differential equation that is a physiologically based mechanistic model for predicting CO uptake and COHb formation and elimination in humans; the model has been validated by empirical data from human studies and is widely regarded by authoritative sources as a reasonably reliable and broadly applicable COHb model for acute exposures.

The next step staff used was to incorporate a criteria that staff developed to evaluate modeled COHb profiles considered indicative of fatal versus nonfatal outcomes. HS staff developed four "COHb Analysis Criteria" to assess whether predicted COHb profiles from modeled residential scenarios were likely indicative of fatal or nonfatal CO exposure in average adults. Where fatal outcome is predicted, the criteria can be used to assess the predicted time to reach fatal exposure during a 24-hour modeling period for each simulated CO exposure. The criteria are intended to reflect that lethal CO health effects are not simply a function of acute hypoxia from a critical drop in blood levels of oxygen delivered to tissues, as indicated by attainment of a specific peak COHb level.[kk] The criteria include some consideration of the level and duration of the predicted COHb elevation, which recognizes that, in addition to reducing oxygen delivery to tissues, CO can enter the non-vascular body compartment and adversely impact important cellular functions by displacing oxygen from various intracellular heme proteins (particularly myoglobin proteins found predominantly in cardiac and skeletal muscles, and certain cytochrome P-450 enzymes involved is cellular respiration). In some prolonged CO elevations, the additional non-vascular adverse effects of CO can result in death at COHb levels that are not typically lethal.[ll]

Although the relationship is not absolute, physiological, epidemiological, and clinical studies provide evidence that acute CO poisoning health effects in healthy adults tend to follow toxicological dose-response principles, and that risk of more serious adverse CO poisoning effects worsens progressively as blood levels of COHb increase.[mm] However, it is clear that lethal CO exposures cannot be defined simply by attainment of a single COHb level. Staff used several information sources to develop COHb assessment criteria to facilitate calculation of benefits estimates predicted for generators with reduced CO emissions. A recent authoritative review of CO toxicity by the Agency for Toxic Substances and Disease Registry indicates that there is a high risk of lethal outcome once COHb levels have reached a critical window, which, for healthy individuals, is generally considered to lie between 40 percent and 60 percent COHb.[17] HS staff reviewed information on COHb levels of victims who experienced acute, generator-related CO poisoning; COHb levels documented in fatal CO poisoning cases reported to CPSC were compared with COHb levels reported for a select group of survivors who received hyperbaric oxygen treatment (HBO-T) for generator-related CO poisoning injuries considered to be of high severity. Staff also considered information on fatal and nonfatal COHb levels reported in nonfire-related CO poisoning cases that did not specifically involve generator-related CO exposures. Based on a review of available data on COHb levels in fatal and nonfatal generator-related CO exposures, and other nongenerator, nonfire-related CO deaths and injuries,

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[kk] Oxygen binding sites of hemoglobin molecules have more than 200-fold higher affinity for CO than for oxygen.

[ll] In reference 14, see Section 3, Summary Information on Carbon Monoxide Pathophysiology.

[mm] For example, loss of consciousness is not generally expected in average adults if peak COHb levels remain below 20 percent, but becomes increasingly more likely as levels approach, and exceed, 40 percent COHb. (Note: staff is referring to the acute COHb blood levels actually reached, or predicted by modeling. This is not necessarily the same as the highest measured COHb levels reported in clinical cases, where initial COHb measurements are typically reduced from peak levels attained, primarily because of the time lag between the end of CO exposure and blood sampling, plus use of supplemental oxygen during this interval).

staff developed the following criteria to distinguish between modeled COHb levels indicative of lethal versus nonlethal outcomes:

1) If peak level is ≥60% COHb, assume death.
2) If peak level is ≥50% COHb but<60%, assume death unless average duration of elevation > 50% COHb is less than 2 hours, and average duration of elevation between ≥40% and <50% COHb is less than 4 hours.
3) If peak level is ≥40% COHb, but <50% COHb, assume death if duration of the average in this range exceeds 6 hours.
4) If peak level is ≤40% COHb, assume survival.

4.3.3. Determination of Deaths Averted

The final part of the modeling study used patterns evident in fatal incident data (such as the known percentages of deaths related to various generator locations for various generator sizes and structure types) to modulate the modeled COHb data in order to estimate the number of fatal CO exposures reported for each generator category, which could have been averted at each reduced emission rate. The modeling included exposure duration of up to 24 hours, estimated on a minute-by-minute resolution and determined the status of living-versus-dead for modeled occupants at each minute in time. The model assumed equal probabilities of intervention over a 24-hour period. This assumption was used because frequently, it was unknown how long an interval between when the generator was started and when the victim died or some other type of intervention occurred based on the incident data.

Although CPSC incident data reflect primarily fatal CO incidents, the assumption that surviving people eventually depart the exposure is supported by staff estimates of at least 25,400 medically attended CO injuries involving generators over the time period of the deaths modeled and that in some fatal incidents there were surviving victims. For each scenario (CO emission rate, structure model, generator location, occupied zone, weather day), the model produced estimated COHb levels. From these COHb levels, a determination was made, at each minute interval, as to the binary event of the victim being dead or alive based on the criteria outlined above. The average per-minute interval over the 28 days produced a probability of fatality at the given time. Under the assumption of equal probability of intervention over the 24-hour period, the average probability of fatality over the 24-hour period is the overall fatality rate for the given scenario. For the current carbureted generator model simulation, the probability was normalized (scaled up) to 100 percent of the allocated deaths because this is based on the actual incident data. The reduced emission rate simulation results were scaled up by the same factor to normalize the data. The difference between the allocated deaths per scenario and the number estimated for the reduced emission levels is the estimate of the deaths averted for the specified scenario. The summation of all the modeled scenarios (at a given emission level) represents an estimate of the potential deaths averted if a reduced emission level generator had been in use in place of the current carbureted types. Thus, the same scenarios and assumptions were used for each generator size, generator location, structure, weather day combination for current and reduced emissions generators so that the comparison was consistent and the assumptions would apply in the same way to current and reduced emissions.

Table 7 presents a summary of the number of deaths that could have potentially been averted over the 2004 to 2012 time span if low emission generators were used in place of the high CO output generators in use during this period. A total of 208 out of 503 deaths were estimatedto be averted. Staff realizes there is uncertainty associated with this estimate given the assumptions and estimations staff used in developing this estimate. However, staff used conservative values and believes the uncertainty in the estimate is within the range of the sensitivity analysis that staff performed on the effectiveness of the emission rates, as described briefly in section 4.4 and in detail in TAB L.

Table 7: Summary of Potential Deaths Averted at Technically Feasible CO Emission Rates When a Generator is Operating in an Enclosed Space at Reduce Oxygen, 2004-2012

Generator Category	CO Emission Rate* Simulating Generator Operation in an Enclosed Space	Actual Fatalities Allocated by Class	Potential Deaths Averted	Potential Lives Saved Rate
Handheld	150	3.7	1.7	46.6%
Class 1	150	176.2	87.7	49.7%
Class 2 Single Cylinder	300	321.3	117.9	36.7%
Class 2 Twin Cylinder	600	1.8	0.3	17.2%
Total	**- -**	**503.0**	**207.6 = ~208**	**41.3%**

*- These rates are 3 times the technically feasible rates at normal ambient oxygen (~20.9%) to account for CO emission rate increase in reduced oxygen. To account for production variation, the CO emission rates in the proposed requirement are 1.5 times the technically feasible rate in normal oxygen.

The numbers are based on the conservative assumption of CO emission rates tripling from technically feasible rates in normal oxygen for each generator category when operating in theorized oxygen depletion. This factor of 3 is based on testing of carbureted generators conducted by NIST (see reference 69) and CPSC staff (see TAB J). However, based on staff's testing of three generators with fuel injected engines having different degrees of closed loop operation (see TAB J), staff believes the factor of increase when the oxygen is 17 percent may be less than 3 for some generators that use closed loop EFI. Furthermore, the results from testing in NIST's garage (see reference 30) indicate the prototype EFI generator depleted the oxygen significantly less than the carbureted generator when tested in each of four matched pair identical test scenario. Therefore, based on both these issues, the factor of 3 likely overstates the weighted CO emission rates for EFI-generators when operated indoors, and understate the reduction in deaths and injuries resulting from the draft standard.

Staff expects that some additional, but unquantified deaths, could be averted in the remaining 24 percent of fatalities that were not modeled, especially in fatal incidents where a generator was operated outdoors, and/or that had co-exposed survivors. Staff's epidemiological benefits analysis is contained in TAB K.

4.4. Preliminary Regulatory Analysis

Staff's preliminary regulatory analysis, contained in TAB L, evaluates the benefits and costs of the staff's draft proposed standard; a brief synopsis is provided here. The analysis is based on 659 deaths reported to CPSC as of 5/21/2015, which occurred during the years 2004 through 2012.[nn] During this period, there was an average of about 73 portable generator-related CO deaths and at least 2,800 generator-related nonfatal CO injuries[oo] annually. The societal costs of these deaths and injuries averaged about $820 million annually. During the same period, there was an average of about 11.1 million portable generators in use, suggesting about 0.66 deaths and at least 25.2 nonfatal CO poisonings per 100,000 portable generators in use.

There are about 80 manufacturers and importers of gasoline-powered portable generators for the U.S. market in recent years. The top 10 manufacturers account for about 84 percent of unit sales of generators in power ranges likely to be purchased by consumers. Although annual sales fluctuate, annual shipments from 2010 through 2014 ranged from about 1.2 million to 1.6 million units. Class 1 generators and class 2 single cylinder generators accounted for about 92.2 percent of portable generators in use during 2004 ─ 2012. Handheld and class 2 twin cylinder generators accounted for 0.7 percent and 7.1 percent of portable generators in use, respectively.

The base case analysis suggests substantial net benefits (benefits minus costs) for most generators. The estimated *gross* benefits per generator ranged from about $215 to $255 for the handheld, class 1, and class 2 single cylinder models. However, because of the small proportion of deaths involving the class 2 twin cylinder generators, and the relatively high acceptable CO emission rate in the draft proposed rule, the expected gross benefits for generators in this category amounted to only about $4 per unit.

The estimated costs of the draft proposed standard were generally similar across generator types, ranging from about $110 to $120 per generator for the handheld, class 1, and class 2 single cylinder models, to about $139 for the class 2 twin cylinder models. The retail price increases likely to result from increases in manufacturing costs could reduce portable generator sales by roughly 50,000 units annually, an overall sales reduction of about 3 to 4 percent.

Given these findings, *net benefits* (*i.e.*, benefits minus costs) ranged from about $100 to about $130 per generator for the *handheld, class 1, and class 2 single cylinder models*. However, net benefits were a *negative* $135 for the class 2 twin cylinder models (*i.e*., benefits of $4 per generator minus costs of $139 per generator). Staff considered exclusion of class 2 twin-cylinder generators from the scope of the rule, however exclusion of class 2 twin- cylinder generators from the scope of the rule could create an economic incentive for manufacturers of generators with larger single- cylinder engines to either switch to twin- cylinder engines for those models.

[nn] As stated in section 3.1, for the purpose of staff's benefits analysis (TAB K) and staff's preliminary regulatory analysis (TAB L), the data from years 2013 and 2014 are not included because, due to reporting delays, the statistics for these years are considered incomplete. Also excluded are 7 deaths from 5 incidents that occurred in 2004 through 2012 that involved stationary generators and generators that were part of welding machines. Therefore, these two analyses are based on 659 deaths in 493 incidents that occurred from 2004 through 2012.

[oo] Based on NEISS and ICM estimates, there was a minimum of about 25,400 during the 9-year time period.

The estimated per unit benefits and costs can be converted to aggregate annual estimates, given information on the production and sale of portable generators. Based on annual sales estimates, the draft proposed rule would result in aggregate annual benefits of about $297.6 million and aggregate annual costs of about $153.0 million. Aggregate *net benefits* would therefore amount to about $144.6 million annually.

However, because the costs of the draft proposed rule for generators with Class II twin engines (about $139 per unit) substantially exceeded the benefits (about $4 per unit), aggregate net benefits would be increased to about $153.2 million annually if the two-cylinder Class II engines were excluded from the rule.

The sensitivity analysis generally supported the findings of the base analysis. For each variation analyzed (*i.e*., expected product life; the discount rate; compliance costs; the value of statistical life applied; and the estimated effectiveness of each generator category in reducing CO emissions), the overall estimated net-benefits of the draft standard were found to be positive; and, as with the base analysis, class 2 twin cylinder generators were found to have estimated costs that are greater than the present value of projected benefits.

4.5. Initial Regulatory Flexibility Analysis

As required by the Regulatory Flexibility Act (5 USC 601 – 612), staff has prepared an initial regulatory flexibility analysis (IRFA) that describes the impact that the proposed rule would have on small businesses and other entities. Staff believes that about nine small manufacturers and 20 small importers could be impacted by the draft proposed rule. Staff's full analysis is provided in TAB M; a brief synopsis is provided here.

As discussed in the preliminary regulatory analysis (TAB L), the cost to manufacturers for complying with the draft proposed rule is expected to be, on average, about $114 per unit for handheld generators, $113 per unit for class 1 generators, $110 for class 2 single cylinder generators, and $138 for class 2 twin cylinder generators. These estimates include the variable costs related to the emission control technologies staff expects will be needed to meet the proposed performance requirements.The estimates also include the fixed costs associated with the research and development required to redesign the generators' engines, tooling costs, and the costs associated with testing and certification establishing that the redesigned engines comply with the EPA's Phase 3 regulation, along with any testing manufacturers decide is necessary to certify that their portable generators meet the requirements of the draft proposed rule. The EFI-related costs range from $67 to $75 per unit, depending on the engine class. The cost of adding a 3-way catalyst ranges from $7 to $49 per unit, depending on the engine class. A more detailed discussion of these costs can be found in TAB L.

To comply with the draft proposed rule, small manufacturers would incur the costs described above to redesign and manufacture their generators. However, to the extent that the volume of generators produced by small manufacturers is lower than that of the larger manufacturers, the costs incurred by smaller manufacturers may be higher than the average costs reported above. One reason to expect that costs for lower-volume manufacturers could be higher than average is that some of the costs are fixed. Therefore, the cost per unit produced would be higher for a low-volume producer than a higher-volume producer. Additionally, the costs of the components necessary to modify the engines might be higher for manufacturers that purchase only a few thousand components at a time than for a manufacturer that purchases more than 100,000 units. On the other hand, although the cost for small, low-volume manufacturers of their own engines might be higher than for high-volume manufacturers, small portable generator manufacturers often do not manufacture the engines used in their generators, but obtain them from engine manufacturers, such as Honda, Briggs and Stratton, and Kohler, as well as several engine manufacturers based in China. These engine manufacturers often supply the same engines to other generator or engine-driven tool manufacturers. Because these engine manufacturers would be expected to have higher production volumes and can spread the fixed research and development and tooling costs over a higher volume of production, the potential disproportionate impact on lower-volume generator producers might be mitigated to some extent.

Small manufacturers and importers that serve the low end of the market and compete mostly on the basis of price might be more severely impacted by the draft proposed rule because their customers may be more price sensitive and, compared with larger manufacturers, they may not have the same options of reducing other costs to mitigate the impact of the draft proposed rule on the price of generators. Suppliers of name-brand generators or suppliers that compete on a basis other than price might be able to make other adjustments, such as using less expensive, but still adequate engines or other components to mitigate the impact of the draft proposed rule on the price of their generators.

The impact on small importers would be expected to be similar to the impact on small manufacturers. One would expect that the foreign suppliers would pass on much of the costs of redesigning and manufacturing portable generators that comply with the draft proposed rule to their domestic distributors. Therefore, the cost increases experienced by small importers would be similar to those experienced by small manufacturers.

As discussed in the regulatory analysis (TAB L), the retail prices that staff observed for portable generators from manufacturers and importers of all sizes ranged from a low of $133 to $4,399, depending upon the characteristics of the generator. On a per-unit basis, the draft proposed rule is expected to increase the costs of generators by an average of $110 to almost $140. Generally, for purposes of RFA analysis, CPSC staff considers impacts that exceed 1 percent of a firm’s revenue to be potentially significant. Because the estimated average cost per generator would be between about 3 percent and 80 percent of the retail prices (or average revenue) of generators, the draft proposed rule could have a significant impact on manufacturers and importers that receive a significant portion of their revenue from the sale of portable generators.

4.6. Regulatory Alternatives

Staff considered several regulatory alternatives that the Commission could consider to address the risks of CO poisoning from consumer use of portable generators (TAB L). The alternatives considered included: (1) establishing less-stringent (higher allowable) CO emission rates; (2) excluding class 2 twin cylinder generators from the scope of the rule; (3) reducing consumer exposure to CO by using an automatic shutoff; (4) establishing later compliance dates; (5) relying upon informational measures only; and (6) taking no action at all.

4.6.1. Less-Stringent (Higher Allowable) CO Emission Rates

Cost savings from higher allowable CO emission rates might result if rates were set high enough so that many generators could meet the requirements without the use of catalysts. Eliminating the use of catalysts could reduce the cost of the draft requirements by an average of $14 per unit for generators with Class I engines and $30 per unit for engines with Class II engines. However, if the emission rates under the draft standard were increased by one-third, the expected reductions in societal costs (*i.e*., benefits) from CO poisoning in scenarios analyzed by staff could be about 30 percent for units with handheld engines; about 36 percent for units with Class I engines; about 30 percent for generators with single cylinder Class II engines, and; about 11 percent for generators with twin cylinder Class II engines. Staff estimates that these reductions in societal costs would be reflected in decreased present value of benefits per-unit of nearly $90 for generators with handheld engines (a decrease of 37%); about $70 for generators with Class I engines (– 28%), and; about $40 for units with single cylinder Class II engines (– 19%) (TAB L). It seems likely that cost savings from less-stringent CO emission requirements and therefore, the reduced burden on small businesses, would be less than expected reductions in benefits. Therefore, net benefits of the rule would probably decrease under this regulatory alternative.

4.6.2. Alternative Scope: Limit Coverage to Generators with One-Cylinder Engines, Exempting Portable Generators with Two-Cylinder Class II Engines from the Rule

Staff considered limiting the scope of the rule to generators with single-cylinder engines (handheld, class 1, and class 2 single cylinder generators). Class 2 twin cylinder generators have been associated with relatively few deaths: only about 1.2 percent of portable generator deaths. Because of this, the estimated net benefits that would be associated with class 2 twin-cylinder generators are negative $135 per unit; thus, the net benefits of the rule could be maximized by excluding these generators from the scope (TAB L). Excluding class 2 twin-cylinder generators could increase the net benefits of the draft proposed rule and reduce the burden on any small manufacturer or importer of these portable generators (TAB M).

Exclusion of class 2 twin-cylinder generators from the scope of the rule could create an economic incentive for manufacturers of generators with larger single-cylinder engines to switch to twin-cylinder engines for those models, or if they already have twin-cylinder models in their product lines, they could be more likely to drop larger single-cylinder models from their product lines. The precise impacts of such business decisions on aggregate net benefits of the rule are not known at this time.

However, because of differences in characteristics of single- and twin-cylinder models, it would likely be of marginal significance. As described at Tab L, class 2 twin-cylinder generators are heavier, more powerful, and generally much more expensive than the class 2 single-cylinder generators. Moreover, there appears to be a clear demarcation in the engine displacement for these two categories of generators. All identified twin-cylinder generators have an engine displacement of 530cc or more. In contrast, all identified single-cylinder models have an engine displacement of 459cc or less. We have no evidence that any of the single-cylinder models would be converted into twin cylinder models to avoid the costs associated with the draft proposed rule; or, even if such conversion did occur in some cases, we do not know whether the impact would be significant. Moreover, it seems unlikely that the higher cost of manufacturing the twin-cylinder generators could be offset by any cost advantage that would result from avoiding the requirements of the proposed rule.

If it would be technologically feasible and cost-effective for manufacturers to use smaller twin-cylinder engines for generators in lower power-ratings that are associated with greater per-unit societal costs, the reduction in scope of the rule might also specify a minimum engine displacement. For example, if this issue were a concern to the Commission, it could exempt generators with twin cylinders, but only if the twin-cylinder models had a displacement above a specified value of total engine displacement.

Staff recommends including class 2 twin cylinder generators in the scope of the proposed rule and recommends the Commission seek comments and input whether class 2 twin cylinder generators should be excluded from the scope and on possible shifts in the market of generators powered by two-cylinder engines such as those discussed above that might result if two-cylinder generators were excluded from the scope of the rule. Staff also recommends that the Commission seek comments on what an appropriate limit on displacement would be if generators with two cylinder engines above a certain displacement were excluded from the scope to avoid creating a market incentive for small twin cylinder generators that avoid the scope of the draft proposed rule.

4.6.3. Alternate Means of Limiting Consumer Exposure: Automatic Shutoff Systems

CPSC staff considered options for reducing the risk of CO poisoning that would require portable generators to shut off automatically if they sensed that a potentially hazardous situation was developing or if they were used in locations that are more likely to result in elevated COHb levels in users. Four shutoff strategies/technologies were evaluated by CPSC engineering staff: (1) a generator-mounted CO-sensing system, which would (ideally) sense higher CO levels during operation indoors and shut off the engine before dangerous levels build up; (2) a CO-sensing system located away from the generator (*e.g.*, inside the dwelling) that relies on the user to place the sensing unit in a location where it can communicate with the generator and send a signal remotely, causing the engine to shut down; (3) a generator-mounted global-positioning (GPS) system intended to infer operation of the generator indoors (from detection of reduced satellite signal strength) and automatically shut down the engine; and (4) for generators equipped with EFI, an algorithm programmed into the engine control unit (ECU) that relies on system sensors to infer indoor operation, signaling the ECU to shut down the engine. The findings of the CPSC engineering evaluation reports on each of the shutoff strategies are summarized in detail in Section 3.5.2 of this memorandum.

As alternative means of limiting exposure to CO, automatic shutoff systems could be incorporated into a standard that limits CO production per hour (such as the draft proposed standard), or they could enable compliance with an alternative standard that requires generators to shut off automatically if they are used in conditions that could lead to accumulation of hazardous levels of CO. Allowing the use of automatic shutoff systems, as either a supplement to limits on CO production per hour or under an alternative shutoff standard could potentially be less costly for manufacturers, and result in greater reductions in CO poisoning for consumers.

However, CPSC staff does not believe that an automatic shutoff standard or option is feasible at this time. As noted above, CPSC engineering staff investigated four different approaches for an automatic shutoff system, and staff was not able to demonstrate how any of the shutoff systems could be implemented satisfactorily. Unresolved concerns with the automatic shutoff technologies studied by CPSC staff include: (1) possibly creating a false sense of safety, which could lead to increased use of portable generators indoors; (2) alternatives that require CO sensors that could falsely identify hazards, which would detrimentally affect the utility of the generator when used in proper locations and could lead to consumers overriding the mechanism; (3) the system would have to be shown to be durable and be capable of functioning after being stored for long periods and being used under widely different conditions; and (4) use of algorithms to shut off engines with ECUs would have to be engine-specific and tailored to how each engine functions, requiring a significant amount of additional testing on this system. These concerns would have to be resolved before a standard incorporating an automatic shutoff option could be developed.

4.6.4. Different (Longer) Compliance Dates

If the Commission were to adopt the draft proposed rule, the rule would become effective 1 year after the final rule is published in the Federal Register, and generators powered by Class II engines would have to comply by that time. Generators powered by handheld and Class I engines would have to comply with the requirements 3 years after publication of a final rule. Staff considered later compliance dates than these, which could potentially reduce the impact on manufacturers of generators, including small manufacturers, by providing them with more time to develop engines that would meet the requirements of the draft proposed rule, or, in the case of small manufacturers that do not manufacture the engines used in their generators, by providing them with additional time to find a supplier of compliant engines so that their production of generators would not be interrupted. Later compliance dates would also provide small importers with additional time to locate a supplier of compliant generators. On the other hand, later compliance dates could delay the introduction of complying generators, thereby reducing the expected benefits of the proposed rule (TAB M).

Because of the experience gained by some engine manufacturers in recent years, staff thinks 1 year is an appropriate lead time for generators powered by Class II engines (TAB I). Staff is recommending a later compliance date (3 years after the publication of a final rule) for generators powered by handheld and Class I engines to address manufacturers' reported concerns that there may be different challenges associated with accommodating the necessary emission control technologies on these smaller engines (even though industry has also gained some limited experience with incorporating fuel injection on handheld and Class I engines). Therefore, staff believes that the compliance dates in the draft proposed rule provide sufficient time for manufacturers and importers to bring their products into compliance.

4.6.5. Informational Measures

CPSC staff considered focusing on informational measures instead. This would reduce the burden on small manufacturers and importers because they would not incur the costs of developing a new technology. OMB (2003) notes that informational measures will often be preferable when agencies are considering regulatory action to address a market failure arising from inadequate information. However, although labels for generators were improved in 2007 with the introduction of mandatory warning labels, as discussed in section 3.6, deaths and injuries from the improper placement of newly purchased generators suggests that some consumers still do not understand and process the information contained in the operating instructions and warning labels and continue to put themselves and others at risk through the improper placement of generators in enclosed areas. The findings of other studies on the effectiveness of labels also "make it seem unlikely that any major reductions in fatalities should be anticipated due to the introduction of these labels" (TAB H).

Other informational measures that the Commission could take include increased provision of information, through government publications, telephone hotlines, or public interest broadcast announcements. CPSC has previously taken and continues to take actions to alert consumers to the dangers of CO poisoning by portable generators, and staff recognizes that continued involvement in these activities is warranted. However, evidence of problems in processing information, and continued occurrence of deaths and injuries from improper use of portable generators, indicates that informational measures do not adequately address the risks presented by these products.

4.6.6. No Action to Establish a Mandatory Standard

The Commission could take no further regulatory action to establish a mandatory standard on portable generators. Given that some generator manufacturers have demonstrated that it is technologically feasible to produce generators that emit significantly lower levels of CO, taking no regulatory action to establish a mandatory standard would allow manufacturers to market low CO-emitting generators if they believe that there would be a market for such products. In addition, it would allow fully informed consumers to purchase low CO-emitting generators if they value the reduced risk. However, staff does not expect that a significant number of generators with CO emission rates proposed by the draft proposed standard would be marketed voluntarily, at least in the short run.

5. Conclusions

Staff believes technically feasible reductions in generator CO emissions rates will effectively reduce the risk of fatal CO poisoning and high-severity CO poisoning injuries. Staff used conservative input values in the modeling studies conducted for the epidemiological benefits analysis. The results indicate that, in many scenarios where fatalities have been documented with current carbureted generators, staff's conservative estimates of technically feasible reduced CO emission rates could have averted an estimated 208 of 503 deaths that occurred during the 9-year period, 2004 through 2012. Aggregate net benefits, based on 1-year's production and sale of the handheld, class 1, and class 2 single cylinder generators amounted to $153 million. Including the class 2 twin-cylinder models (which account for only about 7 percent of portable generators in use), would reduce aggregate net benefits to about $145 annually.

6. Recommendations

CPSC staff recommends that the Commission publish the draft NPR for portable generators, provided with this briefing package, which includes specific performance requirements for the CO emission limits of four different generator categories. These requirements are stated in the draft NPR.

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TAB A

Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004–2014

Matthew V. Hnatov
U.S. Consumer Product Safety Commission
Directorate for Epidemiology
Division of Hazard Analysis
4330 East West Highway
Bethesda, MD 20814
June 2015

This analysis was prepared by the CPSC staff and it has not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

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Executive Summary

This report summarizes non-fire carbon monoxide (CO) incidents associated with engine-driven generators and other engine-driven tools that occurred between 2004 and 2014, and were reported to U.S. Consumer Product Safety Commission ("CPSC") staff as of May 21, 2015. It should be noted that due to incident reporting delays, statistics for the most recent years should be considered incomplete, as data collection is still ongoing. In this report, the two most recent years, 2013 and 2014, are identified as being incomplete because the numbers for these years most likely will increase in future reports. Throughout this report, the number of deaths represents a count of the fatalities associated with generators and other engine-driven tools, such as power lawn mowers, garden tractors, portable pumps, power sprayers and washers, snow blowers, and concrete saws that were reported to CPSC staff. Additionally included in this report are summaries of fatal, non-fire CO incidents, where an engine-driven tool ("EDT") and one or more other fuel-burning consumer products[1] also may have been involved, and the EDT was believed to be, at least, a contributing factor to the fatal levels of CO. These fatalities are characterized in the "Multiple Product" category. This report also provides a more detailed summary of fatal, non-fire CO-poisoning incidents associated with engine-driven tools, with particular emphasis on cases involving generator use, based on information found in the CPSC's In-Depth Investigation ("INDP") File.

Some of the findings of this report are provided below:

CO Fatalities Associated with All EDTs and by EDT Product Type:

- As of May 21, 2015, for the 11-year period 2004 through 2014, 864 fatalities from 673 incidents were associated with the use of engine-driven tools, or engine-driven tools used in conjunction with another potentially CO-emitting consumer product.
- The total number of reported fatalities for 2004 through 2014, had a net increase of 56 from the 808 fatalities summarized in the June 2014 report, including
  - 35 deaths in 2014;
  - new information on 15 deaths for 2013, and five for 2012 that were previously not reported;
  - an additional two deaths were discovered from a 2007 incident that was already reported and that had been erroneously identified as having only one fatality when, in fact, there were three deaths; and
  - one reported fatality, which occurred in 2012, has been removed because newly obtained information identified the associated product as an out-of-scope farm tractor instead of a lawn tractor, as originally identified.
- There were 35 reported non-fire CO fatalities in 2014, from a total of 26 incidents. Twenty-eight of these deaths (20 incidents) involved only a portable generator and no other product; one death involved what appears to be a welder, identified as an installed generator, and used to power a house; four deaths (four incidents) were associated with a non-generator

[1] Combustion consumer products produce heat or energy by burning a fuel source. It should be noted that all fuel-burning consumer products may produce gases that contain CO because CO is a by-product of incomplete combustion.

other engine-driven tool ("OEDT"); and two deaths (one incident) were associated with multiple fuel-burning consumer products, one was a generator.

- From 2004 to 2014, of the 864 fatalities from 673 incidents:
    - 702 fatalities (81%) from 523 incidents were associated with generators (including five fatalities from three incidents involving fixed location, permanently installed stationary generators);
    - 110 fatalities (13%) from 108 incidents involved other engine-driven tools; and
    - 52 fatalities (6%) from 42 incidents involved multiple fuel-burning consumer products, where one product was either a generator (49 of 52 deaths) or an OEDT (3 of 52 deaths), and the other product was a non-EDT.
- In 41 of the 42 incidents that involved multiple consumer products, the second product involved was either a heating or cooking product. Most commonly, the second product was a portable liquid propane ("LP")- or kerosene-fueled portable heater. The one incident not associated with a heating or cooking product involved a gas-fueled lawn mower and a gas-fueled hedge trimmer.
- Twenty-five percent of the generator-related, non-fire CO incidents (139 of 562) caused multiple fatalities; while only two of the OEDT-related incidents (2%) involved multiple fatalities.

Socio-Demographic Characteristics of Victims and EDT-Use Patterns:

- Eighty-three percent of generator-related victims were known to be 25 years old or older. By contrast, 99 percent of OEDT-related victims (all but one) were 25 years old or older.
- Three-quarters of the generator-related, non-fire CO victims were male; while 96 percent (all but four) of the OEDT-related fatalities were male.
- Twenty-four percent of generator-related, non-fire CO fatalities were non-Hispanic Black or African American, nearly double the non-Hispanic Black or African American proportion (13%) of the U.S. population. Eighty-eight percent of other engine-driven tool-related, non-fire CO fatalities were non-Hispanic White, much higher than the non-Hispanic White proportion (65%) of the U.S. population.
- Nearly half of generator-related, non-fire CO fatalities (368 of 751) occurred in the four cold months of the year (November through February); while CO fatalities associated with OEDTs were more evenly distributed across the year with the cold months (37%) slightly higher than in the transition and warm months (34% and 29%, respectively).
- Seventy-five percent of the generator-related fatalities occurred in fixed-structure homes; while 71 percent of OEDT fatalities occurred in fixed-structure homes.
- Fifty-eight percent of the EDT-related fatalities are known to have occurred in urban areas. Sixteen percent occurred in small rural and isolated areas, nearly double the proportion of the U.S. population that lives in such areas.

CO Alarm Usage:

- A CO alarm was reported to have been present in only 21 of 258 incidents where alarm presence was known, which accounted for 31 of 354 (9%) EDT-related CO fatalities. In eight of the incidents (15 deaths), the alarm was inoperable due to no batteries, batteries inserted incorrectly, probable drained batteries, or no electric current. The alarm sounded in six incidents (seven deaths), but the signal was either misunderstood, the alarm was subsequently disarmed (batteries removed after alarming), or the alarm sounded inside the house while the fatality occurred inside an attached garage (presumably, the death occurred in the garage before CO levels increased inside the house sufficient to set off the CO alarm). Additionally, there were seven incidents (nine deaths) in which the presence of a CO alarm was noted, but it is unknown if the alarm sounded during the event.

Hazard Patterns Associated with Generators:

- Twenty-eight percent of all generator-related, non-fire CO deaths (211 of 751) from 2004 through 2014 were associated with power outages, mostly due to weather-related issues. The two most common causes of weather-related outages leading to fatal incidents were ice/snow storms (74 incidents, 98 deaths) and hurricanes/tropical storms (42 incidents, 61 deaths). The second most common reason for generator usage in the reported CO fatalities was due to power shut-off, accounting for 20 percent (153 deaths from 116 incidents) of the all reported fatalities.
- Five hundred sixty-five non-fire CO fatalities (422 incidents) that occurred in fixed-structure homes were associated with a generator or a generator in use with another potential CO-generating consumer product. Seventy percent (395 deaths, 289 incidents) occurred when the generator was placed inside the living area of the home, including the basement, closets, and doorways, but excluding the attached garage, enclosed carport, or attached barn.
- Two-thirds of generator-related, non-fire fatal CO incidents (66%) in fixed-structure homes (for which information on ventilation of the generator was available) occurred when no ventilation of the generator was attempted.
- Fifty-eight percent of the generator-related, non-fire fatal CO incidents in fixed-structure homes, where the size of the home was known and the generator was not located in an external structure, occurred in houses less than 1,500 square feet in size; 84 percent occurred in houses less than 2,000 square feet in size.

Carboxyhemoglobin Levels in CO Fatality Victims:

- Of the CO fatality victims associated with engine-driven tools, 80 percent had carboxyhemoglobin (COHb) levels at or above the 50 percent level when the COHb level was known.[2]

Note: Throughout this report, the years 2013 and 2014 are italicized in table headings, indicating that incident and death counts may change as additional information is received due to reporting delays. Incident and death counts may change for other years, but to a much smaller extent.

[2] As levels rise above 40 percent COHb, death is possible in healthy individuals and becomes increasingly likely with prolonged exposures that maintain levels in the 40 percent to 60 percent range.

Introduction

The following U.S. Consumer Product Safety Commission ("CPSC") databases were searched to prepare the statistics recorded in this report: the In-Depth Investigation ("INDP") File, the Injury or Potential Injury Incident ("IPII") File, and the Death Certificate ("DTHS") File. See Appendix A for the codes and keywords used in the database searches. The data records were combined and collated to develop the most complete records possible in a single database. At this stage, each record was reviewed to determine whether the incident was in scope for this report and to correct any discrepancies between information from the different sources (See Appendix A for the specifics of scope determination). It should be noted that reporting may not be complete, and this report reflects only incidents reported and entered into CPSC databases on or before May 21, 2015. All fatal, unintentional, non-fire carbon monoxide (CO) incidents associated with engine-driven tools ("EDTs") found during the database search that were determined to be in scope were included.

CPSC records contain information on 864 non-fire CO fatalities associated with EDTs during the years 2004 through 2014. Last year's report, dated June 2014, contained summary information and analyses for the 10-year period, 2004−2013. Since the last report, there have been 56 new CO fatalities associated with engine-driven tools reported to CPSC. This is an increase of 56 fatalities from the 808 fatalities over the period of 2004−2013 reported in the June 2014 report on non-fire CO fatalities associated with EDTs, which included data entered into CPSC databases as of May 1, 2014.[3]

Changes to previous report:

- 2007 – Two additional fatalities were discovered in police reports of an incident that was originally thought to be a single-fatality incident.
- 2012 – Five new single-fatality incidents added and one single fatality incident was removed having been determined to be out-of-scope based on newly acquired information, for a net change of four total fatalities.
- 2013 – Fourteen new incidents added, accounting for 15 deaths.
- 2014 – Twenty-six incidents added, accounting for 35 deaths.

All but two of the 35 fatalities reported to CPSC that occurred in 2014 were associated with generators or other engine-driven tools ("OEDT") as the only known sources of the CO. Two additional fatalities from a single incident were associated with the use of a generator and a portable kerosene heater.

Incidents associated with generators that were specifically reported as integral parts of recreational vehicles ("RVs"), motor homes, or boats are not within the jurisdiction of the CPSC; and thus, these incidents were considered out of scope and were not included. For example, generators that were reportedly mounted to an RV were not included, nor were boat generators that were installed by the

[3] Hnatov, M. V. *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004–2013. U.S. Consumer Product Safety Commission. June 2014.*

boat manufacturer. Because incidents in recreational vehicles and boats can be associated with a portable generator or an integral generator, those incidents in which the type of generator could not be determined were also excluded from the analysis. Any incident that was determined to be other than unintentional in nature was considered to be out of scope, as were work-related incidents, which are not within the jurisdiction of the CPSC.

This report is divided into four sections:

I. Reported Numbers of Fatalities by EDT Product Type. This presents an overall picture of CO fatalities associated with engine-driven tools.
II. Socio-Demographics of Victims and EDT Use Patterns. This presents various socio-demographic summaries focused on identifying specific characteristics of CO fatality victims and usage patterns, such as when and where fatalities occurred.
III. Alarm Usage. This presents information on CO alarm usage during fatal CO events.
IV. Hazard Patterns Associated with Generators. This presents data specific to generator usage patterns that may lead to fatal CO poisoning events.

Additionally, Appendix B presents summary findings on carboxyhemoglobin (COHb) levels in the blood of victims of CO poisoning involving EDT use, which are helpful in assessing the hazard presented by the product and the speed of onset of harm.

I. Reported Numbers of Fatalities by Engine-Driven Tool (EDT) Product Type

As of May 21, 2015, CPSC staff had records indicating that there were 26 fatal, non-fire CO exposure incidents involving EDTs between January 1, 2014 and December 31, 2014. Thirty-five deaths occurred in these 26 fatal CO incidents. Table 1 presents the reported fatal incidents and the number of deaths in 2014, along with a summary of CO incidents and fatalities associated with engine-driven tools for the 11-year period from 2004 through 2014. The table records the number of incidents and deaths by the broad categories of “Generators,” OEDTs and “Multiple Products.” Multiple product incidents are fatal CO poisonings that involved multiple fuel-burning consumer products that generate CO, at least one being an EDT, or in which investigating authorities could not determine which of multiple consumer products in use at the time of the incident was the source of the CO. CPSC staff is aware of 52 fatalities associated with multiple consumer products, occurring between 2004 and 2014; two of these fatalities occurred in 2014. Multiple product incidents, where one of the sources of CO is not under the CPSC’s jurisdiction, such as automobiles, boats, or recreational vehicles, were determined to be out of scope and are not included in this report. Following Table 1, Multiple Product incidents will be included in the summary for the involved engine-driven tool type, either “Generators” or OEDTs.

Within each broad category, the frequency of reports is summarized by product type. Staff is aware of 673 incidents with a total of 864 deaths due to non-fire CO exposure that occurred between 2004 and 2014, involving EDTs.

In Table 1, the product type “welder” appears in both the “Generator” and OEDT categories. Some welding equipment is designed to be used as a welder or as an electric generator. Three of the fatal, non-fire CO incidents associated with the use of welding equipment that occurred between 2004 and 2014, involved the use of the welder as a generator during a power outage. Each of these three incidents involved a single death. There were three fatal, non-fire CO incidents between 2004 and 2014, which were associated with the use of welder equipment, where it was not specifically identified as being used as a generator. Of these three incidents, one incident involved two deaths.

All but one of the 52 non-fire, CO fatalities in the “Multiple Products” category for 2004–2014 involved a heating- or cooking-related consumer product other than an EDT. The one incident not involving a heating- or cooking-related consumer product involved a gasoline-fueled, walk-behind mower, and a gasoline-fueled trimmer, also running in a closed garage.

Table 1: Number of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Associated with Engine-Driven Tools, 2004–*2014*

Product	*2013*		*2014*		Total: 2004–*2014*	
	Number of Incidents	***Number of Deaths***	***Number of Incidents***	***Number of Deaths***	**Number of Incidents**	**Number of Deaths**
Total Engine-Driven Tools	***50***	***62***	***26***	***35***	**673**	**864**
Generators	***39***	***51***	***21***	***29***	**523**	**702**
Generator, portable	*39*	*51*	*20*	*28*	517	694
Generator, fixed	*0*	*0*	*0*	*0*	3	5
Welder (used as a generator)[1]	*0*	*0*	*1*	*1*	3	3
Other Engine-Driven Tools (OEDT)	***7***	***7***	***4***	***4***	**108**	**110**
Lawn mowers	*3*	*3*	*1*	*1*	55	55
Riding lawn mower/Garden tractor	*2*	*2*	*0*	*0*	46	46
Push lawn mower	*0*	*0*	*0*	*0*	2	2
Powered lawn mower, unspecified type	*1*	*1*	*1*	*1*	7	7
Power washer/sprayer	*0*	*0*	*1*	*1*	12	12
Snow blower	*2*	*2*	*1*	*1*	13	13
All-terrain vehicle	*0*	*0*	*1*	*1*	8	9
Welder (used as welder or other reason)[1]	*0*	*0*	*0*	*0*	3	4
Water pump	*1*	*1*	*0*	*0*	5	5
Concrete saw	*0*	*0*	*0*	*0*	2	2
Air compressor	*0*	*0*	*0*	*0*	2	2
Paint sprayer	*0*	*0*	*0*	*0*	1	1
Snowmobile	*0*	*0*	*0*	*0*	1	1
Go-cart	*0*	*0*	*0*	*0*	1	1
Tiller	*0*	*0*	*0*	*0*	1	1
Small engine (unknown use)	*0*	*0*	*0*	*0*	1	1
Edger	*0*	*0*	*0*	*0*	1	1
Stump Grinder	*1*	*1*	*0*	*0*	1	1
Wood Splitter	*0*	*0*	*0*	*0*	1	1
Multiple Products[2]	***4***	***4***	***1***	***2***	**42**	**52**
Generator + Other Consumer Product	*3*	*3*	*1*	*2*	39	49
OEDT + Other Consumer Product[3]	*1*	*1*	*0*	*0*	3	3

1 Some welding equipment is designed to be used as either a welder or a generator.

2 "Multiple Products" includes incidents involving generators or OEDTs with other combustion fuel-burning consumer products. "Other Consumer Products" includes one or more of the following: portable LP-fueled heaters, portable kerosene-fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.

3 The two incidents associated with an OEDT and another consumer product includes the following engine-driven tools: one incident involved two gasoline-fueled lawn mowers and an LP heater, and the other incident involving a gasoline-fueled lawn mower and a gasoline-fueled trimmer.

Note: Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Five hundred and twenty-three of the 673 incidents (78%) reported to CPSC staff during the 2004−2014 period were associated with a generator and accounted for 702 of the 864 CO deaths (81%). Additionally, 49 other CO fatalities from 39 incidents were associated with the use of a generator and another combustion consumer product—most commonly an LP- or kerosene-fueled heater. Throughout the remainder of this report, incidents associated with all non-generator engine-driven tools are reported as a group. In addition, because the majority of incidents were associated with generators, characteristics of these incidents are reported separately in Section IV. More than half of the non-fire, non-generator engine-drive tool-related CO incidents (58 of 113, 51%) involved a garden tractor or other powered lawn mower (including all three of the multiple product incidents). Deaths associated with powered lawn mowers were often associated with an individual repairing or working on the product in an enclosed space.

CPSC staff examined the number of deaths associated with each fatal incident (Table 2). Of the 673 fatal incidents, 79 percent involved a single fatality. Seventy-five percent (423 of 562) of the fatal generator-related incidents involved a single fatality. One incident involving a generator resulted in the deaths of six individuals, and two others involved five fatalities. Of the 111 fatal incidents in the OEDTs category, two incidents resulted in more than one fatality.

Table 2: Number of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Associated with Engine-Driven Tools by Number of Deaths per Incident, 2004–*2014*

Number of Deaths Reported in Incident[1]	All Engine-Driven Tools (EDTs)		Generator		Other Engine-Driven Tools (OEDTs)	
All Incidents	**673**	**100%**	**562**	**100%**	**111**	**100%**
1	532	79%	423	75%	109	98%
2	106	16%	104	19%	2	2%
3	23	3%	23	4%	0	0%
4	9	1%	9	2%	0	0%
5	2	< 1%	2	< 1%	0	0%
6	1	< 1%	1	< 1%	0	0%

SPECIAL NOTE ABOUT COUNTS IN THIS TABLE ONLY: One incident included in this table involved an in-scope, generator-related death and an out-of-scope death (work related). Because two fatalities were involved in the incident, this incident is included as a two-fatality incident. The out-of-scope fatality is not included elsewhere in the report. Therefore, in this table only, there is one additional fatality reported. The in-scope fatality was a generator-related fatality, so it is included in the "Generator" and "Total" columns.

Notes: Totals may not add to 100 percent due to rounding.

Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

CPSC staff summarized the number of reported deaths associated with EDTs by year of death (Table 3). It should be noted that the values in Table 3 represent the number of deaths reported to CPSC staff as of May 21, 2015. Some deaths are reported to CPSC staff shortly after an incident occurs, while other deaths are reported to CPSC staff months, or even years, after an incident occurs. Therefore, counts for more recent years may not be as complete as counts for earlier years and may change in the future. Thirty-eight percent (21 of 56) of the reported fatalities new to the report were for years before 2014.

The average number of non-fire CO fatalities associated with both generators and OEDTs for years 2010 through 2012, is also presented in Table 3. These three years represent the most recent years for which CPSC staff believes reporting are substantially complete. Due to reporting delays, these averages may change slightly in the future, when data are complete. Figure 1 in Appendix C illustrates the historical trend in EDT-related, non-fire CO fatalities since 1999.

Table 3: Number of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Associated with Engine-Driven Tools by Year, 2004–*2014*

Year	All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTs)	
	Incidents	**Deaths**	**Incidents**	**Deaths**	**Incidents**	**Deaths**
Total	***673***	***864***	***562***	***751***	***111***	***113***
2004	50	62	35	47	15	15
2005	93	116	80	103	13	13
2006	79	109	63	93	16	16
2007	69	84*	58	73*	11	11
2008	77	102	70	95	7	7
2009	55	76	45	66	10	10
2010	46	57	36	45	10	12
2011	81	108	69	96	12	12
2012	47	53	42	48	5	5
2013	*50*	*62*	*42*	*54*	*8*	*8*
2014	*26*	*35*	*22*	*31*	*4*	*4*
Average: 2010–2012	**58**	**73**	**49**	**63**	**9**	**10**

Notes: Detail averages may not sum to total average due to rounding.
* In previous reports, review of supplemental police record information of an incident that was reported to be a single fatality incident indicated that there were actually three fatalities. Therefore, the number of generator-related fatalities in 2007 was corrected from 71 to 73. This correction is carried through the entire document.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

II. Socio-Demographic Characteristics of Victims and EDT Use Patterns

This section presents socio-demographic information about the victims of reported fatal CO incidents associated with EDTs. Tables 4, 5, and 6 present summaries of socio-demographic characteristics of the victims. Table 4 presents the distribution of ages of the victims. Victims age 25 years or older accounted for about 85 percent (732 of 864) of reported non-fire, CO poisoning deaths associated with all EDTs. By comparison, according to the 2010 Census, 66 percent of the U.S. population is over 25 years old. Victims with a reported age of 25 years or older accounted for about 83 percent (620 of the 751 victims where the age was known) of non-fire CO poisoning deaths associated with generators and accounted for all but one of the deaths (112 of 113) associated with other EDTs. Eighty-seven percent of the non-fire CO fatalities associated with non-generator, EDTs (98 of 113) involved victims age 45 or older.

It appears from the data summary that EDT-related CO fatalities have been occurring to older consumers at a higher rate. Fifty-six percent of the CO fatalities were over the age of 44, while only 39 percent of the U.S. population was above 44 years of age during this time period. By contrast, only 14 percent of EDT-related victims were below the age of 25, while 34 percent of the U.S. population was below 25 years of age during this time period.

Table 4: Number of Reported Non-Fire Carbon Monoxide Fatalities Associated with Engine-Driven Tools by Age of Victim, 2004–*2014*

Age	2010 Estimated U.S. Resident Population[1]	All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTS)	
		Deaths	Percentage	Deaths	Percentage	Deaths	Percentage
Total	**100%**	**864**	**100%**	**751**	**100%**	**113**	**100%**
Under 5	7%	11	1%	11	1%	0	0%
5–14	13%	33	4%	33	4%	0	0%
15–24	14%	80	9%	79	11%	1	1%
25–44	27%	248	29%	234	31%	14	12%
45–64	26%	335	39%	278	37%	57	50%
65 and over	13%	149	17%	108	14%	41	36%
Adult, age unknown	-	8	1%	8	1%	0	0%

This percentage represents the 2010 Census estimated percentage of the U.S. population, the approximate mid-point of the 10-year range Notes: Totals may not add to 100 percent due to rounding.

Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

U. S. Census Department, Annual Estimates of the Resident Population by Sex, Age, Race, and Hispanic Origin for the United States and States: April 1, 2010 to July 1, 2013

Table 5 presents the distribution of the gender of the victims. Male victims accounted for 78 percent of the deaths associated with all EDTs when the gender of the victim is known. Male victims comprised 75 percent of the deaths associated with generators and 96 percent of non-generator, EDT fatalities.

Table 5: Number of Reported Non-Fire Carbon Monoxide Fatalities Associated with Engine-Driven Tools by Gender of Victim, 2004–*2014*

Gender	All Engine-Driven Tools (EDTs)		Generators		All Other Engine-Driven Tools (OEDTs)	
	Deaths	Percentage	Deaths	Percentage	Deaths	Percentage
Total	**864**	**100%**	**751**	**100%**	**113**	**100%**
Male	675	78%	566	75%	109	96%
Female	187	22%	183	24%	4	4%
Unknown	2	< 1%	2	< 1%	0	0%

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Table 6 presents a summary of the race/ethnicity of the reported CO fatalities associated with EDTs. The percentage of generator-related CO fatalities identified as “Black/African American” (24% of deaths) was nearly double the proportion classified by the U.S. Census Bureau as “Black/African Americans” in the U.S. population (an estimated 13%). The percentage of the non-generator, EDT-related CO fatalities identified as non-Hispanic “White” (88% of deaths) was much higher than proportion classified as non-Hispanic “White” by of the U.S. Census Bureau (an estimated 65% of the U.S. population).

Table 6: Number of Reported Non-Fire Carbon Monoxide Fatalities Associated with Engine-Driven Tools by Race/Ethnicity of Victim, 2004–*2014*

Race / Ethnicity	2010 Estimated U.S. Resident Population[1]	All Engine-Driven Tools (EDTs)		Generators		All Other Engine-Driven Tools (OEDTs)	
		Deaths	Percentage	Deaths	Percentage	Deaths	Percentage
Total		**864**	**100%**	**751**	**100%**	**113**	**100%**
White	65%	535	62%	435	58%	100	88%
Black/African American	13%	183	21%	180	24%	3	3%
Hispanic (any race)	16%	87	10%	85	11%	2	2%
Asian	5%	14	2%	13	2%	1	1%
Native American	1%	6	1%	6	1%	0	0%
Other / Unknown	< 1%	39	5%	32	4%	7	6%

1 This percentage represents the 2010 Census estimated percentage of the U.S. population, the approximate mid-point of the 10-year range. All categories, with the exception of "Hispanic (any race)" are non-Hispanic averages. Percentages represent single-race figures as multi-race are seldom available from available information. Two percent of the U. S. population identifying themselves as multiracial.

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Sources: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.
U. S. Census Department, Annual Estimates of the Resident Population by Sex, Age, Race, and Hispanic Origin for the United States and States: April 1, 2010 to July 1, 2013

Staff examined reported deaths associated with EDTs by the time of year that the incident occurred (Table 7). The non-fire CO fatalities were classified into one of three categories, depending on the month in which the incident occurred: Cold months, Warm months, and Transitional months. "Cold months" are November, December, January, and February; "Warm months" are May, June, July, and August; and "Transitional months" are March, April, September, and October.

Nearly half (49%) of the non-fire CO deaths associated with generators occurred in the cold months of November through February. Many of the fatalities can be directly associated with the use of generators during power outages due to weather conditions, such as ice or snow storms. Thirty percent of the generator-related CO deaths occurred in the transitional months of March, April, September, and October. A large portion of the non-fire CO fatalities in the transitional months can be directly associated with the use of generators during power outages, due to hurricanes and tropical storms, many of which occurred in September, and to a lesser extent, October. Additional details on this issue are presented in Section IV of this report.

OEDT-related CO fatalities occur relatively evenly across the year. Thirty-seven percent of the fatalities occurred in the cold months, 34 percent in the transitional months, and 29 percent in the warm months.

Table 7: Number of Reported Non-Fire Carbon Monoxide Incidents and Fatalities Associated with Engine-Driven Tools by Season, 2004–*2014*

Season Incident Occurred		All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTs)	
Total	**Incidents**	**673**	**100%**	**562**	**100%**	**111**	**100%**
	Deaths	**864**	**100%**	**751**	**100%**	**113**	**100%**
Cold months	Incidents	324	48%	283	50%	41	37%
	Deaths	410	47%	368	49%	42	37%
Transitional months	Incidents	195	29%	158	28%	37	33%
	Deaths	262	30%	224	30%	38	34%
Warm months	Incidents	154	23%	121	22%	33	30%
	Deaths	192	22%	159	21%	33	29%

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Incidents involving deaths are further summarized in Table 8 by the location where the death occurred. The majority of non-fire, CO poisoning deaths (741 of 864, or 86%) reported to CPSC staff associated with EDTs occurred at home locations. Seventy-five percent of the deaths occurred at fixed-structures used as a residence, which include houses, mobile homes, apartments, townhouses, and structures attached to the house, such as an attached garage. Another 8 percent occurred in external or detached structures at home locations, such as detached garages or sheds. A large portion of these external structure fatalities were related to OEDTs, such as lawnmowers running in sheds or detached garages. Thirty-three percent (24 of 72) of fatalities occurring in external structures at the home involved OEDTs.

Three percent of deaths associated with engine-driven tools occurred in nontraditional homes, such as travel trailers, houseboats, or storage sheds used as permanent residences. The "Temporary shelter" category includes incidents in which victims died from CO poisoning from portable generators or other EDTs, while the victims were temporarily occupying trailers, horse trailers, RVs, cabins (used as a temporary shelter), tents, and campers. Incidents that occurred in a temporary shelter, where the generator was an integral part of the temporary shelter, such as built-in generators or generators built specifically for use in an RV, are not within the purview of the CPSC; and thus, they are out of scope for this report and were excluded from the analyses. The "Boat/Vehicle" category only includes incidents in which a generator or other engine-driven tool was not an integral part of the boat─but was brought onto the boat─and incidents where an EDT was brought into a vehicle, such as a van. As with temporary shelters, incidents involving generators that were built-in or specifically designed for a boat are not within the purview of CPSC and are not included in this report. The "Other" category includes incidents that occurred in office buildings, utility buildings, and storage sheds (offsite from home).

Table 8: Number of Reported Non-Fire Carbon Monoxide Incidents and Fatalities Associated with Engine-Driven Tools by Location, 2004–*2014*

Location		All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTs)	
Total	**Incidents**	**673**	**100%**	**562**	**100%**	**111**	**100%**
	Deaths	**864**	**100%**	**751**	**100%**	**113**	**100%**
Home, fixed Structure[1]	Incidents	501	74%	422	75%	79	71%
	Deaths	645	75%	565	75%	80	71%
Home, detached Structure[2]	Incidents	70	10%	46	8%	24	22%
	Deaths	72	8%	48	6%	24	21%
Home, non-house[3]	Incidents	20	3%	16	3%	4	4%
	Deaths	24	3%	20	3%	4	4%
Temporary shelter	Incidents	47	7%	47	8%	0	0%
	Deaths	74	9%	74	10%	0	0%
Boat/Vehicle	Incidents	19	3%	18	3%	1	1%
	Deaths	25	3%	23	3%	2	2%
Other	Incidents	13	2%	11	2%	2	2%
	Deaths	16	2%	14	2%	2	2%
Not reported	Incidents	3	< 1%	2	< 1%	1	1%
	Deaths	8	1%	7	1%	1	1%

1 This refers to a fixed-structure used as a residence, including: houses, mobile homes, apartments, townhouses, and structures attached to the house, such as an attached garage.
2 This refers to detached structures at home locations, including detached garages and sheds.
3 This refers to non-fixed location residences, including travel trailers and houseboats.
Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Table 9 presents the number of non-fire, CO poisoning deaths reported to CPSC staff and associated with EDTs, categorized by the population density of the place of death. All fatal incidents were assigned to one of four rural/urban categories, based on the Rural-Urban Commuting Area ("RUCA") codes developed by the Economic Research Service ("ERS") of the U.S. Department of Agriculture ("USDA"). The four categories are "Urban Core," "Sub-Urban," "Large Rural," and "Small Rural/Isolated". Details on the process of determining population density or rurality can be found at the USDA website at: http://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes.aspx. Additional information regarding the cross-referencing of zip codes to RUCA codes can be obtained from the University of Washington, WWAMI[4] Rural Health Research Center website at: http://depts.washington.edu/uwruca/.

Fifty-eight percent (503 of 864) of CO fatalities associated with the use of EDTs reported to CPSC staff occurred in urban areas, while the estimated proportion of the U.S. population living in urban core areas is 71 percent. Forty-two percent (361 of 864) of CO fatalities occurred in non-urban core

[4] The WWAMI name is derived from the first letter of each of the five cooperating states in a partnership between the University of Washington School of Medicine and the states Wyoming, Alaska, Montana, and Idaho.

areas (sub-urban, large rural, and small rural/isolated areas), where an estimated 29 percent of the U.S. population lives. There appears to be an unusually high proportion of fatalities in small rural/isolated areas. Sixteen percent (136 of 864) of the CO fatalities known to CPSC staff to be associated with EDTs occurred in small rural and isolated areas, where only an estimated 9 percent of the U.S. population lives.

Table 9: Number of Reported Non-Fire Carbon Monoxide Fatalities Associated with Engine-Driven Tools by Population Density of Place of Death, 2004–*2014*

Population Density		Estimated Percentage of U.S. Population[1]	All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTs)	
Total	**Incident**	**100%**	**673**	**100%**	**562**	**100%**	**111**	**100%**
	Deaths		**864**	**100%**	**751**	**100%**	**113**	**100%**
Urban Core	Incident	71%	383	57%	325	58%	58	52%
	Deaths		503	58%	444	59%	59	52%
Sub-Urban	Incident	10%	89	13%	73	13%	16	14%
	Deaths		112	13%	96	13%	16	14%
Large Rural	Incident	10%	96	14%	73	13%	23	21%
	Deaths		113	13%	89	12%	24	21%
Small Rural /Isolated	Incident	9%	105	16%	91	16%	14	13%
	Deaths		136	16%	122	16%	14	12%

1 Percentages are determined from the estimated 2010 U.S. population categorized by RUCA designation. U.S. population estimates by RUCA classification were determined by cross-referencing the WWAMI RUCA zip code table with the 2010 U.S. Census population estimates by zip code area, the most current census data available by zip code area. 2010 is the approximate mid-point year of the 10-year range.

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.
WWAMI Rural Research Center at the University of Washington Economic Research Group, USDA.
U.S. Census Bureau, 2011.

III. Alarm Usage

Table 10 presents a summary of known CO fatalities characterized by CO alarm usage and alarm status. In 62 percent of the fatal incidents (415 of 673) and 59 percent of reported CO poisoning deaths (510 of 864), the presence of a CO alarm at the location of the incident was unknown or unreported. Of the 258 fatal incidents (354 CO fatalities) associated with EDTs in which it was known whether a CO alarm was present or not, a CO alarm was present in only 21 incidents (9%) involving 31 CO fatalities. Of these 21 fatal incidents, the alarm was known to be inoperable in eight incidents (15 fatalities) due to missing, improperly installed, or possibly drained batteries in a battery-powered alarm (non-plug-in type), or because the alarm was a plug-in type and power was out at the location of the incident. All eight fatal incidents (15 fatalities) with inoperable alarms were associated with generator usage.

For the remaining 13 fatal incidents (16 fatalities) where an alarm was known to be present, the alarm was known to have sounded in only six incidents (seven deaths):

- In one incident, the victim’s family reportedly did not understand that the alarm-sounding pattern (sounding every few minutes) was indicating CO present in the home; they thought the alarm sounding simply meant that the alarm was working.
- In one fatal incident, the victims thought the “beeping” meant that the batteries were low, so they replaced the batteries. The batteries were inserted incorrectly, thus disabling the alarm. One family member died and two survived.
- In one incident, the alarm sounded, and the victim removed the batteries, thus disabling it. The victim was transported to the hospital but was pronounced dead.
- In two incidents, a CO alarm was heard sounding inside the house when the victim was discovered. In both cases, the victims were found inside an attached garage, apparently working on an engine-driven tool (a lawn tractor in one case, and a snow blower in the other), which presumably had been running.
- In another incident, two victims were found in a home in which a CO alarm was sounding. It is unclear if the alarm triggered after the victims became incapacitated by CO poisoning, or if the victims simply misunderstood or ignored the signal.

There were also nine deaths from seven incidents in which a CO alarm was present in the house, but it was unknown whether the alarm sounded or if the alarm was operable.

Table 10: Carbon Monoxide Alarm Usage Associated with Engine-Driven Tools Non-Fire Carbon Monoxide Poisoning Deaths, 2004–*2014*

CO Alarm Status	Number of Deaths and Percentage of Deaths when Alarm Status was Known								
	All Engine-Driven Tools (EDTs)			Generators			Other Engine-Driven Tools (OEDTs)		
	Incidents	Deaths	% of Deaths	Incidents	Deaths	% of Deaths	Incidents	Deaths	% of Deaths
Total	**673**	**864**	**-**	**562**	**751**	**-**	**111**	**113**	**-**
Alarm Status Known	**258**	**354**	**100%**	**227**	**321**	**100%**	**31**	**33**	**100%**
No Alarm	**237**	**323**	**91%**	**210**	**294**	**92%**	**27**	**29**	**88%**
Alarm Present	**21**	**31**	**9%**	**17**	**27**	**8%**	**4**	**4**	**12%**
Alarmed	6	7	2%	4	5	2%	2	2	6%
Did not alarm, batteries removed, incorrectly inserted, or drained	5	10	3%	5	10	3%	0	0	0%
Did not alarm, plug-in type, no power	3	5	1%	3	5	2%	0	0	0%
Alarm present, Unknown if it alarmed	7	9	3%	5	7	2%	2	2	6%
Alarm Status Unknown	**415**	**510**	**-**	**335**	**430**	**-**	**80**	**80**	**-**

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

IV. Hazard Patterns Associated with Generators

This section presents information about the usage patterns associated with fatal CO poisoning specific to generators, as well as information about the homes where fatal generator incidents occurred. As of May 21, 2015, CPSC staff is aware of 562 generator-related incidents from 2004 through 2014, which resulted in non-fire CO fatalities. Staff completed, or otherwise resolved, IDIs for 533 of 562 (95%) fatal CO incidents associated with generators that occurred from 2004 through 2014. For the remaining 29 incidents in which an IDI was not performed or was not completed by the May 21, 2015 cut-off date, attempts were made to augment the data from reports of the incident in IPII records or from death certificate information. Summaries of generator-related incidents in this section also include incidents where multiple fuel-burning consumer products were involved, including a generator.

A review of records for the 562 incidents resulting in 751 generator-related, non-fire CO deaths reported to CPSC staff suggests two primary reasons reported for using a generator. One reason cited was to provide electricity to a location that did not have electricity due to a temporary situation (*e.g.*, a power outage), and the other was to provide power after a shutoff to the residence by the utility company, due to bill dispute or nonpayment. Table 11 provides a breakdown by year, listing the reasons why a generator was in use at the time of the incident. Twenty-seven percent of the incidents (28 percent of the reported deaths) involving generator-related, non-fire CO fatalities were associated with the use of generators during a temporary power outage stemming from a weather problem or a problem with power distribution. Twenty-one percent of the fatal incidents (20 percent of deaths) were associated with the use of generators after a power shutoff by the utility company for nonpayment of a bill, a bill dispute, or other reason. For 19 percent of the fatal incidents (18 percent of deaths), it could not be determined why the generator was in use, or why there was no electricity at the location of the incident.

Most of the generators that were associated with fatal CO poisoning were gasoline-fueled. In 52 of the 562 incidents, the fuel type could not be ascertained. Of the 510 cases where the fuel type used in the generator was known, 99 percent (506 of 510) were gasoline-fueled. Of the remaining incidents, three involved propane-fueled generators, and the other incident involved a diesel-fueled generator.

Table 11: Number of Reported Non-Fire Carbon Monoxide Fatalities for Incidents Associated with Generators[1] by Reason for Use, 2004–*2014*

Reason for Use		Total	2004	2005	2006	2007	2008	2009	2010	2011	2012	*2013*	*2014*
Total	**Incidents**	**562**	**35**	**80**	**63**	**58**	**70**	**45**	**36**	**69**	**42**	***42***	***22***
	Deaths	**751**	**47**	**103**	**93**	**73**	**95**	**66**	**45**	**96**	**48**	***54***	***31***
Power outage due to weather, or problem with power distribution	Incidents	152	7	37	11	15	19	10	5	19	15	*11*	*3*
	Deaths	211	11	53	17	23	26	17	6	27	16	*12*	*3*
Electricity turned off by power company due to bill dispute, nonpayment, or other reason	Incidents	116	6	11	17	13	13	6	12	17	5	*9*	*7*
	Deaths	153	6	12	23	16	19	9	16	25	6	*11*	*10*
Provide power to storage shed, trailer, boat, camper, cabin, campsite	Incidents	65	3	8	13	8	5	8	2	8	5	*4*	*1*
	Deaths	91	4	11	19	9	7	11	5	13	6	*4*	*2*
New home or homeowner, and power not yet turned on, home under construction or renovation	Incidents	59	10	4	6	5	7	5	5	5	3	*6*	*3*
	Deaths	86	14	6	9	5	13	6	5	10	4	*11*	*3*
Provide power to home or mobile home that normally does not have electricity	Incidents	39	3	6	3	4	4	3	3	4	4	*2*	*3*
	Deaths	54	4	6	5	5	5	7	3	4	6	*2*	*7*
Working on or preparing a home for predicted storm	Incidents	5	0	0	1	0	4	0	0	0	0	*0*	*0*
	Deaths	5	0	0	1	0	4	0	0	0	0	*0*	*0*
Provide power to a shed or garage that normally does not have electricity	Incidents	6	0	0	0	0	2	0	1	2	1	*0*	*0*
	Deaths	6	0	0	0	0	2	0	1	2	1	*0*	*0*
Other (previous fire in house, power shut off by owners, servicing power supply, or other usage)	Incidents	11	0	1	1	0	3	2	1	1	1	*1*	*0*
	Deaths	13	0	1	1	0	3	2	1	2	1	*2*	*0*
Unknown why electricity off	Incidents	109	6	13	11	13	13	11	7	13	8	*9*	*5*
	Deaths	132	8	14	18	15	16	14	8	13	8	*12*	*6*

1 Number of deaths associated with generators includes incidents where other consumer products may also have been involved. Other products include one or more of the following: lawn mowers, portable LP-fueled heaters, portable kerosene-fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

For the 152 fatal incidents associated with a power outage due to weather or a problem with power distribution, Table 12 provides a further breakdown by year and cause of the power outage. Ninety-three percent of the fatal incidents associated with power outages were known to be due to specific weather conditions. Ice or snow storms are associated with the largest percentage of weather-related CO fatal incidents accounting for nearly half (49%) of the power outage-related incidents. Hurricanes and tropical storms are also associated with 28 percent of CO fatal incidents over the 11-year period from 2004 to 2014. More than half (31 of 61) of the generator-related CO fatalities that were hurricane- or tropical storm-related (20 of 42 fatal incidents) occurred in 2005.

Table 12: Number of Reported Non-Fire Carbon Monoxide Fatalities for Incidents Associated with Generators[1] by Reason for Power Outage, 2004–*2014*

Reason for Power Outage		Total	2004	2005	2006	2007	2008	2009	2010	2011	2012	*2013*	*2014*
Total	**Incidents**	**152**	**7**	**37**	**11**	**15**	**19**	**10**	**5**	**19**	**15**	***11***	***3***
	Deaths	**211**	**11**	**53**	**17**	**23**	**26**	**17**	**6**	**27**	**16**	***12***	***3***
Ice or snow storm	Incidents	74	1	15	6	9	7	9	3	10	5	*8*	*1*
	Deaths	98	2	20	8	13	9	14	4	14	5	*8*	*1*
Hurricane or tropical storm	Incidents	42	5	20	1	0	6	0	0	3	7	*0*	*0*
	Deaths	61	8	31	1	0	8	0	0	5	8	*0*	*0*
Wind storm	Incidents	6	0	0	2	1	1	0	0	1	1	*0*	*0*
	Deaths	10	0	0	6	1	1	0	0	1	1	*0*	*0*
Thunderstorm or rainstorm	Incidents	10	0	1	2	1	1	0	2	2	0	*0*	*1*
	Deaths	12	0	1	2	1	2	0	2	3	0	*0*	*1*
Tornado	Incidents	3	0	0	0	0	2	0	0	1	0	*0*	*0*
	Deaths	5	0	0	0	0	3	0	0	2	0	*0*	*0*
Storm, unspecified	Incidents	7	0	0	0	2	1	0	0	1	2	*1*	*0*
	Deaths	9	0	0	0	4	1	0	0	1	2	*1*	*0*
Unknown or other reason for outage	Incidents	10	1	1	0	2	1	1	0	1	0	*2*	*1*
	Deaths	16	1	1	0	4	2	3	0	1	0	*3*	*1*

1 Number of deaths associated with generators includes incidents where other consumer products may also have been involved. Other products include one or more of the following: lawn mowers, portable LP-fueled heaters, portable kerosene-fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.

Note: Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U.S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

As shown in Table 8 above, 565 generator-related, non-fire CO fatalities occurred in a fixed-structure home. The category “fixed-structure home” is defined as a permanent, fixed-structure used as a residence, including: houses, mobile homes, apartments, townhouses, and structures attached to the house, such as an attached garage. Travel trailers, campers, and RVs are not included in this classification, nor are external structures at the home, such as detached garages or sheds.

Of these 565 generator-related deaths that occurred in a fixed-structure home, information was available for 474 deaths (84%) regarding the victim’s location in relation to the generator. One hundred and six of these 474 fatalities (22%) occurred in the same room or space as the generator.

The 565 deaths that occurred in a fixed-structure home were the result of 422 incidents (Table 13). These incidents were further classified by the specific location of the generator within the home. The category “Living Space (non-basement)” includes rooms reported as bedrooms, bathrooms, dens, living rooms, landings, home offices, rear rooms, enclosed porches, and converted garages. This category does not include attached garages or basements. The category “Outside the home” includes incidents where the generator was placed outside a home but near an open window, door, or vent of the home. Sixty-nine percent (290 of 422) of the CO fatal incidents at home locations occurred when a generator was placed inside the home, including the living space (148), a basement (98), closet (4), doorway (2), or inside the house, with no further information provided (38). Another 26 percent of the fatal incidents (108 of 422) occurred when the generator was placed in an attached garage, enclosed carport, or attached barn. Nearly half (49%) of the fatal incidents (206 of 422) occurred when the generator was placed in an attached structure (108) or in the basement or crawlspace (98).

Fifteen deaths from 11 incidents were associated with the use of a generator placed outside the home. Usually, this involved placing the generator too near an open window or vent. This category also includes an incident where a generator was running outside the home but inside a building (*e.g.*, outside an apartment but still inside the building).

Table 13: Non-Fire Carbon Monoxide Poisoning Deaths in the Fixed-Structure Home Location[1] by Location of the Generator,[2] 2004–*2014*

Generator Location		Total	2004	2005	2006	2007	2008	2009	2010	2011	2012	*2013*	*2014*
Total	**Incidents**	**422**	**28**	**55**	**40**	**44**	**52**	**35**	**29**	**54**	**35**	***32***	***18***
	Deaths	**565**	**38**	**70**	**57**	**58**	**71**	**52**	**35**	**76**	**40**	***43***	***25***
Living space (non-basement)	Incidents	148	12	17	12	15	20	17	14	17	9	*8*	*7*
	Deaths	200	18	23	17	19	27	23	14	24	13	*10*	*12*
Garage / enclosed carport / attached barn	Incidents	108	6	17	13	10	13	8	5	13	13	*8*	*2*
	Deaths	140	8	18	20	17	15	11	6	18	13	*12*	*2*
Basement / crawlspace	Incidents	98	6	12	9	9	11	6	5	16	6	*11*	*7*
	Deaths	139	7	15	11	12	20	11	8	25	6	*15*	*9*
Inside house, no further information reported	Incidents	37	1	2	4	5	5	3	4	4	4	*3*	*2*
	Deaths	42	1	2	4	5	5	6	6	4	4	*3*	*2*
Closet in home	Incidents	4	0	1	1	1	0	1	0	0	0	*0*	*0*
	Deaths	11	0	6	3	1	0	1	0	0	0	*0*	*0*
Outside the home	Incidents	12	1	4	0	3	0	0	1	1	1	*1*	*0*
	Deaths	16	2	4	0	3	0	0	1	2	2	*2*	*0*
Doorway to home	Incidents	2	1	0	1	0	0	0	0	0	0	*0*	*0*
	Deaths	3	1	0	2	0	0	0	0	0	0	*0*	*0*
Unknown location, but at home	Incidents	13	1	2	0	1	3	0	0	3	2	*1*	*0*
	Deaths	14	1	2	0	1	4	0	0	3	2	*1*	*0*

1 This refers to a fixed-structure used as a residence, including houses, mobile homes, apartments, townhouses, and structures attached to the house, such as an attached garage. Not included here are incidents that occurred in detached structures at home locations (*e.g.*, detached garages, sheds) or at non-fixed location residences (*e.g.*, travel trailers, houseboats).

2 Number of deaths associated with generators includes incidents where other consumer products may also have been involved. Other products include one or more of the following: lawn mowers, portable LP-fueled heaters, portable kerosene-fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.

Notes: Totals may not add to 100 percent due to rounding.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Table 14 presents a summary of non-fire CO fatalities that occurred in the fixed-structure home characterized by ventilation status. Many of the incidents with generator-associated fatalities in the home (193 of the 422 incidents) did not contain information about the ventilation of the generator. In 152 of the 229 incidents (66%), accounting for 213 deaths, in which information on ventilation of the generator was available, there was no ventilation being provided when the incident occurred. In five of these fatal incidents (seven deaths), a window or door was open during some period of use but later closed. There were 77 incidents associated with generators in which it was reported that some type of ventilation was attempted. Of these 77 incidents, 54 were associated with incidents in which it was reported that there was an open or partially open window, door, garage door, or a combination of these, accounting for 67 CO deaths. As noted here and in Table 13, eleven incidents (15 deaths) were associated with generators that were placed outside the home near open windows, doors, or vents, where carbon monoxide entered the home. In twelve incidents (23 deaths), consumers actively attempted to vent generator exhaust outside through a window or door, or through the use of a fan, but these measures failed to adequately vent the CO from the victims' location. An additional fatality occurred when a victim placed a generator outside of an apartment in the unventilated hallway of a building.

Table 14: Non-Fire CO Fatalities in the Fixed-Structure Home[1] Reported to CPSC Staff and Associated with Generators[2] Categorized by Status of Ventilation, 2004–*2014*

Ventilation Status	Number of Incidents	Number of Deaths	Percentage of Deaths	Percentage of Deaths Where Ventilation is Known
Non-fire CO fatalities in the home	**422**	**565**	**100%**	**100%**
Some ventilation attempted	**77**	**104**	**18%**	**33%**
Open window(s), open door(s), an open garage door, or a combination of these	53	65	12%	21%
Actively trying to vent either by fans or by directing exhaust out a window or door	12	23	4%	7%
Placed outside, but near a window, door or A/C unit[3]	11	15	2%	4%
Placed outside apartment, but inside building	1	1	< 1%	< 1%
No ventilation	**152**	**213**	**38%**	**67%**
Open windows or doors closed sometime later	5	7	1%	2%
No ventilation attempted	147	206	36%	65%
Unknown ventilation	**193**	**248**	**44%**	**-**

1 This refers to a fixed-location structure used as a residence, including houses, mobile homes, apartments, and townhouses, as well as structures attached to the house, such as an attached garage. Not included here are incidents that occurred in detached structures at home locations (*e.g.*, detached garages and sheds) or at non-fixed location residences (*e.g.*, travel trailers and houseboats).

2 Number of deaths associated with generators includes incidents where other consumer products may also have been involved. Other products include one or more of the following: lawn mowers, portable LP fueled heaters, portable kerosene fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.

3 One death occurred when a generator was placed outside an apartment in an unvented hallway and one occurred when the generator was placed outside a trailer that was located inside an enclosed, unvented garage.

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

Table 15 presents a summary of the fatal CO incidents and fatalities characterized by the size of the home in which the fatalities occurred. For 40 percent (169 of 422) of the fatal incidents and 39 percent of the deaths (220 of 565), CPSC staff could not ascertain the size of the home. Home size information was available for 253 of 422 fatal incidents (345 of the 565 deaths). Information regarding the size of the home reported in this document is from one of two sources. The first source is the CPSC IDIs, which include information gathered from police, fire department, or public records. The second source is from Internet databases of real estate information, which contain public record data. In most cases, Internet databases agree on the size of the home because both databases are based on public records from the county, state, or municipality.

Fifty-nine percent (150 of 253) of the reported fatal incidents (204 of 345 CO fatalities) associated with generators that occurred in the home, where the size of the structure was known, occurred in homes that were less than 1,500 square feet, and 85 percent (216 of 253) of the reported incidents and 86 percent of the deaths (295 of 345) occurred in houses that were less than 2,000 square feet. This portion of the fatal incident location includes most incidents that occurred in apartments and mobile homes. Fatal incidents that occurred in a detached structure are not included in this figure. The median home size involved in fatal generator-related CO poisoning deaths, where home size information is known, was 1,328 square feet. As a point of reference, according to the U.S. Census Bureau's, *American Housing Survey for the United States: 2011*, the median housing unit as of 2010 was 1,800 square feet. Comparing the percentages of fatal incidents by home size to the U.S. Census figures, it appears that the fatal CO incidents are skewed toward smaller homes. Whether this is due to economic reasons, or because smaller-volume structures are filled more quickly by deadly carbon monoxide, is unclear. Perhaps it is a combination of the two factors, or some yet-unidentified reason.

Table 15: Non-Fire CO Fatalities in the Fixed-Structure Home[1] Reported to CPSC Staff and Associated with Generators[2] Categorized by Size of Home, 2004–*2014*

Home Size (in sq. feet)[3]	Number of Incidents	Number of Deaths	Percentage of Incidents	Percentage of Incidents Where Home Size is Known	Estimated Percentage of U.S. Occupied Housing Units (2010)[4]
Total	**422**	**565**	**100%**	**100%**	**100%**
Under 500	2	3	< 1%	1%	1%
500–999	56	76	13%	22%	9%
1,000–1,499	89	125	21%	35%	24%
1,500–1,999	66	91	16%	26%	25%
2,000–2,499	21	32	5%	8%	18%
2,500–2,999	8	9	2%	3%	9%
3,000 or Larger	8	9	2%	3%	14%
Unknown	169	220	40%	-	-

1 This refers to a fixed-location structure used as a residence, including houses, mobile homes, apartments, and townhouses and structures attached to the house, such as an attached garage. Not included here are incidents that occurred in detached structures at home locations (*e.g*., detached garages and sheds) or at non-fixed location residences (*e.g*., travel trailers and houseboats).
2 Number of deaths associated with generators includes incidents where other consumer products may also have been involved. Other products include one or more of the following: lawn mowers, portable LP-fueled heaters, portable kerosene-fueled heaters, camp stoves, lanterns, outdoor cookers, furnaces, and wood stoves.
3 Home size based on CPSC IDIs or from various Internet real estate databases.
4 The 2011 housing unit figures represent an approximate mid-point year.
Note: Totals may not add to 100 percent due to rounding.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.
U.S. Census Bureau, American Housing Survey for the United States: 2011.

Conclusions

Between 2005 and 2014, 864 non-fire CO poisoning deaths from 673 incidents were reported to CPSC staff that was associated with EDTs. The majority of these deaths (751) involved generators or both a generator and another consumer product. OEDTs, including garden tractors, lawn mowers, power washers or sprayers, and others, were associated with a much smaller number of deaths. The majority of fatal incidents reported to CPSC staff involved a single fatality. Most reported deaths occurred while an individual was at home.

Victims age 25 years and older accounted for about 83 percent of the non-fire CO poisoning deaths that were associated with generators reported to CPSC staff, and the majority (75 percent) of the victims were male. Seventy-five percent of the reported deaths associated with generators occurred at fixed-structure home locations. Sixty-nine percent of the fatal incidents known to have occurred in the home and involving generators occurred when a generator was placed in the living area or basement of the home. Another 26 percent occurred when a generator was used inside an attached garage or shed.

Generators were often used as alternative sources of electricity due to temporary power outages or as power sources for temporary shelters. Power outages, most commonly weather-related, were the single most common reason for generator usage that resulted in a non-fire CO fatality, accounting for at least 211 of the 751 fatalities (28 percent). Generators were often used with little or no ventilation. In only about nine percent of the fatalities was it known that there was a CO alarm installed—and many of these were inoperable at the time of the fatal incident. Conclusions about why consumers used generators indoors or determinations about whether users were aware of the potential non-fire CO-poisoning hazard were not possible to make with the available information.

Victims age 25 years and older accounted for 99 percent of the non-fire CO poisoning deaths reported to CPSC staff that were associated with OEDTs. Males accounted for 96 percent of the deaths associated with OEDTs. Deaths associated with garden tractors and lawn mowers were often associated with an individual repairing or working on the product in an enclosed space.

Visit the CPSC's Carbon Monoxide Information Center— http://www.cpsc.gov/en/Safety-Education/Safety-Education-Centers/Carbon-Monoxide-Information-Center/—for the latest information on recalls, safety tips, safety standards, CO alarms, and downloadable injury prevention materials.

References

Hnatov, Matthew V. *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2013*. U.S. Consumer Product Safety Commission. June 2014. <https://www.cpsc.gov//Global/Research-and-Statistics/Technical-Reports/Home/Portable-Generators/GeneratorsandOEDTFatalities-2014-FINAL.pdf>

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University of Washington, WWAMI Rural Health Research Center. Rural-Urban Commuting Area Codes (RUCAs) <http://depts.washington.edu/uwruca/>

Appendix A: Epidemiology Data Retrieval Specifics

The queries below were submitted through EpiSearch, CPSC staff's epidemiology data access application, accessing data from The Consumer Product Safety Commission Risk Management System ("CPSRMS"). Query results were reviewed to include only non-fire carbon monoxide poisoning fatality incidents related to EDTs and to exclude duplicates and out-of-scope cases, which were cases that were intentional in nature or occurred during a work-related activity.

For this report, a fatal incident was deemed in scope if none of the following criteria were violated:

- Carbon monoxide was the primary or contributing factor in the fatality.
- The carbon monoxide was not fire-related.
- The source of the CO was an EDT, or an EDT used in conjunction with another non-fire-related CO generating source.
- The fatal injury was unintentional in nature.
- The EDT involved was a consumer product.
- The incident was not work-related.

Date of Queries: 05/21/2015

Incident Dates: 1/1/04-12/31/14
Product Codes: 113, 606, 800-899, 1062, 1400-1464, 3285-3287
Narrative/Text Contains: "CARB" or "MONO"

Appendix B: Carboxyhemoglobin Levels Present in CO Fatalities

Carboxyhemoglobin (COHb) is a complex of carbon monoxide and hemoglobin that forms in red blood cells when carbon monoxide is inhaled. COHb poisoning can be fatal in large doses as it hinders delivery of oxygen to the body. COHb data are helpful in estimating the concentration of CO in the product exhaust and the lethality of the product, which affects the speed of onset of harm. This information may be used by CPSC staff to assist in determining the best way to address the CO hazard presented by generators and other EDTs.

In healthy adults, a COHb level of 40–50 percent in the blood approximately correlates with symptoms of confusion, unconsciousness, coma, and possible death; a level of 50–70 percent approximately correlates with symptoms of coma, brain damage, seizure, and death; and a level greater than 70 percent is typically fatal.[5] COHb levels were available for 481 of the 864 fatalities (56% of the CO fatalities). Table B-1 shows the frequency of reports by COHb level categories. Percentages in the table are the category proportions of reported COHb levels. Eighty percent (385 of the 481) of fatalities had reported COHb levels of 50 percent or greater.

Table B-1: Carboxyhemoglobin Levels Associated with Engine-Driven Tools Non-Fire Carbon Monoxide Poisoning Deaths, 2004–*2014*[1]

COHb Level	All Engine-Driven Tools (EDTs)		Generators		Other Engine-Driven Tools (OEDTs)	
Total	**864**	**-**	**751**	**-**	**113**	**-**
Reported Levels	**481**	**100%**	**419**	**100%**	**62**	**100%**
Less than 30%	24	5%	22	5%	2	3%
30–39.9%	29	6%	25	6%	4	6%
40–49.9%	43	9%	35	8%	8	13%
50–59.9%	102	21%	93	22%	9	15%
60–69.9%	134	28%	118	28%	16	26%
70–79.9%	115	24%	97	23%	18	29%
80–89.9%	29	6%	24	6%	5	8%
90–99.9%	5	1%	5	1%	0	0%
Not reported	383	-	332	-	51	-

1 Percentages shown are the percentage of reported COHb levels per category.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.
Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2015.

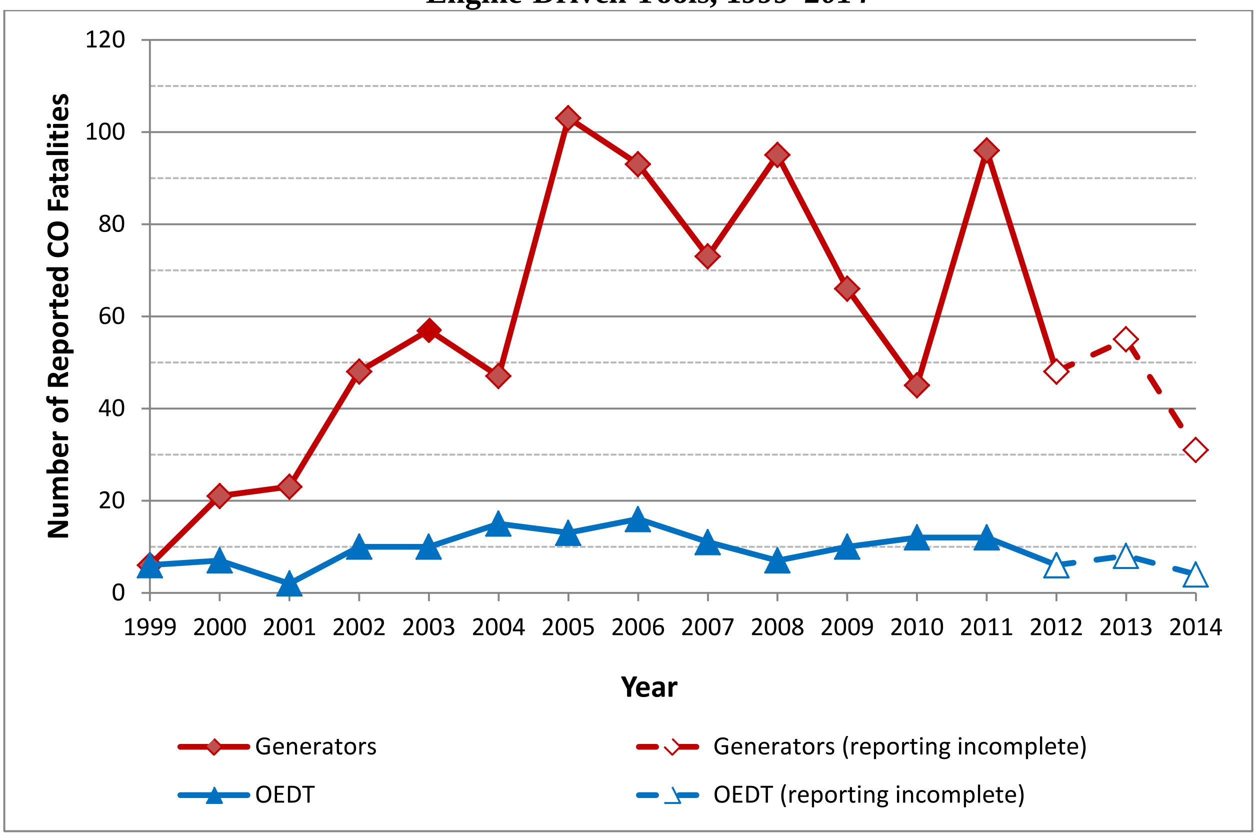
[5] Inkster S.E. *Health hazard assessment of CO poisoning associated with emissions from a portable, 5.5 Kilowatt, gasoline-powered generator*. Washington, D.C.: U.S. Consumer Product Safety Commission. 2004.

Appendix C: Historical Data

Figure 1 illustrates the trend in the number of non-fire CO fatalities associated with the use of generators and other EDTs from 1999 to 2014. The number of generator-related fatalities increased at a steady rate from six in 1999 to 103 in 2005. After which, the number of yearly fatalities has oscillated between 40 and 100 fatalities per year (excluding 2014, which is, however, considered to be incomplete at the time of this report). It should be noted that, due to reporting delays, fatality counts reported in future annual reports for the most recent years are likely to increase. Over the last seven annual reports, including this one, the most recent year's counts have increased by about an average of 28 percent from the previous report. Two years back, the average increase, report to report, is about an additional 9 percent.

The number of CO fatalities associated with the use of non-generators EDTs has been relatively steady over the period 1999 through 2014.

Figure 1: Number of Reported Non-Fire Carbon Monoxide Fatalities Associated with Engine-Driven Tools, 1999–*2014*



TAB B

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: September 30, 2016

TO : Janet Buyer, Project Manager
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

THROUGH: Kathleen Stralka, Associate Executive Director
Directorate for Epidemiology

Stephen Hanway, Director
Division of Hazard Analysis

FROM : Matthew Hnatov
Mathematical Statistician

SUBJECT : Generators Involved in Fatal Incidents, by Generator Category, 2004-2014

Staff has previously published a report that summarizes CO incidents associated with engine-driven generators and other engine-driven tools. Staff is using this report to provide the base number of incidents for the rulemaking. As of May 21, 2015,[a] CPSC databases contained reports of at least 751 generator-related non-fire consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014.[1] Staff's analyses for the notice of proposed rulemaking (NPR) do not include the data for years 2013 and 2014, which amounted to 85 deaths in 64 incidents. Data collection is ongoing and the death count most likely will increase for these years in future reports, and thus, are considered incomplete.

Also excluded from staffs' analyses for the NPR are five deaths in three incidents that occurred in 2011, which were known to involve stationary generators and two deaths in two incidents that occurred in 2005 and 2007, which were known to involve generators that were part of welding machines. Stationary generators and generators that are part of welding machines are excluded because they are not within the scope of the draft proposed rule. They are excluded because stationary generators are not portable and generators that are part of welding machines are considered atypical consumer products. Staff notes that these exclusions are consistent with the two U.S. voluntary standards for portable generators,[b] and both exclude these machines from their scopes. Therefore, staff's analyses for the rulemaking are based on 659 deaths in 493 incidents that occurred from 2004 through 2012.

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[a] The report this data refers to is an annual staff report and staff typically begins analysis of the data entered in the CPSC's databases in the third quarter of each fiscal year; in this case, the date was May 21, 2015.

[b] Underwriters Laboratories, Inc. UL 2201 *Safety Standard for Portable Generator Assemblies* and Portable Generator Manufacturers Association ANSI/PGMA G300-2015 *Safety and Performance of Portable Generators*.

Table 1 provides a summary of the generators, broken down by category, according to the engine and year of incident, and based upon staff's review of the in-depth investigation report (IDI).[1,2] Because almost all the generators involved in these incidents were gasoline fueled,[c] staff categorized the generators according to the U.S. Environmental Protection Agency's (EPA) small spark ignition (SI) engine classifications and also the number of cylinders that the engine has. EPA broadly categorizes small SI engines as either non-handheld or handheld, and within each of those categories, distinguishes them into different classes based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cubic centimeters (cc) up to 225 cc, and Class II having displacement at or above 225 cc, but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc.

When the IDI did not report the generator's engine displacement, or it was not obtainable from other information in the IDI, staff considered the reported wattage of the generator, if that was available in the IDI. Based on an online review of generators, staff classified generators with a reported wattage of 3.5 kW and larger as being powered by a Class II engine and those less than 3.5 kW as powered by either a handheld or a Class I engine. To distinguish the handheld powered generators from the Class I powered generators when there was no information to ascertain the engine displacement, generators with wattage 2 kW and larger, up to 3.5 kW, were considered to have a Class I engine. There was only one generator with wattage below 2kW in which the engine displacement could not be ascertained. That was a 1,000-watt generator, which staff classified as a handheld generator because staff's online review of generators nominally in this size showed them being powered by handheld engines. Staff chose to divide the broad size range of the Class II engine-powered generators into two smaller categories by considering whether the engine had a single cylinder or two cylinders (also called twin cylinders). To distinguish the single cylinder Class II engines from the twin cylinder Class II engines, staff found from looking at the EPA's exhaust emission certification database[3] that twin cylinder Class II engines largely have a maximum engine power of nominally 12 kW and higher. From an online review of manufacturers' generator specifications, staff found that generators with engines having power equal to or greater than 12 kW typically have a rated power of 9kW and higher. Therefore, generators with rated power of 3.5 kW up to 9 kW were considered powered by a single-cylinder Class II engine, and those 9 kW and greater were considered powered by a twin-cylinder Class II engine when there was no information to ascertain the engine displacement and number of cylinders.

[c] Most of the generators that were associated with fatal CO poisoning were gasoline-fueled. In 52 of the 562 incidents, the fuel type could not be ascertained. Of the 510 cases where the fuel type used in the generator was known, 99 percent (506 of 510) were gasoline-fueled generators. Of the remaining incidents, three involved propane-fueled generators, and the other incident involved a diesel-fueled generator.

Table 1. Generators Involved in Fatal Incidents, by Engine Category, 2004-2014

	Handheld		Class I		Class II, Single Cylinder		Class II, Twin Cylinder		Unknown		Total	
Year	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	**2**	**2**	**87**	**126**	**160**	**233**	**3**	**7**	**314**	**397**	**562**	**751**
2004	0	0	5	5	14	21	0	0	16	21	35	47
2005	1	1	10	13	23	33			46[#]	56[#]	80[#]	103[#]
2006			13	18	21	34			29	41	63	93
2007			9	13	16	22	1[#]	1[#]	31	36	57[#]	72[#]
2008			12	17	22	29	1	1	35	48	70	95
2009			5	8	12	19			28	39	45	66
2010	1	1	6	8	13	15			17	22	37	46
2011			13	22	15[+]	24[+]	1	5	40[+]	45[+]	69[+]	96[+]
2012			7	10	6	7			29	31	42	48
2013			8	12	17	21			18	22	42[#]	54
2014			2	3	5	10	1[#]	1[#]	26	30	22	31

\# These counts include an incident with one fatality that involved a generator/welder.
+ In 2011, three incidents involved stationary generators: one incident classified as a Class II, Single Cylinder (two deaths), and two incidents of unknown classification (one involving two deaths and the other involving a single death).

In the majority of cases (55 percent), CPSC staff was unable to obtain sufficient information to categorize the involved generator. In the incidents where engine classification could be determined, slightly more than one-third (35 percent) involved Class I engine-powered generators; and slightly less than two-thirds (63 percent) involved single-cylinder Class II engine-powered generators. Handheld powered generators were known to be involved in two incidents (two fatalities) during this time, while twin-cylinder Class II engine-powered generators were known to be involved in three incidents and seven fatalities.

References

[1] Hnatov, Matthew, *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014*, U.S. Consumer Product Safety Commission, Bethesda, MD, June 2015. (available online at: https://www.cpsc.gov/s3fs-public/pdfs/GeneratorsandOEDTFatalities2015.pdf and in www.regulations.gov in Docket Identification CPSC-2006-0057-0026).

[2] Hnatov, Matthew, *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2005-2015*, U.S. Consumer Product Safety Commission, Bethesda, MD, June 2016. (available online at: https://www.cpsc.gov/s3fs-public/Generators%20and%20OEDT%20Fatalities%202005-2015.pdf and in www.regulations.gov in Docket Identification CPSC-2006-0057-0029).

[3] www3.epa.gov/otaq/certdata.htm#smallsi.

TAB C

DATE: August 15, 2016

TO: Janet L. Buyer, Project Manager, Portable Generators Project, Division of Mechanical and Combustion Engineering, Directorate for Engineering Sciences

THROUGH: Joel R. Recht, Ph.D., Associate Executive Director, Directorate for Engineering Sciences

Rana Balci-Sinha, Ph.D., Director, Division of Human Factors, Directorate for Engineering Sciences

FROM: Timothy P. Smith, Senior Human Factors Engineer, Division of Human Factors, Directorate for Engineering Sciences

SUBJECT: Consumer Responses to Reduced Carbon Monoxide Emissions from Portable-Generator Engines and to Carbon Monoxide Poisoning Symptoms

BACKGROUND

In 2006, staff of the U.S. Consumer Product Safety Commission (CPSC) prepared a briefing package for an advance notice of proposed rulemaking (ANPR) that presented strategies for reducing carbon monoxide (CO) poisoning deaths involving portable generators (Buyer, 2006). The Commission published the ANPR in the *Federal Register* on December 12, 2006.

In the briefing package, staff concluded that the most reliable way to limit consumer exposure to harmful CO levels from portable generators would be to reduce or limit the amount of CO produced by the generator engine. However, some people, including one of the 10 public commenters received on the ANPR (CC 07-3-6), have expressed concern that mandatory performance requirements on CO emissions could create a false sense of security among consumers who currently operate generators outdoors and prompt them to operate these “safer” low-CO emission generators indoors. Thus, staff of CPSC’s Directorate for Engineering Sciences, Division of Human Factors (ESHF), has been asked to assess the likelihood of behavioral adaptations of this sort in response to reduced CO emissions.

On September 14, 2012, CPSC released a staff report on a technology development and demonstration program focused on developing a portable generator powered by an engine with a substantially reduced CO emission rate. The staff report, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*, was posted for review and public comment in the Voluntary Standards section of the CPSC website. CPSC received 13 comments.

Reduced CO emissions, and therefore, reduced CO exposure, would provide those exposed to CO with an opportunity to recognize developing CO-poisoning symptoms and to remove themselves from the environment. However, one of the public comments received on the staff report stated that staff did not provide data to support the contention that slowing the onset of CO poisoning symptoms will result in consumers removing themselves from the CO-containing environment. Thus, this memorandum also considers how consumers who operate a low-CO emission generator in an improper location might respond if they begin to experience slow-onset CO poisoning symptoms.

DISCUSSION

INDOOR USE IN RESPONSE TO REDUCED CO EMISSIONS

One argument against requiring reduced CO emissions for portable generators is that such a requirement might prompt consumers to operate portable generators indoors. The available incident data show that some consumers already operate generators indoors (*cf.* Hnatov, 2011). Thus, the question of whether reduced emissions would lead to indoor use is not relevant to this group of consumers. Rather, the pertinent question is to what extent people who currently would *not* operate generators indoors might choose to do so in response to reduced CO emissions.

Any behavioral adaptation in response to a safety intervention requires the affected people to be aware of the implemented intervention in some way. Because CO is undetectable to human senses,[1] reducing CO emissions from portable generator engines is one technical approach to reducing CO exposure that seems to have the potential to avoid behavioral adaptations entirely, if consumers are uninformed about these reductions. Packaging labels, advertisements, and other forms of notification or publicity about reduced CO emissions introduces the possibility of consumers changing the way they use the product. Thus, before divulging information to consumers about reduced CO emissions, one must consider carefully what safety benefits would be realized by providing this information. The remaining discussion presumes that the proposed regulation is in effect and consumers are aware that their generator produces reduced CO emissions.

INJURY LIKELIHOOD AND PERCEIVED SUSCEPTIBILITY

Research has found that risk or hazard perceptions associated with consumer products are driven strongly by the severity level of the expected injury (Riley, 2006; Vredenburgh & Zackowitz, 2006). The potential for death will remain when generators are used indoors, even with reduced CO emissions, and portable generators will continue to carry warnings alerting people to this danger.[2] However, research also indicates that the perceived likelihood of injury plays a greater role in hazard perceptions once the severity of injury reaches a very high level or threshold, such as death (Riley, 2006; see also Slovic, 1987), and several models of persuasion cite perceived

[1] Except indirectly through the flu-like symptoms, such as headaches, nausea, and vomiting that can accompany CO exposure.
[2] Staff does not propose any changes to the mandatory warning label currently required in 16 C.F.R. part 1407.

susceptibility to the hazard as a significant determinant of behavioral compliance (*cf.* Cameron & DeJoy, 2006; Kalsher & Williams, 2006; Stiff & Mongeau, 2003).

Consumer perceptions of injury likelihood and susceptibility most likely would change with the knowledge that CO emissions have been reduced. Consumers are likely to believe that a generator with this trait is less likely to lead to injury or death, and this could lead some consumers to use such a generator within an enclosed or partially enclosed space, especially if use is expected to be brief.

Confirmation Bias and Anchoring

People tend to seek out, focus on, and emphasize information that confirms their hypothesis about the current state of affairs, and to dismiss or ignore disconfirming evidence and alternative hypotheses, even after such rejections are no longer warranted (Lehto & Nah, 2006; Wickens & Hollands, 2000). This tendency, known as confirmation bias, suggests that consumers who already believe that the use of generators indoors is dangerous would be less likely than others to interpret safety improvements, such as reduced CO emissions for generator engines, as indicating that these products are now safe to use indoors. Moreover, these consumers are likely to be more skeptical of information presented to them about reduced CO emissions, especially considering the warnings against indoor use that will continue to accompany these generators. The confirmation bias also suggests that people who formerly did not believe that indoor use of a generator was especially hazardous, would view information about reduced CO emissions as further supporting their belief that there is little danger associated with such use. Even so, this information is unlikely to cause behavioral adaptation because these people are inclined to use a generator indoors in the first place.

These conclusions are consistent with people's tendency to generate estimates through a process of anchoring and adjustment, in which one starts with an initial estimate, and then adjusts that estimate based on new information, until they reach a final value (Tversky & Kahneman, 1974). Research consistently has found that the one's initial estimate acts as an "anchor" that has a major impact on the person's final value and causes this value to remain relatively close to the original estimate, even after being adjusted to account for new information (Hastie & Dawes, 2001). Thus, if a person views the risk associated with operating a generator indoors to be high, compelling evidence that suggests a contrary view, such as information about low CO emissions from the generator engine, may lower that person's perceived risk. However, that person's final estimate of risk should remain higher than someone who originally viewed the risk to be lower, and then was exposed to the same evidence. In sum, these findings suggest that consumers who operate generators outside because of the hazards associated with indoor use would be less likely than others to believe that generators with reduced CO emissions will be safe to use indoors.

Information Presentation Issues

The anchoring and adjustment process also suggests that people without a strong opinion about the safety of operating a portable generator indoors will be strongly influenced by the order in which relevant information is presented to them. Thus, people who encounter information about the dangers of using a generator indoors before receiving information about reduced CO emissions would be less likely to operate a generator indoors than people who encounter this information in the reverse order, despite both sets of people having been exposed to the exact same information. The prominence or salience of information about reduced CO emissions, therefore, impacts the extent to which people would believe that it is safe to operate a low-CO emission generator indoors, and de-emphasizing this information relative to information about the dangers of indoor use would be of utmost importance.

The phrasing or "framing" of information about reduced CO emissions also will influence consumers' judgments or perceptions of safety (*cf.* Slovic, 2000; see also Hastie & Dawes, 2001), but staff cannot assess consumers' perceptions or possible misinterpretations that might lead to unsafe behavior without specific language to review. Yet regardless of how this information is presented, research has shown that highly credible sources, determined largely by the perceived expertise and trustworthiness of the source, produce greater attitude and behavioral changes than less credible ones (Cox & Wogalter, 2006; Stiff & Mongeau, 2003). Because consumers are likely to view CPSC as a credible source on product safety issues (*cf.* Wogalter, Kalsher, & Rashid, 1999 as cited in Cox & Wogalter, 2006), extreme care must be taken with how CPSC communicates information to the public about reduced CO emissions. Information about safety improvements, without strong caveats about the continued dangers associated with indoor use, could be interpreted to mean that indoor use is now acceptable.

BEHAVIORAL ADAPTATION AND ITS IMPACT ON RISK

From the discussion above, one could reasonably conclude that reducing CO emissions and strongly advertising these reductions to the public might lead some consumers who currently operate a generator outdoors to operate a generator within a partially enclosed space. This possibility, however, does not necessarily negate the potential benefits of this safety intervention. For example, if a generator engine were engineered to emit less CO, some people might choose to operate the generator in an open garage rather than outdoors. Although such behavior is undesirable, this reduction in emissions still could result in a net decrease in the CO-poisoning risk to consumers, depending on the size of the reduction, the generator run time, the location of the people within the house, and the placement of the "improved" generator, relative to where an "unimproved" generator would have been placed. These variables make it difficult to quantify the ultimate effect that this safety intervention will have on risk. However, reducing CO emissions from generator engines has the added advantage of benefiting those people who do *not* adapt their behavior in response to this reduction in CO emissions, such as consumers who would tend to use a generator in the home or in an open garage, regardless of the generator's CO emission levels.

Furthermore, portable generators will continue to carry a warning against indoor use, regardless of any reductions in CO emissions, to meet performance requirements. Those people who are most likely to comply with the warning currently (people who use generators outside because of the risk of CO poisoning) are the people least likely to ignore the same warning on a generator with reduced CO emissions. Thus, the overall level of behavioral adaptation among generator users may be low.

CONSUMER RESPONSES TO CO-POISONING SYMPTOMS

SYMPTOM DETECTION

CO is invisible, silent, odorless, and tasteless. Thus, without a functioning and salient CO alarm that is near the consumer, the only likely way for consumers to detect the presence of CO directly would be through the symptoms that can accompany CO poisoning. Common symptoms of acute CO poisoning can include headaches, dizziness, nausea, cognitive impairment and confusion, and vomiting (Inkster, 2004). The ability to detect these symptoms depends on the alertness of the exposed individual. For example, a sleeping consumer might never experience or detect CO-poisoning symptoms.[3] Additionally, these symptoms are similar to those associated with influenza and similar illnesses; therefore, consumers who are already ill could experience CO-exposure symptoms but fail to distinguish them from their preexisting symptoms, until it is too late to respond effectively. This is discussed in more detail below.

INTERPRETATION AND DIAGNOSIS

CO-poisoning symptoms are not especially diagnostic; they do not point consumers to a single, unambiguous cause. The difficulty of successfully diagnosing CO poisoning is demonstrated by cases of misdiagnosis even among health professionals, such as emergency medical services and emergency department physicians (*cf.* Dolan, Haltom, Barrows, et al., 1987 as cited in Nikkanen & Skolnik, 2011). The symptoms of CO poisoning are easily attributed to, and commonly misdiagnosed as resulting from, influenza-like viral illnesses, food poisoning, or other maladies (Blumenthal, 2001; Dolan, 1985). People generally are excellent at seeking out patterns and tend to interpret data and evidence in light of their own experience, knowledge, and expectancies. Although consumers who previously have experienced CO poisoning might effectively recognize the symptoms, correctly deducing that the symptoms stem from CO exposure, rather than the flu or some other cause, may be challenging.

For example, consumers who are already ill most likely would attribute any new, noticeable symptoms they are experiencing to their current illness, rather than from CO poisoning. Even if healthy, many consumers would tend to assume that the flu or some other illness is the probable cause because: (1) such a hypothesis is likely to come to mind more readily than CO poisoning, or alternative hypotheses; and (2) the symptoms are highly representative of the symptoms of these illnesses, which consumers are more likely to have experienced before.[4] As discussed, consumers who have formulated a hypothesis about their current situation tend to seek out confirmatory evidence and tend to neglect or explain away evidence to the contrary. People's pattern-seeking tendencies, combined with the strong similarity between CO-poisoning symptoms and flu symptoms, are likely to lead consumers who lack detailed knowledge about CO to conclude that their symptoms are caused by the flu. Moreover, these consumers might

[3] Generator exhaust may contain other emissions that would be detectable through smell, but odors are not very effective at waking someone from sleep (Proctor & Proctor, 2006).

[4] People consider "available" hypotheses (those that readily come to mind) first, and tend to choose a hypothesis by evaluating the extent to which the cues that are relevant to the decision or diagnosis (in this case, the symptoms) are "representative" of that hypothesis, based on experience (*cf.* Wickens & Hollands, 2000).

cling to this belief tenaciously, despite other cues that suggest a different cause.[5] Consumers who do not have CO alarms in their homes, and who must rely upon CO-poisoning symptoms to diagnose and appropriately respond to the situation, may be less familiar with and knowledgeable about both CO and the symptoms associated with CO exposure, than consumers who do have CO alarms in their homes. If true, these consumers would be less likely than others to arrive at the correct diagnosis for their symptoms, and they are especially unlikely to even consider CO poisoning as a possibility.[6] Warning labels and other safety information associated with CO cannot reach all consumers. Thus, some percentage of consumers inevitably will lack the knowledge required to make the correct diagnosis.

In principle, the presence of other environmental cues that could be used to confirm the presence of CO would assist consumers in arriving at a proper diagnosis. However, CO offers few such cues. The most obvious cue would be a CO alarm sounding, but few fatal incidents associated with generators or other engine-driven tools occur near a functioning CO alarm.[7] Thus, most at-risk consumers are unlikely to have the benefit of this cue. One might expect that the sound of a running generator could guide a consumer who experiences CO-poisoning symptoms to the correct diagnosis by creating an association between the symptoms and the presence of the generator. Although this scenario initially seems plausible, given people's proficiency at seeking out patterns, the sound of a running generator may not be as strong a cue as one might think. People tend to habituate to familiar and stable stimuli, so that they pay less attention to these stimuli over time (Sternberg, Mio, & Mio, 2009). Accordingly, the sound of a generator starting might initially distract you, but the sound of the generator running will become less novel and noticeable over time. Additionally, the constant droning sound of the generator motor may lack the variation needed to recapture a consumer's attention after attention has been lost. These two factors combined make it likely that consumers will habituate to the sound of a running generator, which would limit the extent to which consumers can rely upon this cue to determine the possible cause of their symptoms. The smell of generator exhaust,[8] could also serve as a cue, but probably would be susceptible to similar habituation problems.

RESPONSE SELECTION

Even if they arrive at the correct conclusion about the cause of their symptoms, consumers still must select and perform an appropriate response to avoid possible death from CO poisoning. As described in CPSC Document #466, *Carbon Monoxide Questions and Answers*, CPSC recommends that consumers who are experiencing CO poisoning symptoms get outside to fresh

[5] For example, the presence of similar symptoms among others in the household, especially during the "flu season," may provide additional support for such a misdiagnosis, even though this detail also serves as a cue that CO poisoning might be the cause.

[6] Moreover, this lack of awareness may very well lead these consumers to operate a portable generator in an inappropriate location that could expose them to the CO hazard.

[7] In reviewing fatal non-fire CO incidents associated with engine-driven tools from 1999 through 2010, CPSC staff found that a CO alarm was present in 14 of the 232 fatal incidents in which the presence of a CO alarm was known (Hnatov, 2011). The alarm was known to be inoperable in 7 of these 14 incidents. In four of the remaining seven incidents, the CO alarm was known to have sounded; in two other incidents, the alarm failed to sound, and in the one remaining incident, it is unknown whether the alarm sounded.

[8] This is not to be confused with CO, which has no smell, in the exhaust.

air immediately. ESHF staff is not aware of any published research that shows how consumers actually respond to known CO exposures. However, other research suggests that consumers are likely to engage in behaviors that could delay or supplant escape from the CO-containing environment.

For example, smoke and CO alarms, like CO poisoning symptoms, serve as cues to inform people about the presence of a hazard. Research on people's responses to smoke alarms demonstrates that a person's initial response to an alarm sounding in the home is to investigate the cause of the alarm activation; if a fire is discovered, the common response is to attempt to fight the fire (Proulx, 2007). Thus, a probable response to recognizing that one's symptoms are caused by CO exposure from a portable generator would be for the consumer to locate and attempt to shut off the portable generator, rather than immediately escape the CO-containing environment.[9] Additional CO-fighting measures in which consumers might engage could include opening windows and doors in an attempt to ventilate the environment. Calling the fire department or 911 might be another common response because this response appears to be fairly common in house fires (Proulx, 2007).

It is unclear to what extent such behaviors are due to a lack of understanding by affected consumers about how they are supposed to respond, versus a deliberate choice by consumers because of competing motivational factors. Unlike a fire, in which consumers have some visual feedback to gauge whether efforts to fight it are likely to fail, CO does not provide clear feedback about its concentration in the environment. Without such information, consumers might not appreciate the level of hazard posed by the CO that is present, and they may assume that shutting off the source of CO is a reasonable and less "costly" alternative to escaping the environment, soliciting help from their neighbors, contacting emergency responders, and taking other actions that might be necessary to respond as safety advocates recommend. Attempting to shut off the CO source would put consumers in close proximity to the generator and result in greater exposure to potentially increased concentrations of CO. Additionally, if other people are in the CO-containing environment, offering assistance to others would most likely take precedence over immediate escape, even if, and perhaps especially if, consumers were well-informed about the dangers of CO to those who remain in the environment.

Given the likelihood that consumers will engage in active CO-fighting behaviors and other behaviors that will delay escape, and because of the physical and cognitive impairments that can occur with increasingly severe CO poisoning that can prevent affected consumers from escaping at all, reducing the rate of increase in CO levels in the environment is of utmost importance. Although performance requirements that reduce or limit CO emissions from portable generators are unlikely to prevent all deaths involving indoor generator use, such requirements should increase the chances of survival by providing consumers with more time to detect and correctly

[9] This behavior assumes that consumers are aware that a portable generator is the source of the CO. The process of self-diagnosis probably will result in consumers identifying the generator as the source, but it is possible that certain situations, such as incidents in which a consumer recognizes the symptoms as stemming from CO, but the generator is being used outside rather than indoors, might require the consumer to deduce the source of the CO. Such cases would result in additional delays before action is taken to mitigate exposure, and the cognitive impairments that can occur with increasingly severe CO poisoning might exacerbate such delays.

diagnose their symptoms, and likewise, allow them to escape or perform other actions that might reduce CO exposure.

Review of Incidents with Survivors

To validate ESHF staff's assessment of probable consumer responses to CO-poisoning symptoms, ESHF staff examined 67 in-depth investigations of generator-related incidents with at least one survivor from 2008 through October 1, 2014. Staff evaluated the information on survivors of generator-related CO-poisoning incidents to inform the extent to which consumers can successfully diagnose their symptoms to be from CO or the generator. In addition, staff used this information to help identify the types of responses that one might expect from consumers who correctly diagnose their symptoms. ESHF staff recognizes, however, that consumers who survive such incidents may be inherently more likely to successfully diagnose their symptoms or to respond in ways that would lead to survival.

Symptom Diagnosis

ESHF staff's review of the 67 investigation reports revealed that, in most (45) cases, none of the survivors provided a clear indication of whether they thought the generator was the cause of their symptoms. In another five incidents, the survivor apparently did not experience any symptoms. Of the 17 remaining incidents, 11 incidents included a survivor who correctly deduced, or appeared to correctly deduce, that CO or the generator was the cause of their symptoms, and 7 incidents included survivors who incorrectly diagnosed their symptoms or believed that the cause of their symptoms was something other than the generator.[10]

As staff discussed, the symptoms of CO poisoning are easily attributed to influenza or other illnesses. Thus, many consumers are likely to conclude that such an illness is the probable cause, unless they have prior experience with, or knowledge of CO poisoning, or consumers have a working CO alarm that confirms that CO is the source. Staff's review of the seven incidents involving consumers misdiagnosing their symptoms is generally consistent with staff's earlier assessment, because these consumers attributed their symptoms to illness or sickness (2 incidents), food poisoning (2 incidents), possible poisoning (1 incident), being overly tired (1 incident),[11] or some other unknown cause.[12] Furthermore, in one case, the surviving consumers initially misinterpreted their symptoms as tiredness. However, after a CO alarm began to sound, they concluded that CO was the likely source (see footnote 10). But for the working CO alarm, this incident may very well have remained a misdiagnosis.

[10] The total number of incorrect and correct diagnoses exceeds the total of 17 because, in one case (140221HCC1402), the survivors initially thought they were just very tired, but they changed their conclusion after their CO alarm sounded.
[11] This was the initial diagnosis of the one incident described in footnote 10.
[12] In the case involving an unknown cause (080918HNE3776), the consumer, when questioned, explicitly stated that he did not think the cause was CO. However, he did not state what he believed the cause to be.

Consumer Responses

Staff's review of the 11 cases in which one or more survivors correctly deduced the cause of their symptoms to be CO, or the generator, revealed that the survivors' responses generally were consistent with ESHF staff's earlier predictions. For example, CPSC recommends that consumers who are experiencing CO-poisoning symptoms immediately get outside to fresh air; but staff previously identified several likely consumer responses that could delay escape, such as calling the fire department or 9-1-1, attempting to locate and shut off the generator, and opening windows and doors in an attempt to ventilate the environment.

Consistent with these predictions, in only 1 of these 11 incidents did the surviving consumer attempt to exit the CO-containing environment immediately.[13] Moreover, in most of the remaining 10 cases, the surviving consumers did not appear to attempt to leave the CO-containing environment. Many of the consumer responses in the latter 10 incidents were very similar to those predicted by ESHF staff. For example:

- In seven incidents, consumers responded by calling 9-1-1, the fire department, or a relative for assistance.[14] In an additional two incidents, the consumer called someone for assistance before experiencing symptoms because they had already found other victims who were incapacitated or experiencing symptoms.[15]

- In four incidents, consumers shut off or asked others to shut off the generator.[16] In one of the four cases, the 9-1-1 operator instructed the consumer to perform this action.[17]

- In three incidents, consumers opened doors or windows in an attempt to ventilate the space or to bring in fresh air.[18] In one of the three cases, the 9-1-1 operator instructed the consumer to perform this action.[17]

In summary, these data support ESHF staff's prior conclusion that, even if consumers successfully conclude that CO or a generator is the source of their symptoms, many of these consumers are likely to engage in CO-fighting behaviors or other behaviors (*e.g.*, calling 9-1-1 or others for assistance) that will delay escape. The data also suggest that performing these behaviors may lead consumers to conclude that they do not need to escape the CO-containing environment. All of these findings support the need to limit or reduce CO emissions from portable generators.

[13] IDI 110711HCC2658.
[14] IDIs 080929HWE7762, 111214HCC3230, 121102HCC1133, 130116HCC2354, 130213HNE0001, 140108HCC2264, and 140221HCC1402.
[15] IDIs 080610HNE3486 and 130423HWE0002.
[16] IDIs 080929HWE7762, 121119HCC1214, 130213HNE0001, and 140108HCC2264.
[17] IDI 130213HNE0001.
[18] IDIs 080929HWE7762, 130213HNE0001, and 140108HCC2264.

ADDITIONAL FINDINGS

Although ESHF staff recognizes that consumers might fail to properly diagnose their symptoms and are likely to respond in ways that delay or prevent escape from the CO-containing environment, the available incident data also suggest that at least some of these consumer responses ultimately led to survival. For example, although the surviving consumers who correctly diagnosed their symptoms tended to respond in ways that delayed escape or that apparently led them to conclude that they did not need to escape, their responses almost always included calling 9-1-1, the fire department, or someone else for assistance. This action allowed first responders, relatives, and others to provide assistance and to help evacuate affected consumers from the CO-containing environment. Reduced CO emissions from portable generators arguably would provide first responders and others even more time to respond, or might remove CO-poisoned consumers from the environment even earlier, thereby reducing their overall CO exposure.

In addition, some surviving consumers who *failed* to diagnose their symptoms correctly still responded with behaviors that limited CO exposure. This suggests that reduced CO emissions would increase the window of time for consumers to respond and be removed from the CO-containing environment. For example, of the 56 incidents that did not include a consumer who correctly diagnosed his or her symptoms,[19] roughly one-third (18) apparently involved a surviving consumer contacting emergency personnel, such as by calling 9-1-1. In 9 of these 18 incidents, emergency personnel were contacted because the consumer found someone else in the environment unconscious or unresponsive, and in 7 of the 18 incidents, emergency personnel apparently were contacted because of the adverse symptoms experienced by the consumer.[20] In two additional cases, beyond the 18 incidents, the surviving consumers deliberately left the CO-containing environment because of their symptoms. Assuming that some fatal incidents are the result of consumers being overcome before they can respond appropriately to their symptoms, these data suggest that limiting or reducing CO emissions might allow time for consumers to experience CO-poisoning symptoms more slowly and respond in ways that lead to their survival, even if they do not understand what is causing their symptoms.

In many of the 56 incidents mentioned above, the specific actions taken by surviving consumers are unknown or unclear. This finding might be because of a lack of relevant information in the investigation report, or possibly because the consumer simply took no obvious action. Regardless, consumers in these cases typically survived because they were found by a family member, neighbor, or someone else, before the poisoning turned fatal. Although these incidents suggest, not surprisingly, that some consumers may fail to take action to get out of a CO-containing environment, the incidents also suggest that survival is still possible because CO-poisoned consumers might be found by others. Limiting or reducing CO emissions on portable generators most likely would increase the time window during which CO-poisoned consumers can be found and rescued.

[19] The 67 incidents reviewed by ESHF staff, minus the 11 incidents that included at least one consumer who correctly deduced the cause of their symptoms to be CO or the generator.
[20] In one incident (100415HCC1605), the consumer called 9-1-1 because of their symptoms *and* because someone else in the environment was unresponsive. This incident is represented in both counts.

Finally, ESHF staff notes that in 11 of the 67 total investigated incidents that were examined, the generator involved in the incident either definitely included or most likely[21] included the mandatory “DANGER” label for portable generators specified in 16 C.F.R part 1407. This label warns about the dangers associated with using a portable generator indoors, even if doors and windows are open, and the label instructs consumers to use generators outside and far from windows, doors, and vents. However, in all 11 incidents, the generator was located in an enclosed space. For example, in 7 of the 11 incidents, the generator was used in the basement; in 2 incidents, the generator was used in a crawl space; and in another 2 incidents, the generator was used elsewhere in the living space. Although ESHF staff believes that the mandatory labeling of portable generators may prevent some incidents of CO poisoning and death, these incidents confirm that labeling alone is not sufficient to address the hazard, and that performance requirements for portable generators are needed.

CONCLUSIONS

Once consumers become aware of newly implemented performance requirements or safety interventions for portable generators and understand that these changes are intended to reduce consumer exposure to CO, behavioral adaptations will always be possible. Nevertheless, consumers who currently operate generators outside are the people most likely to be aware of the hazards posed by operating a generator indoors and to consider such behavior to be risky. These consumers also are less likely than others to believe that safety improvements to generators would render generators safe to use indoors, especially given the continued presence of labeling warning of the dangers of indoor use. Lastly, behavioral adaptations to safer generators would not necessarily translate into an increase in CO poisoning risk. For example, even if consumers operate improved generators in a more confined or enclosed space than they would otherwise, the total amount of CO to which consumers would be exposed might still be lower than that delivered by current generators in a larger or more open space. These improved generators would also have the potential to reduce the incidence of CO poisoning and death among consumers who would be inclined to operate even current generators in an enclosed or partially enclosed space. The effect of reduced emissions in this situation might be analogous to the introduction of catalytic converters on automobile engines in 1975 to meet U.S. Environmental Protection Agency (EPA) emissions standards. This change yielded an approximate 76 percent decrease in the engines’ CO emission rate, which reduced unintended vehicle-related CO deaths about 81 percent in the years 1975 through 1996, compared to earlier years (Mott, Wolfe, Alverson, Macdonald, Bailey, Ball, Moorman, Somers, Mannino, & Redd, 2002).

Consumers who begin to suffer from the symptoms of CO poisoning are likely to have difficulty successfully diagnosing the symptoms as stemming from CO exposure, rather than food poisoning, the flu, or some other illness. These difficulties are demonstrated by cases of misdiagnosis among health professionals, such as emergency medical services and emergency department physicians. Moreover, even if consumers correctly diagnose their symptoms, their probable response will be to engage in active CO-fighting behaviors and other behaviors that will

[21] Based, for example, on the purchase date of the portable generator, relative to the effective date of the regulation (May 14, 2007).

delay escape. This finding is supported by the available incident data. Given this, and because the physical and cognitive impairments that can occur with increasingly severe CO poisoning can prevent affected consumers from escaping at all, reducing the rate of increase in CO levels in the environment is of utmost importance.

Moreover, the available incident data suggest that survival-relevant behaviors can occur, even when consumers do not understand the cause of their symptoms. In addition, the data suggest that increasing the time to consumer incapacitation increases the likelihood that consumers will have sufficient time to respond in appropriate ways or will be found by others. Although performance requirements that reduce or limit CO emissions from portable generators are unlikely to prevent all deaths involving indoor generator use, such requirements should increase the chances of survival, by providing consumers with more time to detect and correctly diagnose their symptoms, to escape or perform other actions that might reduce CO exposure, or to be found by others. The data additionally demonstrate that the mandatory "DANGER" label, alone, is not sufficient to address the hazard, and performance requirements, such as those described above, are needed.

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TAB D

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
BETHESDA, MD 20814

MEMORANDUM

Date: May 26, 2016

TO: Janet L. Buyer, Project Manager, Portable Generator Project
Division of Mechanical and Combustion Engineering (ESMC)
Directorate for Engineering Sciences (ES)

THROUGH: Joel Recht, Ph.D., Associate Executive Director for ES

Mark Kumagai, Division Director for ESMC

FROM: Han Lim, Mechanical Engineer, ESMC

SUBJECT: Engineering Staff Responses to CO-Sensing and Exhaust Ventilation-Related Public Comments on 2006 ANPR for Portable Generators; 2012 CPSC Staff Report, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator;* and related staff and contractor reports.

INTRODUCTION

In 2006, the U.S. Consumer Product Safety Commission (CPSC or Commission) published an advance notice of proposed rulemaking (ANPR) to initiate a rulemaking proceeding that could result in a mandatory performance standard for portable generators.[1] The *Federal Register* notice discussed a broad range of regulatory approaches that could be used to reduce portable generator-related deaths and injuries, especially those incidents related to carbon monoxide (CO) poisoning. The Commission invited public comment on the regulatory alternatives and any other approaches that could reduce portable generator-related deaths and injuries due to carbon monoxide poisoning, as well as other generator-related hazards, such as shock/electrocution, fire and burns. The Commission also invited interested persons to submit an existing standard to address the risk of injury described in the ANPR. The Commission received 10 public comments in response to the ANPR.[2] This summarizes the comments received on the ANPR, as well as staff responses to the engineering-related aspects of specific comments received on the ANPR,

[1] Federal Register, Volume 71, Number 238, December 12, 2006, Proposed Rules, U.S. Consumer Product Safety Commission. Portable Generators; Advance Notice of Proposed Rulemaking; Request for Comments and Information. Internet Source: https://www.cpsc.gov//PageFiles/95179/pganpr.pdf.
[2] The comment source documents are available on www.regulations.gov. Each set of comments can be searched by typing in the docket number in the search box.

particularly regarding CO sensing technologies to mitigate the CO hazards associated with portable generator use.

In addition, this memorandum provides staff's responses to similar comments received on two CPSC staff reports [(Buyer, 2012)[3], (Lee, 2006)[4]] and a National Institute of Standards and Technology (NIST) Technical Note (TN)[5], written for CPSC as part of an inter-agency agreement (Emmerich, 2013).

Comments on ANPR are in Docket Identification:

- CPSC-2006-0057-0007: ANPR Comments CC 07-3-1 through CC 07-3-10 - as of February-15-2007. (http://www.regulations.gov/document?D=CPSC-2006-0057-0007)

- CPSC-2006-0057-0004: Public Comments on CPSC Staff Report Technology Demonstration of Prototype Low Carbon Monoxide Emission Portable Generator - September-14-2012 - As of January-23-2013 (http://www.regulations.gov/document?D=CPSC-2006-0057-0004)

- CPSC-2006-0057-0006: Comments to CPSC on NIST Technical Note 1781 (http://www.regulations.gov/document?D=CPSC-2006-0057-0006)

Staff categorized the comments into common topics because many commenters provided similar or overlapping comments. The comments were grouped together according to the following topics:

- Generator-Mounted CO Sensing Shutoff Systems,
- Remotely-Located CO-Sensing Shutoff Systems, and
- Flexible Exhaust Pipe Extension.

The following sections present the public's comments and staff's responses.

ANPR COMMENTS ABOUT GENERATOR-MOUNTED CO-SENSING SHUTOFF SYSTEMS

[3] Buyer, Janet, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*, September 2012. (available online at: https://www.cpsc.gov/s3fs-public/129846%20portgen.pdf in docket identification CPSC-2006-0057-0002.)

[4] Lee, Arthur, *Demonstration of a Remote Carbon Monoxide Sensing Automatic Shut Off Device*, U.S. Consumer Product Safety Commission, Bethesda, MD, August 2006. (available one at http://www.cpsc.gov/PageFiles/113776/COaslpostvet2.pdf and in www.regulations.gov in docket identification CPSC-2006-0057-0015.)

[5] NIST TN 1781 Emmerich, Steven J., A. K. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), Feb 2013. (available online at: http://www.cpsc.gov/Global/Research-and-Statistics/Technical-Reports/Home/Portable-Generators/PortableGenerators041213.pdf and in www.regultations.gov in docket identification CPSC-2006-0057-0005.)

Comment: Table 1 summarizes comments submitted on the concept of shutoff systems using CO sensing technology. Three of the four commenters (#1, #9, #10) advocated for a generator-mounted system, and one advocated against it (#6). Two commenters (#6 and #7) advocated against a remote CO sensing shutoff system.

Table 1. Summary of Comments on Docket Identification CPSC-2006-0057-0007 Referring to Use of CO Sensor Technology

Comment number	Comment Source	Comment
1	Kenneth Frank	Commenter recommended the use of residential CO alarm technology.
6	David P. Murray WILLKIE FARR & GALLAGHER Counsel for Yamaha Motor Corporation Michael A. Brown LLP BROWN & GIDDING Counsel for U. S. A. Counsel for American Honda Motor Co., Inc. Patricia M. Hanz BRIGGS & STRATTON CORPORATION Counsel for Briggs & Stratton Corporation	Commenters did not recommend the use of residential CO alarm technology. Commenters believed CO sensing technology near a generator may impair its operation, causing users to disconnect the sensors to ensure a steady source of electricity. Commenters also noted that CO sensors require routine maintenance, and their capabilities can degrade with time and during extended periods of inactivity, adding that it may be unreasonable to expect consumers to regularly check and maintain the CO sensing equipment, particularly when the generator is not even being used. Commenters believe that a CO alarm incorporated into a generator may create a false sense of security, leading consumers to believe that no further precautions are necessary to avoid exposure to CO associated with portable generator use. Commenters expressed additional concerns with remote CO detection/shut-off system for portable generators.
7	Nick Moore Product Compliance Engineer Briggs & Stratton Corporation	Commenter expressed numerous concerns with remote CO detection/shut-off system for portable generators.
9	Albert Donnay, MHS Environmental Health Engineer, Toxicologist and Certified CO Analyst	Commenter recommended a CO sensor that is used to activate ventilation systems in parking garages can also be used for turning off the generator when it senses 35 ppm CO. To ensure the consumer replaces worn or depleted sensors every 2-3 years, the commenter recommends that the Generator is cannot start (interlocked) after 2-3 years or until the user replaces the sensor. The commenter is also recommending requiring a tamper proof mechanism to prevent operation if the user disables the system Commenter also recommended CO sensors that can reportedly analyze the air in the passenger compartment of vehicles and can interlock the ignition if CO is detected.
10	Donald L. Mays, Senior Director Product Safety and Consumer Sciences Consumers Union Peter Sawchuk, Program Leader Outdoor Power Equipment Consumers Union Janell Mayo Duncan, Senior Counsel Consumers Union Rachel Weintraub Direct of Product Safety, Senior Counsel Consumer Federation of America	Commenters recommended the use of residential CO alarm technology.

Response: Staff is also concerned that using CO sensing technology near a portable generator may impair the sensor operation or trigger nuisance shutoffs, causing users to disconnect the sensors. Staff agrees that it is unreasonable to expect consumers to check and maintain CO sensing equipment regularly, particularly when a generator is not being used. Early in the portable generator project, CPSC staff investigated one version of the concept of an on-board CO sensing shutoff system. The investigation and its findings are documented in the staff report, *Phase 2 Test Report: Portable Generator Equipped with a Safety Shutoff Device* (Brown, 2013)[6]. The goals of the investigation were to: (1) determine if a CO sensor/alarm output signal from commercially available residential CO alarms (meeting the requirements in UL 2034 *Single and Multiple Carbon Monoxide Alarms*), when retrofitted with circuitry connected to the generator, could trigger a shutoff device installed on a portable generator when the CO alarm activated; and (2) measure CO concentrations around the generator when operated in multiple environments to assess CO migration and levels that might occur under several scenarios. Test environments examined included outdoors, in a two-sided structure, as well as both inside and under a temporary modular storage (TMS) building.

In that investigation, staff found that when the generator was operated inside the TMS building, the CO migrated and accumulated on the far side of the room more quickly than near the generator. The CO alarms on the generator never activated before those located elsewhere in the space activated, with the time difference generally ranging from 5 to 10 minutes. In some tests, CO levels in some parts of the room reached up to 1,000 ppm before the CO alarm on the generator activated and shut off the generator. When the generator was operated in outdoors in a wide-open area with a light breeze blowing, CO concentrations ranging up to 340 ppm were measured in the immediate vicinity of the generator. Although this did not activate the CO alarms mounted on the generator to shut it off, it is reasonable to expect that shutoff could occur in some circumstances. This would detrimentally affect the utility of the generator when used in a proper location.

In addition to these performance deficiencies, staff is concerned about the ability of CO sensors to survive the environments produced by an operating generator. Currently available electrochemical and semiconductor CO sensors, which dominate the CO-sensing market, have numerous vulnerabilities that will compromise their ability to maintain accuracy, if used in an atmosphere containing high concentrations of hydrocarbons, as are present in a generator's exhaust, particularly when used in a confined space.

Regarding commenter #9's recommendation to use CO sensors that turn on ventilation fans in parking garages, a recent energy-efficiency study examining the performance of parking garages that have CO-sensing activated ventilation indicates that this type of system is subject to failure if not maintained on the manufacturer's recommended schedule (California Utilities Statewide Codes and Standards Team, 2011). Systems employing both electrochemical and

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[6] Brown, Christopher, *Engine-Driven Tools, Phase 2 Test Report: Portable Generator Equipped with a Safety Shutoff Device*, U.S. Consumer Product Safety Commission, Bethesda, MD, July 2008. (available online at: http://www.regulations.gov/document?D=CPSC-2006-0057-0010

solid-state technology that were 5 and 12 years old respectively, failed in all likelihood because the systems had not been calibrated. A properly maintained 2-year-old electrochemical sensor-equipped system performed well. Commenter #9 suggested that, to account for the referenced 2 to 3-year expected sensor life, the consumer should replace the sensor at the end of the sensor's useful life. Staff believes that it is not appropriate or reasonable to expect consumers to replace a primary safety device, let alone replace it every 2 to 3 years when the life of the overall product is much longer. Furthermore, making the sensor replaceable makes it vulnerable to tampering. Notwithstanding the previously mentioned CO concentrations that staff measured around a generator operating in a proper location, the conflict between making the sensor consumer-replaceable and tamper-proof leads staff to conclude that currently available sensors are not likely to be effective, given the long service life of portable generators. Regarding the recommendation for a 35 ppm CO set point for an on-board sensor, within 11 minutes after starting the generator, CPSC staff measured CO concentrations in excess of 35 ppm in the immediate vicinity of the generator while operating outdoors (Fig C2 in Brown, 2013). A 35 ppm maximum for shutoff would greatly limit the utility of portable generators when used properly.

The commenter also stated that the National Highway Traffic and Safety Administration (NHTSA) funded a study in 1991, which stated that ignition interlocks that detect CO in vehicle cabins could be installed in vehicles for $11.39 each.[7] Staff believes that this relatively low cost quoted by the commenter is taken out of context. Per the commenter's own website,[8] the $11.39 cost only accounts for the parts, and in 1991 U.S. dollars. It is uncertain what the increased cost of the sensors, installation, and maintenance would be in 2014 U.S. dollars.

The commenter petitioned the U.S. Department of Transportation (DOT), NHTSA in 2005, to require automobiles to be equipped with CO sensors that would turn off engines if 200 ppm of CO was detected.[9] NHTSA denied the commenter's petition. NHTSA stated: " . . . costs would have been unjustifiable in relation to the benefits. The effectiveness of CO detectors lessens substantially over time and most vehicle-related CO deaths involve older vehicles." These costs include installation, maintenance, and eventual replacement of the CO sensing technology. These actions would require the services of the CO technology manufacturers and the due diligence of the consumers to have the CO sensing technology serviced. As NHTSA pointed out, there will be instances where some consumers will fail to maintain and replace the worn out, defective CO sensors, rendering them useless.

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[7] Grace, R. et al. *"Carbon Monoxide Monitor for Automobile Passenger Compartment. Final Report,"* Report Number DOT-VNTSC-NHTSA-91-3, Carnegie Mellon Research Institute, prepared for National Highway Traffic Safety Administration (NHTSA), 1991.

[8] Multiple Chemical Sensitivity (MCS) Referral and Resources, Topic: *"Petition to: United States' National Highway Traffic Safety Administration (NHTSA) and Transport Canada's Road Safety Directorate (RSD) Re: Rulemaking Requested to Prevent Illness and Death Caused by Carbon Monoxide from Motor Vehicle Exhaust,"* Internet source: http://www.mcsrr.org/pressreleases/nhtsa01p.html#12.

[9] Federal Register, Volume 70, Number 186, September 27, 2005, Proposed Rules, U.S. Department of Transportation, National Highway Traffic Safety Administration, Denial of Petition for Rulemaking.

Staff concurs with NHTSA's rationale for denying the petition for rulemaking on automobiles and believes that these same issues would apply if the CO sensing technology were to be implemented on generators. Staff does not believe the commenter has provided sufficient evidence to support the practical feasibility of on-board CO sensors to reduce CO deaths and injuries associated with portable generators. Therefore, staff disagrees with the commenter.

ANPR COMMENTS ABOUT REMOTELY LOCATED CO-SENSING SHUTOFF SYSTEMS

Comment: Referring to Table 1, two commenters raised concerns about the concept of a remotely located CO sensing shutoff system, such as that investigated and documented in the staff report, "*Demonstration of a Remote Carbon Monoxide Sensing Automatic Shut-Off Device for Portable Generators*" (Lee, 2006). Conceptually, a remotely located CO sensing shutoff system would use a CO sensor located indoors to monitor for CO infiltration at that location; and when it detects an unsafe CO concentration, the sensor would communicate with the generator to shut off the generator. The report presents staff's investigation of one version of such a concept, consisting of a CO alarm retrofitted with a wireless transmitter, placed by the user in an indoor location, which communicated with a wireless receiver mounted onto a portable generator operating in an attached garage. When the CO alarm activated, the alarm energized a circuit on the generator and shut off the generator.

Commenter #6 raised a number of behavioral and technical issues on the utility of such a system. This commenter noted that the same technical comments they made on the generator-mounted safety shutoff concept, discussed above, also apply to the remote-sensing concept as well. Commenter #6 also noted that remote-sensing technologies require consumers to take affirmative actions to properly locate sensors inside buildings and to monitor them to make sure that they continue to be operational. The commenter stated that the risk of the CO poisoning hazard would not be mitigated when consumers fail to locate or use the sensing technology properly or detect malfunctions due to infrequent use or lack of maintenance.

One commenter (#7) also expressed concerns about the concept of such a system and specific concerns about the staff report. Regarding the former, the commenter enumerated a number of concerns that included the following:

- Sensor performance affected by ambient conditions,
- Battery life,
- Consumers' ability to install the system,
- Consumers' ability to disable the system after nuisance trips,
- The need to maintain proper battery charge, and
- Consumers' ability to start generator, and remove the remote sensor to an area without CO, to allow the generator to operate.

Regarding the staff report, the commenter objected that only one model generator was included in the tests and only a limited number of hazard scenarios were tested. The commenter provided a list of nine options that would need to be investigated to document acceptable remote-CO sensing device acceptability. The options include: (1) effectiveness of the mandatory warning label; (2) effects of environmental conditions on CO dispersion in a building; (3) effect of generator load profile on CO dispersion; (4) the effect of walls and building materials on the sensor's radio frequency (RF) signal to the generator; and (5) maximum distance between sensor/transmitter and the generator. Additional options include: (6) consumer's ability to reset the system in adverse conditions (darkness, storms); (7) timing of product sales (pre or post storm); (8) minimum component performance requirements; and (9) minimum battery requirements.

Response: Staff agrees that there are multiple challenges with a remote CO shutoff concept for portable generators, including many of those identified by the commenters. Staff notes that the staff report concluded with the following:

The study was limited to proof-of-concept and did not consider certain issues, such as life expectancy, reliability, usability, and environmental conditions. All of these factors would need to be considered in developing a remote CO detection/shut-off system for portable generators for consumer use.

In addition to having the same sensor-related concerns as those stated in staff's response to the on-board CO sensing shutoff concept, staff has additional concerns. One primary concern is that a system of this sort would need to be provided with the generator and would require the consumer to install the sensing devices properly. The consumer could easily defeat the features by operating the generator in an enclosed location and intentionally placing the sensor outdoors or other locations away from where the CO is infiltrating to keep the generator running. Another scenario involves the user placing the CO sensor in a room where he/she thinks the CO will infiltrate. However, testing s showed that the CO infiltrates faster in another room that the system is not monitoring. Transmitter range and interference is another concern: if a consumer properly locates the generator outdoors at a distance far enough from the dwelling to prevent CO infiltration, the distance may render the generator inoperable if it is not within range of the sensor signal. Based on the concerns mentioned above, staff is not pursuing this concept as a means of reducing the CO hazard associated with portable generators.

ANPR COMMENTS ON FLEXIBLE EXHAUST PIPE EXTENSION

Comment: One commenter (#9) recommended using an exhaust hose that has one end that fits over the tailpipe and a laterally expandable window fitting on the other end to direct exhaust out through a window. The commenter recommended that the hose should have an electrical circuit wired through its entire length, which plugs into the generator to prevent operation if the hose is not properly attached**.**

Response: There are several drawbacks to this approach. First, if the hose must be attached for the generator to operate, then it must be attached even if the generator is correctly located away from the house. Staff believes this is not practical. Secondly, the CPSC database includes fatal CO incidents where the generator was located outside the dwelling, but not so far away to prevent exhaust from entering the home through leaks or openings (Hnatov, 2015). Thirdly, staff believes that it is unlikely that an expandable window insert can be routinely installed in such a way as to be leak tight. Lastly, as with the remote sensing shutoff system, this system's successful use depends on the consumer's ability to properly install both the hose and the window fitting. Given these concerns, the hose extension is not a technically feasible approach to address the carbon monoxide poisoning hazard associated with engine-driven portable generators.

- **PUBLIC COMMENTS ON CPSC STAFF AND CONTRACTOR REPORTS** (Docket Identification CPSC-2006-0057-0004, Docket Identification CPSC-2006-0057-0006)

As noted, the Commission has published staff and contractor reports on www.cpsc.gov and solicited stakeholder comments. The engineering-related comments about these reports, particularly comments on the use of CO sensing technologies to mitigate the CO hazards associated with portable generator use, are summarized here, along with CPSC staff's responses.

Comment: One commenter (#20) stated: "if generator manufacturers formed a consortium to jointly purchase a mutually agreed upon model of CO controller for the largest possible economy of scale, their unit cost would be less than that of currently available hardwired home CO alarms designed to the UL 2034 standard with a digital display and 9v battery backup. I estimate this additional cost to be in the range of $20-$40."

Response: Staff is not aware of any commitment by manufacturers to form a consortium to address the deaths and injuries associated with CO emissions from generators. The commenter did not provide any source for his cost estimate. For these reasons, staff cannot respond to this comment.

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TAB E

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

Date: October 3, 2016

TO: Janet Buyer,
Project Manager, Portable Generators,
Division of Combustion and Fire Sciences, Engineering Sciences

FROM: Susan Bathalon
Combustion Product Area Team Lead,
Office of Hazard Identification and Reduction

SUBJECT: Responses to comments concerning the CPSC report titled, 'Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator"

In 2012, U.S. Consumer Product Safety Commission (CPSC) staff posted a memorandum entitled, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*[i]. This memorandum contained CPSC staff and contractor reports documenting a demonstration program of a prototype low carbon monoxide (CO) emission portable generator. The demonstration program included: (1) the development of a prototype low CO emission portable generator and demonstration of its performance regarding durability and compliance with the U.S. Environmental Protection Agency's (EPA) small engine exhaust emissions standards at the end of the engine's rated useful life, and (2) a presentation of the prototype generator's performance concerning predicted health impacts on hypothetical occupants when empirically tested in a common fatal residential scenario. On November 13, 2012, the Truck and Engine Manufacturers Association (EMA) and American Honda Motor Company, Inc., provided comments on the technology demonstration memorandum.

The November 13, 2012, EMA and Honda letters predominantly expressed concern about the reliability and cost of exhaust emission technologies adapted onto portable generators f to reduce carbon monoxide (CO) production. This memorandum summarizes key points or concerns from these letters and provides CPSC staff's responses.

1. *EMA states that significant design changes would be required to incorporate and adapt emission technologies for use in portable generators engines. EMA states that engine changes presented in the prototype generator design are possible, but may not be best suited for all engines powering portable generators, especially when considering price and reliability considerations.*

To reduce the CO exhaust levels in portable generator units, staff developed the prototype generator with commercially available parts for better fuel delivery controls and exhaust emission controls. The prototype generator engine was built from a readily available unit with a carburetor engine, which was retrofitted with sensors and components for electronic microprocessor controls of the intake manifold fuel injection and combustion spark timing. The prototype generator did not require extensive design changes because the electronic fuel controls required no disassembly between the engine cover, engine block or cylinder head. Therefore, the head gasket and cylinder compression rings were left in their original condition. The primary prototype design strategy for reduction of CO emissions targeted a reduction of excess fuel for combustion. The less significant and secondary approach of CO reduction in the prototype design included incorporating a metal monolith catalytic converter in the muffler. Staff believes that some combination of these two engine CO exhaust reduction strategies could be tailored to other portable generator engines. Of the two strategies, CO emissions are believed to be most dependent on the fuel-to-air ratio. Staff encourages other research approaches to mitigate the risk of fatal and severe CO poisoning associated with portable generators. Considering price, staff agrees that there is an added cost to EFI engines, as discussed in the preliminary regulatory analysis in this briefing package. As to reliability, staff notes that the prototype generator was successfully durability tested for longevity in service for 500 hours, which was the rated useful life, as established by the manufacturer.

2. *EMA asserts that similar engine designs, including basic fuel injection and ignition design are uniform across several manufacturer product lines of gasoline-fueled engines, where possible. Products like lawn mowers and portable generator may use a similar engine design and components, and EMA states that this uniformity across many products provides manufacturing flexibility and economy of scale. Further, EMA states the implementation of a different engine design in portable generators, such as described in the prototype program, may impact cost and availability of the product.*

The prototype design was specifically originated and developed through available off-the-shelf electronic fuel controller and components adapted onto an existing marketed portable generator engine. The prototype generator was successfully durability-tested for 500-engine operation hours with continual full-to-no generator electrical loading. The acquired 500 hours, which was the rated useful life as established by the manufacturer, durability testing evaluated the prototype generator's performance and longevity.

CPSC staff acknowledges the EMA concern that adoption of a portable generator engine specifically designed to reduce CO emissions may have different engine component pricing compared to the current portable generator engine without the emission reduction. Staff notes that portable generators with EFI (though not specifically designed for low CO emissions) have been increasing in availability in the market as new models have been introduced.

3. *The Honda letter states the photos of the prototype unit cylinder head may indicate that combustion gases had been leaking to the outside because the head gasket was in the early stages of failure prior to the time that the engine was disassembled. Honda indicates they made these findings based on the carbon deposits on the prototype cylinder head fin and head gasket seating surface.*

The cylinder heads, pistons and several other components are photographed and compared in the post durability wear analysis section of Contractor University of Alabama's report, *Low Carbon*

Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation.[ii] Figure 22 of this report is referenced in the Honda letter. The Figure shows a side-by-side comparison of the cylinder heads from the baseline generator (an unmodified unit), to the prototype generator unit after completion of the 500 hours of durability testing. CPSC staff partly agrees with the Honda photo assessment because more carbon deposits are visible on the prototype cylinder head gasket surface, compared to the same component in the baseline. However, the prototype's head gasket endured approximately 585 engine hours of the durability program and subsequent emission testing. According to the University of Alabama report, the head gasket with the baseline unit leaked after 175 engine hours into the durability test and was replaced. The cylinder head referenced photos, which compares the generator units after completion of the durability test, showing less carbon deposit on the baseline engine's cylinder head gasket seating surface may be explained by fewer accumulated engine hours on the newer head gasket. Furthermore, staff notes that the prototype engine had been run for 585 hours by the time the photograph was taken, which was 85 hours beyond the manufacturer's rated useful life of the engine.

4. *The Honda letter conveys that the increased combustion temperature due to the prototype's stoichiometric air-to-fuel mixture and reliance on radiant cooling is insufficient as evident in the condition of photographed engine components, such as the pistons, after completion of the durability test.*

CPSC staff agrees with Honda that leaner fuel ratios generally result in increases in combustion temperatures. Increasing the air-to-fuel ratio available for combustion was intentional in the prototype engine, to influence and reduce the CO mass flow in the exhaust emission. Cylinder head temperatures were measured in generator units at all various load profiles for each occurrence of emission testing. These emission tests occurred before modifications to engine or durability testing, during the durability testing to accumulate of engine hours, and after the durability tests.

Emission and engine test data were collected on the as-received carburetor-fueled generators units. According to the University of Alabama report, *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation*, the as-received generator unit selected to become the prototype, but not yet modified, measured a 13.98 AFR at full-generator loading (mode 1), with an associated 227º C-cylinder head temperature. In addition, the range of AFR values for this pre-modified prototype generator measured 13.98 - 11.26, with progressively richer AFRs toward idle or no-load (page 25). The maximum cylinder head temperatures with the stoichiometric EFI after prototype engine modification were no hotter than the original unit. Staff believes the 14.0 AFR carburetor design offered no cylinder head cooling capacity over the stoichiometric EFI design. Throughout the prototype generator program, including independent laboratory dynamometer emission testing after 500 cyclic engine hours of operation, the engine demonstrated a cylinder head temperature less than 227°C at full load. The mid-to-no-load operating temperatures were cooler. All of these recorded measurements of the prototype cylinder head temperatures, including full load, were well below the manufacturer-recommended temperature limits.

Another comparison of cylinder head temperatures involves the baseline generator, which remained unmodified as the original unit, and the prototype generator. According to the *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation* report, the carburetor fuel system of the baseline generator delivered 13.4 to 10.5 AFR values for the range of generator loads throughout the durability program (Appendix B, pages 57-61). Similar to the pre-modified prototype generator, progressively richer AFRs occurred in the baseline generator towards idle or no-load. Alternatively, the prototype generator fuel strategy sought to maintain the same stoichiometric AFR across all loads. These differences in AFR values created an average elevated temperature of 28°C in the prototype unit to the baseline unit. Staff believes the 28°C average hotter temperatures across all loads created more discoloration in the prototype piston. There appears to be more blackened areas of the piston ring, and more coloring below the seated position of the piston ring indicates hotter operating temperatures in the prototype cylinder, compared to the baseline unit. However, as mentioned, the recorded measurements of the prototype cylinder head temperatures, including full load, were well below the manufacturer-recommended temperature limits. For the technology demonstration program, the prototype's leaner AFR to minimize CO exhaust production was believed to be balanced with higher, but acceptable, cylinder temperatures.

5. *The EMA letter coveys some deterioration of the prototype engine occurred with accumulation of engine hours. The EMA letter states that greater CO emission levels occurred with the prototype portable generator at 500 hour and end-of-life compared to zero hour engine and emission tests.*

The University of Alabama's report, *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation,* contains Appendix B with prototype and baseline generators engine hour durability emission test results for low-, high- and mid-life engine hours (pages 57-61). This appendix shows the combined loads of prototype portable generator, post-catalyst CO emission results at 2 g/kW-hr near 0 engine-hours and 17.5 g/kW-hr at 500 engine-hours. Staff does not believe that these results reflect deterioration, but rather, a mid-load controller calibration performance issue, which surfaced primarily in the post-durability emission tests.

This 500-hour prototype emission test performance was due to portions of the fuel look-up tables that were not calibrated in the initiation of the engine build. Initially, it was not known that rated engine speeds supporting an alternator would involve extensive variation. Therefore, only certain areas of the controller look-up tables were mapped. Retrospectively, it is known that the mode 4 or mid-load solution was simply to expand the same parameters throughout the ECU look-up tables and all engine speeds. In the final emission tests, larger AFR excursions and higher CO emissions occurred when the engine operated in the unmapped portions of the controller. While the post durability prototype generator CO emissions results show more than 90 percent reduction over the baseline unit, the emission reduction with the prototype could likely be reduced further with more comprehensive calibration of the controller.

6. *Honda states that the CPSC testing did not evaluate engine and generator performance in transient load conditions of performance.*

The empirical testing in the NIST test house included transient loads. The NIST Technical Note 1781[iii], *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level,* measures both prototype and baseline unmodified generator units operating in a garage, with several electrical loading variations, including the generator cyclic load profile in the durability program and emission testing. The measuring test equipment at the NIST test house continuously collects CO measurements as the electrical and engine load profile was altered.

7. *EMA states that consumers may purchase portable generators due to potential electrical service interruption. The EMA concern seems to be that consumers may use the portable generator during the near term emergency power outage and infrequently operate the unit until the next emergency without conducting preventative maintenance. EMA also states fuel degradation or mechanical electrical systems are specific systems that may experience problem due to storage, and furthermore, a unit similar to the prototype engine design will exacerbate these storage problems.*

As of May 21, 2015, the CPSC databases contained reports of at least 751 generator-related CO poisoning deaths resulting from 562 incidents; these incidents occurred from 2004 through 2014. The CPSC database reported reasons for using a generator were: (1) to provide electricity to a location that did not have it due to a power outage stemming from weather problems or a problem with power distribution; or (2) power was shut off to the residence by the utility company due to bill dispute or nonpayment. Given the reported rationale for portable generator use, CPSC staff agrees with the EMA sentiment that portable generators are subjected to storage conditions with periodic use during power outages or the next power outage. Staff believes that consumer patterns of storage and maintenance with portable generator equipment may likely continue, even with product design changes of the electrical mechanical systems.

EMA suggests that the fuel systems similar to those used in the EFI prototype engine may exacerbate performance issues with fuel degradation, compared to the existing market with many gravity feed carburetor systems. Conversely, staff believes that fuel degradation would be less problematic in EFI systems because these fuel systems are pressurized and sealed; whereas, the gravity feed carburetor contains some pathways for air flow. The EFI systems should be less affected by fuel degradation in retaining the fuel, with less ventilation of raw fuel, less evaporation of lighter fuel compounds, and less condensation and absorption of water vapor into the fuel tank or lines.

8. *Honda asserts a multipronged approach is needed to reduce portable generator incidents, which should include raising the consumer awareness of carbon monoxide safety, promoting the use of residential carbon monoxide alarms, and exploring technology that can reduce the levels of carbon monoxide (CO) generated at the source.*

CPSC staff agrees that each of these three approaches is important to reduce the number of carbon monoxide events. Furthermore, CPSC staff continues to be actively involved in each approach to help prevent CO deaths and injuries from exposure to portable generator exhaust.

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[i] Buyer J. *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*. U.S. Consumer Product Safety Commission, Bethesda, MD, September 2012. (Docket Identification CPSC-2006-0057-0002, available online at: www.regulations.gov).

[ii] Puzinauskas, P, Dantuluri, R, Haskew, T, Smelser, J. *Low Carbon Monoxide Emission Prototype Portable Generator Build Description and Performance Evaluation*, The University of Alabama, Tuscaloosa, AL, July 2011.

[iii] Emmerich, S. J., A. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), National Institute of Standards and Technology, Gaithersburg, MD, February 2013.

TAB F

DATE: August 15, 2016

TO: Janet L. Buyer, Project Manager, Portable Generators Project,
Division of Mechanical and Combustion Engineering,
Directorate for Engineering Sciences

THROUGH: Joel R. Recht, Ph. D., Associate Executive Director,
Directorate for Engineering Sciences

Rana Balci-Sinha, Ph.D., Director,
Division of Human Factors, Directorate for Engineering Sciences

FROM: Timothy P. Smith, Senior Human Factors Engineer,
Division of Human Factors, Directorate for Engineering Sciences

SUBJECT: Human Factors Staff Responses to Labeling-Related Public Comments on 2006 ANPR for Portable Generators and 2012 CPSC Staff Report, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*

BACKGROUND

In 2006, staff of the U.S. Consumer Product Safety Commission (CPSC) prepared an advance notice of proposed rulemaking (ANPR) that presented strategies for reducing carbon monoxide (CO) poisoning deaths involving portable generators (Buyer, 2006). The Commission published the ANPR in the *Federal Register* on December 12, 2006, with a closing date for public comments of February 12, 2007. CPSC received 10 comments; some of these comments address issues related to the mandatory labeling of portable generators about the carbon monoxide CO hazard.[1]

Since then, staff activities on portable generators have continued, and on September 14, 2012, CPSC released a staff report on a technology development and demonstration program focused on developing a portable generator powered by an engine with a substantially reduced CO emission rate. Such a generator should reduce the risk of fatal and severe CO poisoning when used indoors, which is contrary to the product warnings and manufacturers' use recommendations. The staff report, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*, was posted for review and public comment in the Voluntary Standards section of the CPSC website. CPSC received 13 public comments; one of these comments addressed issues concerning the mandatory labeling of portable generators.

[1] A CPSC Final Rule containing mandatory labeling requirements for portable generators was published during the comment period and became effective on any generator manufactured or imported on or after May 14, 2007. See Portable Generators: Requirements to Provide Performance and Technical Data by Labeling, 16 CFR §1407 (2007).

This memorandum, prepared by staff of CPSC's Directorate for Engineering Sciences, Division of Human Factors (ESHF), responds to the labeling-related public comments on the ANPR and the staff technology development and demonstration program report.

DISCUSSION

ANPR COMMENTS

Three ANPR comments raised issues concerning the mandatory labeling of portable generators. The first comment (CC 07-3-4) emphasized the need for portable generators to bear a mandatory warning label about the CO poisoning hazard, and the comment outlined several desired characteristics for the label. This comment was submitted after CPSC had published its final rule that contained mandatory labeling requirements for portable generators. Thus, staff is unsure whether the commenter understood that such a rule had already been published. Regardless, the issues raised in this comment appear to have been addressed during that rulemaking activity.

The second comment (CC 07-3-6) acknowledged staff's mandatory labeling requirements and stated: "The effectiveness of these new mandatory labels should be determined prior to advancing additional regulatory proposals…." The effectiveness issue also was raised in one of the public comments on the staff technology development and demonstration program report. Accordingly, ESHF staff will address this issue in the next section.

The final labeling-related comment (CC 07-3-7) compiled three previous submissions to CPSC, one of which requested rationale and documentation for the language and pictograms used in warning labels being considered for rulemaking by CPSC. This submission was dated May 1, 2006, which preceded publication of the notice of proposed rulemaking (NPR) and final rule that contained mandatory labeling requirements. The issues raised in the comment, therefore, were addressed during that rulemaking activity.

STAFF REPORT COMMENTS

The Portable Generator Manufacturers' Association (PGMA) submitted one public comment on the CPSC staff technology development and demonstration program report that addressed issues related to the mandatory labeling of portable generators.[2] Specifically, PGMA stated that the CO hazard will continue to exist, even if staff's demonstrated technology were applied to commercially available generators, adding that "educating owners about the proper use of their generators will therefore remain the first line of defense." PGMA also stated that, for this reason, CPSC should "conduct a study that includes a human factors analysis to determine the effectiveness of the CPSC mandated CO warning adopted in 2007." Lastly, PGMA encouraged CPSC to revise the mandated warning "to incorporate the standards and format" in ANSI Z535.3 – 2011, *American National Standard Criteria for Safety Symbols,* and Z535.4 – 2011, *American National Standard Product Safety Signs and Labels*.

[2] Dated November 12, 2012, from John H. Addington, Executive Director, PGMA, to Janet L. Buyer.

EDUCATION AS A FIRST LINE OF DEFENSE

ESHF staff concurs with PGMA's assertion that the CO hazard associated with portable generators will continue to exist, albeit to a reduced degree, even if CPSC staff's demonstrated technology were applied to commercially available generators. However, it does not necessarily follow that educating owners about the proper use of generators is, should be, or would remain, the *first* line of defense. Human factors and safety literature identify a classic hierarchy of approaches to follow to control hazards, based primarily on their effectiveness in eliminating or reducing exposure to the hazard. Using hazard communications, such as warning labels, is universally recognized as less effective than designing the hazard out of the product or guarding the consumer from the hazard. Thus, the use of warnings and other hazard communications is lower in this "hazard control hierarchy" than the other two approaches (Laughery & Wogalter, 2011; Vredenburgh & Zackowitz, 2005; Williams & Noyes, 2011). Hazard communications are less effective because they do not prevent consumer exposure to the hazard; instead, they must persuade consumers who see and understand the communication to alter their behavior in some way to avoid the hazard. Consequently, hazard communications should be thought of as "last resort" measures that supplement, rather than replace, product redesign or guarding efforts to address residual risks, unless these higher-level hazard-control efforts are unfeasible.

EFFECTIVENESS OF MANDATORY LABELING REQUIREMENTS

ESHF staff is unclear how PGMA's recommendation that CPSC staff conduct a study to determine the effectiveness of the CPSC-mandated CO warning is directly relevant to the staff report or how PGMA is defining "effectiveness" in the context of the warning. However, PGMA's explicit claim is that testing is needed because of the importance of "educating owners about the proper use of their generators." Based on this assertion, ESHF staff can infer that PGMA's measure of effectiveness is the extent to which the warning is understood by consumers, assuming the warning has first captured and maintained the consumers' attention.

CPSC's mandatory labeling requirements for portable generators, 16 C.F.R. part 1407, states that the product label shall be located on a part of the generator that is "prominent and conspicuous to the operator," while performing at least two of the following operations: filling the fuel tank, accessing the receptacle panel, and starting the engine (Section 1407.3(a)(iii)(B)). The rule also requires that the label remain permanently affixed, intact, legible, and largely unfaded over the life of the product (Section 1407.3(a)(iv)). These requirements, as well as the minimum type size requirements,[3] were developed purposefully to address issues related to capturing and maintaining consumer attention, and they should address most concerns of this type, except when the user of the generator is not literate in English. However, the question of whether the label should also be provided in languages other than English was raised and addressed in detail in the final rule (72 FR 1443). In summary: (1) available generator-related incident data have revealed no pattern of incidents involving people who could not read English; (2) the overall positive impact of adding Spanish, or some other language, to a label is likely to be very small;

[3] The signal word "DANGER" must be in letters not less than 0.15 inches and the remaining text must be in type whose uppercase letters are not less than 0.10 inches, or about 10-point type size.

and (3) the regulation does not prohibit the addition of a different language version of the warning message to the mandatory label.

ESHF staff supports the testing of warnings and other hazard communications. However, as discussed in the preamble to the mandatory labeling final rule (72 FR 1443), an independent contractor already performed focus-group testing with low-literacy individuals for the product label initially proposed in the notice of proposed rulemaking (NPR), and ESHF staff revised the final label to address the message text comprehension problems identified during testing. Staff acknowledges that incremental improvements to the label's language might be possible, by conducting additional comprehension testing. However, staff also believes that the most significant label comprehension problems have already been addressed and that additional testing is unlikely to detect problems that would substantially impact comprehension among those at risk.[4] Award-winning linguist and cognitive scientist, Steven Pinker, in his recent book, *The Sense of Style: The Thinking Person's Guide to Writing in the 21st Century* (Pinker, 2014; Young, 2014), explicitly mentions the mandatory portable generator label as an example of good writing. Dr. Pinker is one of the world's foremost writers on language, mind, and human nature, and is Chair of the Usage Panel of the *American Heritage Dictionary*. Thus, ESHF staff is not convinced that there is a substantial benefit to additional comprehension testing.

In addition, as previously noted, the issue of labeling effectiveness was raised in one of the ANPR comments (CC 07-3-6) authored by three PGMA member companies. The comment suggested that mandatory performance requirements may be unnecessary, if the mandatory labeling requirements are effective. However, two of these three member companies previously argued that mandatory labeling is unlikely to be effective. For example, in public comments responding to the NPR for the mandatory labeling of portable generators, these member companies stated the following:

- "… the Commission's experience … strongly suggests that changing the current labels on portable generators will have little impact on reducing the incidence of CO poisoning." (CC 07-2-16, p. 4)
- "… history suggests that addition of the labels proposed in the NPR will, at best, have marginal impact on reducing CO incidents and deaths." (CC 07-2-16, p. 11)
- "Other relevant data further suggest that the proposed CO label may have only a marginal effect on consumer misuse of portable generators." (CC 07-2-17, p. 2)

Comments previously submitted by PGMA member companies, therefore, appear to support the idea that mandatory labeling requirements, alone, are not sufficient to address incidents of CO poisoning involving portable generators.

The available incident data also support this idea. As ESHF staff notes in its other memorandum prepared in support of the current NPR briefing package (Tab C), 11 of the 67 investigated generator-related incidents that ESHF staff examined that included at least one survivor,

[4] Virzi (1992) has found that about 80 percent of all usability problems tend to be detected with only four or five subjects, about 95 percent of all problems are detected with nine subjects, and each additional subject was less likely to detect new usability problems. ESHF staff believes that these general principles are likely to apply to comprehension testing as well, particularly in tests that oversample low-literacy individuals.

involved a generator that definitely or most likely included the mandatory "DANGER" label (Smith, 2016; see Tab C). Hanway (2016; see Tab H) also examined the impact of the mandatory portable generator labeling and concluded that the available data do not provide sufficient evidence to conclude that the mandatory label has reduced or eliminated the CO fatality risks associated with portable generators. Thus, although ESHF staff believes that the mandatory label for portable generators might prevent some incidents of CO poisoning and death, evidence suggests that labeling alone is not sufficient to address the hazard, and that performance requirements for portable generators are needed.

On August 12, 2016, ESHF staff participated in a public teleconference with representatives of PGMA and Exponent, Inc. ("Exponent") to discuss the status of focus-group testing that is being conducted by Exponent to examine whether there may be room for improvement, in terms of consumer comprehension, with the current mandatory label. The test plan involves six focus groups, consisting of five people each, and final comprehension testing involving 30 people. The first few focus groups involve participants developing key words, phrases, and "proto warnings" without exposure to the mandatory label; the mandatory label will be introduced to later focus groups to help develop the final labels to be tested for comprehension. ESHF staff has provided feedback to PGMA and Exponent on the testing, and PGMA intends to seek additional feedback from CPSC staff as work progresses.

Consistency of Mandatory Labeling with ANSI Z535-Series Standards

ESHF staff is unsure why PGMA believes that the mandatory labeling should be revised "to incorporate the standards and format" in ANSI Z535.3 – 2011 and Z535.4 – 2011. Staff compared the mandatory label and its requirements to the requirements in both ANSI standards and found virtually no differences, except for a specific label format requirement specified in Section 6 of ANSI Z535.4. That section states that a product safety label "consists of a signal word panel plus a message panel," and that "[a] safety symbol panel may be used to communicate a part or all of the elements of a message panel." The panel arrangement requirements in this section, and the figures provided as examples, suggest that the warning message and safety symbols are to be in their own distinct panels and not intermixed. In contrast, the mandatory labeling separates the safety symbols into two panels and includes text relevant to the safety symbols within those panels, as shown in Figure 1.

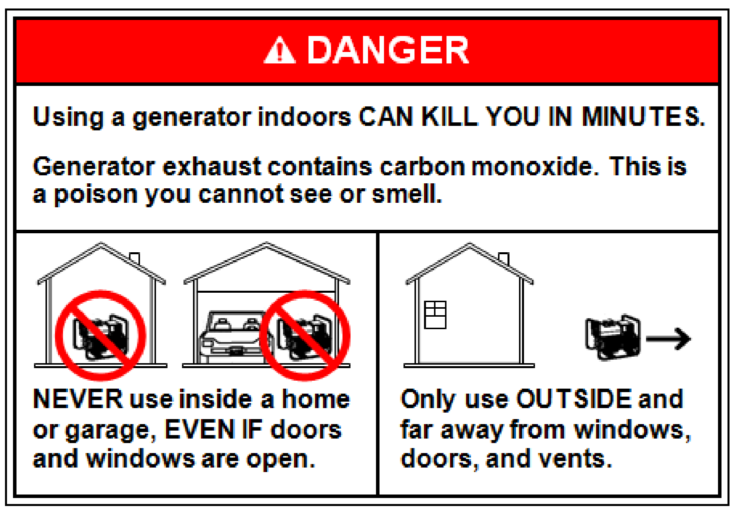

Figure 1. Mandatory label for portable generators.

Although ESHF staff acknowledges that the formatting of the mandatory label technically does not match the panel format requirements of ANSI Z535.4, staff notes the following:

- As illustrated in Figure 11 of ANSI Z535.4 – 2011, the safety symbol and message panels need not always be separated by a border, but rather, they can be separated by white space.

- Section B6.3 of ANSI Z535.4 includes formatting options for multi-hazard labels that include multiple symbols. In the examples illustrated, the individual symbols are separated by borders, rather than being enclosed as a group in a single border. In addition, although the option that shows the symbols arranged horizontally uses a single message panel below the symbols, with the relevant text ordered vertically, the alternative formatting option shows the symbols arranged vertically, with the relevant text arranged "so they line up opposite the appropriate safety symbol panel."

- The formatting of the figures within the ANSI Z535.4 standard generally follows the rule that text or captions that are relevant to a particular graphic or figure, appear immediately below that graphic or figure.[5] ANSI Z535.3 follows a similar rule, and ESHF staff calls particular attention to Figure A17 of that standard, which includes several graphics, each with a graphic-relevant text label immediately below.

For the reasons stated, ESHF staff believes that revising the mandatory label is neither appropriate, nor desirable. When initially developing the label, staff had considered other formatting alternatives, such as the use of a single symbol panel. However, staff found that the format selected for the final rule more clearly linked the safety symbols to the relevant message text and made the most efficient use of the labeling space. Additionally, although this is not directed specifically to product labels, instruction-design guidelines recommend placing each graphic and its corresponding text as close together as possible (*e.g.*, Singer, Balliro, & Lerner, 2003). Staff believes that revising the label to strictly meet the panel format requirements of ANSI Z535.4 would not improve the effectiveness of the label and could actually have a negative impact.

CONCLUSIONS

ESHF staff believes that hazard communications, such as warning labels, should not be considered the "first line of defense," but rather, "last resort" measures that supplement product redesign or guarding efforts to address residual risks. The mandatory product label for portable generators has already undergone testing with low-literacy individuals during the associated rulemaking. Therefore, staff is not convinced of a substantial benefit from additional comprehension testing or that such testing would substantially contribute to safety.[6] ESHF staff also notes that the formatting and requirements of the mandatory generator label are virtually identical to the requirements of ANSI Z535.4 – 2011 and Z535.3 – 2011. Although staff acknowledges that the formatting of the mandatory label technically does not match the panel format requirements of ANSI Z535.4, these differences were deliberate and intended to improve warning comprehension. In addition, the Z535 series of standards include exceptions and

[5] See, for example, Figures 3 through 12 on pages 10 and 11 of the standard.
[6] See ESHF staff's other memorandum in support of the current NPR briefing package for a discussion of reasons why mandatory labeling alone is not sufficient to address the CO hazard (Smith, 2016; see Tab C).

examples that are consistent with the formatting of the mandatory label. Revising the mandatory label to strictly meet the panel format requirements of Z535.4 is unlikely to improve the effectiveness of the label. Moreover, staff believes that changes like separating the safety symbols from their corresponding warning messages actually could have a negative impact on comprehension. Thus, ESHF staff believes that such revisions are neither appropriate, nor desirable.

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TAB G

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
BETHESDA, MD 20814

Memorandum

Date: July 21, 2016

TO : Janet L. Buyer, Portable Generator Project Manager, Division of Mechanical Engineering, Directorate for Engineering Sciences

THROUGH: DeWane Ray, Acting Assistant Executive Director, Office of Compliance and Field Operations

Mary F. Toro, Director, Division of Regulatory Enforcement

FROM : Troy W. Whitfield, Mechanical Team Leader, Division of Regulatory Enforcement

SUBJECT : Portable Generator Compliance Activity

PURPOSE

This memorandum responds to a request from the Project Manager for the Portable Generator rulemaking team for information on compliance activities relevant to enforcement of 16 C.F.R. Part 1407 *Portable Generators: Requirements to Provide Performance and Technical Data by Labeling*. In January 2007, the Commission published a final rule requiring manufacturers to label certain portable generators with performance and technical data related to performance and safety concerns. The prescribed labeling notifies the consumer of the hazards of carbon monoxide associated with the use of portable generators. The labeling includes the safety alert symbol (⚠) along with the signal word DANGER and the following warnings:

"Using a generator indoors CAN KILL YOU IN MINUTES."
"Generator exhaust contains carbon monoxide. This is a poison you cannot see or smell."
"NEVER use inside a home or garage, EVEN IF doors and windows are open."
"Only use OUTSIDE and far away from windows, doors, and vents."

Pictograms are included as part of the on-product labeling as well as the principal display panel(s) of the packaging. The signal word "DANGER" is required to be in letters not less than 0.15 inch (3.8mm) high and shall appear in white on a red background. The safety alert symbol shall immediately precede the signal word with the area inside the triangle shape being white and the exclamation mark being safety red. The remaining text of the warnings shall be of such a type that the uppercase letters are not less than 0.1 inch (2.5mm) high. The required label must be in English, although it does not prohibit the use of alternate language versions of the same warning.

COMPLIANCE ACTIVITIES

The performance standard 16 C.F.R. Part 1407 (Standard) became effective for products manufactured or imported on or after May 14, 2007. The scope covers all portable generators rated no higher than 15 kilowatts and 250 volts intended to be moved for temporary use at a location where utility-supplied electric power is not available. Since the effective date of the Standard, Compliance staff has routinely inspected retailers and import shipments of generators for compliance with the labeling rule. In most cases, the generators and their packaging met the labeling requirements. There were, however, some violations found over the course of several years where: 1) labeling was not on the product, 2) labeling was not on the packaging, 3) the text on the labeling was not in the correct font size, 4) pictograms were missing, and/or 5) the label was not in English. In these cases, Compliance staff asked the manufacturer/importer to stop sale and distribution and correct the labeling (attach labeling to the product and/or packaging) and correct future production of the product to assure compliance with the requirements of 16 C.F.R. Part 1407.

There have been 16 recalls of portable generators from May 2007 through May 2016; 12 involved leaking gasoline lines, valves or filters which presents a potential fire hazard. Another recall was issued as an alert involving the rear frame support on a generator that could fail during lifting, posing a potential impact hazard. Additionally, some of the pages in the owners' manual were missing or duplicated which could deny consumers important operating or safety information. Two recalls involved the electrical components of the generator which could present a shock hazard to the consumer or a risk of fire. Finally, one recall involved the labeling of the battery on the generator. The label was printed in Japanese, rather than English, so consumers handling the battery may not be able to adequately avoid risks associated with the battery. There have been no recalls associated with violations of 16 C.F.R. part 1407 *Portable Generators: Requirements to Provide Performance and Technical Data by Labeling.*

TAB H

Date: July 21, 2016

TO : Janet Buyer, Project Manager
Division of Combustion and Fire Sciences
Directorate for Engineering Sciences

THROUGH: Kathleen Stralka, Associate Executive Director
Directorate for Epidemiology

FROM : Stephen Hanway, Director
Division of Hazard Analysis

SUBJECT : Assessing the Impact of the 2007 Generator Label Requirements

On January 12, 2007, the U.S. Consumer Product Safety Commission (CPSC) published a rule requiring manufacturers of portable generators to warn consumers of carbon monoxide (CO) hazards through a new "Danger" label. 15 U.S.C. § 1407. The label states: "Using a generator indoors CAN KILL YOU IN MINUTES." The "Danger" label rule[1] (also please see correction[2]) went into effect on May 14, 2007, and applies to any portable generator manufactured or imported after that date. By examining incidents reported to CPSC that occurred before May 14, 2007, and incidents received afterwards, CPSC can gauge whether an apparent change in the generator fatality rate has coincided with introduction of the mandatory label.

Table 1: Estimated Portable Generator Units in Use, 2007-2012

Year	2007	2008	2009	2010	2011	2012	Six-Year Average
Total Units in Use	10,541,281	10,929,475	11,245,308	11,628,854	11,966,999	12,459,571	11,461,915
Units Made since May 2007	419,159	1,601,950	2,755,258	4,001,345	5,204,473	6,541,111	3,420,549
Percent of Units in Use Made since May 2007	4.0%	14.7%	24.5%	34.4%	43.5%	52.5%	29.8%

Source: Directorate for Economic Analysis, CPSC

[1] Federal Register/Vol. 72, No. 8/Friday, January 12, 2007/Rules and Regulations pp.1443–1453. https://www.federalregister.gov/documents/2007/01/12/07-80/portable-generators-final-rule-labeling-requirements
[2] Federal Register/Vol. 72, No. 11/Thursday, January 18, 2007/Rules and Regulations pp. 2184–2185. https://www.federalregister.gov/documents/2007/01/18/07-193/portable-generators-final-rule-labeling-requirements

Table 1 presents estimates prepared by CPSC staff on the degree to which units labeled "Danger" were in use by consumers through 2012. The estimated proportion of units labeled "Danger" increased between 9 and 11 percent each year after 2007.

Table 2 presents the reported fatal, non-fire carbon monoxide incidents and deaths reported in CPSC databases for the years 2004 to 2015. The table also indicates whether staff could determine if a "Danger" label was present. The two total generator columns show that year-to-year variances in generator incidents can occur, even without label changes. The number of reported incidents ranged from 35 to 80 in the pre-label period of 2004 to 2006, and the number of reported deaths ranged from 47 to 103 during that time. Every year after the label was introduced saw more incidents than the number of incidents reported in 2004. Only 2010 saw fewer deaths than were reported in 2004.

The additional columns in Table 2 identify incidents in which a date of manufacture was known; a "Danger" label was observed; or other detail was provided in the reports to CPSC that were indicative of a "Danger" label being present. Likewise, a number of incidents that occurred after May 2007, involved generators made before May 14, 2007, or otherwise indicated that a "Danger" label was absent. However, in a number of the reported fatal incidents, staff could not determine whether a label was present.

Table 2: Number of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Involving Generators by Year and Presence of Mandatory Label, 2004–*2015*[3]

Year	Generators (Total)		Generators with Mandatory Label		Generators w/o Mandatory Label		Labelling Unknown	
	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	***607***	***820***	***47***	***82***	***276***	***376***	***284***	***362***
2004	35	47	0	0	35	47	0	0
2005	80	103	0	0	80	103	0	0
2006	63	93	0	0	63	93	0	0
2007	57	72	2	4	31	42	24	26
2008	70	95	3	3	22	30	45	62
2009	45	66	2	4	11	14	32	48
2010	37	46	3	5	13	15	21	26
2011	69	96	9	18	11	17	49	61
2012	42	48	7	9	4	6	31	33
2013	43	55	10	16	4	5	29	34
2014	*34*	*44*	*6*	*10*	*2*	*4*	*26*	*30*
2015	*32*	*55*	*5*	*13*	*0*	*0*	*27*	*42*

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2016.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

[3] See "Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2005–2015", Hnatov 2016.

Table 3 shows the proportion of generator incidents and fatality reports involving generators that included the mandatory label. Because the presence or absence of a label is frequently unknown, the proportion with a mandatory label increases substantially when the unknown incidents are removed.

Table 3: Proportion of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Associated with Generators with Mandatory Label by Year, 2004–2015

Year	Generators with Mandatory Label		Generators w/o Mandatory Label		Generators (Total)		Proportion of Total w/ Mandatory Label		Proportion w/ Mandatory Label of Known Status	
	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	***47***	***82***	***276***	***376***	***607***	***820***	***607***	***820***	***321***	***458***
2004	0	0	35	47	35	47	0%	0%	0%	0%
2005	0	0	80	103	80	103	0%	0%	0%	0%
2006	0	0	63	93	63	93	0%	0%	0%	0%
2007	2	4	31	42	57	72	4%	6%	6%	9%
2008	3	3	22	30	70	95	4%	3%	12%	9%
2009	2	4	11	14	45	66	4%	6%	15%	22%
2010	3	5	13	15	37	46	8%	11%	19%	25%
2011	9	18	11	17	69	96	13%	19%	45%	51%
2012	7	9	4	6	42	48	17%	19%	64%	60%
2013	10	16	4	5	43	55	23%	29%	71%	76%
2014	*6*	*10*	*2*	*4*	*34*	*44*	18%	23%	75%	71%
2015	*5*	*13*	*0*	*0*	*32*	*55*	16%	24%	100%	100%

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2016.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Table 4 shows the number of generator incidents and fatalities that we would have received notice of if the incidents with generators with unknown label status had the same proportion of "Danger" labels as the incidents with known label status. Assuming constant proportionality, more than 200 deaths would have occurred involving generators with "Danger" labels since the labels were introduced. In years like 2011 and 2015, we would have seen more deaths involving products labeled "Danger" than incidents in the pre-label year of 2004, if the known proportionality extended to unknowns.

There is no assurance that the unknowns would resemble the knowns, however. Therefore, these numbers should be considered with some caution. For example, it seems intuitively likely that there would be at least one fatal incident in 2015 that involved a generator without a label present.

Even though only known "Danger" labelling statuses are considered, the 47 incidents involving 82 deaths where a mandatory label was present, still suggest that the labels, by themselves, are not sufficient to eliminate the risk of a fatality associated with portable generators. Each year after 2011, more fatal generator incidents and deaths were reported that involved generators where the mandatory label was known to be present than known to be absent. There were 96 generator fatalities in 2011, the second highest year for which generator fatality counts were produced (which began in 1990).

Table 4: Proportion of Reported Fatal Non-Fire Carbon Monoxide Exposure Incidents and Deaths Associated with Generators with Mandatory Labels by Year, 2004–*2015*

Year	Generators with Mandatory Label		Generators w/o Mandatory Label		Proportion w/ Mandatory Label of Known Status		Additional Generators w/ Mandatory Labels Among Unknowns		Total Generators with Mandatory Labels	
	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	***47***	***82***	***284***	***362***	***321***	***458***	***125***	***165***	***172***	***247***
2004	0	0	0	0	0%	0%	0	0	0	0
2005	0	0	0	0	0%	0%	0	0	0	0
2006	0	0	0	0	0%	0%	0	0	0	0
2007	2	4	24	26	6%	9%	1	2	3	6
2008	3	3	45	62	12%	9%	5	6	8	9
2009	2	4	32	48	15%	22%	5	11	7	15
2010	3	5	21	26	19%	25%	4	7	7	12
2011	9	18	49	61	45%	51%	22	31	31	49
2012	7	9	31	33	64%	60%	20	20	27	29
2013	10	16	29	34	71%	76%	21	26	31	42
2014	*6*	*10*	*26*	*30*	75%	71%	20	21	26	31
2015	*5*	*13*	*27*	*42*	100%	100%	27	42	32	55

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2016.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

A hypothesis suggests that a change in the frequency of power outages could be obscuring declines in generator fatality rates.[4] Despite the relatively modest increases in usage numbers described in Table 1, an increase year-after-year in power outages might be causing these products to be used much more frequently. However, analysis of the reasons why generators were used (see Hnatov, 2015 and 2016[5]), as summarized in Table 5, shows that in most years before and after the "Danger" labels were required, most of the fatal incidents were not due to power outages, but were due to other reasons. The reasons include: shutoffs by the power company for nonpayment; power to non-building structures, such as sheds, trailers, boats, or campers; power for homes under construction; power for structures that do not normally have electricity, like garages, campers or mobile homes; and preparation work for anticipated storms.

[4] Recht, Joel, Log of Meeting, *PGMA Technical Summit on Carbon Monoxide (CO) Hazard Mitigation for Portable Generators*, March 17, 2016.
[5] Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014. U.S. Consumer Product Safety Commission. June 2015. Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2005-2015. U.S. Consumer Product Safety Commission. June 2016.

Table 5: Number of Reported Non-Fire Carbon Monoxide Fatalities for Incidents Associated with Generators by Reason for Use, 2004–*2015*

Year	Generators (Total)		Power Outage Due to Weather or Problem with Power Distribution		All Other Known Reasons		Unknown why Generator Used	
	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	***607***	***820***	***157***	***218***	***330***	***455***	***120***	***147***
2004	35	47	7	11	22	28	6	8
2005	80	103	37	53	30	36	13	14
2006	63	93	11	17	41	58	11	18
2007	58	73	15	23	30	35	12	14
2008	70	95	19	26	38	53	13	16
2009	45	66	10	17	24	35	11	14
2010	36	45	5	6	24	31	8	9
2011	69	96	19	27	37	56	13	13
2012	42	48	15	16	19	24	8	8
2013	43	55	11	12	23	31	9	12
2014	*34*	*44*	*5*	*5*	20	27	*9*	*12*
2015	*32*	*55*	*3*	*5*	22	41	*7*	*9*

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2016.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Table 6 shows the reasons as a proportion of the total fatal incidents and death reports by year. The only year in which outage numbers exceeded other reported reasons was 2005. There is no apparent increasing trend in outages consistent with an outage increase hypothesis.

Table 6: Proportion of Reported Non-Fire Carbon Monoxide Fatalities for Incidents Associated with Generators by Reason for Use, 2004–*2015*

Year	Generators (Total)		Power Outage Due to Weather or Problem with Power Distribution		All Other Known Reasons		Unknown why Generator Used	
	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths	Incidents	Deaths
Total	***607***	***820***	***157***	***218***	***330***	***455***	***120***	***147***
2004	35	47	20%	23%	63%	60%	17%	17%
2005	80	103	46%	51%	38%	35%	16%	14%
2006	63	93	17%	18%	65%	62%	17%	19%
2007	58	73	26%	32%	52%	48%	21%	19%
2008	70	95	27%	27%	54%	56%	19%	17%
2009	45	66	22%	26%	53%	53%	24%	21%
2010	36	45	14%	13%	67%	69%	22%	20%
2011	69	96	28%	28%	54%	58%	19%	14%
2012	42	48	36%	33%	45%	50%	19%	17%

2013	43	55	26%	22%	53%	56%	21%	22%
2014	*34*	*44*	15%	11%	59%	61%	26%	27%
2015	*32*	*55*	9%	9%	69%	75%	22%	16%

Source: U. S. Consumer Product Safety Commission, Directorate for Epidemiology, 2016.
Italicized numbers indicate that reporting of incidents is ongoing. Counts may change in subsequent reports.

Rates computed by combining the total generator fatalities observed with the CPSC estimates of generators in use (see Table 7) do not find dramatic declines in the rate of generator fatalities between 2007 (when an overwhelming majority of generators did not include "Danger" labels and subsequent years (when the proportion of generators in use with "Danger" labels appears to have steadily risen). Two of the five years subsequent to 2007 saw a higher number of fatalities per million units in use.

Table 7: Estimated Portable Generator Units in Use, 2007 - 2012

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Total Units in Use	10,541,281	10,929,475	11,245,308	11,628,854	11,966,999	12,459,571
Generator CO Fatalities Reported	72	95	66	46	96	48
Fatalities per Million Units in Use	6.8	8.7	5.9	4.0	8.0	3.9

Source: Directorate for Economic Analysis and Directorate for Epidemiology, CPSC

In conclusion, the data do not provide sufficient evidence to conclude that the "Danger" label standard has substantially reduced or eliminated the carbon monoxide fatality risks associated with portable generators. Prior work (see Styles et al[6]) casts doubt on how well labels are noticed, recalled, or heeded. These findings make it seem unlikely that any major reductions in fatalities should be anticipated due to the introduction of these labels.

[6] Timothy Styles, MD, Patricia Przysiecki MPH, Gary Archambault, MS, Lynn Sosa, MD, Brian Toal, MPH, Julie Magri, MD, and Matthew Cartter, MD, "Two Storm-Related Carbon Monoxide Poisoning Outbreaks – Connecticut, October 2011 and October 2012, *Arch Environ Occup Health*. 2015 ; 70(5): 291–296. doi:10.1080/19338244.2014.904267.

TAB I

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

MEMORANDUM

DATE: October 3, 2016

TO : File

THROUGH: Joel Recht, Ph.D, Associate Executive Director
Directorate for Engineering Sciences

Mark Kumagai, Director
Division of Mechanical and Combustion Engineering, Directorate for Engineering Sciences

FROM : Janet Buyer, Project Manager
Division of Mechanical and Combustion Engineering, Directorate for Engineering Sciences

SUBJECT : Rationale for Proposed Performance Requirements, Effective/Compliance Dates, and Certification for Staff's Proposed Rule for Portable Generators

1. Introduction

Portable generators present serious risks for fatal and nonfatal carbon monoxide (CO) poisonings. As of May 21, 2015, databases of the U.S. Consumer Product Safety Commission (CPSC) contained reports of at least 751 in-scope[a] generator-related consumer CO poisoning

[a] In-scope cases are unintentional, not work-related, non-fire CO poisoning deaths associated with a consumer product under the jurisdiction of the CPSC. Out-of-scope cases are cases that involve CO sources that are not under the jurisdiction of the CPSC (including motor vehicle exhaust cases), fire or smoke-related exposures, or intentional CO poisonings. Examples of out-of-scope cases include: poisonings due to gases other than CO (*i.e.*, natural gas, ammonia, butane); poisonings from motor vehicle exhaust or generators permanently installed in boats or recreational vehicles; and work-related exposures.

deaths resulting from 562 incidents, which occurred from 2004 through 2014.[b,1] (Staff includes a subset of 659 of these deaths that occurred from 2004 through 2012 in staff's epidemiological benefits and preliminary regulatory analyses for the notice of proposed rulemaking (NPR)). Nearly 75 percent of the 751 deaths occurred in a fixed structure home location, which includes detached and attached houses, apartments, fixed mobile homes, and cabins used as a permanent residence. Another 22 percent occurred at non-fixed home locations or temporary structures (such as trailers, horse trailers, recreational vehicles, cabins used for temporary shelter, tents, campers, boats, and vehicles) or in external structures at home locations (such as sheds and detached garages). The remaining 3 percent occurred at unknown or other locations. In the same 11-year period, 42 deaths from 30 incidents occurred with the generator operating outdoors, where the exhaust infiltrated into a nearby fixed structure home, non-fixed home, or temporary shelter.[2,c] To put generator CO hazards into perspective, relative to the other two potentially fatal hazards of electrocution and fire associated with generators, for the 11-year period of 2004 through 2014, CPSC has records of six non-work-related fatal electrocutions[3] and 15 fire-related deaths from generators.[4]

In the 9-year period of 2004 through 2012, staff estimates there were a minimum of about 25,400 medically attended CO poisoning injuries involving generators.[5] It is unknown how many of these injuries were due to a generator operating in an enclosed or semi-enclosed space, versus outdoors.

In October 2006, staff presented a briefing package to the Commission suggesting that the most reliable way to limit consumer exposure to harmful CO levels is to limit the engine's CO emission rate.[6] This recommendation is consistent with other product safety experts' preferred approach of addressing any hazard by trying to eliminate or reduce it *at its source*.[7] The Commission published in the *Federal Register* on December 12, 2006 an advance notice of proposed rulemaking (ANPR).[8] Staff began to research and investigate technologies that could reduce the risk of CO poisoning associated with portable generators.

Because the overwhelming majority of the generator-related CO fatalities in CPSC's databases involved generators used in enclosed or semi-enclosed spaces, staff investigated several approaches to mitigate the CO hazard, including not only CO emission rate reduction, but other concepts intended to automatically shut off a generator when operated in an enclosed space. Although the use of an automated engine shut-off system for portable generators to prevent excessive CO accumulation could potentially eliminate CO-related deaths and injuries resulting from generator operation in an enclosed or semi-enclosed space, staff's investigations into four different approaches for an automatic shutoff system did not demonstrate that the concept could be implemented satisfactorily.[9,10,11,12] Furthermore, if a shutoff system is not combined with a reduction in the generator's CO emission rate, there would be no improvement in safety, compared to current generators, if the shut off system fails to perform. Therefore,

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[b] Superscripted numbers refer to references listed in section 6 of this memorandum. Superscripted letters refer to footnotes.

[c] This excludes 2 deaths in 2011 caused by a stationary generator operated outdoors.

reliability is of paramount importance. If a shutoff system fails to perform in any of the varied scenarios and extremes of environmental conditions in which consumers use generators, consumers would continue to be exposed to CO emissions at the same rate that generators currently emit.

Staff was not able to demonstrate how an automatic shutoff system could be implemented. However, staff demonstrated the technical feasibility of using existing engine emission control technology installed on a small spark-ignition (SI) engine powering a portable generator to reduce the CO emission rate well below that of current carbureted generators to levels staff expects will reduce CO deaths and injuries.[13,d] Staff also examined the results of a feasibility demonstration program conducted by the U.S. Environmental Protection Agency (EPA) using similar technology to reduce the exhaust emissions from small SI engines.[14] From the EPA's work, CPSC staff concludes that the EPA demonstration program also shows that significantly lower CO emission rates are feasible. Finally, staff measured the CO emission rates from three portable generators (two commercially available and one manufacturer's prototype) with the same emissions control technology used in CPSC's and the EPA's demonstration programs. Again, staff concludes that significantly reduced CO emission rates, as compared to current carbureted generators, are technically feasible. Staff used these findings, described in sections 2, 3, and 4 of this memorandum, to provide the rationale for staff's recommendations for proposed performance requirements, described in section 5 of this memorandum. Section 5 also discusses staff's recommended effective date, compliance date and certification requirements.

Appendices contain additional information. Appendix A contains staff's responses to some of the public comments CPSC received after the ANPR was published and after two reports, both pertaining to the prototype technology demonstration program discussed in section 2, were made publicly available on CPSC's website. Appendix B contains a synopsis of staff's and stakeholders' activities that have taken place within a task group for an Underwriters Laboratories (UL) voluntary standard for portable generators, UL 2201, which formed to develop requirements for UL 2201 to address the CO hazard associated with this product.

2. CPSC's 2-Part Prototype Low CO Emission Generator Technology Demonstration Program

Staff developed a two-part technology demonstration program to show that the small SI engine powering a commercially available portable generator could be modified with existing emission control technology to reduce its CO emission rate to levels expected to reduce the risk of fatal and severe CO poisoning. The objective of the first part of the program was to develop, from a current carbureted engine-driven generator, a prototype with a CO emission rate reduced to the lowest technically feasible level, without negatively impacting the engine's power output,

[d] Staff conducted the demonstration on a generator powered by an SI engine because most of the generators that were associated with fatal CO poisoning were gasoline-fueled generators. Although the fuel type could not be ascertained in 52 of the 562 incidents, of the 510 cases where the fuel type used in the generator was known, 99 percent (506 of 510) were gasoline-fueled generators. Of the remaining incidents, three involved propane-fueled generators, and the other incident involved a diesel-fueled generator.

durability, maintainability, fuel economy, and risk of fire and burn, and ensure that the engine continued to meet EPA small SI engine exhaust emission standard for hydrocarbons and oxides of nitrogen (HC+NOx). For this, staff sought a target CO emission rate reduction of 90 percent. The objective of the second part of the program was to assess the efficacy of the prototype generator in reducing occupant exposure profiles created by the generator's operation in a fatal scenario commonly reported in CPSC's incident data, compared to the exposure profiles created by the unmodified carbureted generator. The first part of the program is described in section 2.1, and the second part is described in section 2.2.[e]

2.1 Part One: Prototype Development and Durability Testing at the University of Alabama

The prototype development and durability phase of the program was conducted under contract[f] with The University of Alabama (UA). The prototype development started with a commercially available generator with an advertised continuous electrical power output rating of 5.0 kW. This generator was powered by a small, air-cooled, single-cylinder, non-handheld Class II[g] carbureted engine with a 389 cubic centimeter (cc) displacement and overhead valve (OHV) configuration. The prototype was a modification of that engine, replacing its carburetor with a closed-loop electronic fuel-injection (EFI) system, using an oxygen sensor in the exhaust for fuel control feedback, that was tuned to stoichiometry[h] and replacing the muffler with a different one that had a small three-way catalyst (TWC) integrated into it. Staff pursued this emission control strategy because of responses from a Request for Information (RFI) (issued by staff before UA's contract), seeking information on ways to significantly reduce engine CO emissions. In addition, staff used input from EPA technical staff. EPA staff and a number of the RFI respondents stated that using a closed-loop EFI system greatly reduces the amount of unburned fuel in the exhaust, which would allow a catalyst to be used as an aftertreatment to reduce by 90 to 95 percent the amount of CO leaving the tailpipe without causing unmanageable heat buildup in the catalyst. EPA staff indicated that combinations of catalytic converters and fuel injectors are already used in the marketplace on small displacement 2-stroke and 4-stroke engines on motor-scooters in China and India and on small displacement motorcycles in the United States.[15,16,17,18,19]

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[e] Complete documentation on the prototype generator and the demonstration program is provided in reference 13.

[f] CPSC-S-06-0079.

[g] The EPA broadly categorizes small SI engines as either non-handheld or handheld and within each of those categories further distinguishes them into different classes, which are based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cc up to 225 cc and Class II having displacement at or above 225 cc but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Some handheld engines are used to power very small portable generators, but the vast majority of generators are powered by Class I and Class II engines. Class II engines typically power generators with 3.5kW or greater rated power output.

[h] Stoichiometry is the theoretical air-fuel ratio (AFR) for complete combustion and is the theoretical point for nearly the lowest amount of CO production. The AFR associated with stoichiometry for typical gasoline formulations is nominally 14.6.

UA subjected the prototype generator to a durability program by operating the generator for a total of 500 hours, which was the manufacturer's rated useful life of the engine at the time of the program. For the durability program, an automated hourly cyclic load profile, consisting of six resistive loads, was applied through the generator's 240-volt receptacle to replicate the 6-mode rated speed test cycle that the EPA uses in its emission test procedures for non-handheld small SI engines,[i] which includes engines used for generator applications. The EPA's 6-mode test cycle was developed with industry to replicate typical in-use operation of small utility engines when used in all types of engine-driven products. The test cycle defines the six modes or loads that the engine needs to power while mounted on a dynamometer as emission rates are measured. Additionally, the test cycle defines the weighting factor that is associated with each mode to represent the duration that the engine operates at each of the six modes over its lifetime. This EPA 6-mode test cycle is based on the approach that these weighting factors represent lifetime engine load levels, regardless of the application in which the engine is installed. Because staff has been unable to find information that is representative of how consumers typically load their generators, staff assumes that the typical load profile of a portable generator used by a consumer is that of the EPA's 6-mode test cycle and it is the *weighted* CO emission rate resulting from the generator's operation at *all* six modes that the consumer is potentially exposed to when using a generator. Therefore, CPSC staff used the weighting factors to determine both the duration for each of the six modes in the hourly cyclic load profile used during the durability program, as well as to determine the generator's weighted CO emission rate in grams per hour (g/hr).[j]

UA made periodic emission measurements with each of the six modes applied with the engine installed in the generator at select times during the 500-hour durability program.[k] Simultaneous to the durability program on the prototype generator, an unmodified baseline

[i] The EPA's applicable regulation is 40 C.F.R. part 1065, *Engine-Testing Procedures*.

[j] It is important to note that the EPA's test procedures require the engine's exhaust emission rate be determined and reported in grams per kilowatt-hour (g/kW-hr), not g/hr, and that the rate is measured when the engine is mounted on a dynamometer, not the end product in which it is used. Because staff is concerned about CO emission rates from an engine when installed and operating in a generator, not on a dynamometer, and there is no industry standard that relates a generator's power output to the engine's maximum power, staff's focus is on the weighted CO rate of a *generator* in *g/hr*, not g/kW-hr. As explained in section 5, staff considers engine size in staff's performance requirements for the proposed rule, by considering the EPA classification of the engine powering the generator, which is a function of engine displacement, not maximum engine power. See **NOTE** at the end of this section for additional information.

[k] The NOTE at end of section 2.1, also explains that mode 1, as defined by the EPA is full engine power, as measured on a dynamometer test platform, and the five other modes (modes 2 through 6), are percentages (75%, 50%, 25%, 10%, and no load, respectively) of mode 1 power. With the engine installed in the generator, full engine power, as determined on the dynamometer by disabling or decoupling the governor from the throttle and physically holding the throttle wide open, was not achievable. Therefore, the electrical power that UA applied for mode 1 was the maximum that could be sustained without tripping the generator's breakers on the 240-volt circuit. This was found to be 5.5 kW, 500 watts greater than the advertised, continuous electrical power rating of the generator. For modes 2 through 6, the engine manufacturer's advertised 8.2 kW maximum power rating of the engine was used with the generator manufacturer's alternator efficiency curve to estimate the electrical load required to achieve those desired engine loads. The loads, in kW, for modes 2 through 6, were determined to be 5.50 4.75 3.25 1.50 0.625 0.0 and the duration for each, derived from the weighting factors, were 5.5, 12, 17.5, 18, 4, and 3 minutes, respectively.

carbureted generator, identical to the unmodified prototype generator, was subjected to the same durability program and emissions measurement procedures to compare performance. After the durability program was completed, end-of-life emission testing, conducted both with the engine installed in the generator, as well as on a dynamometer in accordance with the EPA small SI engine test procedures, was performed by an independent laboratory, Intertek Carnot Emission Services (CES). The dynamometer tests were performed to ascertain whether, at the end of the engine's rated useful life, the prototype engine's emissions would meet the EPA's Phase 2 requirement of 12 g/kW-hr for HC+NOx, to which the unmodified OEM version of the engine was originally labeled certified.[l]

At the completion of the durability program, UA determined that the prototype generator's weighted CO emission rate and its fuel consumption rate were reduced by 93 percent and 20 percent, respectively, compared to the unmodified baseline generator. The prototype's muffler surface temperatures across all six modes ranged from 50°C to 83°C hotter than the muffler on the unmodified baseline unit. Staff believes this increase may largely be attributed to the muffler configuration because the prototype muffler configuration had less internal baffling than the original muffler to provide space inside the muffler to easily and readily accommodate the catalyst, without significant redesign of the muffler. Staff believes that with minimal effort redesigning the muffler, this increase in surface temperature could be addressed. The temperature of the prototype's muffler shroud was 110°C or less when the engine was operated over the range of deliverable power and was significantly lower than the muffler surface temperature range of 266 to 434°C measured on the surface of the unmodified baseline unit's muffler, which was not shrouded.

CES's testing under EPA test procedures showed that the prototype engine, while mounted on a dynamometer and equipped with the muffler with an installed catalyst, had a 6.0 g/kW-hr CO emission rate. This emission rate is 99 percent below the EPA's Phase 2 and Phase 3 CO standard of 610 g/kW-hr. In addition, the prototype had an HC+NOx exhaust emission rate of 6.7 g/kW-hr, which is 45 percent below the EPA's Phase 2 HC+NOx standard for a Class II engine (to which the engine was originally certified) and is 16 percent below the Phase 3 HC+NOx standard that the EPA adopted shortly after CPSC's development program with UA began. CES's dynamometer testing also showed that the prototype engine delivered a maximum power of 7.9 kW, which is within 0.3 kW of the advertised rated power for the unmodified OEM carbureted engine. CES's emission testing of the prototype generator (with the engine still installed in the generator, as opposed to mounted on the dynamometer) measured a weighted CO emission rate of 26.10 g/hr.[m] This met the objective of this phase of staff's technology demonstration program.

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[l] The EPA sets emission standards for all small SI engines. These engines provide power for a wide range of products typically owned by consumers, including portable generators. The EPA's primary emphasis is on regulating emissions that contribute significantly to nonattainment of the National Ambient Air Quality Standards (NAAQS) for ozone, of which hydrocarbons and oxides of nitrogen (HC+NOx) are precursors. For non-handheld engines, the EPA adopted emission standards referred to as Phase1 in 1995, Phase 2 in 1999, and Phase 3 in 2008.

[m] 26.10 g/hr was the highest of three tests. The other two tests yielded weighted CO rates of 23.47 and 19.38 g/hr (reported in CES's test report, which is TAB D in reference 13).

NOTE: The EPA's test procedures require the engine's exhaust emission rate be determined and reported in terms of g/kW-hr. An engine's g/kW-hr emission rate is calculated from the engine's weighted CO rate, divided by the engine's weighted power, as determined *when the engine is mounted on a dynamometer* (not the end product the engine is used in) using the following equation:

CO rate (g/kW-hr) = weighted CO rate (g/hr) / weighted power (kW)

Where
weighted CO rate = $(wf_1 \times m_1) + (wf_2 \times m_2) + (wf_3 \times m_3) + (wf_4 \times m_4) + (wf_5 \times m_5) + (wf_6 \times m_6)$
and
weighted power = $(wf_1 \times p_1) + (wf_2 \times p_2) + (wf_3 \times p_3) + (wf_4 \times p_4) + (wf_5 \times p_5) + (wf_6 \times p_6)$

wf_1 (weighting factor for mode 1) = 0.09
wf_2 (weighting factor for mode 2) = 0.20
wf_3 (weighting factor for mode 3) = 0.29
wf_4 (weighting factor for mode 4) = 0.30
wf_5 (weighting factor for mode 5) = 0.07
wf_6 (weighting factor for mode 6) = 0.05

m_1 through m_6 = CO mass flow rate for modes 1 through 6, (g/hr)

p_1= maximum engine power as measured with the engine mounted on a dynamometer and the throttle physically held wide open (a.k.a. WOT), (kW)
p_2= power at mode 2 = 0.75 x maximum engine power
p_3= power at mode 3 = 0.50 x maximum engine power
p_4= power at mode 4 = 0.25 x maximum engine power
p_5= power at mode 5 = 0.10 x maximum engine power
p_6= power at mode 6 = no load

Applying the weighting factor for each mode to the power at each mode, then
weighted power = 0.467 x maximum engine power

2.2 Part Two: Comparative Testing of Unmodified Carbureted (Baseline) and Prototype Generators at National Institute for Standards and Technology

The second part of staff's technology demonstration program was conducted under an interagency agreement (IAG) with the National Institute for Standards and Technology (NIST).[n] One of the objectives of the IAG was to operate an unmodified carbureted generator (the same model generator as the unmodified baseline generator tested at UA, but referred to at NIST as

[n] CPSC-1-06-0012.

Unmod GenX) and a prototype generator (nearly identical to UA's durability tested prototype[o] but referred to by NIST as GenSO1) in the attached garage of a test house on NIST's campus.[p] A series of paired tests with seven different house configurations[q] was performed on both generators. In each test the CO accumulation in the garage and its transport into the house was measured for the purpose of providing a sense of how quickly a commonly fatal consumer scenario develops with an existing carbureted generator, and what the comparative results are from the same tests with the fuel-injected catalyzed prototype. The other objective of the IAG was to determine each generator's mass CO emission rates at each of the six loads used in the load profile. Both objectives also supported NIST's validation of their multi-zone airflow and contaminant transport model CONTAM, which is used to predict contaminant concentrations throughout a modeled structure resulting from a source mass emission rate located somewhere within the structure. (NIST subsequently used CONTAM in predicting the health effects of the CO rates associated with staff's recommended performance requirements provided in section 5. That modeling effort is described in references 22 and 33.)

By comparing the garage CO concentrations after equal periods of generator run-time in the tests with the garage bay door fully closed, the prototype showed 97 percent reduction in the amount of CO released into the garage compared to the unmodified carbureted generator. This reduction (consistent with UA's findings) translated into much lower levels of CO transporting throughout the house. Staff's health effects modeling on each room's CO time course profile[r] and that of the garage estimated occupants' carboxyhemoglobin (COHb)[s] levels, which staff used to predict the onset of obvious CO poisoning symptoms and incapacitation by using benchmark COHb levels associated with these health effects.[20] Staff's analysis estimated that the time interval for all hypothetical occupants before being incapacitated is significantly extended. For example, in one test in which the garage bay door and connecting door to the house were both closed, the time interval increased by a factor of 12 with the prototype, compared to the unmodified carbureted generator — from 8 minutes to 96 minutes — for the deadly scenario of a

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[o] Although staff preferred to use the exact same model generator for the prototype constructed for testing at NIST as UA's unmodified baseline generator and durability tested prototype and unmod GenX, that model was no longer available when staff tasked UA to construct GenSO1. The generator used for Gen SO1 had the same model engine but had a different alternator with an advertised continuous electrical power output rating of 7 kW. Additionally, the engine control unit (ECU) used on UA's durability tested prototype was no longer supported by its manufacturer. Therefore, an upgraded version provided by the same manufacturer was used for GenSO1. This ECU differed from the previous model in that it used an external manifold air pressure (MAP) sensor and a heated switching oxygen sensor, and it also had some programmed features for improved fuel control.

[p] NIST's test house is single-level, single family, 1,500 square foot house that is configured for conducting indoor air quality studies. Its size is only slightly larger than the median size home involved in fatal generator-related CO poisoning deaths, where home size information is known.

[q] The seven house configurations differed by position of the garage bay door, position of the door connecting the garage to the house, and status of the house's Heating, Ventilating, and Air Conditioning (HVAC) fan.

[r] CO time course profile is the CO concentration versus time.

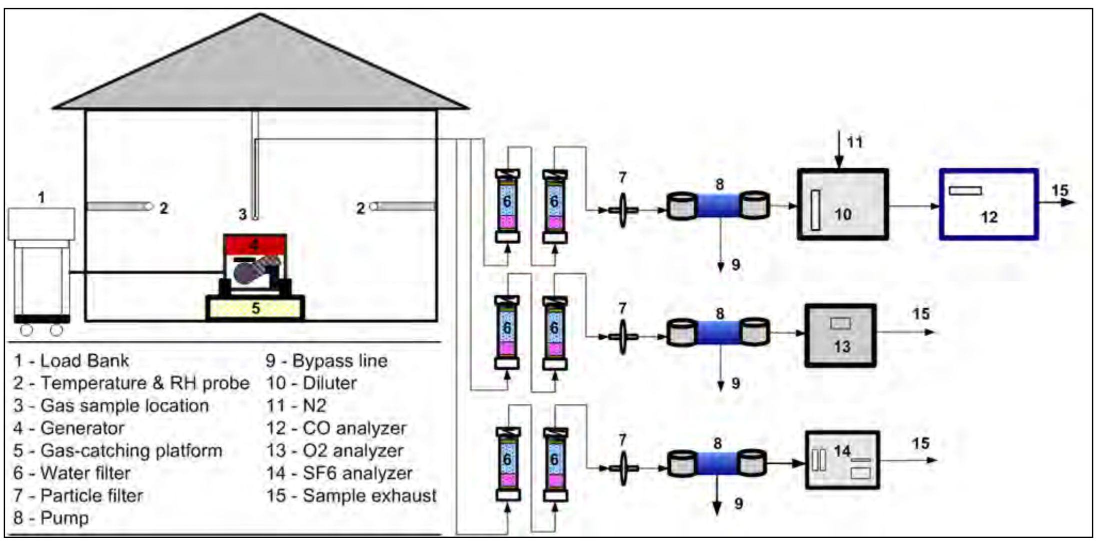
[s] COHb, expressed as a percentage, reflects the percentage share of the body's total hemoglobin pool occupied by CO. Although the relationship is not absolute, percent COHb levels can provide a useful index of CO poisoning severity. It is measured with a blood sample from the exposed person.

consumer in the garage with the generator. The time interval increased even more for occupants inside the house.

Staff believes this increased time interval could give occupants an opportunity to remove themselves from the exposure before being incapacitated (perhaps due to their symptoms or other reasons such as an unrelated need to leave the house) or to be found alive by others. Staff predicts the high CO emission rate of the unmodified carbureted generator would cause some of the occupants, depending on where they are located, to experience relatively quick onset of confusion, loss of muscular coordination, loss of consciousness, and death, without having first experienced milder CO poisoning symptoms associated with low or slowly rising CO-induced hypoxia.

This significant difference in exposure profiles created by the two different generators is due to the different emission rates of CO, which each emitted as the generator operated in the garage. To quantify those emission rates, and to support NIST's CONTAM model validation effort, NIST conducted a series of tests on both generators in a single-zone enclosed space (shed), as depicted in Figure 1.[21]

Figure 1. Schematic of Experimental Setup in Shed

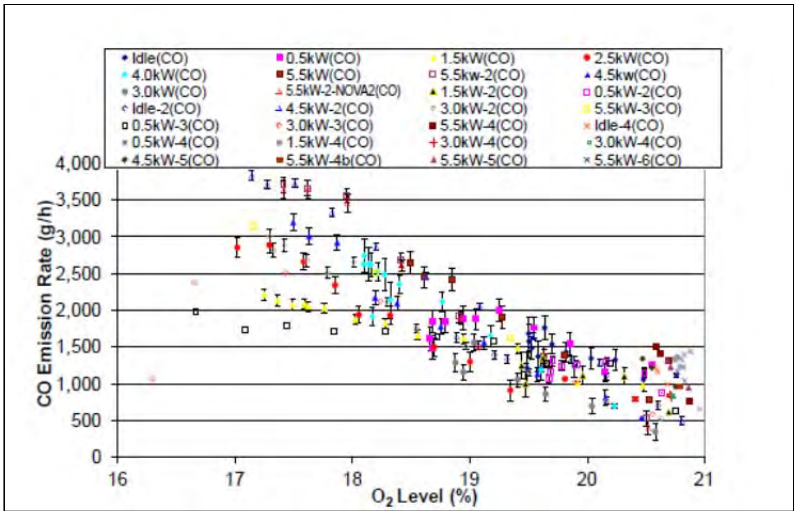


By measuring the rise in CO concentration in the shed over a given time interval, and knowing the shed's volume and air exchange rate through it, NIST calculated the CO emission rate using a differential mass balance equation. NIST calculated the CO rate based on the CO concentration rise over 5-minute time intervals and then associated that CO rate with the oxygen level that was in the shed at the end of that 5-minute interval.

The results from testing the carbureted generator showed that its CO emission rate was, depending on the load, in the range of 500 g/hr to 1500 g/hr at and near normal oxygen (~20.9%); and as the oxygen dropped to nominally 17.0 to 17.5 percent oxygen, the CO rates for the loads increased by a nominal range of 2 to 5 times. See Figure 2. Overall, the generator's weighted CO emission rate increased by a factor of 3.[22] From NIST's garage tests in which the garage oxygen level was measured, oxygen depletion was known to have occurred during the tests with the unmodified carbureted generator because the garage oxygen level dropped to the range of 16.0 to 17.5 percent oxygen in the four tests conducted with the bay door fully closed.

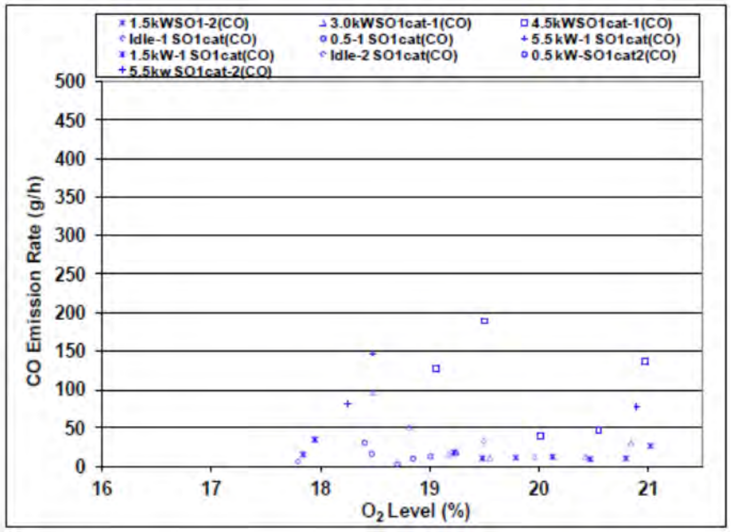
From these results, NIST determined that the weighted CO rate of the unmodified carbureted generator rose to 2567 g/hr in 17 percent oxygen, from a rate of 863 g/hr in normal oxygen.

Figure 2. CO Emission Rates of Carbureted Generator Unmod Gen X



In stark contrast, the prototype's CO emission rates at and near normal oxygen, depending on the load, were, in most cases, below 50 g/hr. Staff acknowledges that the prototype was not tested in the shed in oxygen as low as 17.0 percent; however, the data that were collected did not indicate an obvious or clear trend toward higher emission rates as the oxygen level dropped over the same range as was observed with the carbureted generator. See Figure 3. At the time, staff attributed this performance to the prototype generator's oxygen sensor providing feedback for closed-loop fuel control. In the four closed garage bay door tests with the prototype generator, oxygen depletion also occurred, but to a lesser extent compared to the carbureted generator, because the garage oxygen level was measured in the range of 17.8 to 19.5 percent in those four tests.

Figure 3. CO Emission Rates of Prototype Generator Gen SO1



From these results, NIST determined that the weighted CO rate of the prototype generator is 49 g/hr, regardless of the oxygen level.[t] Compared to the CO emission rate of the carbureted generator in normal oxygen, this represents a 94 percent reduction. This reduction is consistent with UA's reported 93 percent reduction in CO emission rate from the prototype generator, relative to the unmodified baseline generator; and this reduction is also consistent with the reduction NIST determined from the garage tests.

Staff received a number of comments regarding staff's and NIST's reports on the technology demonstration program. A summary of many of these comments and staff's responses are provided in Appendix A.

3. EPA's Technology Demonstration Program Using EFI on Small SI Engines

The EPA has conducted a technology demonstration program using EFI on small SI engines, focused on reducing emissions that contribute significantly to ozone, which are hydrocarbons and oxides of nitrogen (HC+NOx); EPA has not been focused on reducing CO emissions. In this program, the EPA examined the feasibility of two different levels of HC+NOx emission reduction from the Phase 2 standard of 12 g/kW-hr for the Class II engines in particular. For the more stringent of the two levels, the EPA applied EFI and high-efficiency catalysts on two single-cylinder, air-cooled engines, both nominally 500 cc in displacement with OHV configuration.[23,24] Their goal with this work was to demonstrate the safe and effective use of existing emission control systems in reducing the HC+NOx emissions by 70 percent or greater. Because CO and NOx engine emissions have an inverse relationship, the EPA specifically chose to test with catalyst formulations designed to minimize CO oxidation.[u]

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[t] Calculated by applying the weighting factors to the modal CO rates of GenSO1 reported in Table 13 in NIST TN 1781 (reference 21).

[u] Oxidation of CO to carbon dioxide (CO_2) is the means by which CO emissions are reduced in a catalyst.

In this part of the EPA's demonstration program, they used low-cost engine management and fuel-injection systems, similar to what UA used for the CPSC prototype generator, originally developed for motor-scooter and small motorcycle applications. However, to reduce cost as much as possible, EPA chose not to use an oxygen sensor necessary for feedback to make it a closed-loop fuel control system (FCS). For both engines, the EPA replaced the carburetor with open-loop EFI that was calibrated rich (lower air to fuel ratio) of stoichiometry at moderate-to-high loads and near stoichiometry at light-load conditions to achieve the desired emission control of HC+NOx, while maintaining or improving fuel consumption, engine durability, and performance. Integrated catalyst-muffler systems were developed for each, with a total of six different TWC catalysts to investigate different metal loadings and substrate cell densities, all of which were selected to prioritize NOx reduction and HC oxidation over CO oxidation. This is largely the same fuel control and catalytic aftertreatment strategy implemented by UA in which most of the CO reduction is in the engine's combustion process and then the catalyst is used as aftertreatment to primarily reduce NOx. However, UA used a closed-loop system and tuned the fuel control to stoichiometry at all loads.

Staff examined the data from that program and found that the engines achieved 67 and 69 percent reductions in their CO emission rates, even though the catalysts were selected to favor HC+NOx selectivity over CO oxidation.[25] For the Briggs & Stratton engine, its OEM carbureted CO rate was 333 g/kW-hr, and in its EFI/catalyst configuration with the same catalyst that achieved the 1.8 kW-hr HC+NOx rate, it achieved a 120 g/kW-hr CO rate. Looking at the weighted CO rate in terms of g/hr for this engine, the CO rate was reduced from 1503 g/hr to 498 g/hr. For the Kohler engine, its OEM carbureted CO rate was 475 g/kW-hr; and in its EFI/catalyst configuration with the same catalyst that achieved the 2.2 g/kW-hr HC+NOx rate, it achieved a 154 g/kW-hr CO rate. Looking at the weighted CO in terms of g/hr for this engine, the CO rate was reduced from 2017 g/hr to 631 g/hr.

Although the EPA noted that some engines may need improvements (such as redesign of cooling fins, fan design, combustion chamber design, and/or a pressurized oil lube system) to accommodate stoichiometric fuel control, the EPA concluded from this program that *closed*-loop EFI with fuel control at or near stoichiometry *is* technically feasible and *is not* cost prohibitive on *all* Class II engines. Additionally, they concluded that with the average 2.0 g/kW-hr HC+NOx emission rate demonstrated on the two engines, they could have set a 4.0 g/kW-hr HC+NOx emission standard to apply to all Class II engines, based on the results for these two engines.

3.1 Staff's Assessment of Feasible Emission Rates if EPA Had Additional Engineering Focus on Reducing CO emissions

As stated above, even with the EPA intentionally trying to minimize any reduction in CO emissions in their feasibility program (so as to maximize HC+NOx reduction), the EPA achieved an average 68 percent reduction in the CO emission rate while achieving a 74 percent reduction in HC+NOx. Staff believes that had EPA had an engineering focus on reducing CO emissions in addition to HC+NOx, a lower weighted CO emission rate could have been achieved.

Specifically, staff believes a lower CO emission rate could have been achieved by using an oxygen sensor for closed loop feedback, operation closer to stoichiometric at the higher loads, and a different catalyst formulated for higher conversion efficiency of CO. Staff believes that if the EPA had used an oxygen sensor for feedback, fuel control on the Kohler engine could have been tuned to oscillate about 0.98 Lambda[v] without needing any engine design improvements because the Kohler engine appears to have had sufficient headroom with respect to its cooling system design and temperatures to allow some recalibration of the air-fuel ratio (AFR) from that of the OEM carbureted engine. Staff believes the other engine did not have this flexibility as the EPA had to retrofit an oil cooler to keep the oil temperature in the OEM configuration from exceeding 140°C during modes 1 and 2.

As a result, staff focused on the emission data from the EFI-only configuration of the Kohler engine. The EPA had tuned Lambda for modes 1 through 3 to nominally 0.95 and tuned modes 4 through 6 to nominally 1.0. To estimate the engine-out CO emission rates for modes 1 through 3 if Lambda had been tuned to 0.98, staff used figure 4[26], which shows the variation in emission constituents in the exhaust of a SI engine as a function of Lambda or AFR. As Lambda moves closer to stoichiometry from 0.95 to 0.98, staff estimated that those mode's CO and HC emissions are reduced by nominally 50 and 30 percent, respectively, and NOx emission is increased by nominally 30 percent. The resulting CO, HC, and NOx emissions are shown below in Table 1. The weighted CO rate is reduced by 48 percent, from 1232 g/hr to 647 g/hr.

[v] Lambda is ratio of actual air-fuel ratio (AFR) to stoichiometric AFR. So Lambda=1.0 means the fuel control is stoichiometric, the theoretical point of complete combustion and the theoretical point for nearly the lowest amount of CO production.

Figure 4. Variation in Emission Constituents in the Exhaust of an SI Engine as a Function of Lambda or AFR(ref 26)

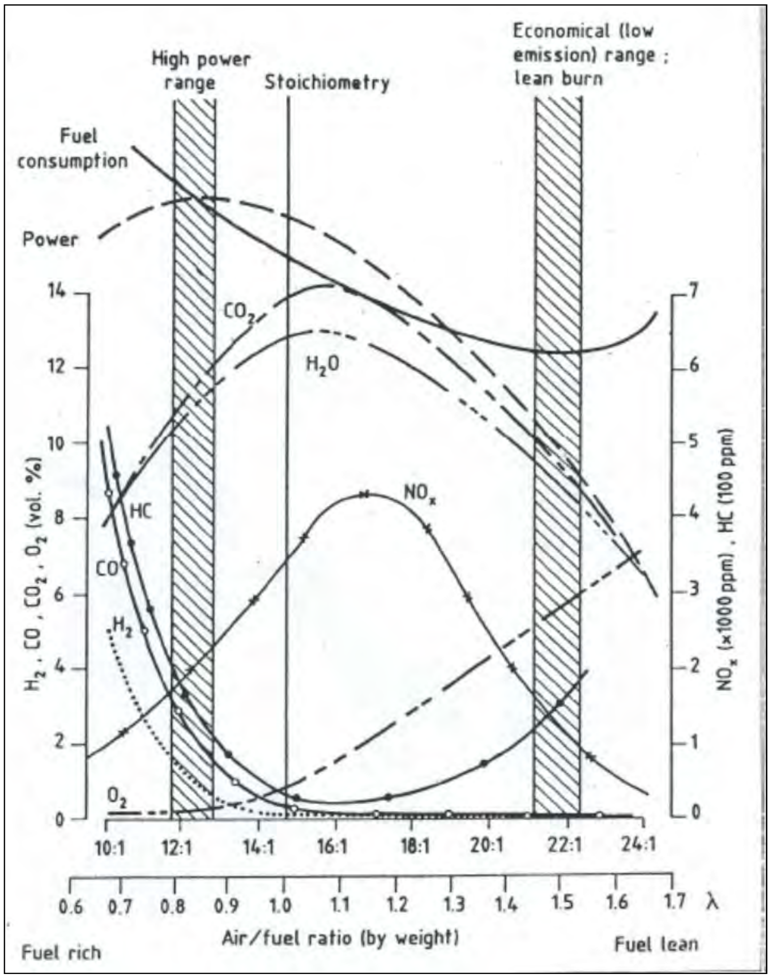


Table 1. CPSC Staff Estimated Emission Rates on Kohler CV490 with Base Metal Catalyst

Kohler CV490 Predicted Emissions with Exhaust-λ at 0.98 for modes 1-3 Instead of 0.95												
	EFI						EFI and BM-4 Catalyst					
EPA A-Cycle Mode #	1	2	3	4	5	6	1	2	3	4	5	6
Emissions Rate, g/hr												
NOx (Corr)	33.37	29.08	18.60	22.86	6.23	0.92	1.67	1.45	0.93	12.12	3.30	0.49
HC	19.92	18.24	17.21	4.18	5.82	1.97	15.94	14.60	13.77	1.80	2.50	0.85
CO	1274	1032	908	137	282	37	229	186	163	4	8	1
Exhaust-λ	0.980	0.980	0.980	1.003	0.992	1.009	0.980	0.980	0.980	1.003	0.992	1.009
Max Net Power (kW)	9.0						9.0					
Weighting factor	0.09	0.2	0.29	0.3	0.07	0.05	0.09	0.2	0.29	0.3	0.07	0.05
Total weighted CO rate, g/hr	647						107					
CO, g/kW-hr	154						25					
HC+Nox, g/kW-hr	8.0						3.3					

For catalytic aftertreatment, because exhaust constituent conversion efficiencies for all catalysts are greatly affected by Lambda, staff then considered data provided by BASF, a member company of the Manufacturers of Emission Controls Association (MECA), on base metal catalysts, shown in Figures 5 and 6 below.[27] Assuming the BM-4 catalyst were to be used, staff estimated the following conversion efficiencies as a function of Lambda for each exhaust constituent:

- CO conversion efficiency of 88% for Lambda of 0.98 (modes 1-3) and 97% conversion efficiency for Lambda of 1.0 (modes 4-6)
- NOx conversion efficiency of 95% for Lambda of 0.98 (modes 1-3) and 47% conversion efficiency for Lambda of 1.0 (modes 4-6)
- HC conversion efficiency of 20% for Lambda of 0.98 (modes 1-3) and 57% conversion efficiency for Lambda of 1.0 (modes 4-6)

Figure 5. CO Conversion Efficiencies of Various Base Metal Catalysts

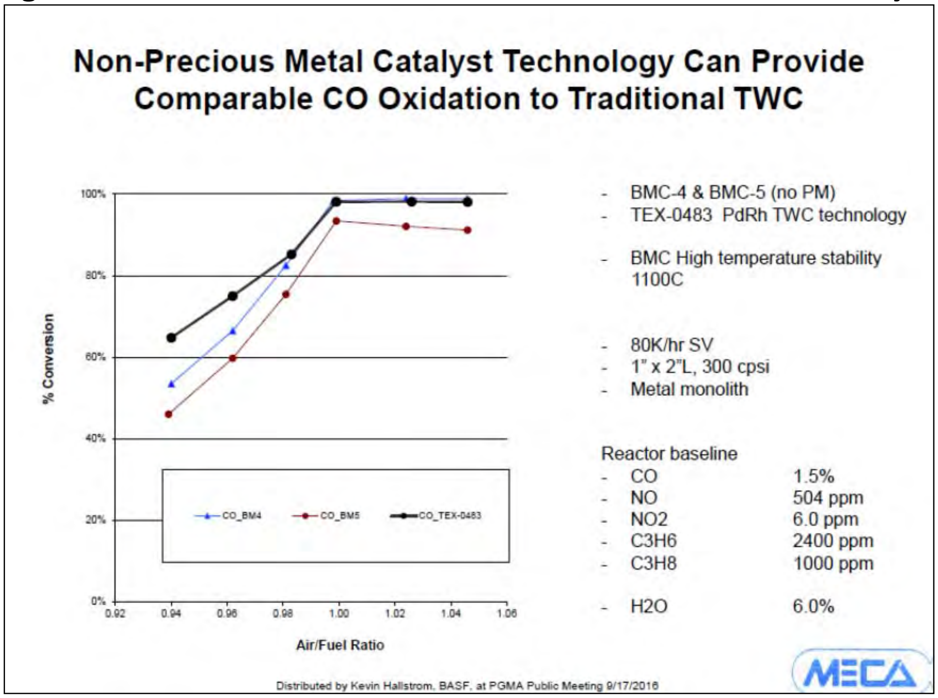
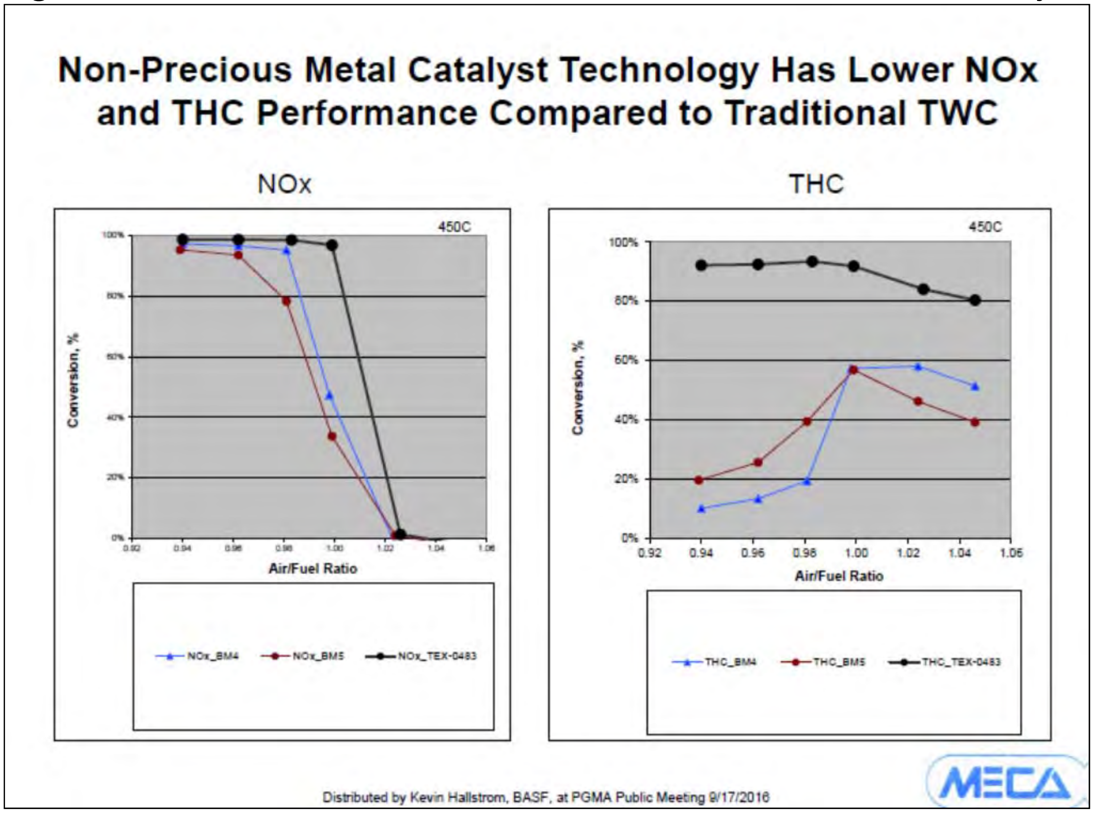


Figure 6 NOx and HC Conversion Efficiencies of Various Base Metal Catalysts



As shown in Table 1, applying these conversion efficiencies to the EFI configuration engine-out emissions would result in a weighted CO emission rate of 107 g/hr, and per EPA, CO emission rate of 25 g/kW-hr and HC+NOx of 3.3 g/kW-hr, which is well below the EPA's Phase 3 HC+NOx standard of 8 g/kW-hr for Class II engines. Staff notes that this overall 83 percent conversion of the weighted CO rate from 647 g/hr to 107 g/hr is in line with the 66 to 89 percent CO conversion efficiencies achieved by the catalyst in the prototype developed by UA during the durability program.[w]

Even though staff expects the weighted CO rate of 107 g/hr would be attainable only while the engine is mounted on a dynamometer and max power achieved by physically holding the throttle wide open, staff believes, for the purpose of determining technically feasible CO rates from a generator powered by a single-cylinder Class II engine, this could be used as the highest weighted CO rate that could be emitted from the tailpipe, if this engine and catalyst were installed in a generator.

4. CPSC's Emission Testing of Manufacturers' Generators with Fuel Injected Engines

Portable generators powered by engines with closed-loop fuel injection are available in the marketplace.[28,29, 30, 31] Manufacturers of fuel-injected engines advertise their many benefits by comparing their performance relative to their carbureted counterparts. Some advertised benefits include: improved performance and reliability; improved start capability, even after long storage periods and in cold weather; faster, smoother response to load transients; more power; improved fuel economy; reduced emissions; elimination of the need for a choke; and elimination of the need to modify the carburetor to compensate for operation in less dense air in higher altitudes. Staff purchased two fuel-injected portable generators from two different manufacturers for testing. Additionally, after learning of some manufacturers who have programs in progress to develop low CO engines to help address the CO hazard associated with portable generators, staff purchased a prototype generator with closed-loop fuel injection from a third manufacturer as well. Staff measured their emission rates in normal oxygen, following a procedure similar to one CES used when emission testing the durability-tested prototype discussed in section 2.1. Staff also tested the generators in reduced oxygen to see how their emission rates are affected.[32]

4.1 10.5 kW Rated Generator

Staff tested a commercially available, closed-loop fuel-injected portable generator powered by a twin-cylinder Class II engine with nominal 700 cc displacement and OHV configuration. Staff believes this generator was not specifically tuned to address CO emissions. Staff observed that this generator does not have a catalyst for aftertreatment and that the engine is calibrated rich of stoichiometry at higher loads and at stoichiometry with closed-loop fuel control at moderate-to-light load conditions. Staff found that in normal oxygen, the generator has a weighted CO

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[w] These efficiencies are determined by comparing the engine-out CO emission rates with the tailpipe CO emission rates (referred to in UA's report as "precatalyst/premuffler" and "postcatalyst," respectively, in appendix B of TAB C of staff's prototype report [reference 13]) for the 0-, 150-, and 250-hour emission tests, excluding the 500-hour test when the AFR for mode 4 was unexpectedly off design.

emission rate of 670 g/hr from loads based on the generator's advertised rated power of 10.5 kW.[x] When operating with 18 percent oxygen in its intake air with the same loads applied, the CO rates for modes 1 through 3, which staff observed were operating in open loop, increased by a nominal range of 2 to nearly 6 times and for modes 4 through 6, which were in closed loop, increased by a nominal range of 1.5 to 2 times. Overall, the generator's weighted CO emission rate increased by a nominal factor of 3.4. Closed-loop operation did not prevent the generator's CO emission rate from increasing.

4.2 5.5 kW Rated Generator

Staff tested a commercially available, fuel-injected portable generator powered by a single-cylinder Class II engine with nominal 400 cc displacement and OHV configuration. Staff believes this generator was not specifically tuned to address CO emissions. It is equipped with an oxygen sensor[y] for some form of partial closed-loop operation and has a catalyst. The engine is calibrated rich of stoichiometry at all loads. Staff found that in normal oxygen, it has a weighted CO emission rate of 584 g/hr from loads based on the generator's advertised rated power of 5.5 kW.[z] When operating in 17 percent oxygen with the same loads applied the CO rates for each load increased by a nominal range of 1.7 to 4.4 times. Overall, the generator's weighted CO emission rate increased by a nominal factor of 2.7. The oxygen sensor, which provides some amount of closed-loop operation, did not prevent the CO emission rate from increasing.

When tested with a maximum generator load of 6.7 kW on the generator in normal oxygen, its weighted rate is 531 g/hr.[aa] When operated in 17 percent oxygen with the same loads applied, the CO rates for each load increased by a nominal range of 1.4 to 8.3 times. Overall, the generator's weighted CO emission rate increased by a nominal factor of 3.3.

4.3 5.5 kW Rated Prototype Generator

Staff tested a prototype portable generator developed by another manufacturer that is powered by a closed-loop fuel injected single cylinder Class II engine with nominal 400 cc displacement and OHV configuration, developed specifically to address CO emissions. It has a catalyst for aftertreatment and the engine is calibrated to stoichiometric AFR with closed-loop operation at all loads. The manufacturer reported operating the generator for approximately 50

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[x] This generator is referred to as Gen 10.5I in reference 32. 670 g/hr is the highest CO emission rate determined from three tests. The other two tests yielded weighted CO rates of 610 g/hr and 563 g/hr.

[y] Staff notes that while the engine is equipped with an oxygen sensor, the manufacturer reported in the EPA's exhaust emission certification database (www3.epa.gov/otaq/certdata.htm#smallsi) that the engine does not have closed loop fuel control.

[z] This generator is referred to as Gen 5.5I in reference 32. 584 g/hr is the highest CO emission rate determined from three tests. The other two tests yielded weighted CO rates of 400 g/hr and 556 g/hr.

[aa] Per reference 32, 531 g/hr is the highest CO emission rate determined from three tests. The other two tests yielded weighted CO rates of 471 g/hr and 512 g/hr.

hours before staff purchased it. Staff found that in normal oxygen this generator has a weighted CO emission rate of 81 g/hr from loads based on the generator's maximum generator load.[bb] When operating in 17 percent oxygen with the same loads applied, the generator's weighted CO emission rate increased by a nominal factor of 1.2. While this factor of increase is not as large as the generators discussed above, staff notes that among the six different loads contributing to the weighted rate, the CO rates for the lowest three loads increased by a nominal range of 1.6 to 4.8 times. Closed-loop operation did not prevent the CO emission rate from increasing.

4.4 Conclusions About Emission Rates of Fuel-Injected Generators in Reduced Oxygen

After observing that the CO emission rate of all three of these fuel-injected generators with various degrees of closed-loop feedback have CO rates that rise in reduced oxygen, staff believes the CO emission rate of CPSC's prototype generator tested in NIST's shed may have increased emissions at reduced oxygen as well but the CO increase may have been masked by the emission rates being so low and not having emission rates measured in the low end of the 17 percent oxygen range.

Before arriving at this conclusion, staff anticipated setting a performance requirement for portable generators while the generator is operating in 17 percent oxygen. This was because NIST's garage testing showed that oxygen depletion occurred when the generators were operated in the garage and most of the generator-related CO fatalities reported to CPSC involved generator operation in an enclosed or semi-enclosed space that is likely smaller or may be equivalent in volume to NIST's garage. As a result, staff felt it was important to ensure generators meeting the performance requirements could do so when operating in reduced oxygen. Because staff had previously assumed that a closed-loop fuel-injected generator will maintain its CO emission rate as the atmospheric oxygen level drops below normal, staff believed that a proposed performance requirement for generators operating in reduced oxygen would be necessary to help ensure that the CO injuries and deaths resulting from the enclosed space scenarios, in addition to injuries and deaths that occur from the outdoor use (normal atmospheric oxygen) scenarios, would be addressed. Therefore, staff was pursuing development of a method for testing a generator's CO emission rate while operating in reduced atmospheric oxygen for verifying compliance to any given CO emission rate performance requirement. However, after observing that the CO emission rate of the fuel injected generators with oxygen sensor/closed-loop feedback showed increases in the CO emission rate in 17 percent oxygen, staff realized that it was unnecessary to measure generator CO emission rates in reduced oxygen. Based on the information developed and reviewed by staff, staff concludes that the CO emission rate rises regardless of the emission control technology. Thus, it is possible to set a standard based on simplified testing at normal atmospheric oxygen concentration.[cc]

[bb] This generator is referred to as Proto 5.5I in reference 32. 81 g/hr was the highest of three tests. The other two tests yielded weighted CO rates of 79 and 75 g/hr.

[cc] For the epidemiological benefits analysis staff performed for the draft proposed rule (described in reference 33), staff assumes a factor of 3 increase in the weighted CO rate in diminished oxygen is representative for generators with open-loop carbureted engines, based on units that NIST and staff tested. Staff also tested three carbureted generators (described in reference 32), and the increase in their weighted CO emission rates was nominally a factor

The methods that staff used for measuring the generators' CO emission rates in reduced oxygen were developed with stakeholders in a voluntary standard task group. A description of the joint effort that led to that development is provided in Appendix B of this memorandum. Staff welcomes comments on whether a test method measuring the CO emission rate of a generator operating in 17 percent oxygen or normal atmospheric oxygen should be used; and if the former, whether there are any comments on the dilution chamber test method in Appendix A2 of reference 32. If the latter, staff welcomes comments on the test method in normal oxygen in Appendix A3 of reference 32.

5. Staff's Proposed Performance Requirements, Effective/Compliance Dates, and Certification

Staff sought to ensure that the recommended CO rate limiting performance requirement for portable generators would be a technically feasible weighted CO emission rate, on a g/hr basis. Staff notes, however, that engine size needs to be considered because, for a given fuel control and emission control strategy, a large engine that delivers more power, compared to a smaller engine, will consume fuel at a higher rate; and a higher fuel consumption rate generally means a higher CO emission rate. Therefore, staff expects that a larger generator will emit a higher rate of CO compared to a smaller generator that uses the same fuel control and emission control strategy. Accordingly, if a performance requirement were limited to the technically feasible weighted CO emission rate for the largest generators, epidemiological benefits would not be as high; and the positive net benefits identified[5] for smaller generators operating at lower emission rates would not be achieved. In other words, the lowest CO rate on a large Class II powered portable generator may be far in excess of what is possible on a small handheld powered portable generator. At the other extreme, the lowest CO rate that is technically feasible for a small portable generator powered by a handheld or non-handheld Class I engine may not be technically feasible for a large portable generator powered by a large non-handheld Class II engine.

As discussed in the note at the end of section 2.1, the EPA takes engine size into account by setting emission standards that are a function of maximum engine power, and that is the reason their standards are specified in terms of g/kW-hr, not g/hr. Using this approach for a portable generator is not practical because there is no industry standard for how a portable generator's power output relates to the maximum power of its engine. Staff considered the possibility of scaling an emission rate requirement for portable generators according to the manufacturer's advertised kW rating of the portable generator. However, through discussions with generator manufacturers, staff learned that there is also no industry standard used by generator

of 3 as well. For generators with fuel-injected engines operating in closed loop, it appears that the factor of increase may be less than 3, based on staff's testing of the units discussed in section 4.3 and 4.1, which had, respectively factors of 1.2, and 1.5 to 2, for modes 4 through 6 that were operating in closed loop. Consequently, staff believes some manufacturers that use closed-loop EFI to meet such a requirement might achieve lower increases in CO emissions in diminished oxygen. Furthermore, in four pairs of matched tests in the garage at NIST's test house, the prototype generator decreased the oxygen less than the unmodified carbureted unit, as discussed in section 2.2. Nevertheless, staff assumes in the benefits analysis a conservative factor of 3 for the increase in CO emissions for low-emission generators when operating at reduce oxygen levels of 17 percent.

manufacturers to define the power of a generator, regardless of whether it is the generator's advertised rated, continuous, maximum, surge, starting, or any other type of power used in marketing generators. Therefore, rather than have CO rate requirements for generators that are a function of either engine power or generator power, staff considered the EPA's classification of the generator's engine, which is a function of engine displacement: a handheld engine, a non-handheld Class I engine, or a non-handheld Class II engine. For a frame of reference, staff observes that based on a review of specifications of generators on the market, in general, generators powered by a handheld engine have an advertised rated power nominally below 2 kW; generators powered by a Class I engine are nominally rated 2 kW up to 3.5 kW; and generators powered by a Class II engine are nominally rated 3.5 kW and higher. To break the broad size range of the Class II powered generators into two smaller categories, staff divided the Class II category based on whether the engine has a single cylinder or two cylinders (also called twin cylinders). Staff observed that generators powered by a Class II engine with twin cylinders are nominally rated 9 kW and higher.[5,33]

Dividing the generators into these four categories allowed staff to consider the technically feasible emission rates for each category and also the associated differences in size, weight, hazard patterns, and costs for each category in establishing their performance requirements. Staff's preliminary regulatory analysis (TAB L) considered these differences among the various categories to determine their relative risks and to assess the net benefits of the draft proposed rule.

Generators Powered by Non-Handheld Class II Single-Cylinder Engines

Based on the information provided above, staff's believes that a 100 g/hr weighted CO emission rate from a generator powered by a single-cylinder Class II engine is technically feasible. This rate of 100 g/hr is nominally four times higher than the rate that was achieved on the prototype developed by UA that has a 389 cc engine. This rate is also nominally 20 percent higher than the rate measured on the manufacturer's prototype with a nominal 400 cc engine. Furthermore, staff believes that the commercially available generator discussed in section 4.2 could achieve a CO emission rate in the 100 g/hr range, if it were operated closer to stoichiometric for at least some of the modes and used a catalyst formulated for higher CO conversion efficiency. As for this rate of 100 g/hr being technically feasible for the largest generators that are powered by single-cylinder Class II engines, staff notes that the 500 cc engines used in the EPA's demonstration program are larger than those used inthe generators manufactured by six large generator manufacturers generally recognized in the United States as the leaders of the generator industry[dd] and those found by staff in a more exhaustive informal retail market survey, listed in reference 5.

[dd] These manufacturers (Briggs & Stratton, Champion, Generac, Honda, Techtronic Industries, and Yamaha) are all members of the Portable Generator Manufacturers Association (PGMA); and per PGMA's website, they are the "major manufacturers of portable generators sold in North America and a significant majority of the industry." Recognizing staff's search was not exhaustive, staff found that the Class II single-cylinder and twin-cylinder engines in these manufacturers' generators were all less than 500 cc and 1000 cc, respectively. See reference 33.

Generators Powered by Non-Handheld Class II Twin-Cylinder Engines

As for the twin-cylinder Class II category, it appears to staff, based on a review of generators on the market, that a nominal 1000 cc engine may be the largest engine used in a generator in this category (twice that of the largest engine in the single cylinder category). Therefore, staff believes it is reasonable to assume that 200 g/hr is a technically feasible rate for generators powered by Class II twin-cylinder engines because this allows for a scaling to the increased size and power of these engines. This is further supported by the generator discussed in section 4.1. Based on staff's testing of this generator and staff's engineering assessment of its physical and operational characteristics, staff believes it is reasonable to expect that this engine could operate closer to stoichiometric at the higher loads and that a catalyst formulated for some CO conversion efficiency could be used for aftertreatment to further reduce its CO emission rate to the 200 g/hr range.

Generators Powered by Handheld and Non-handheld Class I Engines

As for Class I engines, the largest engine in this category by the EPA's definition is just below 225 cc. This is nominally half the displacement of the largest engines staff found in generators powered by Class II single cylinder engines.[33] Based on this fact, in conjunction with staff's online review of generators that indicates all have engines with OHV configurations (and thus expected to behave similarly in terms of emission rates scaled to size as the larger Class II engines), staff believes it is reasonable to assume that the technically feasible rate for generators powered by Class I engines is 50 g/hr, half that of the Class II single cylinder engines.[ee] For the handheld engine-powered generators, staff assumes the same technical feasibility rate as that for Class I engines, 50 g/hr, even though the maximum displacement of a handheld engine is less than a third of the maximum displacement of a Class I engine. Staff makes this conservative assumption, rather than scale down lower in proportion to the engine size because some handheld engines that power generators are 2-stroke engines, unlike the other three categories that are all 4-stroke engines. Although some of these engines have relatively low CO rates, per the EPA's small engine exhaust emission certification database,[34] staff is uncertain of the emission control technologies' efficacy in reducing CO emissions on 2-stroke engines. Staff does note, however, that many 2-stroke handheld engines already have catalysts; and there is even a fuel-injected 2-stroke handheld engine in the marketplace that powers a cut-off saw.[35] Staff also notes that because the EPA has relatively high HC+NOx standards for handheld engines (72 g/kW-hr for the larger class V and 50 g/kW-hr for the smaller Class III and IV handheld engines compared to 8 g/kW-hr for non-handheld Class II engines and 10 g/kW-hr for non-handheld Class I engines), staff speculates that 4-stroke handheld engines might not need a

[ee] Staff notes the valve configuration is important because Class I engines are available in both OHV and side valve (SV) configurations. However, per the EPA's Final Regulatory Impact Analysis for Phase 3 (reference 14), the less expensive SV engines typically have higher emissions, and the emissions deteriorate more than OHV engines. When the EPA adopted Phase 3, SV engines were the predominant type in the Class I inventory, but there were relatively few in the Class II inventory. Because of this, the EPA adopted a higher HC+NOx standard for Class I engines compared to Class II (10 g/kW-hr for Class I compared to 8 g/kW-hr for Class II). Since Phase 3 was implemented, however, SV Class II engines have disappeared entirely, and there are very few left in the Class I inventory.

catalyst, given the catalysts in both CPSC's and EPA's demonstration programs were selected for NOx reduction.

To ensure that the proposed performance requirements are technically feasible, staff applied a scaling factor to account for production variation. Based on the technically feasible rates staff identified above, staff applied a factor of 1.5 to establish the draft proposed rule's performance requirements for the four generator categories shown in Table 2. The factor of 1.5 is based on UA's measured emission rates of two carbureted generators and two prototype generators, which showed a variability up to 28 percent relative to the mean,[ff] along with staff consideration that this very limited data set could easily underestimate the range of variability that manufacturers may have to take into design considerations. Staff recognizes this is a limited data set and welcomes comments and data about appropriate manufacturing variability expectations.

Table 2. Proposed Performance Requirements for Portable Generators

Generator Category	Engine	Draft Proposed CO Standard (g/hr)	Compliance Date (years after publication of final rule)
Handheld	≤ 80 cc	75	3
Class 1	>80 cc to <225 cc	75	3
Class 2 single cylinder	≥225 cc, up to 25 kW maximum engine power and 1 cylinder	150	1
Class 2 twin cylinder	≥225 cc, up to 25 kW maximum engine power and 2 cylinders	300	1

Note: Maximum engine power for both class 2 categories is 25 kW to include the largest SI engines staff found in portable generators.

Staff recommends a draft proposed rule requiring portable generators within the scope (discussed below) to meet the applicable requirements in Table 2 when sold after the applicable compliance date. Staff notes that these requirements are a performance requirement for emission rates and that the proposed rule does not prescibe how the rates are reached. Manufacturers can choose the technologies and methodologies they prefer to meet the rates in Table 2.

Staff recommends that the proposed rule not prescribe a particular test that manufacturers must use to assess compliance with the performance requirements. Instead, staff recommends that the Commission adopt a proposed rule that would describe the test procedure and equipment

[ff] For the two prototype units, UA measured a weighted CO rate of 9.3 g/hr for PT1 at 0 hours and a rate of 5.2 g/hr for modGen X (measured after approximately 70 hours of operation at NIST in unmodified carbureted configuration and after UA modified it into the same configuration as PT1). For the two carbureted units, UA measured a weighted CO rate of 1078 g/hr on the unmodified baseline generator and 712 g/hr on the pre-modified Prototype (when it was in carbureted OEM condition, before configured as prototype).

that staff would use to assess compliance with the standard (provided in Appendix A3 of reference 32). Manufacturers, however, need not use this particular test, so long as the test they use effectively assesses compliance with the standard. Staff believes this approach provides added flexibility to manufacturers to reduce testing burdens. Staff welcomes comments on the benefits and costs of this approach versus requiring a specifc test method for manufacturers to demonstrate compliance.

CPSC staff would use the test procedure and equipment provided in Appendix A3 of reference 32 to determine whether generators covered under the proposed scope comply with the applicable performance requirement in Table 2. Staff reiterates that this is a weighted CO emission rate emitted from the generator when operating in ambient atmosphere with normal oxygen content (nominally 20.9%). This procedure is largely based on the reduced oxygen test method that was developed in a collaboration with industry stakeholders, as mentioned in section 4, and described in more detail in Appendix B. Briefly, staff would perform the tests in ambient temperature in the range of 10-38 ^{0}C (50-100^{0}F) using E10 gasoline. The emission rate would be measured while each of six different loads are applied to the generator to determine the generator's weighted CO emission rate. The six loads would be determined from the generator's maximum load capability. Maximum load capability would be determined by increasing the load applied to the generator to the maximum observed power output without causing the voltage or frequency to deviate by more than 10 percent of the nameplate rated voltage and 5 percent of the nameplate rated frequency and can be maintained for 45 minutes with stable oil temperature. The loads would be applied using a resistive load bank, capable of achieving each specified load condition to within 5 percent, and will be measured using a power meter with an accuracy of ± 5 percent. The emissions measurement equipment staff would use is a constant-volume sampling (CVS) system, as described in the EPA's regulations 40 C.F.R. part 1054 and 40 C.F.R. part 1065, as of 2016. If the generator is equipped with an economy mode or similar feature that has the engine operate in low speed when not loaded, the setting that produces the highest weighted CO emission rate will be used to verify whether the applicable rate in Table 2 is met.

The CPSA requires that manufacturers (the term includes importers) certify their products comply with applicable CPSC standards and regulations. 15 U.S.C. § 2063(a)(1). Should the portable generator rule become final, manufacturers, including importers, would need to certify that the product conforms to the standard, based on either a test of each product, or based on any reasonable alternative testing method to demonstrate compliance with the requirements of the standard. For products that manufacturers certify, manufacturers would issue a general certificate of conformity (GCC).

Staff recommends that the performance requirements in Table 2 apply to all portable generators that fall under the following scope: single phase, 300 V or lower, 60 hertz, portable generators driven by small handheld and non-handheld (as defined by the EPA at 40 C.F.R. § 1054.801) SI utility engines intended for multiple use that are provided with receptacle outlets for the AC output circuits and intended to be moved, though not necessarily with wheels. The standard would not cover generators powered by compression-ignition (CI) engines, permanently installed stationary generators, 50 hertz generators, marine generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, generators intended to be mounted in truck beds, and generators that are part of welding machines.

The scope excludes CI engines because staff considers diesel generators atypical consumer products and also notes that CI engines have relatively low CO emission rates.[gg] Stationary generators, marine generators, and generators installed in recreational vehicles are excluded because they are not portable. Generators intended to be pulled by vehicles, intended to be mounted in truck beds, generators that are part of welding machines, and 50 hertz generators are excluded because staff considers them atypical consumer products. Staff notes that these inclusions and exclusions, with the exception of diesel generators and generators that are intended to be pulled by vehicles and generators intended to be mounted in truck beds, are largely consistent with the scopes of the two U.S. voluntary standards for portable generators, UL 2201 and PGMA G300.

Staff considered a compliance date of 180 days following the publication of the final rule, but staff determined that 180 days may not provide adequate time to allow some Class II engines to come into compliance, due to the possible need for design modifications. To meet the proposed performance requirements, staff believes manufacturers will modify portable generators to use closed-loop fuel injection and, except for some handheld engines, a catalyst. Staff believes that 180 days following publication of the final rule may not provide adequate time due to possible need for modifications to use closed-loop fuel injection and possible modifications to accommodate fuel control closer to stoichiometry, such as adding cooling fins and a fan. Staff believes that 1 year after the rule is promulgated is sufficient lead time for portable generators powered by Class II engines. For portable generators powered by Class I and handheld engines, staff believes that an additional 2 years may be necessary, due to increased challenges related to maintaining smaller sizes for these generators while noting that fuel injection has been implemented in the marketplace on a handheld engine and that staff is also aware of at least one manufacturer who offers two models of fuel-injected portable generators powered by Class I engines.[36] In 2006, when the EPA drafted the Regulatory Impact Analysis for Phase 3,[14] they estimated that manufacturers needed 3 to 5 years to implement closed-loop EFI and to make any necessary engine improvements if the EPA had adopted a 4.0 g/kW-hr HC+NOx standard for Class II engines. Staff has observed that over the subsequent decade, Class II single- and twin-cylinder fuel-injected engines have come into the marketplace in a variety of applications, including several portable generators and the two generators discussed in sections 4.1 and 4.2. As a result, staff thinks a 1 year lead time is sufficient for generators powered by Class II engines.

Staff recommends that the Commission propose to adopt anti-stockpiling provisions as part of the draft proposed rule.[5] Specifically, staff recommends that the draft proposed rule prohibit the manufacture or importation of noncomplying portable generators, by generator category, in any period of 12 consecutive months between the date of promulgation of the rule and the effective date at a rate that is greater than 125 percent of the rate at which they manufactured or imported portable generators in the same category during the base period for the manufacturer. The base period is any period of 365 consecutive days, chosen by the manufacturer or importer,

[gg] The current EPA standard for CO emissions is 8.0 g/kW-hr for CI engines rated below 8 kW, which is significantly lower than the EPA standard of 610 g/kW-hr applicable to small SI engine classes used in portable generators.

in the 5-year period immediately preceding the promulgation of the rule. Staff has observed that generator sales can vary substantially from year to year, depending upon factors such as widespread power outages caused by hurricanes and winter storms. Annual unit shipment and import data obtained by CPSC staff show that it is not uncommon for shipments to vary by 40 percent or more from year-to-year at least once in recent years. The anti-stockpiling provision is intended to allow manufacturers and importers sufficient flexibility to meet normal changes in demand that may occur in the period between promulgation of a rule and its effective date, while limiting their ability to stockpile noncomplying generators for sale after the effective date.

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Appendix A

Staff received comments from the public on the ANPR and on two reports, both pertaining to the prototype technology demonstration program discussed in section 2. The comments were received after the reports were made publicly available on CPSC's website. One of the reports is staff's report on the two-part technology demonstration program (reference 13 above), and the other is the final report by NIST on the generator testing that NIST performed as the second part of that same two-part technology demonstration program (reference 21 above). Staff received comments from a total of 10 people or entities on the ANPR, 12 people or entities on staff's report, and four people or entities on NIST's report.[hh] The following is a synopsis of a number of those comments and staff's responses to them.[ii]

Comment: One commenter asserted that the prototype's components may cause exacerbated reliability issues after long-term storage. **Response**: Fuel injection can improve reliability relative to a carbureted unit after long-term storage. A fuel-injected system is sealed, so the fuel is not exposed to air like the vented system associated with a carburetor. Exposure to air is what causes the gasoline to degrade during long-term storage and, in turn, causes problems with starting and running the engine. Manufacturers advertise this as one of the benefits of products with fuel injection.

Comment: One commenter asserted that it is harder to apply EFI and catalyst on the smaller engines used in 1 kW - 3 kW units and that they are sold in higher numbers than 5 kW units. In a similar comment, another commenter noted that CPSC's prototype used a commercial-grade engine in open-frame; yet, closed-frame units are more popular. **Response**: Staff has observed that there are fuel-injected handheld and Class I engines, with and without catalysts, available in the marketplace. Staff acknowledges, however, that there may be more challenges associated with implementing the emission control technology on these smaller engines and the generators they power. Thus, staff recommends a later compliance date for these models, relative to the larger generators powered by Class II engines. Based on staff's analysis of market data, staff concurs that the smaller generators are becoming more popular, relative to the larger generators. In the technology demonstration program, staff used a larger generator, with a nominal 5.0 kW rating powered by a Class II single-cylinder engine because staff's incident data showed when the program was started that generators with the same nominal power rating were associated with most of the fatalities compared to other ranges of power ratings in which staff categorized the generators. Even currently, almost two-thirds of the CO deaths involving generators that have been reported to CPSC, when the size of the generator is identified for the years from 2004 through 2012, involve generators powered by class II single-cylinder engines. Staff's recommendation for lower proposed performance requirements for smaller generators is expected to reduce deaths that could otherwise be expected to occur with increasing popularity of these smaller units.

[hh] The comments are available online at: www.regulations.gov, under docket CPSC-2006-0057, document identification numbers 0007, 0004, and 0006, respectively.

[ii] Other comments and staffs' responses are provided elsewhere in this briefing package.

Comment: One commenter stated that stable engine operation under transient loads requires richer-than-stoichiometric AFR. Without it, they asserted, there is unreliable operation that can result in damaged electrical loads and warranty claims. **Response**: Staff acknowledges this operating challenge, and for this reason staff recommends a performance requirement based on measuring emissions while the generator is operating with a steady load applied, as opposed to transient load.

Comment: One commenter noted that their company uses more severe modes and requirements to test product durability and they are doubtful the prototype would have survived. In a related comment, a commenter asserted that significantly reduced CO emissions at the highest loads resulting from operation near stoichiometric fuel control will negatively impact engine durability. **Response**: Staff notes that the proposed performance requirement for generators powered by Class II single-cylinder engines is nominally six times higher (less stringent) than the CO rate that the prototype generator achieved. Staff believes the proposed CO emission requirements can be achieved on many existing engines by replacing the carburetor with closed-loop EFI and integrating a catalyst without engine design modification and without negatively impacting engine durability. Staff notes, however, that for some engines, modifications might be needed to enable operation closer to stoichiometry. For other engines that cannot be improved through design modifications, those could still be employed in generator applications by using a product-integration strategy that precludes installed engine operation at loads where fuel enrichment is needed.

Comment: One commenter stated that the performance standard for CO emission rate must take into account deterioration of emissions to achieve the target exposure over the life of the engine. **Response**: Staff took deterioration into account in developing the performance requirements because staff believes deterioration of CO emissions to be minimal, based on both the performance of CPSC's durability-tested prototype at end of life, as measured by CES, as well as deterioration factors for CO that staff observed in the EPA's exhaust emission database for model year 2015. The EPA's database shows that deterioration factors for CO, which is a measure of the increase in CO emissions for an aged engine relative to its emissions when new, shows that a vast majority of the engines have a deterioration factor below 1.1 (thus, indicating that the emissions deteriorate less than 10 percent above initial emissions).

Comment: One commenter stated that the target CO emission rate in terms of g/kW-hr should be based on engine displacement, with a lower rate (in terms of g/kW-hr) for larger engines to achieve the same target exposure. **Response**: Staff believes that lower CO emission rates are technically feasible for smaller engines compared to larger engines. Consequently, staff is recommending performance requirements for four different size categories of generators that are each based on technical feasibility and analysis of benefits and costs as a function of engine displacement, and for the largest category, also whether the engine has one or two cylinders. The epidemiological benefits considered exposure differences for the different generator categories by allocating known incidents based on the location of the generator in various house types.

Comment: One commenter asserted that reducing CO emissions will increase other pollutant emissions and the risk of fire and burn hazards. **Response**: CPSC staff disagrees with the comment about other pollutants; based on the emission results from CPSC's prototype generator, as well as those from the EPA's demonstration program, reducing CO emission rates also results in reduced HC+NOx emissions. Staff acknowledges that for CPSC's prototype, the leaner air fuel ratio resulted in elevated exhaust temperatures compared to the carbureted configuration. Staff notes, however, that the muffler that was used was chosen to easily accommodate integration of the small catalyst. This muffler had less internal baffling, which resulted in average muffler surface temperatures of approximately 70^{o}C hotter than the OEM design. Consequently, UA shrouded this muffler and that resulted in shroud surface temperatures that were lower than the OEM muffler, which was not shrouded. Staff notes that use of better designed mufflers, and if needed, improved flow of cooling air over the exhaust, could mitigate the effect of elevated exhaust temperatures.

Comment: One commenter stated that EFI systems are becoming more low cost and noted that an oxygen sensor of one particular design can serve as a safety switch, if the engine starts operating rich of stoichiometric. **Response**: Staff has observed that small SI engines with EFI have entered the marketplace in recent years and expects that would mean they have become less expensive. Staff is interested in combining reduced CO emissions with a strategy that will shut off a generator when operated in an enclosed or semi-enclosed space.

Comment: One commenter stated that the results from testing the generators in the NIST garage should not be relied upon for any rulemaking related to portable generator safety because the attached garage on NIST's test house is not sufficiently representative of how garages are conventionally constructed. **Response**: Staff used the results from NIST's test house as an example of the reduction in exposure from the reduced CO emission rate on the hypothetical occupants' compared to the hypothetical occupant's exposure from a current carbureted generator operated in the same garage. Staff bases the performance requirements for the draft proposed rule on technically feasible CO emission rates, along with an assessment of the impact of those rates through indoor air quality modeling of 40 structures,which are primarily based on a collection of structures representative of the U.S. housing stock where generators were operated in 503 of the deaths in CPSC's databases that occurred from 2004 through 2012.

Comment: Several commenters expressed concern about CO deaths caused by generators and they support reducing generators' CO emission rates and believe it is technically feasible to do so. **Response**: Staff agrees with the commenters.

Comment: One commenter asserted that pursuant to § 31 of the Consumer Product Safety Act (CPSA), the CPSC lacks authority to regulate the risk of injury associated with CO emissions from portable generators because that risk could be addressed under the Clean Air Act (CAA). Specifically, the commenters rely on Section 213 of the CAA, which directs the EPA to conduct a study of emissions from non-road engines to determine if they cause or contribute to air pollution, "which may reasonably be anticipated to endanger public health or welfare." 42 U.S.C. 7547(a)(1)(2006). Under this provision of the CAA, the EPA has promulgated regulations governing CO emissions from portable generators. In particular, 40 C.F.R. part 90 imposes requirements to control emissions from non-road spark-ignition engines, which includes portable generators, at or below 19 kilowatts. **Response:** Section 31 of the CPSA does not establish an absolute prohibition to CPSC action whenever the CAA is implicated. Rather, the Commission lacks authority to regulate a risk of injury associated with a consumer product if that risk "could be eliminated or reduced to a sufficient extent through actions" taken under the CAA. 15 U.S.C. § 2080(a). Case law and the legislative history of § 31 confirm this. See *ASG Industries, Inc. v. Consumer Product Safety Comm'n*, 593 F.2d 1323 (D.C. Cir. 1979) (under section 31, CPSC is to consider all aspects of the risk and make a judgment whether the alternate statute can sufficiently reduce the risk of injury).

The legislative history indicates that Congress contemplated a stricter ban on the CPSC's jurisdiction and rejected it. Specifically, the Senate version of the bill for § 31 would have precluded CPSC's jurisdiction if the product was "subject to safety regulations" under one of the statutes listed in section 31 of the CPSA. S.Rep.No.92-749, 92d Cong., 2d Sess. 12-13 (1972). In contrast, under the House version of the bill, which was eventually enacted, the Commission must consider the ability of the other agencies' statutes to address the risk to consumers H.R. Rep. No.92-1593, 92d Cong., 2d Sess. 38 (1972).

The CAA and the EPA regulations promulgated under it that address CO emissions from portable generators have not sufficiently reduced or eliminated the risk of CO poisoning associated with portable generators that the CPSC seeks to address. Deaths and injuries associated with CO emissions from portable generators have increased since the EPA adopted its regulations limiting CO emissions from the type of engines used in portable generators.

The CAA and the EPA's regulations create national standards intended to address large-scale ambient air pollution, not acute CO exposure from portable generators. The CAA and the EPA's regulations, created under 42 U.S.C. § 7407, are designed to reduce CO emissions in regional areas, that exceed National Ambient Air Quality Standards. These requirements are not designed to reduce the localized risk to consumers from acute CO poisoning when portable generators are used in the home.

Additionally, EPA's 2008 adoption of an averaging program for CO emissions from marine engines further demonstrates that its regulations are not concerned with the risk of acute CO poisoning but only large-scale overall emission levels. This averaging program allows a manufacturer to exceed the EPA's CO emission limits for a group of similar engines, as long as it offsets that increase with another "engine family" with emission levels below the EPA's limit. 73 Fed. Reg. 59,034 (Oct. 8, 2008). It is noteworthy that this averaging program applies to CO emissions from marine engines, which the EPA explicitly acknowledges are associated with "a substantial number of CO poisonings and deaths." 73 Fed. Reg. 59,034, 59,048 (Oct. 8, 2008). Under this program, emissions from an individual engine are inconsequential to EPA's rule, and so is the individual consumer's exposure level. Rather, the EPA's determination of CO emission limits focuses on ambient air pollution on a large scale.

Finally, the structure of the CAA and its delegations of authority prevent the EPA from adequately addressing the risk of injury associated with CO poisoning to consumers from portable generators. Under the CAA, the EPA sets National Ambient Air Quality Standards (NAAQS) and has oversight and enforcement authority; however, the states retain primary responsibility for ensuring air quality. Section 107 of the CAA sets out states' responsibilities for ensuring air quality, including determining how they will meet NAAQS and identifying attainment and non-attainment areas. 42 U.S.C. 7407. The U.S. Supreme Court has emphasized that the EPA is "relegated by the [CAA] to a secondary role," as long as states adopt plans that meet the general requirements. *Train v. Natural Resources Defense Council, Inc.*, 421 U.S. 60 (1975). This broad leeway provided to states indicates that the CAA and the EPA's regulations are not intended to and cannot provide sufficient specificity to mitigate the risk of CO poisoning.

Appendix B

In January 2014, staff wrote a letter[1] to Underwriters Laboratories (UL), who, at the time, had the only U.S. voluntary standard dedicated to portable generators, UL 2201 *Safety Standard for Portable Generator Assemblies*. In the letter, staff outlined a framework of requirements, based on the work described in section 2 above, which staff recommended could be the starting point for a task group to develop into a proposal of requirements for UL 2201 to address the CO hazard. Staff requested that UL form a task group to develop the proposal so that UL's standards technical panel (STP) for UL 2201 could then vote on it for adoption into UL 2201.

UL agreed to form the task group and solicited volunteers to serve on the task group and chair it. A roster of 37 members was formed that represent a broad range of stakeholder interests, including among them, manufacturers of engines, generators, fuel control systems, and emission control components; public health officials; first responders; medical experts; indoor air quality experts; academia; and government representatives from the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), NIST, and CPSC staff. The first meeting of the task group was held in May 2014.

Following is a synopsis of the major discussion points that have taken place in 27 teleconference meetings held through August 2016:

- May 2014: Staff presented an overview of staff's recommendations in the letter to UL, including a description of the prototype development and demonstration program, its findings, and staff's recommendations for CO mitigation strategies, based on CO emission reduction, as well as some requirements staff envisions are necessary for a reliable shutoff system.[2]
- July 2014: Staff presented an overview of staff's investigation and findings regarding shutoff concepts and the rationale behind staff's recommendations for shutoff requirements that staff included in the letter.[3] Subsequently, a subgroup of volunteers within the task group formed to develop specific requirements for shutoff systems, using staff's recommendations as a starting point.
- August 2014: NIST presented a proposal to the full task group for a test method for measuring a generator's CO emission rate in reduced oxygen. The proposal is based on NIST's test method using the shed described in section 2.2, but modified to a laboratory-grade chamber (referred to by the Task Group as an exhaust recirculation chamber) with flexibility to try to accommodate generators of all sizes.[4] Task group members representing engine and generator manufacturers expressed numerous concerns, including too much costly infrastructure, repeatability and reproducibility of results, safety regarding extremely high CO concentrations circulating inside the chamber, shifting liability of emissions from engine manufacturer to generator manufacturer by testing with the engine installed in a generator instead of on a dynamometer, among others.
- October 2014: The task group decided that an acceptable test method needs to be agreed upon before a performance requirement for an acceptable CO emission rate can be discussed. A subgroup within the full task group was formed to develop a test method that would be more acceptable and familiar to industry than NIST's proposed chamber test. ElectroJet, a

fuel control system developer, concurred with staff's hypothesis that the reason CPSC's prototype did not exhibit an apparent increase in its CO emission rate as the oxygen dropped was due to its oxygen sensor providing feedback to the fuel control system. The Electrojet representative suggested, as a way to satisfy some of the members' concerns discussed above, to develop a method for testing just the fuel control system's (FCS) performance in reduced oxygen, instead of the engine or generator so that a generator with a "certified" FCS would not need to be tested in reduced oxygen. Only generators that do not have engines with a certified FCS would have to be tested in reduced oxygen.

- November 2014: The subgroup for development of shutoff requirements reported to the full task group their conclusion that a shutoff system is not feasible with the mass emission limit (proposed by staff) that was predicted to prevent serious or lasting CO injuries. The subgroup stated that, given the high CO emission rates that generators emit, shutoff would have to occur in such a short amount of time, within a few minutes, that it was not feasible, and further advised that the shutoff subgroup had disbanded. At a later meeting, one of the shutoff subgroup members cited staff's recommendations in the letter for durability and tamper-resistance requirements to be overly onerous and a contributing factor in the subgroup disbanding. Staff offered that the subgroup could choose to deviate from staff's recommendations, just as the subgroup that formed to develop a more acceptable test method did; staff also suggested that the subgroup start anew and continue their work. The shutoff subgroup did not reconvene.
- February 2015: Staff presented an initial draft test method to the test method subgroup reflecting all of the concerns, comments, and suggestions made during the meetings that had been held.[5] In the test method, staff introduced the concept of a tube connected directly to the engine intake allowing nitrogen to flow to reduce the intake air oxygen content and to verify whether the FCS behaves acceptably in reduced oxygen, in addition to using the exhaust gas recirculation chamber. Staff also suggested that this tube (referred to as a dilution tunnel) could be used on generators as the means to reduce oxygen at the intake while using emission measurement equipment familiar to manufacturers.
- February 2015: Kerdea Technologies, an oxygen sensor developer and manufacturer, presented to the test method subgroup his schematic of a concept he developed that injects nitrogen into a small chamber covering the generator as a way to reduce oxygen, not only in the engine's intake, but also in the air surrounding the generator (referred to as a dilution chamber) rather than using the dilution tunnel on the engine intake.[6]
- August 2015: Honda, an engine and generator manufacturer, presented to the test method subgroup Honda's results from using a dilution tunnel as well as injecting nitrogen directly into the intake on two of their generators.[7] Techtronic Industries (TTi), a generator manufacturer, presented a mark-up of the draft test method staff presented in February based on their work measuring a generator engine's FCS performance with the generator operating in a shed.[8] TTi's mark-up also offered a method for determining the generator's maximum load capability. After noting that both manufacturers tested their generators in reduced oxygen, staff suggested abandoning the concept of certifying the FCS from the test method.
- October 2015: Staff presented to the test method subgroup a test method that uses a dilution chamber for testing generators.[9]
- December 2015: TTi offered its version of a test method using a dilution chamber constructed by TTi.[10] Honda provided a method for calculating maximum generator power and Honda's test method using a load bank.[11]

- December 2015: PGMA presented to the subgroup their markup of the draft test method staff presented to the subgroup in Feb 2015. PGMA reinserted into the test method the exhaust gas recirculation chamber for testing generators and added the option for emission testing engines mounted on a dynamometer.[12]
- January 2016: Staff presented to the subgroup staff's concerns and comments on PGMA's markup, including reintroducing the recirculation chamber into the test method to measure CO emission rates in reduced oxygen because PGMA had expressed strong concerns about a recirculation chamber when NIST introduced it in August 2014.[13]
- February 2016: TTi presented to the subgroup a revised version of the dilution chamber method TTi uses to determine a generator's CO emission rate in reduced oxygen.[14]
- May 2016: PGMA presented to the full task group the current state of the test method, as well as a summary of a technical summit PGMA hosted seeking solutions, other than reduced emissions, to mitigate the CO hazard.[15] TTi also gave a presentation, which they had delivered at PGMA's technical summit, on their low CO emission generator development program.[16]

Appendix B References

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[3] Buyer, Janet, *CPSC Staff Recommendations to UL 2201 for Shutoff System Requirements and Staff's Investigations of Various Shutoff Concepts*, U.S. Consumer Product Safety Commission, Bethesda, MD, July 2, 2014. (available online at: http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/UL2201TaskGroupMeeting070214.pdf)

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[8] TTi mark-up of Test Method, August 12, 2015.

[9] Brookman, Matthew, letter to K. Dunn, *Subj: CPSC Staff Proposal for Determining Carbon Monoxide Emissions from Portable Generators in a Reduced Oxygen Environment Using the Dilution Chamber Method*, October 6, 2015. (available online at: http://www.cpsc.gov/PageFiles/99044/CPSCStaffLettertoK.DunnforUL2201TaskGroupDiscussionofDilutionChamberTestMethod.pdf)

[10] TTi Proposed Dilution Chamber Test Method, dated 11/30/2015, presented at 12/1/2015 test method subgroup meeting.

[11] Honda's Method of Max Generator Power, and Honda's Load Bank Test Method, presented at 12-1-2015 task subgroup meeting.

[12] PGMA letter to Kevin Dunn, dated 12/17/2015, Subj: *PGMA Comments on "Draft Test Method for UL 2201 Task Group for Determining CO Emission Rate of Portable Generators*," presented at 12/18/2015 test method subgroup meeting.

[13] Buyer, Janet, letter to K. Dunn, Subj: *CPSC staff's comments for the UL 2201 "Standard for Portable Engine-Generator Assemblies" CO Task Group, Subgroup for Emissions Test Method Development, Concerning Referenced PGMA Correspondence,* U.S. Consumer Product Safety Commission, January 11, 2016. (available online at: http://www.cpsc.gov/Global/Regulations-Laws-and-Standards/Voluntary-Standards/Portable-Generators/CPSCstaffcommentsPGMAmarkupUL2201tasksubgroupdrafttestmethoddoc.pdf)

[14] TTi presentation, *UL Sub-Task Group Feedback: Low CO Emissions Enclosed Generator Test Method & Chart*, February 24, 2016.

[15] PGMA, *Overview of PGMA Technical Summit Held March 17, 2016*, May 20, 2016.

[16] Recht, Joel, Log of Meeting, *PGMA Technical Summit on Carbon Monoxide (CO) Hazard Mitigation for Portable Generators*, U.S. Consumer Product Safety Commission, 3/17/16. http://www.cpsc.gov//Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf

TAB J

U.S. Consumer Product Safety Commission

Development of Test Methods for Determining the Carbon Monoxide Emission Rate of Portable Generators in Normal and Reduced Atmospheric Oxygen

October 3 , 2016

Prepared By Matthew J. Brookman, P.E.

Directorate for Laboratory Sciences
United States Consumer Product Safety Commission
National Product Testing and Evaluation Center
5 Research Place
Rockville, MD, 20850

This report was prepared by the CPSC staff, and it has not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

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Executive Summary

From 2014 to 2016, U.S. Consumer Product Safety Commission (CPSC) staff evaluated a variety of test methods to determine the carbon monoxide (CO) emission rate of portable generators operating in an enclosed space. When a portable generator is operated in an enclosed space, the oxygen level is reduced (1). Oxygen reduction affects the combustion process and can result in an increase in CO emissions (2). This report presents the results of emissions tests performed using three methods and provides a recommendation for using the dilution chamber to determine the CO emission rate of a portable generator in a reduced oxygen environment. This test method, as well as a method for determining the CO emission rate of portable generators in normal atmospheric oxygen, is provided in the Appendix.

Staff performed emissions testing using a constant volume sampling (CVS) emissions tunnel system, based on 40 C.F.R. part 1065, *Engine-Testing Procedures*, on each generator assembly at normal oxygen levels (~20.9 percent by volume). Staff compared these data to CO emission rates in reduced oxygen to determine a factor that correlates the increase in CO emission rate in normal oxygen to that in a low oxygen environment. Generators equipped with open-loop or partially open-loop fuel control systems emit approximately three times more CO in low oxygen levels than in normal oxygen levels. Staff also found that generators tested with closed-loop fuel control systems also increase their CO emission rates as intake oxygen levels are reduced.

Staff recommends the dilution chamber test method for determining the CO emission rate of portable generators in a low oxygen environment that can result when a portable generator is operated in an enclosed space. This method uses commonly available test equipment and can provide a higher level of repeatability and operational safety than previously evaluated test methods. The dilution chamber test method is provided in Appendix A2. Additionally, a test method for determining the CO emission rate of portable generators operating in normal atmospheric oxygen is provided in Appendix A3.

Background

Portable generators present serious risk of fatal and nonfatal, high-severity CO poisoning. As of May 21, 2015, CPSC's databases contained reports of at least 751 generator-related consumer CO poisoning deaths resulting from 562 incidents, occurring from 2004 through 2014 (3). (A subset of 659 of these deaths is being included in staff's analyses for the notice of proposed rulemaking (NPR)). The majority of these deaths occurred when the generator was operated in an enclosed or semi-enclosed space. Nearly 75 percent of the 751 deaths occurred in a fixed-structure home location, which includes detached and attached houses, apartments, fixed mobile homes, and cabins used as a permanent residence. Another 22 percent occurred at non-fixed home locations or temporary structures (such as trailers, horse trailers, recreational vehicles, cabins used for temporary shelter, tents, campers, boats, and vehicles) or external structures at home locations (such as sheds and detached garages). The remaining 3 percent occurred at unknown or other locations. In the same 11-year period, 42 deaths from 30 incidents occurred with the generator operating outdoors, where the exhaust infiltrated into a nearby fixed-structure home, non-fixed home, or temporary shelter[1] (4). In addition to these deaths, staff estimates that in the 9-year period from 2004 through 2012, there were 8,703 generator-related CO poisoning injuries treated in emergency rooms, an average of about 970 CO injuries per year (5). It is unknown how many of these injuries were due to a generator operating in an enclosed or semi-enclosed space, versus outdoors.

To address the CO hazard associated with portable generators, in 2006, the Commission published an advanced notice of proposed rulemaking (ANPR). Staff began research to investigate technologies that could reduce the risk of CO poisoning associated with portable generators (6). Staff subsequently investigated several approaches to mitigate the CO hazard and concluded that reducing the engine's CO emission rate is the best strategy. This report supports the next phase of rulemaking, the notice of proposed rulemaking (NPR).

Test Samples

Table 1 provides the specifications of the generators used during evaluation of different test methods. The designations for each generator identify the manufacturer's rated continuous output in kilowatts and the fuel control system, either carbureted (C), or fuel injected (I).

All generators, with the exception of Proto 5.5I, were available on the market at the time of testing. Each was purchased new and set up per the manufacturer's instruction manual, with the exception of Proto 5.5I, which had previously been operated for approximately 50 hours. Thermocouples were installed to measure cylinder head temperature (CHT) and oil temperature. Remote shutoff devices were added for safety. An ignition ground switch was used to shutoff generators without a fuel pump. For generators with a fuel pump, the shutoff switch opened the electrical circuit supplying the fuel pump. A cone with a V-band flange was welded to the exhaust of each generator to adapt exhaust piping and other equipment to measure emissions. All tests used 87 octane E10 gasoline.

[1] This excludes two deaths in 2011, caused by a stationary generator operated outdoors.

Table 1. Sample Portable Generator Specifications

Name	Approx. Displacement (cc)	Rated Cont. Output (kW)	Fuel Control	O2 Sensor	After-treatment	Test Methods Applied
Gen 1.6C	100	1.6	Carbureted	No	None	• Dilution Chamber • Normal Oxygen CVS
Gen 2.3C	170	2.3	Carbureted	No	Air Injection/ Catalytic Converter	• Dilution Chamber • Normal Oxygen CVS
Gen 5.5C	400	5.5	Carbureted	No	None	• NIST 1834 • Dilution Chamber • Normal Oxygen CVS
Gen 5.5I	400	5.5	Open Loop* EFI	Yes	Catalytic Converter	• NIST 1834 • Dilution Chamber • Normal Oxygen CVS
Gen 10.5I	700 Twin	10.5	Closed Loop EFI	Yes	None	• Dilution Tunnel • Normal Oxygen CVS
Proto 5.5I	400	5.5	Closed Loop EFI	Yes	Catalytic Converter	• Dilution Chamber • Normal Oxygen CVS

* Staff notes that although the engine is equipped with an oxygen sensor, the manufacturer reported in the EPA's exhaust emission certification database that the engine does not have closed-loop fuel control. The presence of the oxygen sensor suggests that there is some form of feedback on the fuel control system.

Preliminary Test Method Evaluation

This section discusses the test methods that staff evaluated before developing the dilution chamber test method. Data from these tests are provided to support indoor air quality modeling to estimate the effects of portable generator exhaust on indoor CO levels (7).

In 2014, NIST Technical Note 1834 (TN 1834) reported on a collaborative effort with CPSC staff to develop a test method to determine CO emission rates from portable generators in a reduced oxygen environment due to operation in an enclosed space (8). This test used recirculated engine exhaust from the generator to reduce the oxygen in a known volume. The air exchange rate in the volume must be precisely controlled to achieve equilibrium at a desired oxygen level. In the same year, CPSC staff began a test program to evaluate the NIST TN 1834 draft test method provided in the appendix of the TN 1834 report. This evaluation, along with input from a CO hazard reduction task group created to support the enhancement of UL 2201, *Standard for Portable Engine-Generator Assemblies*, determined that infrastructure requirements and safety concerns may be a significant burden on industry (9).

CPSC staff considered the input from the CO hazard reduction task group and developed a test method using a CVS emissions tunnel system that is common in the engine testing industry. This test method, called the dilution tunnel test method, used a long tunnel affixed to the intake of the generator assembly to introduce a well-mixed stream of nitrogen and air to the engine. The addition of nitrogen displaced a portion of the oxygen provided to the generator, simulating a low oxygen environment. Exhaust emissions were collected using a CVS system and measured when the intake oxygen concentration was 18 ± 0.25 percent by volume. Although this test offered a significant reduction in equipment, infrastructure, and safety concerns, it was not without fault. The dilution tunnel did not address the air reference on an oxygen sensor for use with some fuel-injected generators. Additionally, if the engine speed began to oscillate, the oxygen concentration at the intake would vary significantly. This variation prevents reliable and repeatable measurement of emissions, relative to a low target oxygen concentration at the intake.

After reviewing the performance of the dilution tunnel test, staff developed a new test that incorporated a small chamber and dilution via nitrogen injection. The dilution chamber test method uses nitrogen to displace oxygen in a small volume surrounding the generator. The exhaust emissions from the generator are excluded from the volume and evacuated to a CVS system. Similar to the dilution tunnel test method, this method uses common emissions measurement equipment. However, unlike the dilution tunnel test method, it provides a uniform oxygen concentration around the generator assembly and can provide a steady oxygen concentration during dynamic engine speed fluctuation.

NIST Technical Note 1834 Test Method

The NIST TN 1834 test method is provided in appendix B of NIST Technical Note 1834 (8).

Equipment

NIST TN 1834 provides specifications for the equipment and verification of experimental setup. The sections below identify the basic requirements of the test method and the specifications of the system used for evaluation.

Chamber: Tests are to be performed in a single-zone chamber constructed of materials capable of withstanding contact with engine exhaust gases and that can be used at sustained temperatures of 90 °C (200 °F). The chamber must be well sealed, maintain a negative pressure differential relative to its surroundings of at least 2.5 Pa (0.01 in. W.C.), and remain well mixed during testing. The volume of the chamber is dependent on the size of the engine and must be capable of satisfying the oxygen concentration requirements specified in Section C of NIST TN1834.

The chamber used for evaluation was a 57.1 m^3 (2016 ft^3), insulated steel environmental chamber. This volume was sufficient to test generators with an engine displacement of approximately 400 cc. The chamber was outfitted with a cooling system and mixing fans.

Chamber Ventilation Fan and Measurement: The exhaust fan must provide a variable flow rate sufficient to satisfy the requirements of TN 1834 Draft Test Method, Section C. The ventilation rate shall be measured to within ±5 percent of the actual value.

The ventilation system used for evaluation consisted of a variable speed blower and damper system on the intake and exhaust of the chamber. The air exchange rate was managed using a proportional-integral-derivative PID controller with input from mass flow meters in the exhaust duct and a differential pressure transducer.

Gas Concentration Measurement of CO and Oxygen: Gas measurement equipment must have a manufacturer’s specified accuracy of 1 percent of range and the peak CO concentration during testing must achieve at least 25 percent of the range in use during testing.

Gas measurement was performed using a Rosemount model NGA 2000 multi-gas analyzer with a data acquisition rate of 0.1 Hz. The gas sampling line was located near the center of the chamber.

Air Temperature and Humidity: Air temperature and humidity sensors must have accuracies of ± 1 °C and ± 5 percent relative humidity, respectively.

Air temperature and humidity were measured and recorded to verify conformance to the test method.

Load Bank and Power Meter: An AC electric load bank shall be used to simulate electric loads on the generator. The load bank must be capable of achieving each specified load condition to within 5 percent. Applied load will be measured using a power meter with an accuracy of ± 5 percent.

The load bank used for evaluation was a Simplex Swift-E with a 10000 W rating and 250 W incremental adjustments. Target loads were achieved to within 125 W. An Acuvim IIR power meter with 0.2 percent accuracy was used to measure the load.

Fuel and Lubricants: Generators must be tested with a full tank of fuel. Fuel and lubricants must meet the manufacturer's specifications for the generator.

Fuel and lubricants used for testing met the requirements specified in the manuals provided with the generators.

Procedure

The following procedures describe the methods used during evaluation. See Appendix B of NIST Technical Note 1834 for draft procedures of this test method. Measurement equipment was calibrated per the manufacturer's instruction. Gas measurement systems were calibrated at the beginning of every test day.

Evaluation Procedures for NIST TN 1834 Test Method:

1) Inspect generator for proper function and lubrication.
2) Fill fuel tank completely.
3) Place generator in the center of the chamber with load bank and remote shutoff connected.
4) Set chamber conditioning system to maintain 21 °C (70 °F).
5) Initiate sample flow to gas analyzers, and switch on mixing fans.
6) Set chamber airflow to maximum, and start the generator.
7) Warm up generator per manufacturer's instructions, and operate for minimum of 20 minutes.
8) Shut off generator, and ventilate chamber until normal gas concentrations return to levels before operating the generator.
9) Set test ventilation rate based on theoretical oxygen consumption rate, determined by testing or engine displacement and load.
10) Start generator and within 2 minutes, set desired load, and seal the chamber.
11) Operate the generator until the oxygen level is reduced to the specified range and CO equilibrium is achieved, based on the criteria in NIST TN 1834 Appendix B, Section C.7
12) Calculate CO emission rate using guidance in NIST TN 1834 Appendix B, Section D.

Results and Discussion

Results from evaluating the NIST TN1834 test method are summarized in Table 2. Repeated observational tests were performed to determine the sensitivity of various parameters. Establishing an appropriate airflow and precisely measuring the air exchange rate was critical to the success of a test. Seven tests met the requirements of NIST TN 1834. The airflow was changed for each test to evaluate the effect of different equilibrium oxygen concentrations on the calculated CO emission rate.

Table 2. NIST TN1834 Test Method Results

NIST TN 1834 Test Method Results						
Generator	**Load (W)**	**Air Exchange rate (1/hr)**	**O2 @ Equilibrium (%)**	**O2 Consumption Rate (g/hr)**	**CO @ Equilibrium (ppm)**	**CO Rate @ Equilibrium (g/hr)**
Gen 5.5C	2750	2.5	18.2	3943	8893	1472
	5500	3.0	17.2	6397	16167	3250
	5500	3.5	17.7	5987	13554	3121
	5500	4.0	18.4	5509	8512	2268
Gen 5.5I	2750	2.0	17.9	3667	7047	937
	5500	3.0	17.6	5904	9168	1904
	5500	4.0	18.2	5851	12495	3293

Each test reported in Table 2 met the requirements of NIST TN 1834. There is a large variation in the CO emission rate at various equilibrium oxygen levels. Therefore, the range of acceptable oxygen concentrations reduces repeatability. Limiting the range would increase repeatability. However, achieving a specific oxygen level using this method is very complicated and time consuming. Performing preliminary air exchange tests to determine the appropriate airflow may be necessary.

Figure 1 shows the CO emission rate of the mode 1, 5500 W, generator-rated power tests versus the achieved oxygen level at equilibrium. CPSC staff performed tests using a 6-mode test based on 40 C.F.R. part 1065 (10). Modes are percentages of the total maximum power being tested and are as follows:

Mode 1 – 100 percent
Mode 2 – 75 percent
Mode 3 – 50 percent
Mode 4 – 25 percent
Mode 5 – 10 percent
Mode 6 – 0 percent

For the NIST TN 1834 testing, only modes 1 and 3 were performed based on the generators advertised rated continuous power output. Data for Gen 5.5C demonstrates a rising CO emission with reducing oxygen that may peak around 17 percent oxygen. This curve is similar to the results in Figure 8(a) of NIST Technical Note 1781 (1). The data for Gen 5.5I indicates a reduction in CO emissions with lower oxygen levels acceptable to the range required in NIST TN 1834. This may be caused by the power demand from the load bank overcoming the power capability of the engine when the oxygen level is decreased sufficiently. In either case, the variation of results produced from tests meeting the requirements of NIST TN 1834 presents a concern for repeatability.

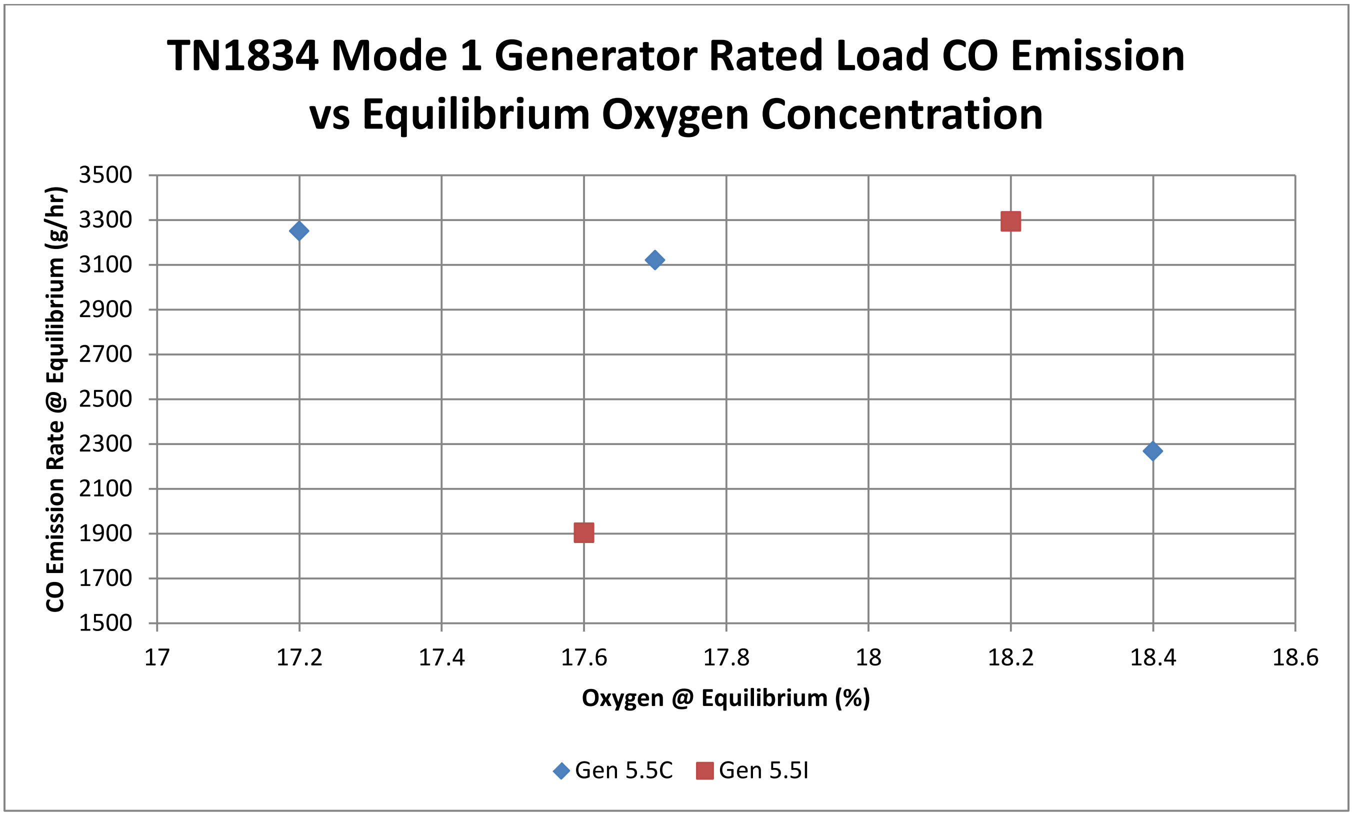

Figure 1. TN1834 Mode 1 Generator Rated Load CO Emission vs. Equilibrium Oxygen Concentration

CPSC staff modified the NIST TN 1834 test method for further validation of results. Tests were performed with a high air exchange rate to maintain near-normal oxygen concentrations while the generator was operated at six different modes. Due to limitations in air flow, oxygen was maintained above 20.3 percent for all modes. The two generators tested had a manufacturer-rated, continuous output of 5500 W. The modes tested were 100 percent, 75 percent, 50 percent, 25 percent, 10 percent and 0 percent of the generators rated continuous output, congruent with the six modes identified in 40 C.F.R. § 1065 (10). Once CO equilibrium was achieved in the chamber, the average CO concentration during that time was measured to determine the emission rate based on the chamber airflow. The resulting data were compared to three CVS tests performed with guidance from 40 C.F.R. § 1065 (10). Figure 2 and Figure 3 provide the modal CO emission rates and indicate that the NIST TN 1834 test fixture used for evaluation results in lower measured emission rates. This may be attributed to the cumulative error in the system derived from volume, airflow, and mixing dependencies.

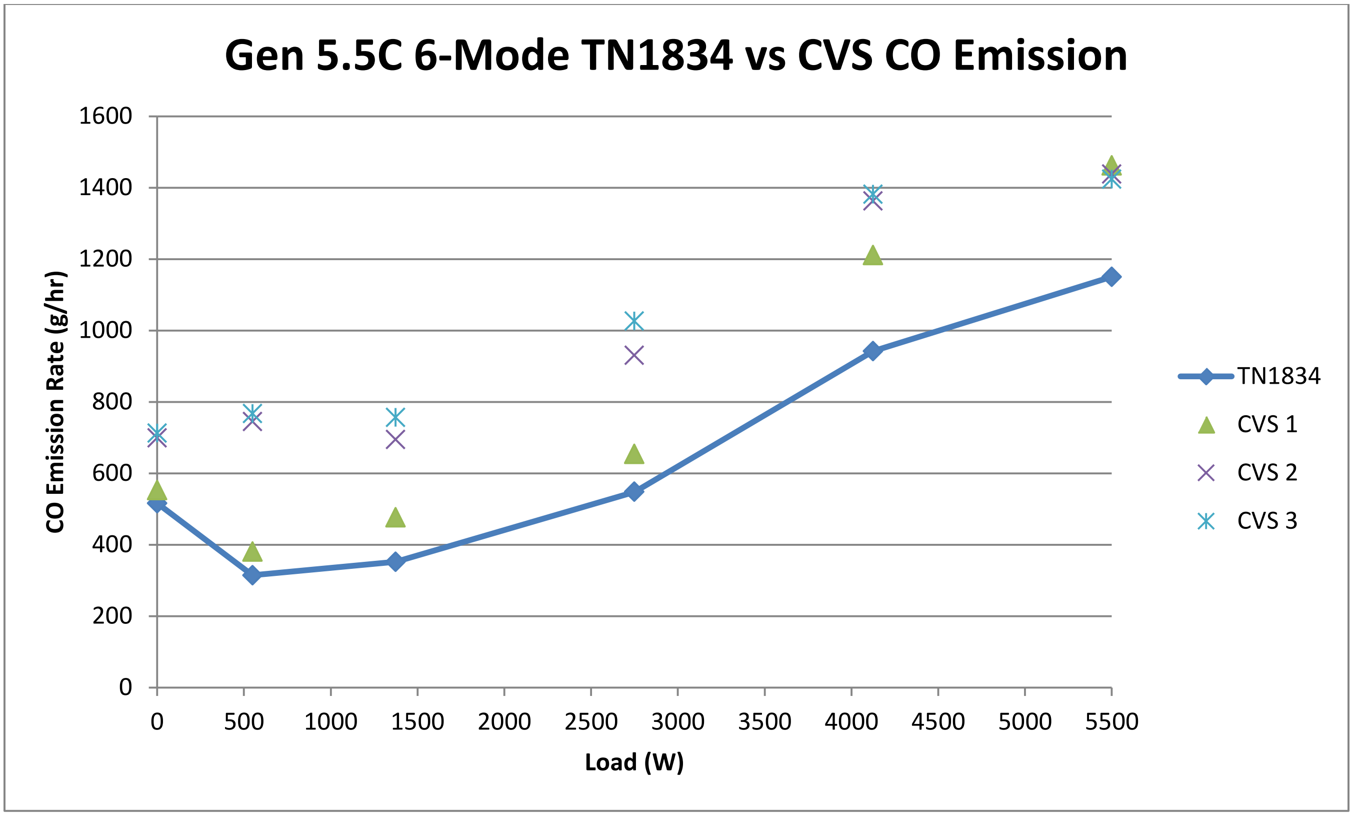

Figure 2. Gen 5.5C 6-Mode TN1834 vs CVS CO Emission

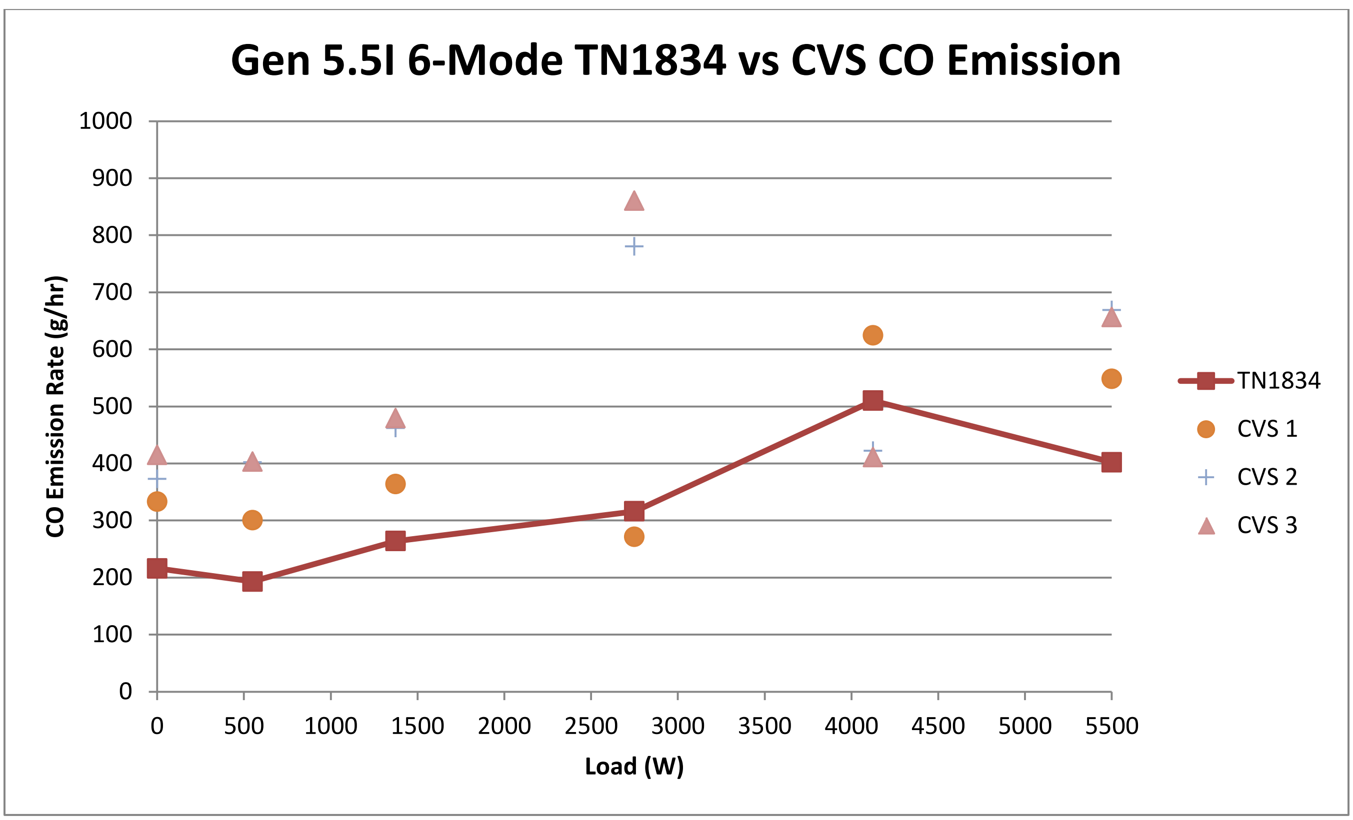

Figure 3. Gen 5.5I 6-Mode TN1834 vs CVS CO Emission

The NIST TN 1834 test method was the first testing development to evaluate portable generator CO emission rates in a reduced oxygen environment (8). It was developed through CPSC and NIST testing of portable generators (1) (2) (11). Although this method was based on sound research, this evaluation and discussions with industry determined that it may not provide the necessary performance. When this method was proposed, it was understood that the infrastructure required for testing was substantial. Industry members in the UL 2201 CO hazard reduction task group agreed that the infrastructure would be a significant burden. Members also indicated that a large test volume filled with high concentrations of CO presented concerns for personnel safety. CPSC's evaluation of the test method identified issues with repeatability and concerns that the test method may require several iterations to achieve the appropriate equilibrium oxygen concentration. An iteration of testing may take up to 3 hours. Additionally, this test method only measures the CO emission rate at two different loads. Considering these results, CPSC staff focused efforts on determining other test methods with improved repeatability, less risk to personnel safety, and reduced burden on industry.

Dilution Tunnel Test Method

The dilution tunnel test method was originally developed to determine full-time, closed-loop operation of a fuel-injected engine for all steady-state loads in a reduced oxygen environment. No modifications were required to apply the tunnel system to a generator assembly while tested to a 6-mode CVS test. The dilution tunnel test method used a large duct connected to the engine intake that was long enough to provide a well-mixed combination of air and bottled nitrogen. Nitrogen for dilution was injected at the far end from the engine intake. The percent oxygen by volume provided for combustion was measured near the engine intake. This system provided control of the oxygen concentration to the engine without the need for a large chamber to recirculate exhaust gases. When compared to the NIST TN 1834 test method, specific steady-state oxygen levels could be achieved in minutes rather than hours and a CVS system could be used for emissions analysis.

Equipment

Equipment for the dilution tunnel test method included a dilution tunnel system with environmental diagnostics and a CVS emissions test tunnel. The dilution tunnel required fabrication of a manifold that could be affixed to the generator without affecting the normal flow characteristics of the intake assembly. The test generator, Gen 10.5I, is shown in Figure 4 and Figure 5 with the manifold and a 60-inch-long, 4-inch diameter smooth-flow duct. The exhaust was collected by a CVS system for analysis.


Figure 4. Dilution Tunnel Manifold for Test Engine

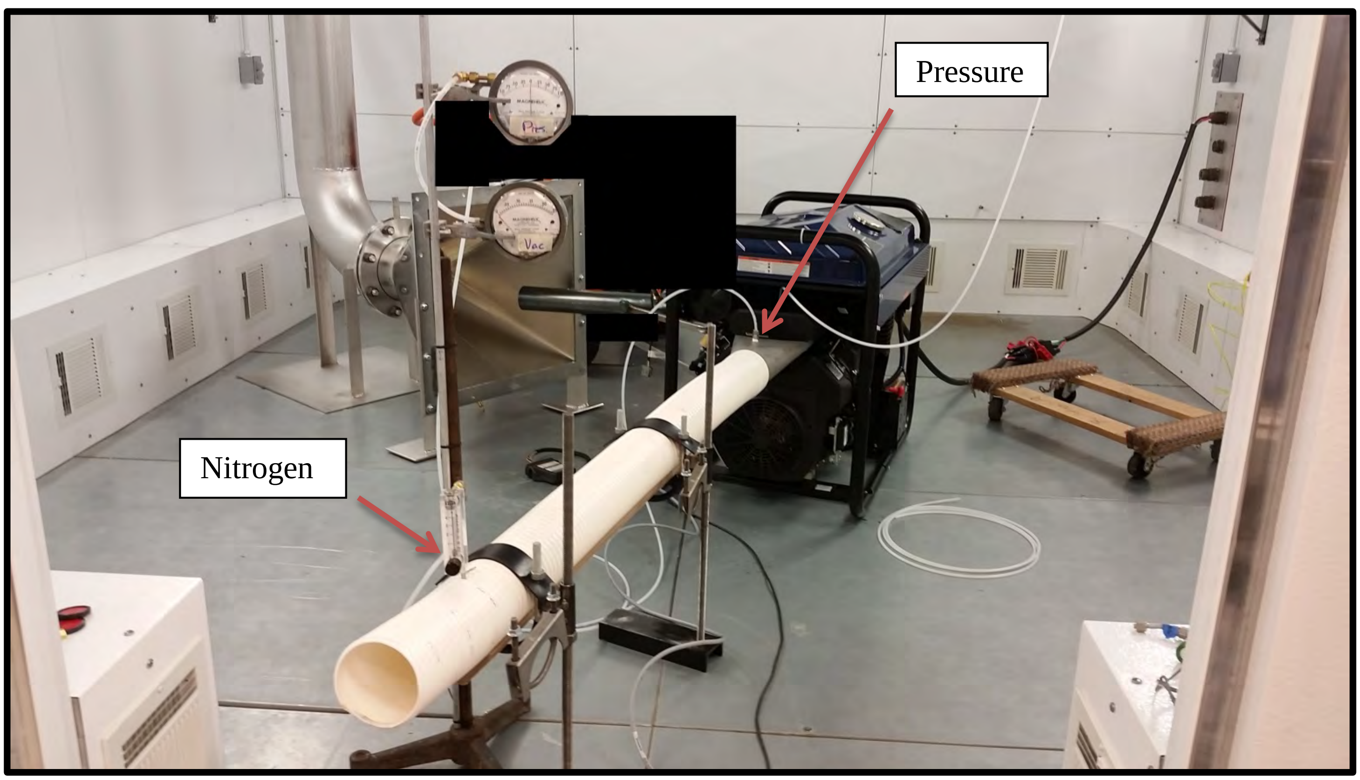

Figure 5. Dilution Tunnel Affixed to Test Generator

The dilution tunnel system was instrumented with a differential pressure gauge in the tunnel manifold and an oxygen sample port at the face of the throttle body. Nitrogen was supplied using the injector in Figure 6. The injector had seven evenly spaced ports supplying nitrogen across the diameter of the duct to promote mixing. Nitrogen flow was controlled using a manual valve.

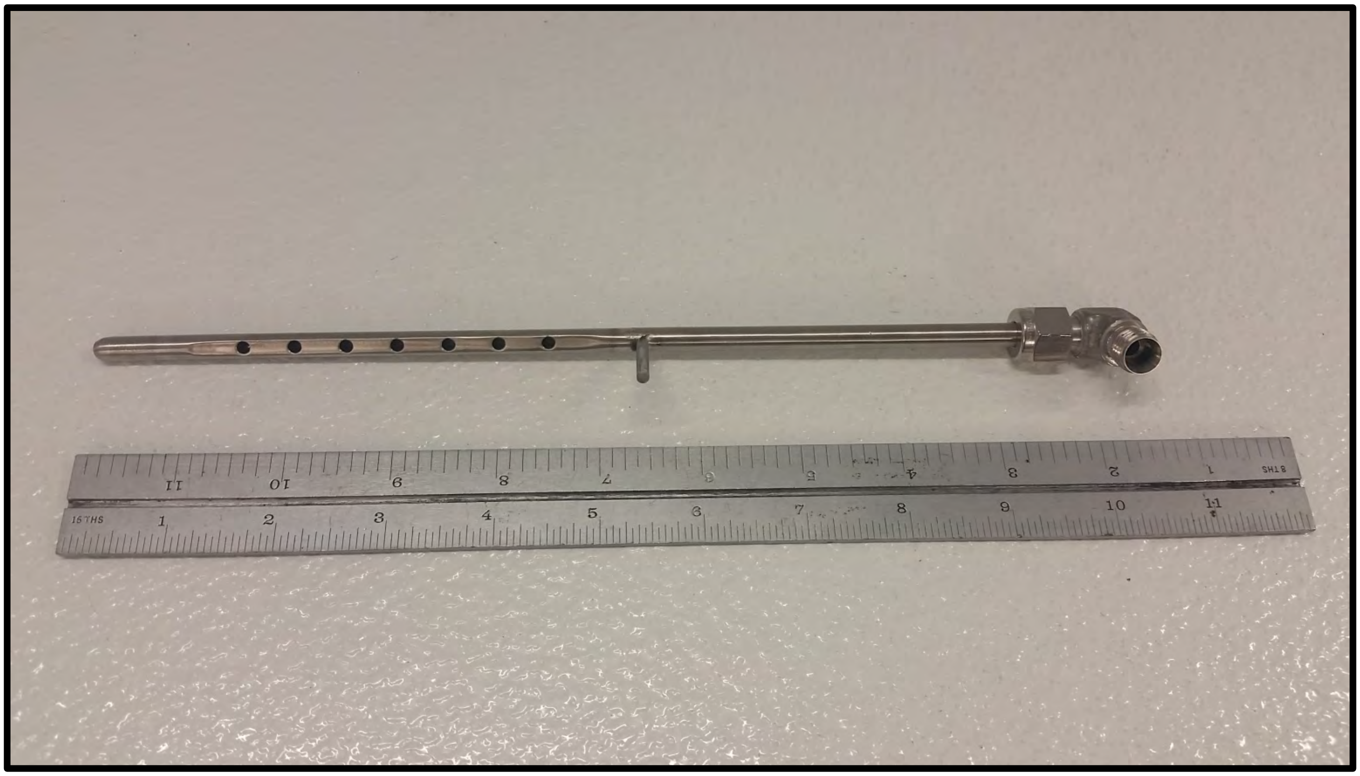

Figure 6. Nitrogen Injection Tube.

Procedure

The procedures used for the dilution tunnel test method evaluation were similar to section 6.2 of the CPSC report, *Draft Test Method for UL 2201 Task Group for Determining the CO Emission Rate of Portable Generators* (12). However, during initial testing of Gen 10.5I, the engine was unable to maintain a stable engine speed below 18 percent oxygen; therefore the target reduced oxygen concentration for evaluation was changed to 18 percent. For a direct injection method, such as the dilution tunnel, providing a steady oxygen concentration to the engine depends on steady engine speed. If the engine speed changes, the volumetric intake flow changes, affecting the proportion of nitrogen required to maintain the desired oxygen concentration. If the nitrogen flow does not change in response to changing engine speed, the oxygen concentration in the tunnel will fluctuate widely. The resulting data would not reflect the performance of the generator in a steady reduced oxygen environment. The dependence on engine speed was identified as a concern for this test; and therefore, the target reduced oxygen concentration was increased to 18 percent for evaluation purposes. The purpose was to isolate the effects of oscillating engine speed to aide in identifying other potential issues.

The following procedures were used for evaluation of the dilution tunnel test method:

1) Inspect generator for proper function and lubrication.
2) Fill fuel tank completely.
3) Start the engine, and warm to operating temperature. The engine was operated for a minimum of 20 minutes with a load greater than 60 percent of the generator's rated continuous power.
4) With the generator still running, adjust the load bank to apply the appropriate mode test point of the generator's rated continuous power.
5) Reduce oxygen steadily at the engine intake by introducing the nitrogen stream until the oxygen concentration, measured at the engine intake is 18 ± 0.25 percent by volume.
6) While maintaining the oxygen concentration at 18 ± 0.25 percent by volume, sample emissions for 3 minutes at a sample rate of 0.1 Hz with the prescribed load applied, and then stop emissions sampling. Record the mean CO emission values for that load.
7) Stop nitrogen flow, and remove the load from the generator.
8) Perform steps 4 through 7 for the following modes, in order of succession:
    - Generator mode 1 power: 100 percent of the generator's continuous power rating
    - Generator mode 2 power: 75 percent of the generator's continuous power rating
    - Generator mode 3 power: 50 percent of the generator's continuous power rating
    - Generator mode 4 power: 25 percent of the generator's continuous power rating
    - Generator mode 5 power: 10 percent of the generator's continuous power rating
    - Generator mode 6 power: no load applied
9) Calculate the generator's weighted CO emission rate using the following equation:

$$\dot{m}_w = 0.09 \times \dot{m}_1 + 0.20 \times \dot{m}_2 + 0.29 \times \dot{m}_3 + 0.30 \times \dot{m}_4 + 0.07 \times \dot{m}_5 + 0.05 \times \dot{m}_6 \quad \textbf{Eqn 1}$$

(Note: The multipliers in this equation are from engine emission test procedures provided in 40 C.F.R. part 1065, *Engine-Testing Procedures*)

where,

$$\dot{m}_w = Weighted\ CO\ Emission\ Rate\ (\frac{g}{hr})$$
$$\dot{m}_1 = CO\ Emission\ Rate\ at\ mode\ 1\ (\frac{g}{hr})$$
$$\dot{m}_2 = CO\ Emission\ Rate\ at\ mode\ 2\ (\frac{g}{hr})$$
$$\dot{m}_3 = CO\ Emission\ Rate\ at\ mode\ 3\ (\frac{g}{hr})$$
$$\dot{m}_4 = CO\ Emission\ Rate\ at\ mode\ 4\ (\frac{g}{hr})$$
$$\dot{m}_5 = CO\ Emission\ Rate\ at\ mode\ 5\ (\frac{g}{hr})$$
$$\dot{m}_6 = CO\ Emission\ Rate\ at\ mode\ 6\ (\frac{g}{hr})$$

Results and Discussion

The dilution tunnel test was performed on only one generator due to time constraints and the requirement to fabricate a manifold to affix the tunnel to each intake assembly. Differential pressure caused by the fixture was less than 62 Pa (0.25 in. W.C.). Results for dilution tunnel testing and normal oxygen CVS testing performed on Gen 10.5I are provided in Table 3. The reduced oxygen CO emission rate factor at the bottom of Table 3 represents the factor of increase of the CO emission rate due to the reduction of oxygen to the target concentration:

$$\boldsymbol{Factor} = \frac{\left(\sum_{i=1}^{n} x_i\right)/n}{\left(\sum_{j=1}^{m} y_j\right)/m} \qquad \textbf{Eqn 2}$$

where,

$$x = weighted\ CO\ emission\ rate\ in\ reduced\ oxygen\ \left(\frac{g}{hr}\right)$$
$$n = number\ of\ tests\ performed\ in\ reduced\ oxygen$$
$$y = weighted\ CO\ emission\ rate\ in\ normal\ oxygen\ \left(\frac{g}{hr}\right)$$
$$m = number\ of\ tests\ performend\ in\ normal\ oxygen$$

Table 3. Gen 10.5I Generator Rated Load Profile CO Emission

Gen 10.5I Generator Rated Load Profile CO Emission				
Mode	**Emission Rates (g/hr)**			
	CVS 1	**CVS 2**	**CVS 3**	**Dilution Tunnel**
1	3351	2921	2629	6942
2	908	863	859	5170
3	369	324	295	990
4	212	224	187	365
5	140	120	110	245
6	127	107	101	185
Weighted	**670**	**610**	**563**	**2082**
Reduced Oxygen CO Emission Rate Factor				**3.39**

Gen 10.5I operated in closed loop at 18 percent oxygen for modes 4 through 6. Modes 1 through 3 caused the fuel control system to default to a fuel-rich, open-loop operation in the reduced oxygen environment. As a result, the CO emission rate for mode 1-3 is nominally 2 to 6 times higher than the emission rates observed in normal oxygen. This factor of increase is similar to those determined for carbureted generators tested by NIST and CPSC staff, discussed later in this report. Even in modes 4 through 6, in which closed-loop operation was maintained, the CO emission rate increased nominally 1.5 to 2 times. The rise of emission rates is evident in Figure 7.

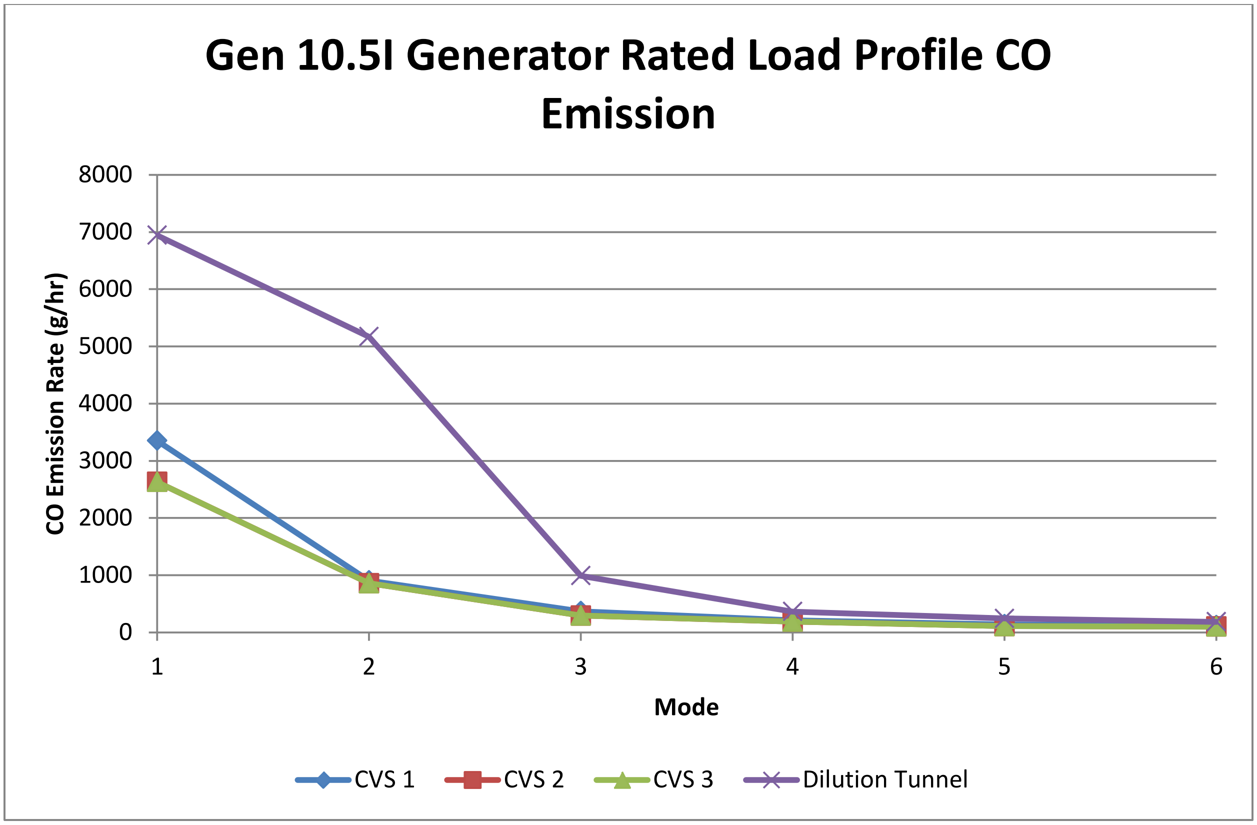

Figure 7. Gen 10.5I Generator Rated Load Profile CO Emission

The dilution tunnel study exposed applicability limitations and repeatability concerns for the fixture and its operation. The operator of this test method must ensure that the flow characteristics of the generator's intake assembly are unaffected by the dilution tunnel fixture. This requires a specialized manifold for each configuration. Closed-frame generators present a challenge for connecting the tunnel because of physical obstructions to the intake. Additionally, some closed-frame generators rely on the intake flow to draw cool air into the housing for engine cooling. Connecting a tunnel to such a generator would affect temperature management of the assembly. Aside from physical constraints and influencing performance from modification, managing nitrogen flow relative to changing engine speed is another challenge.

The governor on a generator may cause the engine speed to oscillate or "hunt" around the desired speed. Large changes in engine speed would require a corresponding change in the nitrogen flow rate to maintain a steady oxygen concentration at the intake. Under high loads while testing Gen10.5I, as nitrogen flow was increased, the generator would reach a point of overload, and the engine speed would drop quickly. Reduced engine speed reduces volumetric intake flow and a disproportionately large concentration of nitrogen would enter the dilution tunnel. This resulted in a rapid decrease in oxygen available to the engine, which, on occasion, caused the engine to stall. Some degree of engine speed oscillation or hunting is normal to the operation of specific engine control configurations. Without the capability to constantly adjust the nitrogen flow proportional to engine speed, the oxygen concentration provided to the engine will not remain constant. Currently, the dilution tunnel does not provide sufficient adjustment to compensate for engine speed oscillation to provide a steady reduced oxygen level for all generator configurations.

Applying the dilution tunnel to a generator with a closed-loop fuel-injection engine may not produce results indicative of the generator's performance in a reduced-oxygen environment. Many oxygen sensors used on fuel-control systems for small engines have an air reference that must be exposed to the same environment as the engine intake. The air reference represents the atmosphere provided for combustion. The difference in oxygen concentration between the air reference and the exhaust gas generates a voltage across a Nernst cell due to the differential of oxygen ion conduction through a zirconia element. Under normal operating conditions of a generator in an enclosed space, the oxygen concentration of the air surrounding the oxygen sensor is the same as the concentration entering the engine intake. The dilution tunnel test method does not provide an equivalent oxygen concentration to the oxygen sensor air reference. This difference in oxygen concentration between the sensor air reference and the intake can affect the fuel adjustments performed by the control system in a manner that does not represent operation in a reduced-oxygen environment. The effects of an uncorrected air reference have not been quantified for this report.

Dilution Chamber Test Method

Staff developed the dilution chamber test method to address the limitations identified by staff during evaluation of the dilution tunnel and by members of the UL 2201 task group. Similar to the dilution tunnel, nitrogen is used to displace oxygen, rather than using the recirculated engine exhaust method from NIST TN 1834. However, instead of directly injecting the nitrogen into a feed to the engine intake, nitrogen is supplied to a small, enclosed volume surrounding the generator. This creates an environment with a precisely controllable oxygen concentration around the entire generator assembly that reduces the effect of engine speed on nitrogen flow. The volume of diluted air dampens the effect of dynamic engine speed on nitrogen flow. The exhaust from the generator is captured by a duct that is sealed to the muffler of the engine, preventing emissions from recirculating in the control chamber. The captured exhaust is directed out of the control chamber to a CVS system for analysis. This method allows for 6-mode testing under various controlled oxygen levels and temperatures, as well as the use of a CVS or raw gas measurement system. A procedure for the dilution chamber test method, developed with input from UL 2201 task group members, is provided in Appendix A2.

The data from this evaluation served two purposes. First, tests were performed multiple times to evaluate repeatability of the test method. Second, the results from tests performed using the dilution chamber test method were compared to normal oxygen concentration CVS test results to correlate the increase in CO emissions to reduction in oxygen.

Equipment

The following section provides the specifications and materials used for evaluation of the dilution chamber test method based on a memorandum submitted to the UL 2201 task group (13). All materials used to construct the chamber and conditioning systems were commercially available. A rendering of the dilution chamber and location, relative to the CVS system collection duct for this study, is provided in Figure 8.

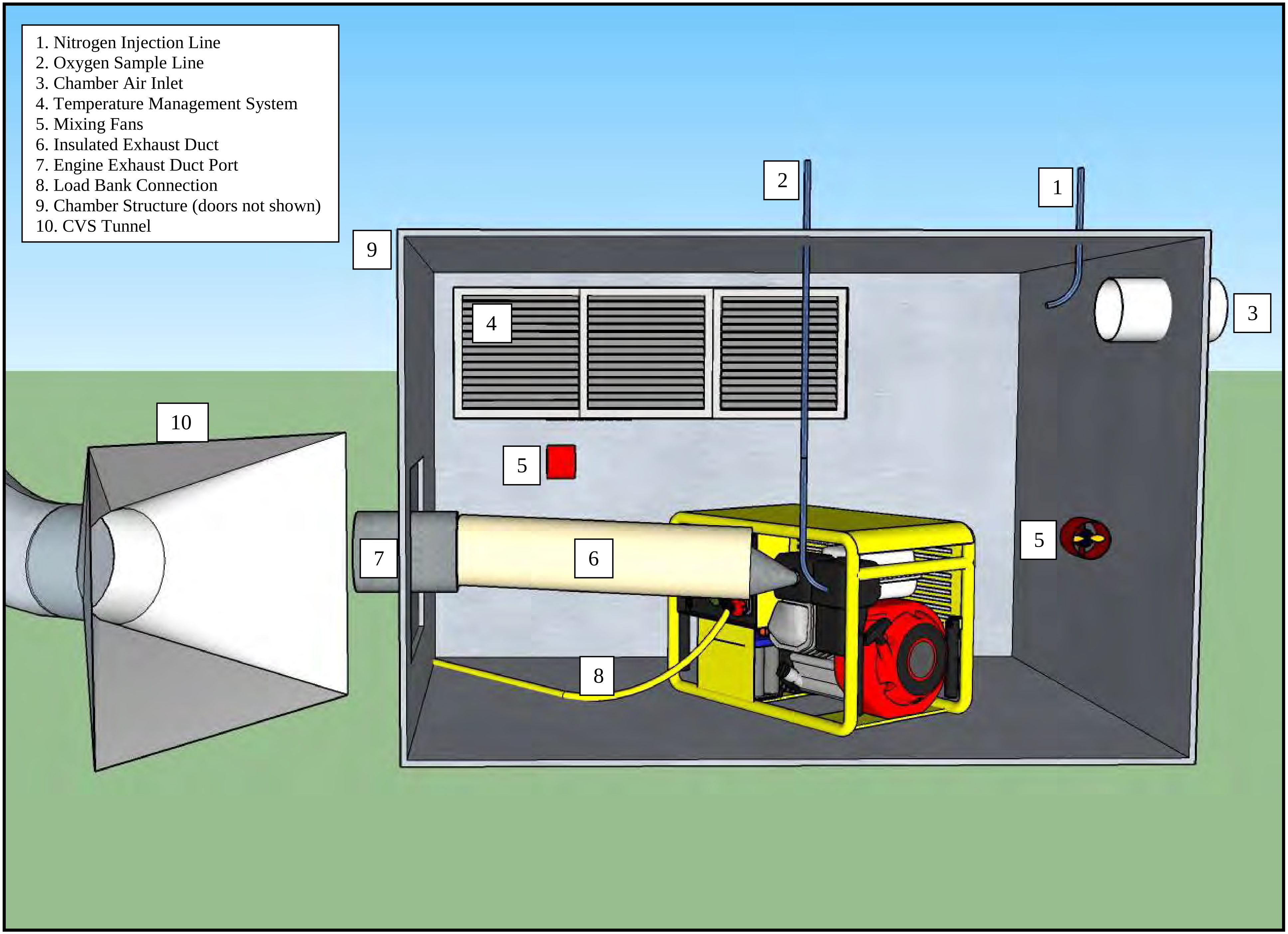

Figure 8. Dilution Chamber Test Method Rendering as Constructed for Evaluation.

Nitrogen Injection Line: The nitrogen injection line provided a variable flow of industrial grade nitrogen to the chamber volume. A gate valve was used to adjust the desired flow. For reference, volumetric flow of up to 114 slpm (4 scfm) with a line pressure of 6.9 Bar (100 psi) were used successfully to reduce oxygen levels to below 16.0 percent for a generator with a nominal rated continuous power of 5 kW.

Oxygen Sample Line: The oxygen sample line, connected to a paramagnetic oxygen analyzer, measured the oxygen concentration near the intake of the engine.

Chamber Air Inlet: The chamber air inlet was of sufficient size to prevent the development of an unrepresentative pressure differential between chamber environment and its surroundings. Differential pressure remained below 12.5 Pa (0.05 in. W.C.) for all tests. The inlet was also positioned to encourage mixing and a steady oxygen concentration at the intake of the engine. For reference, a 6-inch diameter inlet duct was sufficient for a generator nominally rated at 5 kW continuous output.

Temperature Management System: The temperature management system maintained the temperature in the chamber to within the normal expected operating range of the generator. For most tests, the chamber temperature was limited to 38 °C (100 °F). A cooling system capable of removing approximately 9 kW (30,000 BTU/hr) of heat was used successfully for a generator nominally rated at 5 kW continuous output. The cooling was acceptable for the generators tested during evaluation; however, a cooling capacity greater than 10 kW would provide more confidence in temperature control and less temperature rise for a generator of this size. A larger cooling capacity would be required for larger generators.

Mixing Fans: Mixing fans were used to ensure proper mixing and a steady oxygen concentration at the intake of the engine.

Insulated Exhaust Duct: The insulated exhaust duct was sealed to ensure that all of the exhaust from the engine was ported directly out of the chamber to the CVS tunnel. Four-inch V-band clamps were used to connect the generator exhaust to the duct. A cone was welded to the muffler with a v-band flange at one end. CO concentrations were measured inside the chamber to monitor leakage from the exhaust assembly. Any tests that achieved a concentration higher than 200 ppm within the chamber were repeated after repairing any leaks. Hydrocarbons were also monitored for personnel safety with a limit of 25 percent of the lower explosive limit (LEL). The duct was stainless steel and flexible to minimize mechanical stresses on the assembly. It was of sufficient diameter to have no effect on the normal backpressure of the engine. The duct was insulated with fiberglass mat and cloth to reduce heat loading within the chamber.

Engine Exhaust Duct Port: The exhaust duct port directed the engine emissions into the collection hood of the CVS tunnel. It was designed to emit to the open environment surrounding the dilution chamber while ensuring complete capture of emissions by the CVS tunnel. The port was designed to limit heat transfer to the dilution chamber walls because of the material selection for chamber construction.

Load Bank Connection: The load bank connection was routed safely through the chamber wall and to the generator. A resistive load bank was used for evaluation.

Chamber Structure: The chamber structure was a box, approximately 2.8 m^3 (100 ft^3) in volume. This study used a structure built of Oriented Strand Board (OSB) wood with all edges and seams sealed. The exhaust duct port was mounted through 1.6 mm- (.065 in.) thick sheet metal, approximately 0.5 m by 0.5 m (20 in. by 20 in.), to minimize heat transfer to the wood and dampen vibrations transferred through the exhaust duct. One side of the chamber consisted of doors to allow access to the interior for setup and maintenance. Most penetrations through the chamber were sealed. Windows were added to provide visibility of the chamber environment during testing. Braces or other means of mechanically affixing the generator in the chamber were needed, on occasion, to limit movement of the generator assembly due to vibration.

CVS Tunnel: The engine exhaust duct port on the side of the dilution chamber was positioned in the center of the CVS tunnel hood. The exhaust duct port was not attached to the CVS tunnel. Background air was drawn into the CVS tunnel from the environment exterior to the dilution chamber. Background sampling for CVS system calculations was also taken from the environment outside of the chamber.

Procedure

The procedures for determining the weighted CO emission rate of a generator operated in a reduced oxygen environment using the dilution chamber test method are provided in this section. Some tests were performed using mode points based on the manufacturer's rated continuous power output (generator rated load) while other tests based the profile on the maximum power output capability (maximum generator load) of the generator to achieve the maximum engine load for the assembly. For maximum generator load tests, the generators were loaded beyond the rated continuous power identified by the manufacturer. Note that temperature, CO, and total hydrocarbons in the chamber were monitored to ensure integrity of the system and safety of the test operators.

The following procedures were used to perform the dilution chamber tests:

1) Inspect generator for proper function and lubrication.
2) Fill fuel tank completely.
3) Condition chamber to 15 °C (60 °F).
4) Start the engine, and warm to operating temperature. The engine was operated for a minimum of 20 minutes with a load greater than 60 percent of the mode 1 load.
5) With the generator still running, adjust the load bank to apply the required mode test point. Modal testing was performed in order from mode 1 to mode 6.
6) Flow nitrogen into the chamber, and reduce the oxygen concentration to 17.0 ± 0.1 percent.
7) Measure emissions for 3 minutes after the emission rate has stabilized. Verify that the chamber temperature and internal CO concentration are below 38 °C (100 °F) and 200 ppm, respectively.
8) Remove the load from the generator and restore the oxygen concentration back to normal (~20.9 percent). This was achieved by shutting off nitrogen flow and opening the chamber doors for ventilation.
9) Repeat steps 5 through 8 for the all test modes (percentages based on rated continuous power or maximum generator load in the generator, depending on the test):

- Mode 1 power: 100 percent
- Mode 2 power: 75 percent
- Mode 3 power: 50 percent
- Mode 4 power: 25 percent
- Mode 5 power: 10 percent
- Mode 6 power: no load applied

10) Calculate the generators weighted CO emission rate using the following equation:

$$\dot{m}_w = 0.09 \times \dot{m}_1 + 0.20 \times \dot{m}_2 + 0.29 \times \dot{m}_3 + 0.30 \times \dot{m}_4 + 0.07 \times \dot{m}_5 + 0.05 \times \dot{m}_6$$

where,

$\dot{m}_w = Weighted\ CO\ Emission\ Rate\ (\frac{g}{hr})$
$\dot{m}_1 = CO\ Emission\ Rate\ at\ mode\ 1\ (\frac{g}{hr})$
$\dot{m}_2 = CO\ Emission\ Rate\ at\ mode\ 2\ (\frac{g}{hr})$
$\dot{m}_3 = CO\ Emission\ Rate\ at\ mode\ 3\ (\frac{g}{hr})$
$\dot{m}_4 = CO\ Emission\ Rate\ at\ mode\ 4\ (\frac{g}{hr})$
$\dot{m}_5 = CO\ Emission\ Rate\ at\ mode\ 5\ (\frac{g}{hr})$
$\dot{m}_6 = CO\ Emission\ Rate\ at\ mode\ 6\ (\frac{g}{hr})$

Results and Discussion

For this study, five generators were tested to determine their weighted CO emission rate in a reduced oxygen environment. The target oxygen concentration was 17.0 ± 0.1 percent, which was chosen to obtain a CO emission rate representative of the peak output range indicated by Figure 8(a) and Figure 9(a) in NIST TN1781 (1). Atmospheric pressure for an elevation of approximately 150 m (492 ft) was maintained in the chamber for all testing. Temperatures during testing were limited to 38 °C (100 °F), unless otherwise noted in the results. Each generator was also tested in a normal oxygen level using a CVS emissions tunnel test with guidance from 40 C.F.R. § 1065 (10). A reduced-oxygen CO emission rate factor was calculated for each of the generators using Equation 2 from the results and discussion of the dilution tunnel

Gen 1.6C

Gen 1.6C was tested to the dilution chamber procedures, as well as an unconditioned enclosed space scenario. The first test series used a maximum generator load, 6-mode profile. "Maximum generator load" was defined as the maximum continuous power provided by the generator assembly and was considered to be the maximum capable engine load for the assembly. The unconditioned enclosed space scenario was designed to simulate conditions that may develop if this generator was operated in an enclosed space. This unconditioned simulation applied a 6-mode load profile calculated from the generator-rated continuous load specified by the manufacturer. Half of the chamber cooling system was shut down to allow the temperature to rise to an approximate average temperature of 60 °C (140 °F).

Gen 1.6C was equipped with a fuel economy switch that altered the operation of the generator to provide better fuel economy.

The results of these tests are provided in Table 4 and Figure 9. A single asterisk (*) in the charts below denotes that the fuel economy mode was activated. A double asterisk (**) denotes that the fuel economy mode was off. CVS tunnel tests performed in a normal oxygen level are labeled “CVS #.” “Dil Chamber” identifies tests performed in the reduced oxygen environment. The modal CO emission rates determined for the dilution chamber tests performed on Gen 1.6C are similar. Comparing these results to the normal oxygen tests, identified as CVS 1 through CVS 4, the weighted CO emission rate is 84 percent higher when operated in a reduced oxygen environment with a maximum generator load profile.

CVS 4 was performed with the fuel economy mode off, to determine which function was the worst case for CO emissions. The results suggest that when the fuel economy mode is off, the emission rates are higher for smaller loads. The effect of the fuel economy mode on CO emission decreases with an increase in load.

Table 4. Gen 1.6C Maximum Generator Load Profile CO Emission

Gen 1.6C Maximum Generator Load Profile CO Emission						
Mode	Emission Rates (g/hr)					
	CVS 1*	CVS 2*	CVS 3*	CVS 4**	Dil Chamber 1*	Dil Chamber 2*
1	820	867	872	917	1015	1016
2	444	461	493	548	898	859
3	330	318	370	442	666	727
4	213	230	247	331	435	438
5	81	105	92	253	328	327
6	41	45	37	213	275	276
Weighted	**330**	**341**	**367**	**448**	**632**	**642**
Reduced Oxygen CO emission Rate Factor						**1.84**

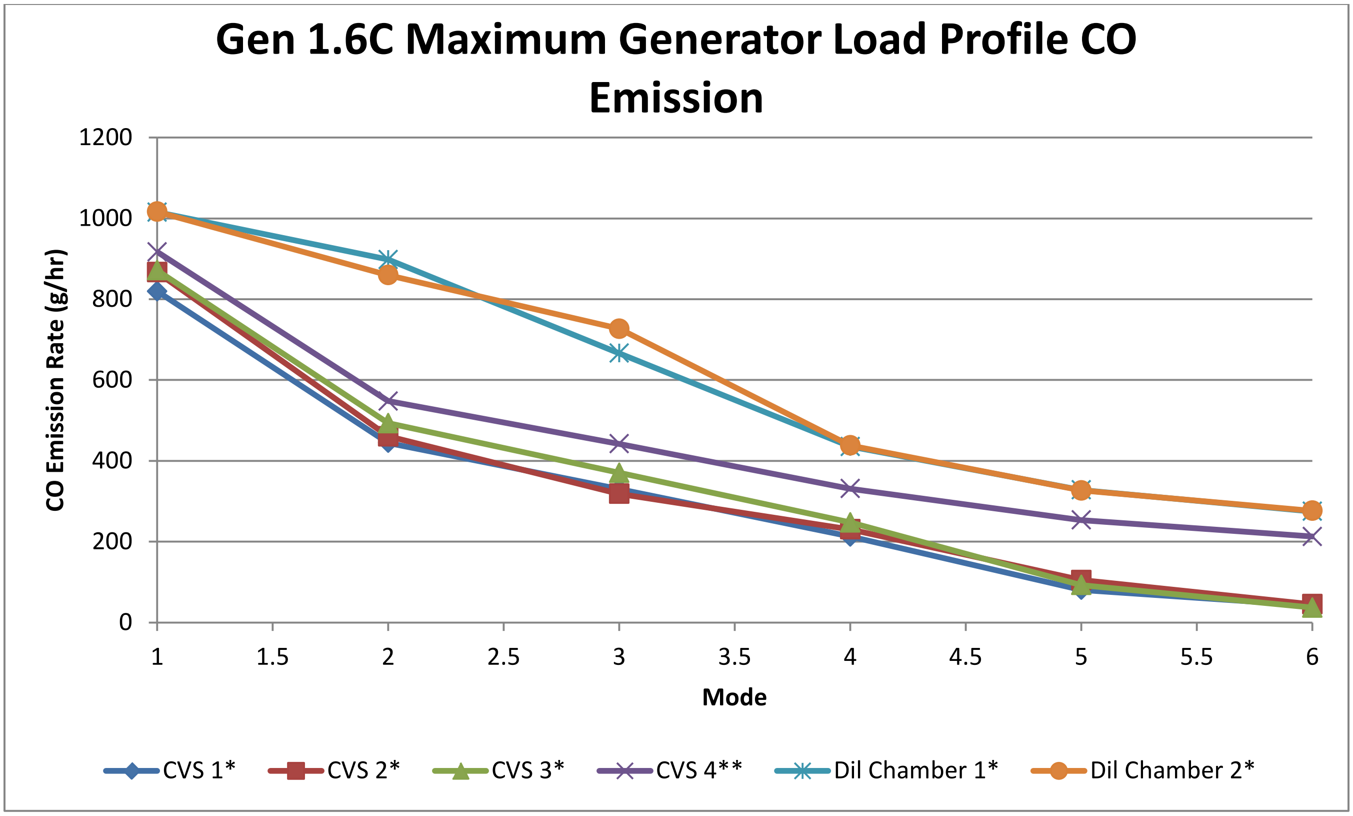

Figure 9. Gen 1.6C Maximum Generator Load Profile CO Emission

The high-temperature test, performed using a load profile calculated from the manufacturer's rated continuous load, resulted in a reduced oxygen CO emission rate factor of 3.56, as shown in Table 5. Modal curves are displayed in Figure 10. The dilution chamber test was performed with an average temperature at each mode of approximately 60 °C (140 °F). CVS GR1, the normal oxygen reference for the high-temperature, reduced-oxygen dilution chamber test, was performed at an average temperature of approximately 21 °C (70 °F). The results provide a factor of CO emission increase, relative to an enclosed space scenario, where the heat from the generator would increase the temperature within the space.

Table 5. Generator Rated Load Profile CO Emission, High Temperature Scenario

Gen 1.6C Generator Rated Load Profile CO Emission, High Temperature Scenario		
Mode	Emission Rates (g/hr)	
	CVS GR1**	Dil Chamber GR1**
1	546	968
2	318	1019
3	283	917
4	115	720
5	57	589
6	51	528
Weighted	**236**	**841**
Reduced Oxygen CO Emission Rate Factor		**3.56**

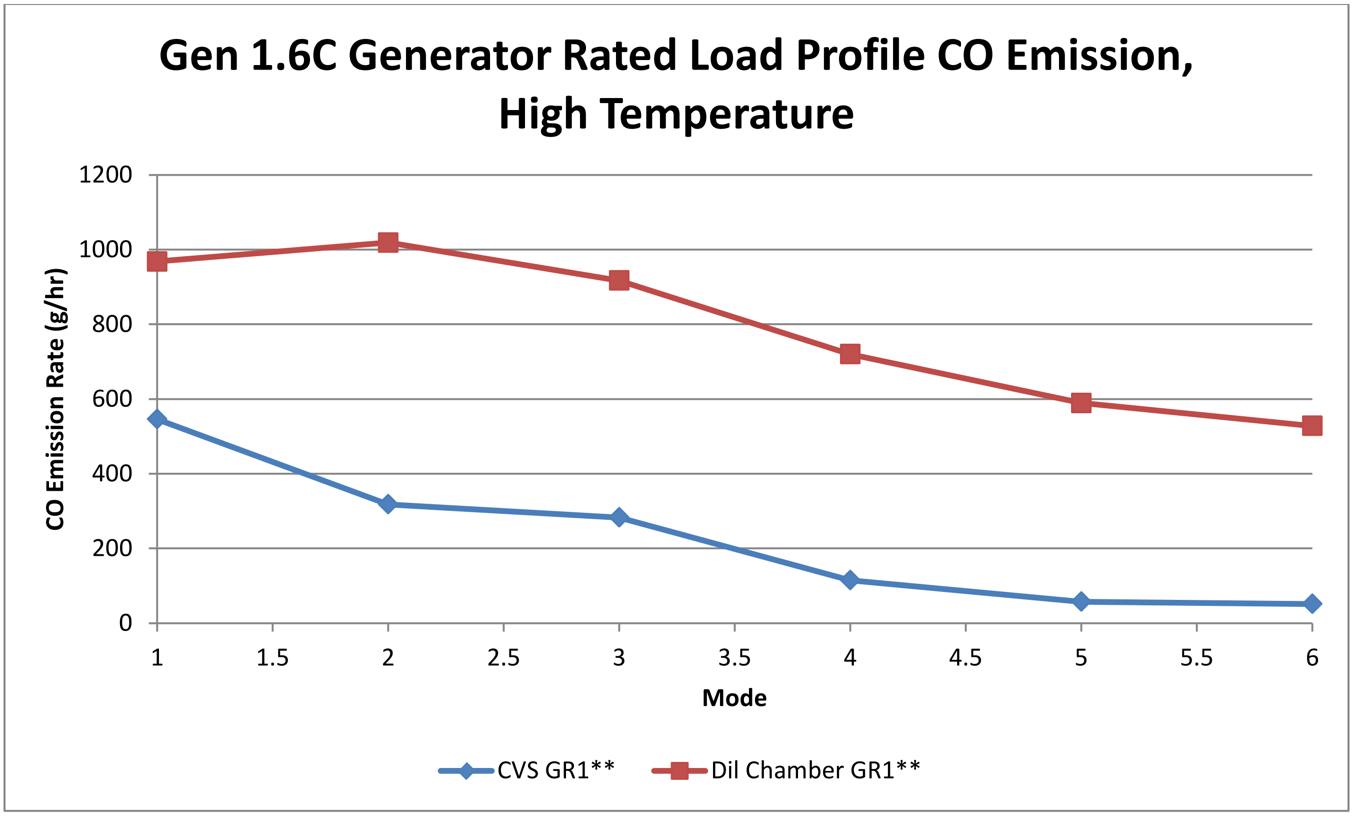

Figure 10. Gen 1.6C Generator Rated Load Profile CO Emission, High Temperature

Normal oxygen tests CVS 1 and CVS 2 were conducted while installed in the dilution chamber for comparison to normal oxygen tests performed without the dilution chamber. Testing the generator while connected to the dilution chamber without reducing the oxygen concentration is similar to performing a CVS tunnel test, such as CVS 3 and CVS 4. Comparing the results from CVS 1 and CVS 2 to a CVS tunnel test without the dilution chamber connected will determine if the chamber affects the performance of the generator, aside from the desired effects from oxygen reduction. CVS 3 was performed with the generator disconnected from the chamber and placed in front of the CVS tunnel. It was also operated with the fuel economy mode on, similar to CVS 1 and CVS 2. A comparison of results for CVS 1 through CVS 3, in Table 4 and Figure 11, suggests that the chamber does not influence the emissions performance of the generator. The weighted CO emission rate difference between the three tests was within 10 percent.

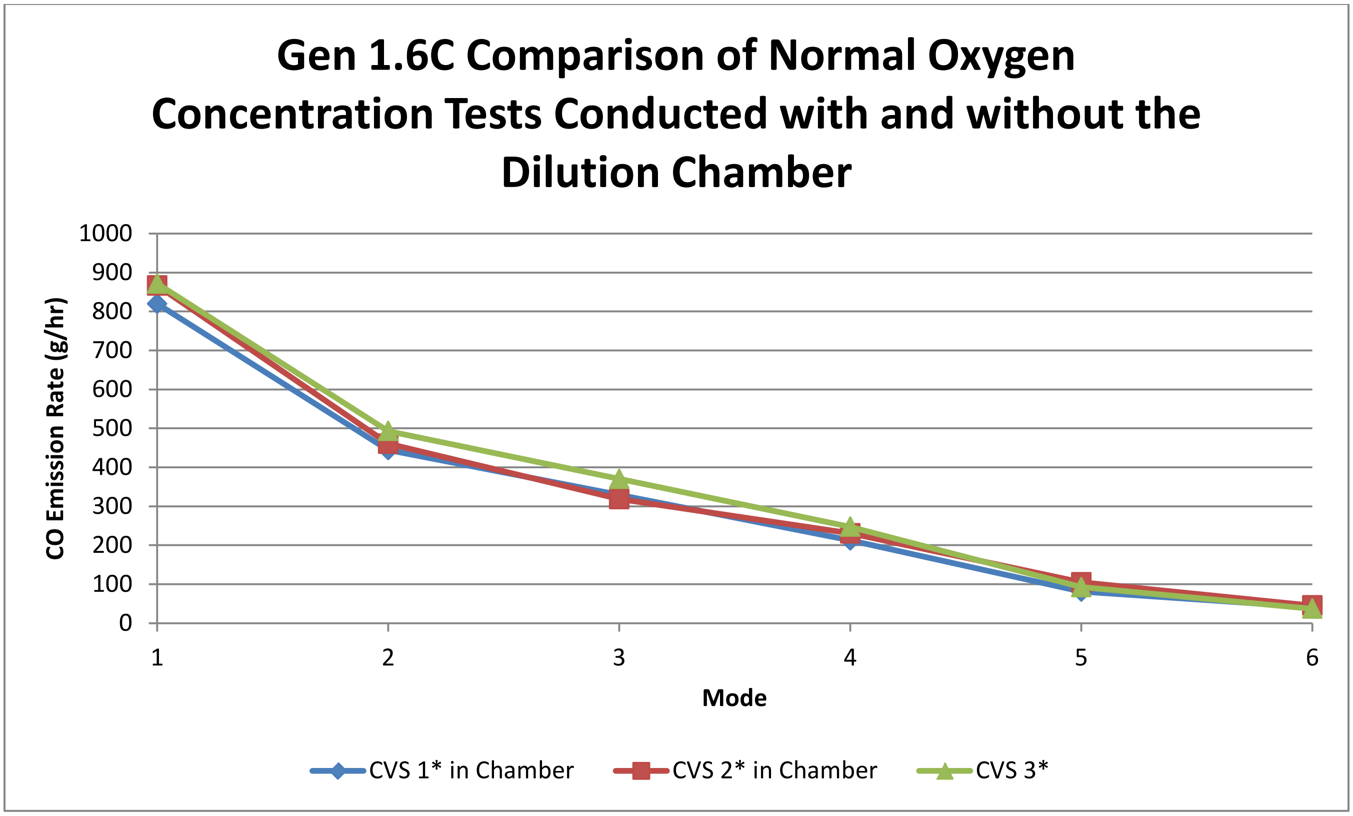

Figure 11. Gen 1.6C Comparison of Normal Oxygen Concentration Tests Conducted with and without the Dilution Chamber

Gen 2.3C

The Gen 2.3C test series included three CVS tunnel tests to determine the baseline normal oxygen performance and one dilution chamber test. A high temperature test was attempted on this generator; however, the overload switch on the generator would activate at elevated temperatures. Staff was unable to stabilize the mode points in high temperatures to record CO emission data in low oxygen. Results are provided in Table 6 and Figure 12. CVS tunnel tests performed in normal oxygen are labeled "CVS #." "Dil Chamber" identifies tests performed in a reduced-oxygen environment.

Table 6. Gen 2.3C Generator Rated Load Profile CO Emission

Gen 2.3C Generator Rated Load Profile CO Emission				
Mode	Emission Rates (g/hr)			
	CVS 1	CVS 2	CVS 3	Dil Chamber
1	544	567	685	98
2	338	234	499	1092
3	149	90	248	806
4	69	40	46	656
5	139	42	16	325
6	86	73	70	342
Weighted	**194**	**142**	**252**	**698**
Reduced Oxygen CO Emission Rate Factor				**3.56**

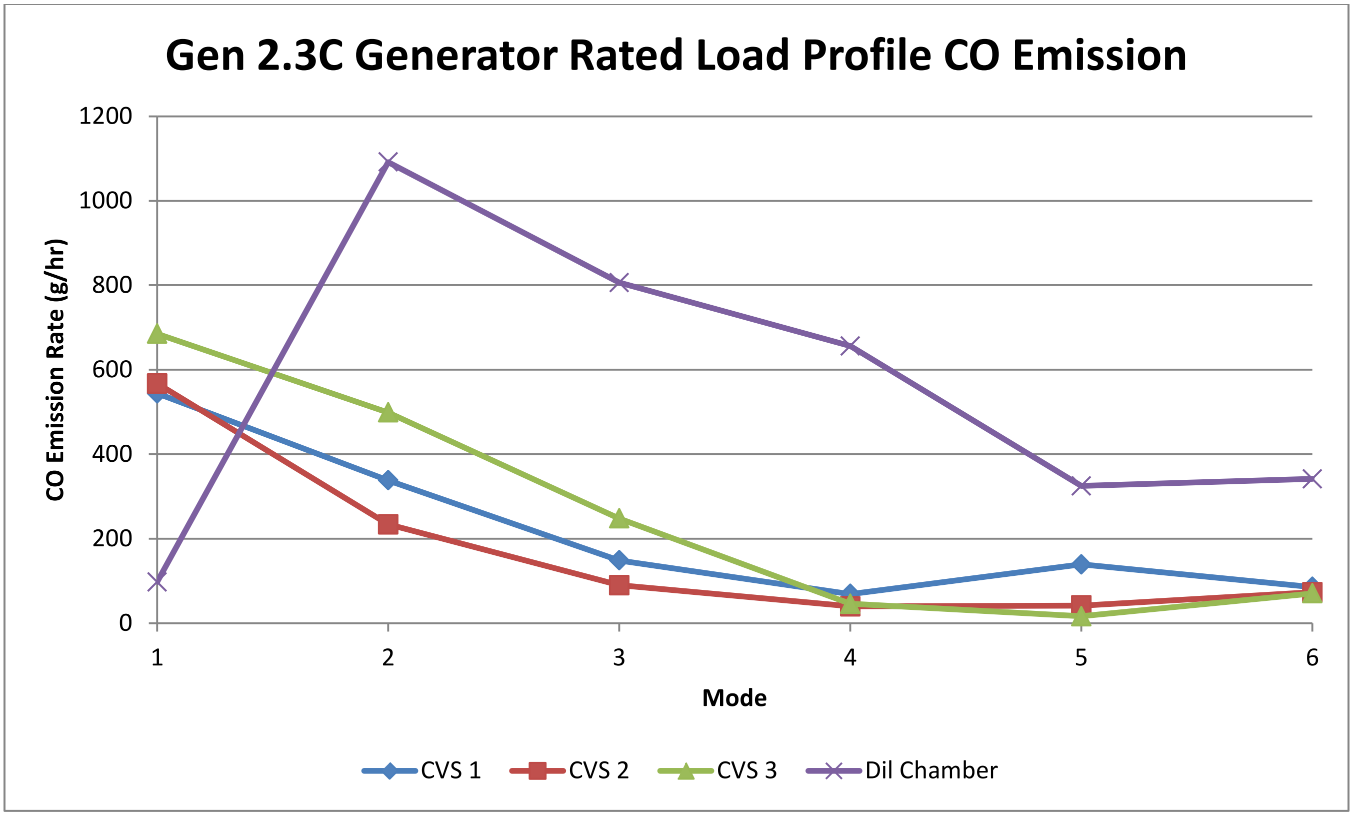

Figure 12. Gen 2.3C Generator Rated Load Profile CO Emission

Comparing the performance of GEN 2.3C in normal oxygen to 17 percent oxygen, the reduced oxygen CO emission rate factor is 3.56. During the dilution chamber test, at mode 1 the CO emission rate does not follow the trend created between emission rate and mode because the generator overload switch activated and the engine began operating at a reduced speed. The overload switch activated before the oxygen concentration and engine temperatures were stabilized. The combination of maximum rated continuous load and reduced oxygen caused the overload switch to activate repeatedly during observational tests. If the generator was capable of maintaining power output at mode 1 during the dilution chamber test, the reduced oxygen CO emission rate factor would likely be higher than 3.56.

Gen 5.5C

The test series for Gen 5.5C included three CVS tunnel tests conducted with a normal oxygen concentration and one high temperature dilution chamber test. An average ambient temperature of approximately 60 °C (140 °F) was used during reduced oxygen testing to simulate an environment that may develop when a generator was operated in an enclosed space. This study was used to support indoor air quality modeling, a parallel project (7). Gen 5.5C was equipped with a fuel economy switch that altered the operation of the generator to provide better fuel economy.

The results of this test series are provided in Table 7 and Figure 13. For this series, all tests were performed with the fuel economy mode activated. This is noted in the results with a single asterisk (*). The reduced oxygen CO emission rate factor was calculated to be 2.72.

Table 7. Gen 5.5C Generator Rated Load Profile CO Emission, High Temperature Scenario

Gen 5.5C Generator Rated Load Profile CO Emission, High Temperature Scenario				
Mode	Emission Rates (g/hr)			
	CVS 1*	CVS 2*	CVS 3*	Dil Chamber*
1	1462	1438	1423	3026
2	1211	1362	1381	3257
3	654	930	1027	2470
4	476	695	757	2126
5	380	744	767	1870
6	553	699	713	1581
Weighted	**761**	**967**	**1018**	**2488**
Reduced Oxygen CO Emission Rate Factor				**2.72**

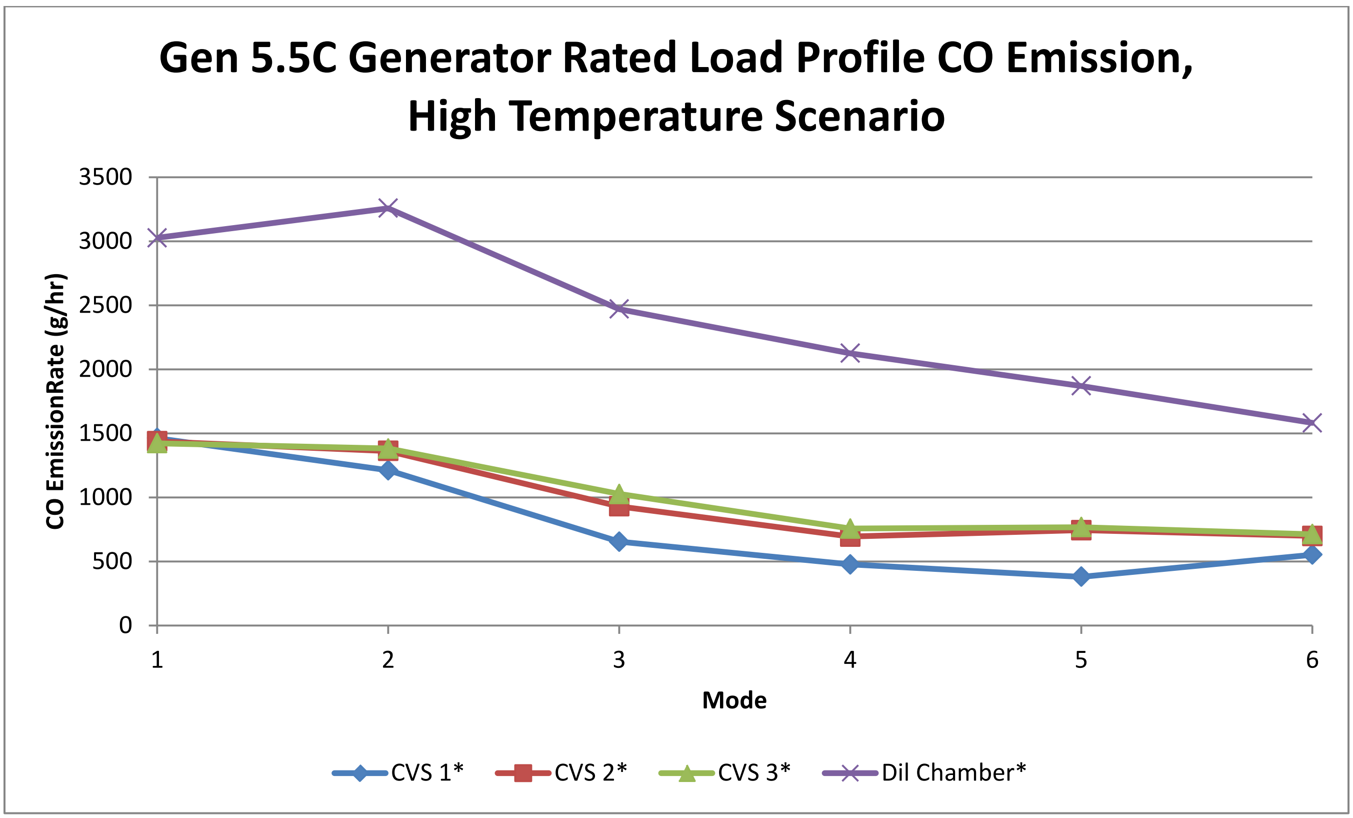

Figure 13. Gen 5.5C Generator Rated Load Profile CO Emission, High Temperature Scenario

Gen 5.5I

The Gen 5.5I test series included a generator rated load profile and a maximum generator load profile. Normal oxygen tests were performed with and without the generator installed in the dilution chamber. The data from these tests was used to determine if the dilution chamber created unintended effects on the emissions performance of the generator. Gen 5.5I used an open-loop fuel injection system with an oxygen sensor. The presence of the oxygen sensor suggests that the fuel control system receives some manner of feedback on the air-to-fuel ratio. This generator was also equipped with a selectable fuel economy mode. For consistency, all tests were performed with the fuel economy mode activated, indicated by a single asterisk (*).

By observation of emissions trends, Staff noted that the fuel control system on Gen 5.5I may perform periodic adjustments to the fuel rate using feedback from the oxygen sensor when the operating conditions of the generator change. The system may make adjustments to achieve a desired air-to-fuel ratio within a specified range for each stabilized load setting. This periodic adjustment may also increase the variance in modal emission data.

Results from the 5500 W generator rated load profile are provided in Table 8 and Figure 14. The reduced oxygen CO emission rate factor for this profile was calculated to be 2.73. CVS GR1 at mode 3 exhibited a much lower CO emission rate than the other two CVS tunnel tests. This may be due to an inconsistent adjustment in the fuel control; however, this was not confirmed because the operating parameters of the fuel control system are unknown. The modal CO emission data produced from the two dilution chamber tests is consistent.

Table 8. Gen 5.5I Generator Rated Load Profile CO Emission

Gen 5.5I Generator Rated Load Profile CO Emission					
Mode	Emission Rates (g/hr)				
	CVS GR1*	CVS GR2*	CVS GR3*	Dil Chamber GR1*	Dil Chamber GR2*
1	548	669	656	2842	2831
2	624	422	411	1825	1708
3	271	780	860	1449	1349
4	364	462	479	981	909
5	300	402	403	933	882
6	333	373	415	836	812
Weighted	**400**	**556**	**584**	**1442**	**1363**
Reduced Oxygen CO Emission Rate Factor					**2.73**

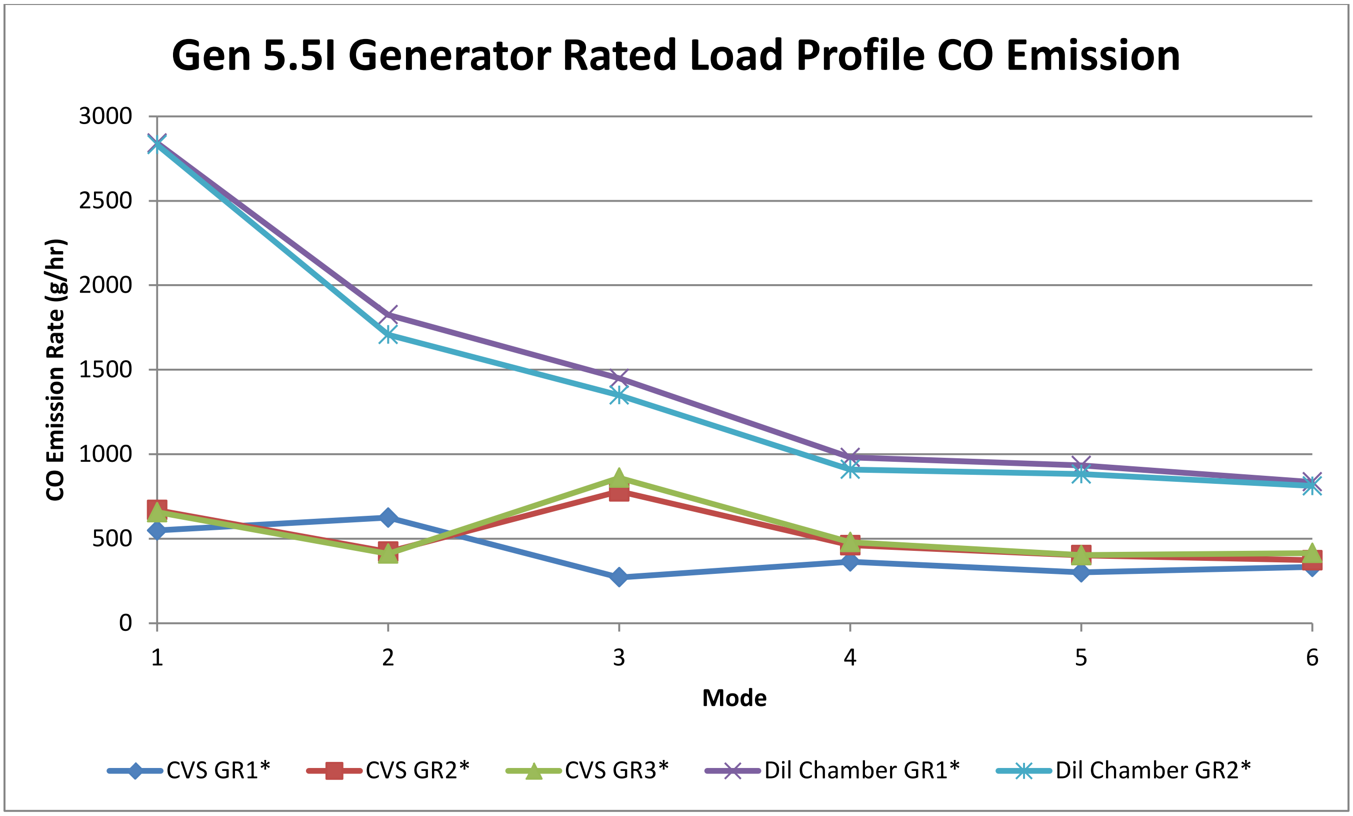

Figure 14. Gen 5.5I Generator rated Load Profile CO Emission

Maximum generator load was determined using a power saturation method. With the engine in the generator assembly, the load applied to the assembly was increased until the system would not provide any additional power. Gen 5.5I was capable of providing a maximum of 6700 W under steady state conditions. Maximum generator rated load profile results for CVS tunnel testing and dilution chamber testing are provided in Table 9 and Figure 15. Five tests were performed at a normal oxygen concentration (~ 20.9 percent). Three dilution chamber tests were performed at 17 percent oxygen. CVS MG1 through CVS MG3 were conducted with the generator installed in the dilution chamber for comparison with CVS MG4 and CVS MG5, which were conducted with the generator separate from the dilution chamber. The reduced oxygen CO emission rate factor for the engine rated load profile tests was calculated to be 3.29. The modal CO emission rate curves display a similar relationship between mode points.

Although staff is not aware of the conditions that cause the generator to operate in closed loop, staff notes that the CO emission rate increased in reduced oxygen compared to the CO rate in normal oxygen for all modes, regardless of the load profile.

Table 9. Gen 5.5I Maximum Generator Load Profile CO Emission

Gen 5.5I Maximum Generator Load Profile CO Emission								
Mode	Emission Rates (g/hr)							
	CVS MG1*	CVS MG2*	CVS MG3*	CVS MG4*	CVS MG5*	Dil Chamber MG1*	Dil Chamber MG2*	Dil Chamber MG3*
1	2078	2002	2098	1925	1929	2940	2985	3074
2	749	622	700	425	543	2847	2831	3004
3	313	229	345	278	200	594	1116	689
4	160	258	178	133	115	1022	1320	910
5	430	203	216	65	230	983	1171	843
6	496	178	293	103	242	798	968	685
Weighted	**531**	**471**	**512**	**388**	**403**	**1422**	**1685**	**1443**
Reduced Oxygen CO Emission Rate Factor								**3.29**

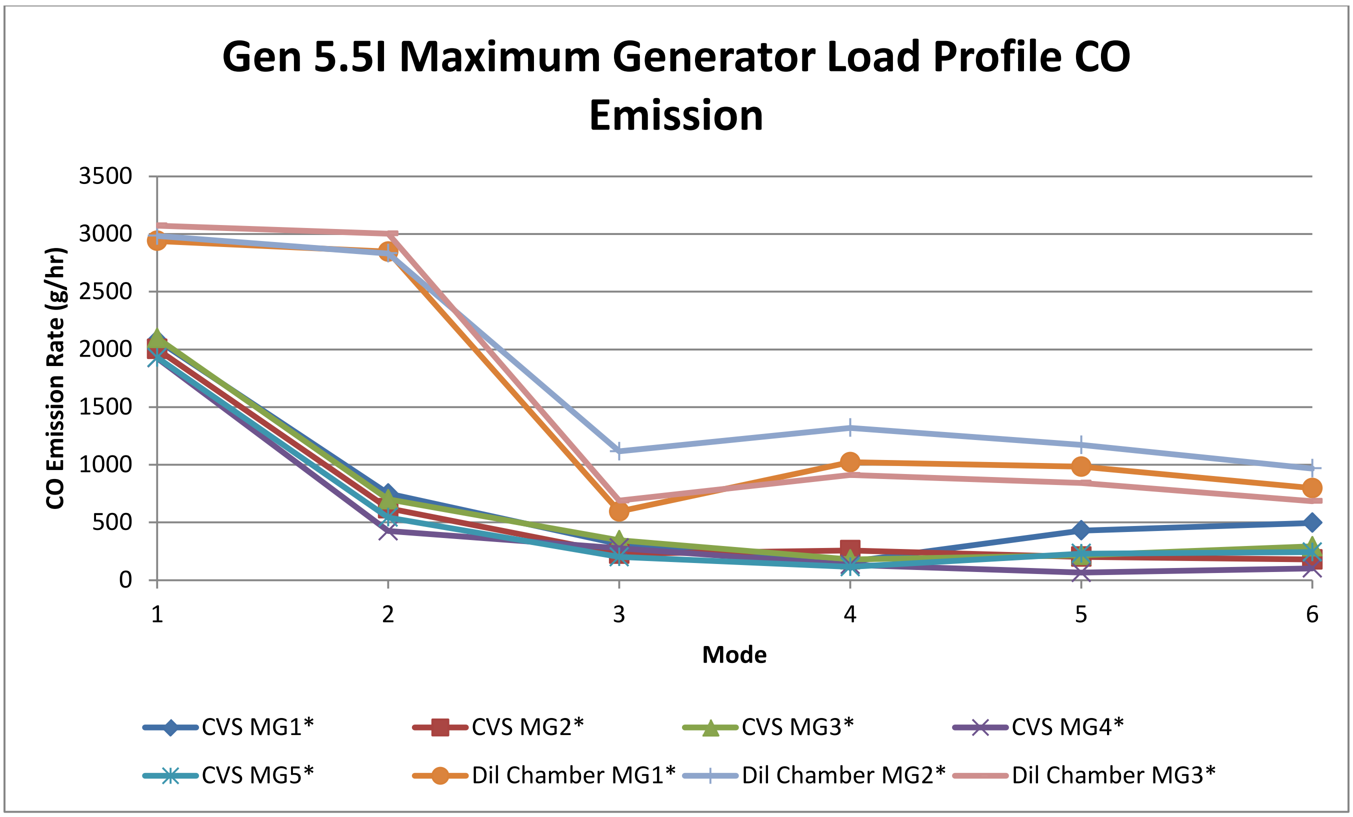

Figure 15. Gen 5.5I Maximum Generator Load Profile CO Emission

Comparison of the results of CVS MG1 through CVS MG5 in Table 9 and Figure 16 suggests that the dilution chamber does not affect the emissions performance of the generator. With the same oxygen concentration, tests performed with the generator in the dilution chamber provided results in agreement with results from tests performed without the dilution chamber. Variations in modal CO emission rates may be due in part from the periodic air-to-fuel ratio adjustments that may be executed by the fuel control system on Gen 5.5I. The difference in weighted CO emission rates between these five tests was within 27 percent. The difference in weighted CO emission rates between the three CVS tunnel tests performed on a generator rated load profile was within 32 percent. This indicates that the variation in data for the five tests used to evaluate unintended effects of the dilution chamber test on generator performance is within the operating bounds of Gen 5.5I.

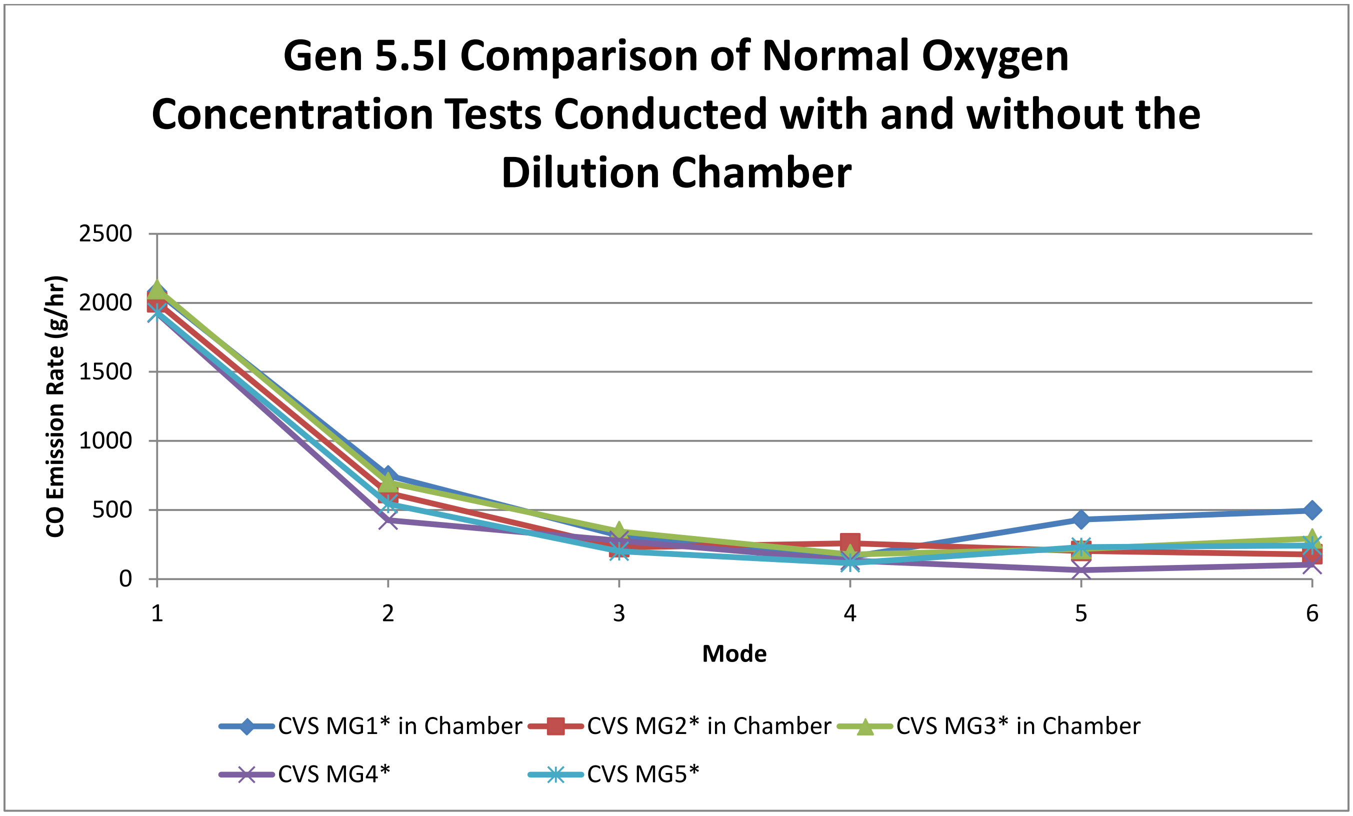

Figure 16. Gen 5.5I Comparison of Normal Oxygen Concentration Tests Conducted with and without the Dilution Chamber

Proto 5.5I

The Proto 5.5I generator was developed specifically to achieve reduced CO emissions. The fuel control system used closed-loop fuel injection. The system operated in open-loop during initial startup and load transitions only. The fuel control system maintained closed-loop operation at wide-open-throttle (WOT) and was tuned to maintain near stoichiometric air-to-fuel ratio (14.7 $AFR_{Gasoline}$ or 1 λ). This generator was tested using maximum generator load profile for three CVS tunnel tests and four dilution chamber tests. Maximum generator load for the assembly was determined as the maximum load carrying capability of the generator assembly while maintaining 60 ± 3 Hz. A catalytic converter was installed to ensure that the generator met 40 C.F.R. part 1054 $HC+NO_x$ requirements (14).

Dilution chamber and CVS tunnel test results are provided in Table 10 and Figure 17. Proto 5.5I continually adjusted the fuel input to maintain near stoichiometric operation, which resulted in low CO emission with limited overall affect from reducing the oxygen. At modes 1, 2, and 3, the generator exhibited lower CO emission rates in most cases when operating in a reduced oxygen environment;

however, while maintaining closed-loop operation, the CO emission rates for modes 4, 5, and 6 increased by a nominal range of 1.6 to 4.8 times. For all tests and all modes, the generator maintained a CO emission rate below 160 g/hr. The reduced oxygen CO emission rate factor was calculated to be 1.21, indicating that the weighted CO emission rate only increased 21 percent due to the reduction of oxygen to 17 percent.

Table 10. Proto 5.5I Maximum Generator Load Profile CO Emission

Proto 5.5I Maximum Generator Load Profile CO Emission							
Mode	Emission Rates (g/hr)						
	CVS 1	CVS 2	CVS 3	Dil Chamber 1	Dil Chamber 2	Dil Chamber 3	Dil Chamber 4
1	81	82	67	69	60	55	68
2	94	83	69	68	72	60	63
3	106	91	105	71	62	47	82
4	63	64	90	153	146	119	146
5	26	28	30	159	140	88	145
6	29	67	36	133	93	54	112
Weighted	**79**	**75**	**81**	**104**	**96**	**75**	**102**
Reduced Oxygen CO Emission Rate Factor							**1.21**

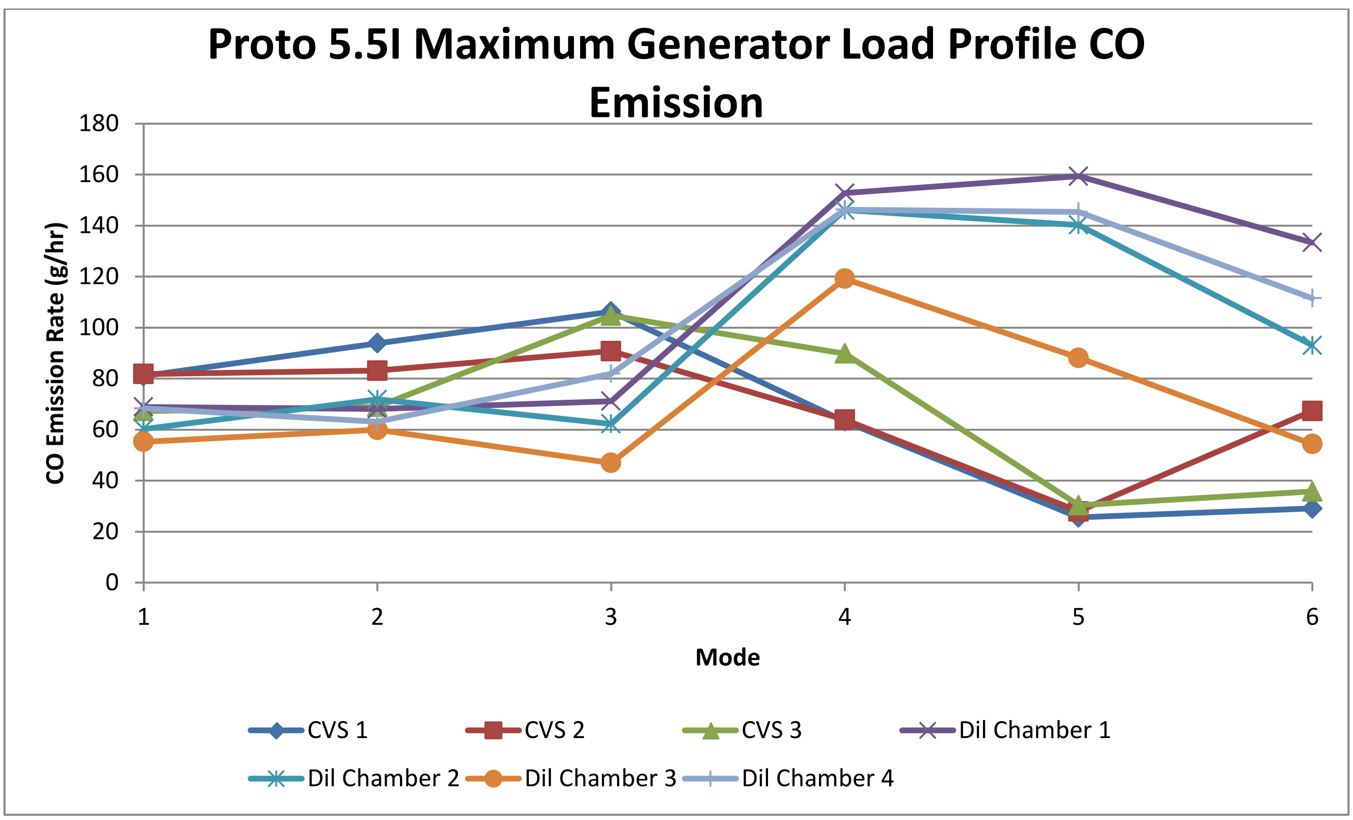

Figure 17. Proto 5.5I Engine rated Load Profile CO Emission

Figure 18 provides the air-to-fuel equivalence ratio and loads for the 4th dilution chamber test (Dil Chamber 4). This test is representative of all dilution chamber tests performed on Proto 5.5I. During all loads and oxygen levels, the generator maintained near stoichiometric operation. The chart shows the entire dilution chamber test duration, including periods of load stabilization in normal oxygen and reduced oxygen testing. The period of exposure to steady 17 percent oxygen is indicated by black arrows. Note that the reduction in oxygen affects the power output at modes 1, 2 and 3. After completion of the mode 2 test, the generator was shut down because the fuel pump required maintenance after losing pressure.

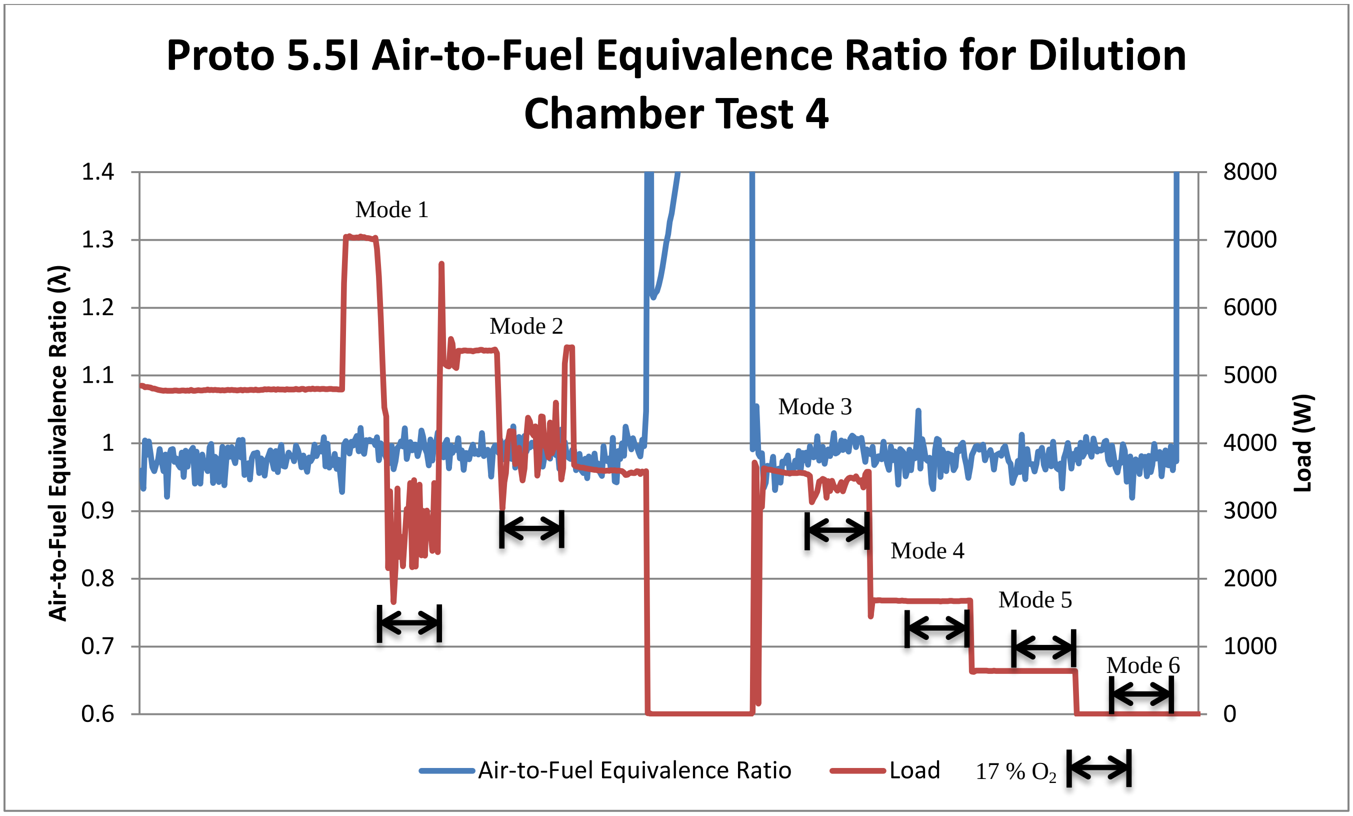

Figure 18. Proto 5.5I Air-to-Fuel Equivalence ration for Dilution Chamber Test 4

Discussion of Dilution Chamber Test Method

The dilution chamber test method addressed the concerns identified in the evaluation of the NIST TN 1834 and dilution tunnel test methods. The test procedure required approximately 2 hours to complete for a single 6-mode test; therefore, a series of three tests could be performed in an 8-hour work period, with consideration for calibrations and other test preparation. The infrastructure is much simpler than the NIST TN 1834 test fixture and can be installed to accommodate existing facilities. The use of a control volume surrounding the generator addresses air reference requirements, effects from dynamic engine speed, and the constraints of various physical configurations of generator assemblies.

The infrastructure required for the dilution chamber test method included a small chamber constructed of wood, a temperature management system, exhaust duct system, tubing for sampling and injection lines, a nitrogen supply, and temperature and pressure gauges. Temperature is controlled in the chamber to enhance reproducibility and repeatability. The emissions measurement equipment was based on 40 C.F.R. part 1065 CVS tunnel emissions test method. Testing did not require recirculation of exhaust gases in a large volume and did not create a hazardous environment and risk to health and safety. A maximum CO concentration of 200 ppm within the chamber was strictly enforced during all testing. This test method also offers the flexibility to test at a variety of load conditions and oxygen levels in a relatively short period of time. A 6-mode test can be completed in less than 2 hours, including the engine warmup period.

The dilution chamber test method addressed the effects of engine speed oscillation on oxygen concentration by using a volume of air surrounding the generator to eliminate the direct dependency of nitrogen flow on engine intake flow rate. The volume dampens the change in oxygen concentration created by changing engine speed to where only minor adjustments were needed, on occasion, to compensate for a loss of engine speed. Achieving and maintaining a target oxygen concentration to within 0.1 percent was easily performed using a gate valve to regulate nitrogen flow. This level of precision was required by the initial test procedures and is included in the test method in Appendix A2.

Compensating for the oxygen sensor air reference used with certain fuel control systems was necessary to ensure that there were no unintended effects on the emissions performance of these generators. Using the dilution chamber method, an equivalent oxygen concentration was provided to the air reference and the intake by diluting the entire volume surrounding the generator. The volume of the chamber, along with mixing fans and flow induced by the generator, created a well-mixed, controllable environment in which the generator could operate. During all data acquisition periods, the oxygen concentration at the intake of the engine remained within 0.1 percent of the target.

Repeated testing of a single generator in the dilution chamber identified stress and mechanical failure concerns with the exhaust duct system. The engine in Proto 5.5I exhibited significant movement during mode 1 testing due to extreme loading and soft engine mounts. This movement created mechanical stresses on the chamber exhaust duct system and the generator's muffler, which subsequently developed cracks. Failure of the exhaust duct system or the muffler was indicated by an increase in CO and hydrocarbons in the chamber. Aside from personnel safety, monitoring CO and hydrocarbon accumulation within the chamber ensured integrity of the exhaust duct system. The other four generators tested did not develop mechanical exhaust failures related to the exhaust duct connection. However, development of an exhaust duct system that minimizes mechanical stresses on the system would reduce the risk of exhaust system failures.

Temperature management was another concern related specifically to the system used for evaluation of the dilution chamber test method. Staff used two window air conditioner units with a combined 9 kW (30,000 BTU/hr) cooling rate. Although this was sufficient to maintain temperatures below 38 °C (100 °F), it did not provide a steady temperature. Temperatures were controlled to within a range of 13 °C (55 °F) to 38 °C (100 °F) during load stabilization and reduced-oxygen data-acquisition periods. This system met the criteria specified in the original procedures; however, a system designed specifically to manage the changing heat loads emitted from a range of generator sizes would offer more flexibility in testing. Insulating and ensuring proper airflow in the chamber will also enhance temperature management.

The chamber volume used for testing provided approximately 30 cm (1 ft) of clear space on all sides and the top of the generators. When the chamber doors were closed before initiating nitrogen flow, it was noted that the cylinder head temperature of the engine would rise slightly. The rise in head temperature was less than 10 °C (18 °F). This indicates that the volume of the chamber could adversely affect the normal airflow required to cool the generator assembly; and therefore, requirements for chamber volume were established within the test method provided in Appendix A2.

Summary

From 2014 to 2016, U.S. Consumer Product Safety Commission (CPSC) staff evaluated several test methods to determine the carbon monoxide (CO) emission rate of portable generators when operated in an enclosed space. Of the three test methods presented in this report, staff recommends the dilution chamber test method for evaluating the CO emission rate of portable generators in a reduced-oxygen environment because the test method is repeatable; it applies to generators of varying sizes, configurations, and fuel control systems; and it uses the CVS tunnel emissions measurement system, a common test fixture within the engine industry.

The NIST TN 1834 test method requires development of substantial infrastructure for the sole purpose of evaluating CO emissions of portable generators in a reduced oxygen environment. Additionally, it requires recirculation of exhaust gases in a large volume, which develops high concentrations of CO, placing personnel safety at risk. The test method requires iterative testing to determine appropriate chamber airflow, and it cannot perform a 6-mode measurement during a single test. Testing may take up to 3 hours to determine the CO emission rate for a single load point.

The dilution tunnel test uses a manifold specifically designed for each generator configuration to affix the tunnel to the engine intake without affecting the normal intake airflow. Design and construction of these manifolds is labor-intensive and unique to each generator configuration. It is critical to the emissions performance of the generator that the engine intake airflow remains unaffected during testing. The dilution tunnel cannot be used to test certain closed-frame generators that use the engine intake to draw cooling air into the housing because connecting a tunnel to the intake would prevent proper cooling of the generator. If the engine speed changes or begins to oscillate during testing, the nitrogen flow into the dilution tunnel must change accordingly. Nitrogen flow, and therefore, oxygen concentration, is highly sensitive to changes in engine speed. Without changing the nitrogen flow, the change in total flow to the engine corresponding to engine speed develops large variation in the oxygen concentration received by the engine. Concurrent with limited control of oxygen concentration using the dilution tunnel test method, this method does not provide equivalently diluted air to the oxygen sensor air reference used with certain fuel-control systems. If the air reference does not measure the same concentration of oxygen that is provided to the engine intake, fuel adjustments performed by the system are not representative of the intended operation of the generator. Similar to the use of a dilution tunnel, direct injection of nitrogen into the intake system of a generator may affect the intake pressure and provide an unsteady oxygen concentration to the engine due to poor mixing and the natural pulse flow of the intake system.

The dilution chamber test method addresses the limitations of the NIST TN 1834 test and the dilution tunnel test. Evacuating the engine exhaust directly from the engine to a CVS emissions tunnel prevents the hazard developed by requiring recirculation of exhaust gases within the chamber. Additionally, it accommodates the use of a CVS emissions tunnel for accurate measurement based on 40 C.F.R. part 1065. By conditioning a control volume around the test generator with nitrogen to dilute the oxygen concentration, the dilution chamber method minimizes the dependency of nitrogen flow on engine speed and also provides an equivalent oxygen concentration to the air reference on an oxygen sensor, if one is present. The infrastructure for the dilution chamber system must be designed to effectively manage temperature, pressure, and mechanical stresses for a variety of generators. To enhance repeatability, the 6-mode load profile should be determined using the maximum continuous generator power, as determined by power saturation with voltage and frequency tolerances. This provides a consistent method for determining the load profile for testing that is independent of the manufacturer's rated continuous power. Based on the results provided in this report, the observations of staff and input from industry members, the dilution chamber test method offers an accurate and repeatable procedure to determine the CO emission rate of a portable generator in an enclosed space.

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Appendix

A1: Summary of Factors

Reduced Oxygen CO Emission Rate Factor Summary		
Generator	**Max Generator Load**	**Generator Rated Load**
Gen 1.6C	1.84	3.56
Gen 2.3C	[redacted]	3.56
Gen 5.5C	[redacted]	2.72
Gen 5.5I	3.29	2.73
Gen 10.5I	[redacted]	3.39
Proto 5.5I	1.21	[redacted]
Average[x]	**2.56**	**3.19**

[x] Proto 5.5I Factor was not used to calculate average.

Note: The generator-rated reduced-oxygen CO emission rate factor is recommended for modeling of indoor air quality. The generator-rated 6-mode load profile represents the normal expected loading of a generator when used by a consumer because all loads are within the manufacturer's-recommended continuous rated capacity. It is expected that, on occasion, a generator may be loaded beyond the manufacturer's continuous rated power, but this condition is not representative of normal loading conditions.

A2: Dilution Chamber Test Method for Determining the Carbon Monoxide Emission Rate of a Portable Generator in a Reduced Oxygen Environment

Warning: Carbon monoxide or hydrocarbon accumulation within the test facility can be a safety hazard. Carbon monoxide is a poisonous gas. Operating an internal combustion engine in an enclosed space can create an accumulation of carbon monoxide and unburnt hydrocarbons. A poisoning hazard may develop from accumulation of carbon monoxide. Accumulation of hydrocarbons presents a fire and explosion hazard. These procedures are not intended to address the safety concerns associated with their use. Appropriate safety measures should be taken by those using these procedures before, during, and after testing.

1. Purpose

This document provides the test method to determine the carbon monoxide (CO) emission rate of a portable generator in a reduced-oxygen environment.

2. Scope

The following test method applies to single-phase, 300 V or lower, 60 hertz portable generators driven by small handheld and non-handheld (as defined by the EPA), spark-ignited utility engines intended for multiple use that are provided only with receptacle outlets for the AC output circuits and intended to be moved, although not necessarily with wheels. Permanently installed stationary generators, 50-hertz generators, marine generators, trailer-mounted generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, and generators that are part of welding machines are not covered. These exclusions are consistent with the scope of UL 2201, *Standard for Portable Engine-Generator Assemblies*.

3. Definitions

3.1 Load bank and power meter: An AC electric resistor load bank used to simulate steady electric loads on the generator. The load bank shall be capable of adjustment to within 5 percent of each required load condition. A power meter is used to measure the actual electrical load delivered by the generator with an accuracy of ± 5 percent.

3.2 Fuel and lubricants: Fuel and lubricants for this test must meet manufacturer’s specifications for the generator being tested.

3.3 Emission measurement system: A constant volume sampling (CVS) emission measurement system described in 40 C.F.R. parts 1054 and 1065.

3.4 Dilution Chamber: A test fixture that encloses the portable generator and reduces the oxygen level of the air at the engine intake by injecting nitrogen into the volume inside the chamber, or the air intake system for the chamber. The exhaust from the engine does not accumulate in the chamber but is ducted directly out of the engine to the exterior of the chamber. The exhaust discharge is directed to a CVS emission measurement system for analysis. Conditions within the chamber shall be uniform and well mixed.

3.5 Oxygen Analyzer: A system capable of measuring oxygen from 21 – 16 percent, with an accuracy of 1 percent of range, recording at a minimum rate of 0.1 Hz. This oxygen analyzer is independent of the CVS emission measurement system and is used to measure and record the oxygen concentration within the dilution chamber.

3.6 Carbon Monoxide Analyzer: A system capable of measuring CO from 0 to 1000 ppm with an accuracy of 1 percent of range. This CO analyzer is independent of the CVS emission measurement system and is used to measure the CO concentration within the dilution chamber to verify compliance to the CO accumulation limit.

3.7 Maximum Generator Load: The maximum output power capability of the generator assembly as determined by the maximum generator load determination procedures. The maximum generator load is used to establish the 6-mode load profile.

4. Dilution Chamber Equipment

4.1 Nitrogen Injection Line: A tube connected to a nitrogen source, and routed into the dilution chamber used to provide nitrogen for oxygen dilution. Nitrogen flow is controlled to provide the required flow rate to achieve and maintain 17 ± 0.1 percent oxygen within the dilution chamber.

4.2 Oxygen Sample Line: A tube secured near the engine intake, supplying a sample of gases to an oxygen analyzer to measure and record the oxygen concentration provided to the engine.

4.3 Chamber Air Inlet: Any manner of providing exterior air to the dilution chamber while ensuring a well-mixed environment and a differential pressure relative to the chamber exterior of no more than 12.5 Pa (0.05 in. W.C.). A dedicated inlet or the chamber's natural leakage paths may be used.

4.4 Temperature Management System: A system capable of maintaining a stable temperature in the dilution chamber between 10 - 38 ^{0}C (50-100 ^{0}F) for the duration of the test.

4.5 Mixing Fans: An optional system to promote mixing and steady oxygen concentrations at the engine intake.

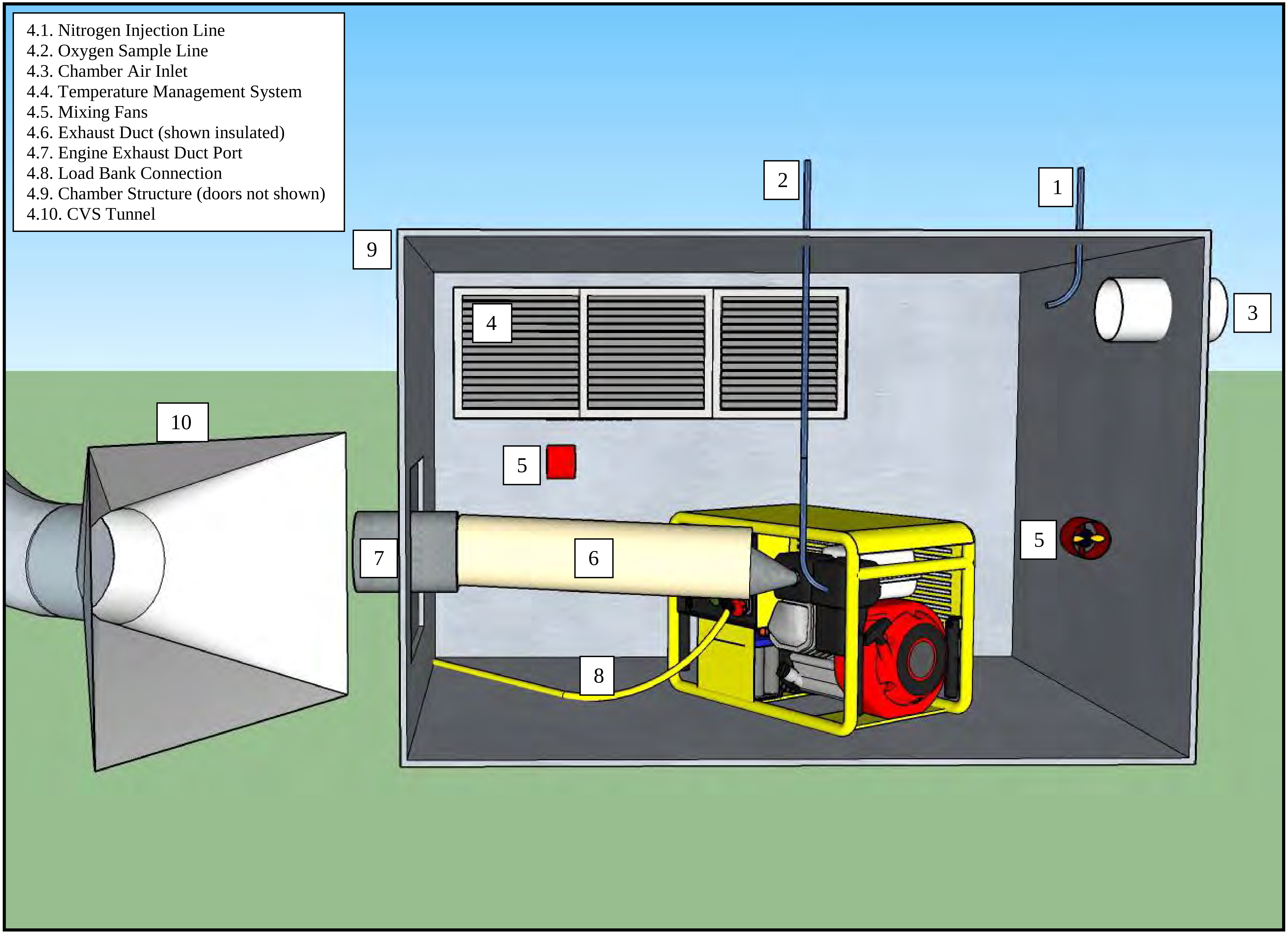
4.6 Exhaust Duct: A system connected to the engine exhaust assembly that directs exhaust emissions to the engine exhaust duct port. The exhaust duct may be insulated to reduce the heat load within the dilution chamber. CO accumulation within the dilution chamber shall be monitored continuously and limited to a maximum of 200 ppm to ensure effective removal of exhaust gases.

4.7 Engine Exhaust Duct Port: A port through the dilution chamber wall that directs engine exhaust emissions from the exhaust duct to a CVS emission measurement system.

4.8 Load Bank Connection: A wiring system that connects the generator assembly to an AC electric resistor load bank.

4.9 Chamber Structure: A fixture that encloses the portable generator, creating a control volume for testing with at least 30 cm (12 in.) of free space on all sides and top of the generator. Vibration, heat, and test sample restraint should be considered for chamber and peripheral system design.

4.10 CVS Tunnel: A collection and sample dilution system described in 40 C.F.R. parts 1054 and 1065. Background air for the CVS tunnel sample dilution is taken from the environment exterior to the dilution chamber. Background samples for CVS emission measurement system calculations are taken from the environment outside of the chamber.



4.1. Nitrogen Injection Line
4.2. Oxygen Sample Line
4.3. Chamber Air Inlet
4.4. Temperature Management System
4.5. Mixing Fans
4.6. Exhaust Duct (shown insulated)
4.7. Engine Exhaust Duct Port
4.8. Load Bank Connection
4.9. Chamber Structure (doors not shown)
4.10. CVS Tunnel
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5. Determining Maximum Generator Load

5.1 Power Saturation Method for Conventional (Non-Inverter) Generator Assemblies

5.1.1 Ensure test facility is at ambient conditions 10 - 38 ^{0}C (50-100 ^{0}F) and approximately 20.9 percent oxygen.

5.1.2 Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

5.1.3 Monitoring voltage and frequency, increase the load applied to the generator to the maximum observed power output without causing the voltage or frequency to deviate from the following tolerances:

5.1.3.1 Voltage Tolerance: ± 10 percent of the nameplate rated voltage.

5.1.3.2 Frequency Tolerance: ± 5 percent of the nameplate rated frequency.

5.1.4 Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

5.1.5 The maximum generator load is the power supplied by the generator assembly that satisfies the tolerances in 5.1.3 when the generator is at stable operating temperature as defined in 5.1.4. Record the maximum generator load.

5.2 Power Saturation Method for Inverter Generator Assemblies

5.2.1 Ensure test facility is at ambient conditions 10 - 38 ^{0}C (50-100 ^{0}F) and approximately 20.9 percent oxygen.

5.2.2 Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

5.2.3 Increase the load applied to the generator to the maximum observed power output.

5.2.4 Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

5.2.5 Maximum generator load is the maximum observed power output that satisfies the criteria defined in 5.2.4. Record the maximum generator load.

6. Test Method to Determine the Modal CO Emission Rates of a Portable Generator

To determine the weighted CO emission rate of a portable generator, determine the modal CO emission rates at six discrete generator loads with oxygen reduced to 17 ± 0.1 percent oxygen by volume. All tests shall be performed at an ambient air temperature of 10 – 38 ^{0}C (50-100 ^{0}F). The oxygen concentration within the chamber shall be measured near the engine intake. If a generator is equipped with a system that provides different engine operating modes such as a fuel economy mode, the generator shall be tested to this Section in all available modes. CO emission performance shall be determined by the highest weighted CO emission rate calculated in Section 7.

6.1 Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature. The dilution chamber shall remain open during the warm up period. The generator shall be affixed to the chamber system and the ambient air temperature shall be maintained at 10 - 38 ^{0}C (50-100 ^{0}F).

6.2 Adjust the load bank to apply the appropriate mode calculated from the maximum generator load. Modal testing shall be performed in order from mode 1 to mode 6. Mode points are determined by a percentage of the maximum generator load:

Mode 1:	100	percent of maximum generator load
Mode 2:	75	percent of maximum generator load
Mode 3:	50	percent of maximum generator load
Mode 4:	25	percent of maximum generator load
Mode 5:	10	percent of maximum generator load
Mode 6:	0	percent of maximum generator load

6.3 Close the dilution chamber and reduce the chamber oxygen concentration over a period of at least two minutes to stabilization by introducing the nitrogen stream into the dilution chamber. Stabilize the oxygen concentration, measured at the engine intake, at 17 ± 0.1 percent by volume. If the generator experiences load loss due to activation of an overload protection device, complete shutdown, or any other cause, repeat the test at the lowest oxygen level above 17 percent where the generator continues to provide power for a period of time sufficient to acquire emissions data. Reduction of power output due to reducing the oxygen concentration provided to the engine is acceptable. During the test, the CO level within the dilution chamber shall be monitored and shall not exceed 200 ppm.

6.4 While maintaining the oxygen concentration at 17 ± 0.1 percent by volume, record emissions for at least 2 minutes at a minimum rate of 0.1 Hz with the prescribed mode applied. Record the mean CO emission value for that mode during the data acquisition period.

6.5 Restore the oxygen concentration to at least 20.5 percent by volume and repeat steps 6.2 to 6.5 for the successive modes listed in 6.2.

6.6 When all mean CO emission rates have been determined, calculate and report the weighted CO emission rate using guidance in Section 7.

7. Weighted CO Emission Rate Calculation and Reporting

7.1 Calculate the weighted CO emission rate using the mean CO emission rates determined in Section 6.

$$\dot{m}_w = 0.09 \times \dot{m}_1 + 0.20 \times \dot{m}_2 + 0.29 \times \dot{m}_3 + 0.30 \times \dot{m}_4 + 0.07 \times \dot{m}_5 + 0.05 \times \dot{m}_6$$

where,

$\dot{m}_w = Weighted\ CO\ Emission\ Rate\ (\frac{g}{hr})$

$\dot{m}_1 = Mean\ CO\ Emission\ Rate\ at\ mode\ 1\ (\frac{g}{hr})$

$\dot{m}_2 = Mean\ CO\ Emission\ Rate\ at\ mode\ 2\ (\frac{g}{hr})$

$\dot{m}_3 = Mean\ CO\ Emission\ Rate\ at\ mode\ 3\ (\frac{g}{hr})$

$\dot{m}_4 = Mean\ CO\ Emission\ Rate\ at\ mode\ 4\ (\frac{g}{hr})$

$\dot{m}_5 = Mean\ CO\ Emission\ Rate\ at\ mode\ 5\ (\frac{g}{hr})$

$\dot{m}_6 = Mean\ CO\ Emission\ Rate\ at\ mode\ 6\ (\frac{g}{hr})$

7.2 Report the following results for the generator:

7.2.1 Weighted CO emission rate in grams per hour.

7.2.2 Mean CO emission rate for each mode. If the mean CO emission rate is measured at any oxygen concentration other than 17 ± 0.1 percent by volume, report the oxygen concentration.

7.2.3 Oil, head, and chamber air temperatures for each mode.

7.2.4 Maximum generator load information as determined in Section 5. Include maximum generator load, voltage, amperage, and frequency.

A3: Test Method for Determining the Carbon Monoxide Emission Rate of a Portable Generator Assembly

Warning: Carbon monoxide or hydrocarbon accumulation within the test facility can be a safety hazard. Carbon monoxide is a poisonous gas. Operating an internal combustion engine in an enclosed space can create an accumulation of carbon monoxide and unburnt hydrocarbons. A poisoning hazard may develop from accumulation of carbon monoxide. Accumulation of hydrocarbons presents a fire and explosion hazard. These procedures are not intended to address the safety concerns associated with their use. Appropriate safety measures should be taken by those using these procedures before, during, and after testing.

1. Purpose

This document provides the test method to determine the carbon monoxide (CO) emission rate of a portable generator assembly.

2. Scope

The following test method applies to single phase; 300 V or lower; 60 hertz; portable generators driven by small handheld and non-handheld (as defined by the EPA) spark-ignited utility engines intended for multiple use which are provided only with receptacle outlets for the AC output circuits and intended to be moved, though not necessarily with wheels. Permanently installed stationary generators, 50 hertz generators, marine generators, trailer mounted generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, and generators that are part of welding machines are not covered. These exclusions are consistent with the scope of UL 2201, *Standard for Portable Engine-Generator Assemblies*.

3. Definitions

3.1 Load bank and power meter: An AC electric resistor load bank used to simulate steady electric loads on the generator. The load bank shall be capable of adjustment to within 5 percent of each required load condition. A power meter is used to measure the actual electrical load delivered by the generator with an accuracy of ± 5 percent.

3.2 Fuel and lubricants: Fuel and lubricants for this test must meet manufacturer's specifications for the generator being tested.

3.3 Emission measurement system: A constant volume sampling (CVS) emission measurement system described in 40 C.F.R. parts 1054 and 1065.

3.4 Maximum Generator Load: The maximum output power capability of the generator assembly as determined by the maximum generator load determination procedures. The maximum generator load is used to establish the 6-mode load profile.

4. Determining Maximum Generator Load

4.1 Power Saturation Method for Conventional (Non-Inverter) Generator Assemblies

4.1.1 Ensure test facility is at ambient conditions 15 - 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen.

4.1.2 Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

4.1.3 Monitoring voltage and frequency, increase the load applied to the generator to the maximum observed power output without causing the voltage or frequency to deviate from the following tolerances:

4.1.3.1 Voltage Tolerance: ± 10 percent of the nameplate rated voltage.

4.1.3.2 Frequency Tolerance: ± 5 percent of the nameplate rated frequency.

4.1.4 Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

4.1.5 The maximum generator load is the power supplied by the generator assembly that satisfies the tolerances in 4.1.3 when the generator is at stable operating temperature as defined in 4.1.4. Record the maximum generator load.

4.2 Power Saturation Method for Inverter Generator Assemblies

4.2.1 Ensure test facility is at ambient conditions 15 - 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen.

4.2.2 Apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

4.2.3 Increase the load applied to the generator to the maximum observed power output.

4.2.4 Maintain the maximum observed power output until the operating temperature of the engine stabilizes. The generator is at stable operating temperature when the oil temperature varies by less than 2 ^{0}C (4 ^{0}F) over three consecutive readings taken 15 minutes apart. For the purpose of determining maximum generator load, if an overload protection device is present, it shall not activate for a period of 45 minutes from the initial operating temperature stability reading. The load may need to be adjusted to maintain the maximum observed power output while the generator temperatures are stabilizing. Record voltage, frequency, amperage, power, and oil and ambient air temperature.

4.2.5 Maximum generator load is the maximum observed power output that satisfies the criteria defined in 4.2.4. Record the maximum generator load.

5. Test Method to Determine the Modal CO Emission Rates of a Portable Generator

To determine the weighted CO emission rate of a portable generator assembly, determine the modal CO emission rates at six discrete generator loads based on maximum generator load using a CVS emissions tunnel described in 40 C.F.R. parts 1054 and 1065, and calculate the weighted CO emission rate. All tests shall be performed under typical operating conditions at an ambient air temperature of 15 – 30 ^{0}C (60-85 ^{0}F) and approximately 20.9 percent oxygen. Testing shall be performed on a complete generator assembly and load shall be applied through the generators receptacle panel. If a generator is equipped with a system that provides different engine operating modes such as a fuel economy mode, the generator shall be tested to this Section in all available modes. CO emission performance shall be determined by the highest weighted CO emission rate calculated in Section 6.

5.1 Place the generator assembly in front of the CVS tunnel with the exhaust facing towards the collector. Connect the load bank and apply a load greater than 60 percent of the manufacturer's rated continuous power for a minimum of 20 minutes to warm the generator to operating temperature.

5.2 Adjust the load bank to apply the appropriate mode calculated from the maximum generator load. Modal testing shall be performed in order from mode 1 to mode 6. Mode points are determined by a percentage of the maximum generator load:

Mode 1:	100	percent of maximum generator load
Mode 2:	75	percent of maximum generator load
Mode 3:	50	percent of maximum generator load
Mode 4:	25	percent of maximum generator load
Mode 5:	10	percent of maximum generator load
Mode 6:	0	percent of maximum generator load

5.3 Stabilize oil and head temperatures by operating at mode for 5 minutes. After the 5 minute stabilization period, record emissions for at least 2 minutes at a minimum rate of 0.1 Hz with the prescribed mode applied. Record the mean CO emission value for that mode during the data acquisition period.

5.4 Repeat steps 5.2 to 5.4 for the successive modes listed in 5.2.

5.5 When all modal mean CO emission rates have been determined, calculate and report the weighted CO emission rate using guidance in Section 6.

6. Weighted CO Emission Rate Calculation and Reporting

6.1 Calculate the weighted CO emission rate using the mean CO emission rates determined in Section 5.

$$\dot{\boldsymbol{m}}_{\boldsymbol{w}} = \mathbf{0.09} \times \dot{\boldsymbol{m}}_{\mathbf{1}} + \mathbf{0.20} \times \dot{\boldsymbol{m}}_{\mathbf{2}} + \mathbf{0.29} \times \dot{\boldsymbol{m}}_{\mathbf{3}} + \mathbf{0.30} \times \dot{\boldsymbol{m}}_{\mathbf{4}} + \mathbf{0.07} \times \dot{\boldsymbol{m}}_{\mathbf{5}} + \mathbf{0.05} \times \dot{\boldsymbol{m}}_{\mathbf{6}}$$

where,

$\dot{m}_w = Weighted\ CO\ Emission\ Rate\ (\frac{g}{hr})$

$\dot{m}_1 = Mean\ CO\ Emission\ Rate\ at\ mode\ 1\ (\frac{g}{hr})$

$\dot{m}_2 = Mean\ CO\ Emission\ Rate\ at\ mode\ 2\ (\frac{g}{hr})$

$\dot{m}_3 = Mean\ CO\ Emission\ Rate\ at\ mode\ 3\ (\frac{g}{hr})$

$\dot{m}_4 = Mean\ CO\ Emission\ Rate\ at\ mode\ 4\ (\frac{g}{hr})$

$\dot{m}_5 = Mean\ CO\ Emission\ Rate\ at\ mode\ 5\ (\frac{g}{hr})$

$\dot{m}_6 = Mean\ CO\ Emission\ Rate\ at\ mode\ 6\ (\frac{g}{hr})$

6.2 Report the following results for the generator:

6.2.1 Weighted CO emission rate in grams per hour.

6.2.2 Modal information including the mean CO emission, and head and oil temperature.

6.2.3 Maximum generator load information as determined in Section 4. Include maximum generator load, voltage, amperage, and frequency.

TAB K

ESTIMATES OF EPIDEMIOLOGICAL BENEFITS ASSOCIATED WITH REDUCED CARBON MONOXIDE (CO) EMISSION RATES COMPARED TO CO EMISSION RATES OF CURRENT CARBURETED PORTABLE GENERATORS

Matthew V. Hnatov, Mathematical Statistician
Sandra E. Inkster, Ph.D., Pharmacologist
Janet L. Buyer, Mechanical Engineer

October 2016

Executive Summary

The number of consumer carbon monoxide (CO) poisoning deaths caused by portable generators continues to grow despite introduction of mandatory, specific on-product warning labels and continued efforts to inform and educate consumers about the CO hazard and safe use of the product. Staff believes a performance standard requiring reduced CO emissions produced by the engine, while running, is the best way to minimize the CO hazard and prevent future deaths and high severity injuries. Staff has previously demonstrated that substantial CO emission reduction is technically feasible for portable generators. In order to assess the epidemiological benefits of generators having reduced CO emissions, CPSC staff contracted with the National Institutes of Standards and Testing (NIST) to perform a series of CO exposure simulations of portable generator operation in specific locations within multiple house models and other structures, and at various CO emission rates. House models, and other structures used in the simulation study, were matched to actual generator-related CO fatality incident data reported to CPSC over the period 2004 to 2012. The CO emission rates modeled in the simulation study were chosen based on 1) staff's estimates of elevated CO emission rates expected for four staff-defined categories of current carbureted generator products when operating in a reduced oxygen environment, and 2) a series of reduced CO generation rates to reflect CPSC staff's assessment of what is technically feasible for each generator category. The four generator categories, defined primarily by the displacement of the engine, with a secondary categorization of the largest generators that distinguishes between engines with one or two cylinders, and the technically feasible rates associated with each are:

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- A handheld generator, which is a generator powered by a small spark ignition (SI) engine with displacement of 80 cc or less, has a technically feasible rate of 50 g/hr.
- A class 1 generator, which is a generator powered by an SI engine with displacement greater than 80 cc but less than 225 cc, has a technically feasible rate of 50 g/hr.
- A class 2 single cylinder generator, which is a generator powered by an SI engine with one cylinder with displacement of 225 cc or greater, up to a maximum engine power of 25 kW, has a technically feasible rate of 100 g/hr.
- A class 2 twin cylinder generator, which is a generator powered by an SI engine with two cylinders with a total displacement of 225 cc or greater, up to a maximum engine power of 25 kW, has a technically feasible rate of 200 g/hr.

The first part of NIST's simulation study used the multi-zone airflow and contaminant transport model CONTAM to predict CO levels in different areas of each structure, over a 24 hour period. The second part used the CONTAM-generated CO profiles, as input values in the non-linear Coburn Forster Kane equation to predict corresponding carboxyhemoglobin (COHb) levels expected in healthy adults, as a function of time. These two steps were programmed to occur sequentially. The simulations included various scenarios of generator location, and matched those as well as house types to the incident data. Staff developed criteria to differentiate between modeled COHb profiles that staff considered indicative of fatal versus non-fatal outcomes. The third part of the modeling study used patterns evident in fatal incident data to modulate the modeled COHb data in order to estimate the number of fatal CO exposures reported for each generator category, which could have been averted at each reduced emission rate. Staff made conservative estimates (*i.e.*, more likely to underestimate benefits than overestimate) of modeled inputs including respiratory volume, occupant activity level, run time and exposure time.

In staff's analysis, epidemiological benefits are the estimated lives that could have been saved (deaths likely avoided) if generators having reduced CO emission rates had been used instead of carbureted generators actually used in fatal exposure scenarios reported to CPSC. Based on actual test data, staff observed that when a generator is operated in an enclosed or semi-enclosed area, a slower rate and lesser degree of oxygen depletion and lesser rise in CO emissions was observed with a prototype reduced emissions generator compared to a current carbureted generator. To account for an expected rise in CO emissions when oxygen depletion occurs, staff based conservative benefits estimates for each generator category on modeled CO emission rates that are three-fold higher than reduced rates considered technically feasible at normal oxygen level. Staff estimates a total of 208 of 503 deaths would have likely been avoided (an overall 42.4% save rate) if the involved generators had met the draft proposed rule's CO emission rates. The estimated reductions in deaths come primarily from class 2 single cylinder (56.8%) and class 1 (41.4 %) generators, which together account for 99% of the estimated lives saved. The subset of 503 deaths used as the basis of the current benefits modeling study represent 76 percent of 659 in-scope portable generator deaths that occurred from 2004 through 2012. Staff expects that additional deaths likely would have been avoided, especially in fatal incidents where a generator was operated outdoors, and/or that had co-exposed survivors, but staff did not quantify the remaining 24 percent of fatalities that were not modeled,. Staff believes that future generator-related CO deaths and injuries will continue to occur in similar numbers as seen currently, unless requirements for substantial reductions in CO emission rates are implemented.

United States
Consumer Product Safety Commission
4330 East West Highway
Bethesda, MD 20814

Memorandum

Date: October 03, 2016

TO: Janet Buyer, Project Manager, Portable Generators
Division of Mechanical and Combustion Engineering, Directorate for Engineering Sciences

Through: Kathleen Stralka, M.S., Associate Executive Director
Directorate for Epidemiology

Alice Thaler, D.V.M., M.S., Associate Executive Director,
Directorate for Health Sciences

Joel Recht, Ph.D., Associate Executive Director
Directorate for Engineering Sciences

Stephen Hanway, M.S., Division Director of Hazard Analysis
Jacqueline Ferrante, Ph.D., Director, Division of Pharmacology and Physiology Assessment
Mark Kumagai, Division Director of Mechanical and Combustion Engineering

FROM: Matthew V. Hnatov, Mathematical Statistician
Sandra E. Inkster, Ph.D., Pharmacologist
Janet L. Buyer, Mechanical Engineer

SUBJECT: Estimates of Epidemiological Benefits Associated with Reduced Carbon Monoxide (CO) Emission Rates Compared to CO emission Rates of Current Carbureted Portable Generators

1. Objective

The primary objective of this staff memorandum is to provide estimates of how many carbon monoxide (CO) poisoning deaths related to consumer use of portable generators could have been avoided if the generators had substantially reduced, yet technically feasible, CO emission rates. The estimates are derived from staff analysis of: a theoretical modeling study of CO exposures and related carboxyhemoglobin (COHb)[a] profiles, based on data patterns in generator-related CO fatalities that occurred from 2004 through 2012, which were reported to U.S. Consumer Product Safety Commission (CPSC) databases as of 05/21/15. This memorandum describes how these estimates were developed from

[a] The % COHb reflects the percentage share of the body's total hemoglobin pool occupied by CO: poisoning severity typically increases as COHb levels increase.

the modeling study and includes justifications for model inputs used and assumptions made by staff. The estimates are intended to provide information about potential improvements in outcomes to inform staff's preliminary regulatory analysis and initial regulatory flexibility analysis for the draft proposed standard for generators.

2. Background

Portable generators present a serious risk of fatal and high-severity nonfatal CO poisoning. From 2005 through 2012, CPSC staff's annual estimates show that generators have overtaken the entire product category of fuel-fired heating systems to become the single product type responsible for the largest estimated number of annual, non-fire-related consumer CO poisoning fatalities, excluding automobiles, which are outside the scope of CPSC jurisdiction.[1]

2.1 CPSC Fatality Data

CPSC staff counts the number of generator-related CO poisoning deaths that are reported to the CPSC databases. As of May 21, 2015, CPSC databases contained reports of at least 751 generator-related in-scope[b] non-fire consumer CO poisoning deaths resulting from 562 incidents, which occurred from 2004 through 2014.[2] For this epidemiological benefits analysis for the draft notice of proposed rulemaking (NPR), staff excluded the data for years 2013 and 2014, which amounted to 85 deaths in 64 incidents because data collection is still ongoing, and the death count most likely will increase for these years in future reports; therefore, the death count is considered incomplete. This analysis also excluded five deaths in three incidents that occurred in 2011, known to involve stationary generators and two deaths in two incidents that occurred in 2005 and 2007, which were known to involve generators that were part of welding machines. Stationary generators are excluded because they are outside the scope of the portable generator rulemaking.[3] Generators that are part of welding machines are excluded from staff's analysis because staff considers that they are atypical consumer products, therefore, has excluded them for the scope of the draft NPR. Staff notes that the two U.S. voluntary standards for portable generators also exclude generators that are part of welding machines.[c] Therefore, staff's analyses for the proposed rulemaking are based on 659 deaths in 493 incidents that occurred from 2004 through 2012.

CPSC staff attempted to investigate most of these deaths to learn as much as possible about the incident. Completed CPSC in-depth investigations (IDIs) vary considerably in the level of detail that can be obtained. In some cases, only minimal details could be obtained beyond the information already found in the source document (Injury or Potential Injury Incident (IPII) report or Deaths record/certificate (DTHS). In other cases, IDIs contained some or all official records of first responders (police, firefighters, emergency medical services[EMS], medical records of victims and/or survivors, death scene investigator's reports, Medical Examiner's/Coroner's autopsy reports, interviews with survivors and other witnesses, and details about the involved generator products. From the available incident information found in collective CPSC databases, staff learned that nearly 75 percent of the deaths (565 deaths, 422 incidents) occurred in a fixed-structure home location, which includes detached and attached houses,

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[b] Per reference 2, a fatal incident was deemed in scope if: CO was the primary or contributing factor in the fatality; the fatality was not fire-related; the source of the CO was a generator, or a generator used in conjunction with another CO-producing product; the fatality was unintentional in nature; the generator involved was a consumer product; the incident was not work-related; and the generator was not permanently installed in a recreational vehicle or boat.

[c] Underwriters Laboratories, Inc. UL 2201 *Safety Standard for Portable Generator Assemblies* and Portable Generator Manufacturers Association ANSI/PGMA G300-2015 *Safety and Performance of Portable Generators.*

apartments, fixed mobile homes, and cabins used as a permanent residence. Another 16 percent (117 deaths, 81 incidents) occurred at non-fixed home locations or temporary structures, such as trailers, horse trailers, recreational vehicles (RVs), cabins (used as a temporary shelter), tents, and campers. These incidents involved separate portable generators that were not pre-installed items, as can be found in boats and RVs. About 6 percent (48 deaths, 46 incidents) occurred in external structures at home locations, such as sheds and detached garages; and 3 percent (21 deaths, 13 incidents) occurred at other or unknown locations. Most of the deaths involved use of portable, gasoline-fueled generators in enclosed or semi-enclosed areas; but 42 deaths in 30 incidents are known to have occurred when exhaust from a portable generator that was operated outdoors infiltrated occupied structures (note: excluded are two additional deaths in 2011, caused by a stationary generator product operated outdoors, which is not considered in-scope for this analysis).[4]

2.2 CPSC Injury Data

Staff recently issued two new reports concerning patients seen in National Electronic Injury Surveillance System (NEISS) Emergency Departments (EDs[d]) for generator-related CO exposures. One report provides details of a minimum case count of 292 patients seen in NEISS EDs from 2004 through 2014, for suspected or confirmed CO poisoning injuries attributed to use of a generator.[5] About 29 percent of victims were younger than 15 years of age. Most patients were examined and/or treated and released (204); some were transferred to other hospitals (35); hospitalized (33); held for observation (13) or left without being seen or against medical advice (6); and one patient died. A random sample of these NEISS cases was supplemented by details obtained in a computer-assisted telephone interview (CATI) survey study that was conducted to try and obtain more specific details about injury incidents. Generator locations reported in NEISS narratives or CATI responses were reported as follows: garage (70); inside the home (86); in the basement (66); outside the home (29); other/unknown (51).

Details regarding why and/or how NEISS patients presented at the ED were identified in 93 of 292 patients:

- In 47 of the 93 cases, (50%) - the patient had realized that a health concern/problem situation was developing and had taken action to get to the ED (called 911 and was transported via ambulance, or arrived in private vehicle, self-driven or driven by a family member or friend.)

  Epidemiologic Investigation Report # 111110HEP9001 is an example of the above scenario: *During an ice storm-related power outage, a 72-year-old man used a 5 kilowatt generator for the first time. He ran it in the attached garage of his detached home with the garage door and windows partially open. Over the next 3 hours, he went in and out of the garage several times. His 65-year-old wife and 57-year-old friend, who were in a first floor room, began to feel dizzy and ill. They called 911 and all three victims were transported to an ED, being given oxygen en route. The 72-year-old man was admitted overnight (18% COHb), and his wife (10.7% COHb) and her friend (5.9) COHb) were treated and released.*

- In the 24 of the 93 cases (25.8%), victims were found in distress by others who arranged their transport to the ED.

[d] CPSC's NEISS database is a national probability sample of Emergency Departments in hospitals in the United States and its territories. Patient information is collected from each NEISS hospital for every emergency visit involving an injury associated with a consumer product(s).

Epidemiologic Investigation Report # 041001HEP9003 is an example of the above scenario. *Two victims, a 67-year-old male and his 66-year-old wife, were exposed to generator exhaust during a Hurricane related power outage. The woman had complained of feeling lightheaded, then woke up early morning feeling unwell, went outside and collapsed. Her husband reported the wind had changed direction and was blowing fumes into the home. He took her to an ED where they complained of headache, dizziness, nausea and confusion. They were found to have 11% COHb (66yF) and 12.5% COHb (67yM), given supplemental oxygen, then released.*

- In at least 20 of the 93 cases (21%) where the patient's actions prompted the ED visit, the generator was known to be located outside.

  Epidemiologic Investigation Report # 070206HEP9084 is an example of the above scenario: *The 67-year-old female victim was diagnosed with CO poisoning after her grandson complained of severe headache and nausea symptoms while a generator was operated on a patio outside a basement window that was cracked open to allow passage of an extension cord. They called 911 and were given oxygen while taken to the ED by ambulance. The woman had 17.9% COHb when measured in the ED; her grandson's COHb level is not reported. They were both given more oxygen at the ED before being released.*

  The victim stated, "*We had a big ice storm and we lost power for 2 weeks and I was finally able to buy a generator so we got it and put some gas in it and I was scared of them so we kept it outside on the patio and only cracked the door for the cord. The only thing we plugged in was the electric space heater. I went to bed and my grandson was in the kitchen and he came back and told me that he had a terrible headache and was sick to his stomach so I right away turned that darned thing off and called 911.*"

- In 22/69 cases (23.7%), the patient presented in response to a CO alarm activation.

  Epidemiologic Investigation Report # 070325HEP6082 is an example of the above scenario: *An 84-year-old man sustained carbon monoxide poisoning when he inhaled CO while sleeping in his bed. The generator was on a transfer switch and was in the garage attached to the house. He and his son had inhaled the CO for approximately one hour. The fire department came but his son took them to the emergency room. The level in his body was equivalent to one pack of cigarettes and his son's was two packs of cigarettes. They were treated and released.*

  The victim stated, *"The lights had gone out and they said they would be out for 4 hrs. and I went to bed to keep warm. Since I can't get cold due to my cancer. The generator was hooked up in the garage and the fire department said the copper pipe melted. We had it installed by the electric company. The CO alarm went off. My son got us out of the house."*

CPSC staff believes that these cases suggest that self-rescue or intervention is a possible scenario for a generator incident. Based on these examples of nonfatal incidents, staff believes that victims who develop early symptoms of CO poisoning, can self-rescue, provided they have sufficient time to react to their developing symptoms or can be rescued by an occupant of the same house or by an outside party.

In the second report, based on a sample size of 248 NEISS records from 2004 through 2012, staff provided a national estimate of 8,703 patients (an average of 967 per year) seen in hospital EDs for CO poisoning exposures or injuries associated with generators. This represents a minimum estimate. An estimated 5,458 patients (an average of 606 per year) were examined and/or treated and released, suggesting relatively low-severity CO exposures. Due to relatively high levels of uncertainty resulting from small sample sizes, the report did not provide national estimates for the number of patients who were hospitalized for treatment of presumably higher-severity CO poisoning injuries (56 of 248 patients), or held for observation (12 of 248 patients).[6]

High-severity, nonfatal, CO poisoning victims triaged in the field are sometimes transported directly to specialized hyperbaric oxygen treatment (HBO-T) facilities, so they are not seen in an ED. This means that the NEISS records, already recognized to be minimum counts or estimates of nonfatal injuries, are likely to underestimate the incidence of high-severity CO poisoning caused by generators (and any other CO source). The majority of NEISS patients who were transferred to other facilities and some admitted for treatment, likely received HBO-T. HBO-T is not without risk, and is generally reserved for a relatively small fraction of CO poisoning victims who have evidence of high-severity injury.[e,7,8]

2.3 Medical Literature

In 2006, a review of nine published reports documenting unintentional CO poisoning injuries and fatalities in 11 different hurricane/tropical and winter storm events from 1993 through 2005 drew attention to the growing problem related to use of generators during unplanned weather-related power outages. The review suggested the potential for targeted intervention by means of on-product warning labels (as subsequently required by CPSC on portable generators, manufactured or imported on or after May 14, 2007[f]) and by "engineering solutions and more stringent controls on generator emissions output."[9]

One of the reports in the review included specific details regarding six deaths in five incidents, and167 nonfatal hospital cases in 51 incidents, which occurred when four hurricanes hit Florida in 2004.[10] In nonfatal cases, the report noted that 81 patients were treated and released the same day; 77 patients received HBO-T; and 13 patients (including 4 of the HBO-T treated group) were hospitalized. All deaths and most nonfatal cases (47 of 51 incidents) were caused by use of portable gasoline-powered generators. Reportedly, most of the nonfatal exposures occurred as a result of overnight use of generators to power refrigerators, fans, and air conditioners (AC); and 111 patients reported to an ED between 5 a.m. and 10 a.m., after waking with symptoms of CO poisoning. Generator locations were: outdoors (16 incidents, mostly near open windows or window AC units); in a garage (16 incidents); inside a home (6 incidents); on an attached porch, deck or patio (4 incidents); in a business (1 incident); in an RV (1 incident); and, unknown (3 incidents). For the six fatalities where death occurred before medical intervention could be implemented, all generators were located inside enclosed structures in a home (2 incidents), garage (1 incident), or an office or business (2 incidents).

Since the 2006 review, a growing number of reports documenting generator-related CO poisoning deaths and injuries, with varying levels of specific detail, have been published in the medical literature. For instance, it has been reported that during a severe ice storm that hit Kentucky in January 2009, CO poisoning was responsible for 10 deaths, 28 HBO-T cases, 26 hospitalized patients, and 202 ED patients. Although kerosene heaters were reported to be the most common source of CO poisoning, generators accounted for the majority of high-severity poisoning cases (16 HBO-T patients) and deaths (8); incorrect

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[e] The medical literature contains several proposed screening systems for identifying CO poisoning victims considered most likely to benefit from hyperbaric oxygen treatment (HBO-T), but universally applied criteria have not been developed, and long-term benefits of HBO-T are still considered controversial.

[f] 16 C.F.R. part 1407, *Portable Generators; Final Rule; Labeling Requirements*, Federal Register, 72 FR 1443, January 12, 2007, and corrected graphic, 16 C.F.R. part 1407, *Portable Generators; Final Rule; Labeling Requirements*, Federal Register, 72 FR 2184, January 18, 2007.

generator location was noted for these eight deaths in five incidents.[11] In September 2008, related to Hurricane Ike, two of 27 unintentional, nonfatal CO poisoning patients seen in Texas hospital EDs were hospitalized, and generator use, predominantly in residential settings was reported in 82 percent of cases. At one regional HBO-T facility, 13 of 15 patients had generator-related exposures; and a generator was operated inside the home or attached garage in six of seven CO poisoning fatalities, all of which occurred at residential locations.[12]

Two 2015 publications reported especially detailed information regarding generator-related CO poisoning. One publication reported findings concerning mostly nonfatal unintentional, CO poisoning related to two extreme weather events in Connecticut, namely a massive snow storm on 10/29/11, which left more than 860,000 people without power for up to 2 weeks, and Hurricane Sandy, which struck 10/29/12 and left more than 625,000 without power for a week.[13] The study was based on patients who had a confirmed elevation of ≥9% COHb, where incident details were obtained by follow-up telephone interviews of patients or a proxy, and/or review of medical records. In 2011, there were 72 incidents involving 133 patients (including 3 fatalities); and in 2012, there were 11 nonfatal incidents involving 30 patients. Although patient disposition by CO source product was not specified, it was reported that, for both storms, 108 patients were treated with normobaric oxygen; 24 were hospitalized; 26 received HBO-T; and five did not require treatment in an ED. A generator CO source was identified in 48 of 83 incidents, (58%; 38 in 2011; 10 in 2012), with incorrect placement (no other details) noted in 44 incidents, and in all three incidents where there were reported fatalities. Some patients reported that weather conditions, theft concerns, or extension cord length influenced their chosen generator location. In both years, half the generator operators were reported to be novice users. Available information on racial/ethnic background indicated that most generator incidents involved non-Hispanic white households; but minority non-Hispanic black and Hispanic households were over-represented, compared to the general population of Connecticut. In 18 incidents (16 in 2011, and 2 in 2102), the generator had been purchased or borrowed specifically to meet power needs related to the respective storm, but no operators recalled being given a verbal warning about the CO hazard when they obtained the generator. In seven cases, a CO alarm was reported to have activated during the event; but some users reported that they did not hear the alarm over the generator noise, or thought it had malfunctioned. In other incidents, CO alarms located in basement areas did not activate because they were too far from the CO source. The effectiveness of information and education (I&E) efforts in combating CO poisoning was questioned, given that in 2011, 35 percent of the individual operators, who were responsible for using any CO source product in an unsafe manner (generator, charcoal grill, propane or kerosene heater), admitted to having heard specific CO media warnings before the winter storm. Warning label effectiveness was also questioned because only 19 percent of generator operators (and 4% of charcoal operators[g]) recalled having seen a pictorial warning label.

The second 2015 paper provides information on characteristics of 263 high-severity, nonfatal CO poisoning victims and one ultimately fatal case, where all patients received HBO-T consequent to 151 generator-related exposure incidents.[14, h] The study's 264 subjects are a subset of a large, convenience survey sample of 1,912 CO poisoning victims (1604 with unintentional CO exposures) who received HBO-T from August 1, 2008 through July 31, 2011.[i,15,16] The authors estimate the survey may have

[g] Since November 1997, CPSC has required a pictogram CO warning label on packages of charcoal sold for use in cooking and heating (see https://www.gpo.gov/fdsys/pkg/FR-1996-05-03/pdf/96-10978.pdf).

[h] The lead author, Dr. Neil Hampson, kindly provided Dr. Inkster with some additional unpublished details from the study data (personal email communication, 03/14/15).

[i] Case details for 1,912 anonymous victims were submitted voluntarily by 63 participating US-base HBO-T facilities in 42 states during a prospective, 3-year survey. The survey data represents the largest single-data collection

captured about 43 percent to 45 percent of all CO poisoning cases treated in HBO-T facilities during this time frame. This suggests that about 600 generator-related HBO-T cases likely occurred in 3 years, which translates to about 200 cases per year, as estimated by the authors, who noted the numbers should be considered minimum estimates. Compared to CPSC fatality data, the nonfatal HBO-T patient gender was less heavily skewed toward adult males (55% males, 38 ± 20 years versus 45% females, 36 ± 20 years, where age represents the mean average ± standard deviation [(SD]). Although Black and Hispanic patients were disproportionately over-represented, relative to racial/ethnic proportions of the U.S. population, English was the primary language of 228 patients, and only 11 of 264 patients did not speak English. One or more relatively low-severity symptoms were commonly reported by patients: headaches (164), dizziness (137), nausea and vomiting (131), and confusion (71). Loss of consciousness (LOC) was reported for 132 patients. Estimated duration of LOC was unknown in 64 cases; less than 11 minutes in 50 patients; from 11 to 60 minutes in 11 patients; from 1 to 6 hours in 6 patients; and >6 to 24 hours in 1 patient. Invasive advanced life support involving endotracheal intubation was needed for 18 patients. Reported blood levels for 182 patients ranged from 2.3 to 48.3 % COHb (22.7% ± 9%, mean ± SD). The interval from the end of exposure to COHb measurement ranged from 0 to 22 hours and averaged 1.9 ± 2.4 hour (mean ± SD), suggesting a skewed distribution indicative of a few especially long intervals that would have reduced the measured COHb level. Evidence of adverse cardiac effects of CO was indicated for 36 patients by abnormalities in measured cardiac enzyme levels (28 patients) and/or electrocardiograms (17 patients), and/or echocardiograms. Most incidents (99) involved domestic activities (normal family relations, sleeping) that occurred in residential settings. There were 34 incidents involving occupational activities; 17 incidents were reported at a workplace (*e.g.*, warehouse), 12 incidents were reported in residential settings, and the remaining cases occurred at other single work sites. Five incidents involving recreational activities were reported in a boat, cabin, or camping trailer. More incidents were reported in winter (55) and autumn (42), than in spring (31), or summer (23). Incidents were reported from 33 states, and nine of the 17 non-reporting states did not have an HBO-T facility. Some states had notably high incident and/or patient numbers, which, in part, reflects states affected by extreme weather events, and in part, also likely reflects states having HBO-T facilities where clinicians specializing in CO poisoning research are based (*e.g.*, Pennsylvania, North Carolina, Washington, Maryland). Clinicians actively engaged in CO poisoning research might be expected to be more proactive in recommending HBO-T for their patients, and reporting data to the survey study.

2.4 Low CO Emissions Prototype

Staff's 2012 report, "Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator" (Prototype Report), described development of a reduced CO emissions prototype generator from a current generator product (*i.e.*, carburetor replaced by closed-loop fuel-injection and catalyst installed in the muffler).[17] The report provided evidence to show the reduced CO emissions approach was technically feasible and could be maintained for the engine's rated useful life without negatively impacting product performance, or compliance with the mandatory engine emissions limits for CO and other criteria pollutants, notably hydrocarbons (HC) and nitrogen oxides (NOx) required by the U.S. Environmental Protection Agency (EPA). After durability testing for the duration of the engine's rated useful life, the prototype unit's CO emissions were approximately 30 grams per hour (g/hr), which was more than a 95 percent reduction of the published CO emission certification data for the unmodified engine. Staff's prototype findings have since been repeated by others who patterned their reduced CO emissions prototype generators on the design concept developed for CPSC by The University of

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describing exposure scenarios and characteristics of CO poisoning survivors who received HBO-T (see Clower, Hampson, et al., 2012; Hampson, Dunn, et al., 2012)

Alabama.[j] Moreover, new generator products with reduced CO emissions, achieved by similar engine design modifications and use of catalysts, are beginning to enter the retail market.[18]

Staff's Prototype Report included an analysis of paired, short-term, empirical tests, which compared the CO hazard presented by generator units, before and after design modifications to reduce CO emissions. As part of a CPSC-funded interagency agreement (IAG) with the NIST staff, the generators were operated for between 2 and 6 hours in the attached garage of a single story, 3-bedroom, detached home (*i.e.*, the NIST test house, designed and equipped for indoor air quality (IAQ) studies), under various ventilation configurations (garage and house door positions, and heating ventilating air conditioning (HVAC) fan's operational status). Overall, the study showed that the rate of CO build up in the garage and CO infiltration into the home were dramatically diminished by a reduced CO emissions prototype generator, as compared to the unmodified generator.[19] CPSC staff's modeling of COHb levels from the empirical CO test data showed that the corresponding formation of COHb predicted for adult occupants located throughout the home was also dramatically slowed, and in most cases reduced, by the prototype generator.[20]

Staff considers one particular NIST test house configuration modeled in the Prototype Study especially important because it is representative of many reported fatal incident scenarios, and it is also the configuration used in the current modeling study for all cases simulating operation of a generator in the attached garage of relevant house models. In this test scenario, the generator was operated in the garage with all exterior garage doors and windows closed and the connecting door to home living spaces opened just 2 inches to allow passage of an extension cord, and the HVAC fan switched off.[k] During a 3-hour test of the carbureted generator, within 2 hours after the engine was started, CO levels measured in the garage, family room (FAM) and master bedroom (MBR), climbed from the zero baseline to 12770[l], 3530, and 1840 parts per million (ppm) CO,[m] respectively. All occupants of these areas were predicted to reach lethal exposure (60% COHb) from 40 to 155 minutes.[n] In contrast, in a subsequent comparative test of the reduced CO emissions prototype (138 minute engine run time with 45 minute natural decay period), peak CO levels recorded in the garage, FAM, and MBR were 300, 140, and 150 ppm, respectively. No occupants of any area were predicted to reach 20% COHb, and although a peak level of 16% COHb was estimated for garage occupants at 168 minutes into the test, peak COHb levels estimated in the two living spaces did not exceed 10% COHb. Overall, the study demonstrated how the prototype reduced the CO hazard by significantly slowing the buildup of CO and reducing peak CO levels attained,

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[j] See Techtronic Industries (TTi) presentation 3/17/16 at PGMA's Technical Summit on Carbon Monoxide Hazard Mitigation for Portable Generators – pages 85 -105 of 178 page pdf file at:
http://www.cpsc.gov//Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf

[k] This scenario, frequently reported in fatal incidents, was simulated using an original carbureted generator (Test B) and a modified reduced CO emissions prototype form with catalyst present in the muffler (Test N) (Inkster 2012).

[l] To provide some perspective: 1,200 ppm is the CO level defined by the National Institutes of Occupational Safety and Health (NIOSH) as being Immediately Dangerous to Life and Health (IDLH), which is defined as "An acute respiratory exposure that poses an immediate threat of loss of life, immediate or delayed irreversible adverse effects on health, or acute eye exposure that would prevent escape from a hazardous atmosphere within 30 minutes."

[m] When the carbureted generator had run for 180 minutes, garage, family room and master bedroom CO levels had climbed to 17,860, 6,380, and 3,330 ppm, respectively, while the garage oxygen level had fallen to ~17.25 percent.

[n] To compare the CO hazard presented by the prototype unit versus the pre-modified unit, staff used different predicted COHb ranges to compare timing, progression, and degree of CO poisoning; attainment of 60% COHb was considered indicative of lethal exposure in the absence of rescue (Inkster, 2012).

which greatly extended the available time for individuals to possibly recognize and remove themselves from a developing hazard, or be found and rescued by outside parties.

Although staff's Prototype Report findings indicated that much-improved safety was possible, if generator CO emission rates were reduced to a similar degree as achieved with the prototype generator, clearly, limited short-duration tests (no more than 6 hour engine run times), in one house model, with one size of generator, cannot be considered representative of all generator use scenarios involved in lethal CO poisoning incidents. It is not feasible to conduct empirical tests reflecting all possible combinations and permutations of lethal generator-related CO poisoning incident scenarios. Therefore, as is common practice in risk assessment, theoretical computer-based models were used to simulate exposure scenarios reported in fatal incident data.

3. NIST CO and COHb Modeling Study

3.1 Modeling Overview

To estimate the number of deaths that could have been averted by generators at various reduced-CO emission rates, staff entered into an interagency agreement with NIST (IAG No. CPSC-I-15-0024). To relate CO emission rates to occupant exposure, the complex interaction between generator operation, house characteristics, weather conditions, and occupant activity must be considered. Therefore, staff engaged NIST's expertise to perform theoretical, computer-simulated IAQ modeling. NIST used a multi-zone airflow and contaminant transport model called CONTAM.[21] CONTAM was used to estimate how CO would be transported throughout a variety of houses and structures (which were chosen on the basis of being broadly representative of those associated with fatal incidents in CPSC's databases), as a function of a generator's location within the structure, its CO emission rate, and its duration of operation, among other factors discussed below.

CONTAM predicts contaminant transport through a structure, by modeling pressure differences within the structure, as well as across the house's exterior envelope, which drive the contaminant through the house's airflow paths, *i.e.*, leakage sites, and open doors and existing ductwork. Therefore, CO transport throughout a house in which a generator is operated in a living space, attached garage, or basement/crawl space is influenced not only by the house's characteristics that define its airflow paths, but also by the weather, because wind and temperature can cause pressure differences across airflow paths in exterior walls. Furthermore, the rate at which a generator produces heat will also affect CO transport, because it will create temperature gradients between rooms, resulting in pressure differences that will drive the airflow between rooms.

The following sub-sections provide summary details of selected parameters and input values that were used in: (1) NIST CONTAM modeling to derive the CO profiles for a 24-hour period, and (2) Coburn Forster Kane (CFK) modeling of the CONTAM-derived CO profiles to predict COHb (described in section 3.4). Detailed descriptions of how staff developed these model input values are found in the Appendices indicated.

3.2 Generator Categories, CO Emission Rates, Run Times, and Heat Release Rates (see Appendix A)

3.2.1 Generator Categories

To determine appropriate model inputs, CPSC staff compiled information pertaining to portable generators powered by a range of small SI engine classes produced by six major generator manufacturers.[o] These manufacturers are identified by the Portable Generator Manufacturers Association (PGMA), as "major manufacturers of portable generators sold in North America and a significant majority of the industry." [22] Using staff's definitions for four generator categories, staff used manufacturers' product specifications, where available, to determine which categories represented the various generators. Staff's four generator categories are: handheld, class 1, class 2 single-cylinder, and class 2 twin-cylinder generators (see Appendix A).[p] The majority of fatal incidents and deaths were associated with the use of class 1 and class 2 single-cylinder generators.

Staff's compiled information, shown in Table 1, was used to develop appropriate input values for the four generator categories regarding carbureted generator run times, CO emission rates, and heat release rates used in the modeling study. Explanations of how staff compiled the information in Table 1, assumptions used, and calculations made, are found in Appendix A.

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[o] Almost all the generators involved in the fatal incidents were gasoline-fueled products known to be powered by SI engines. The EPA broadly categorizes small SI engines as either non-handheld or handheld, and, within each of those categories, further distinguishes different classes, which are based upon engine displacement. EPA divides non-handheld engines into Class I and Class II, with Class I engines having displacement above 80 cc, up to, but not including 225 cc, and Class II having displacement at or above 225 cc, but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Some handheld engines are used to power very small portable generators, but the majority of portable generators are powered by non-handheld engines.

[p] Note that staff describes generators in this memorandum using the categories: handheld generator, class 1 generator, class 2 single-cylinder generator and class 2 twin-cylinder generator. Staff describes engines as handheld, Class I and Class II, based on their EPA classifications, as described in 40 C.F.R. § 1054.801.

Table1. Summary Information on Representative Portable Generators Produced by Six Major Generator Manufacturers (see Appendix A for details).

		Generator Data						Engine Certification Data from EPA Website			Calculated CO and Heat Release Rates		
Generator Description	**CPSC Generator Category**	**Generator make & model**	**Generator rated power, watts**	**Generator max/surge/starting power, watts**	**Engine displacement, cc**	**Fuel tank capacity, gal**	**Half-load runtime on full tank, hrs**	**Service Class**	**EPA CO emission certification data after DF*, g/kW-hr**	**Max engine power, kW**	**Weighted engine CO rate at normal O2, g/hr**	**Weighted engine CO rate at 17% O2, g/hr**	**Heat release rate, kW**
Generators powered by EPA handheld engines	Handheld	Honda EU1000i	900	1000	49.4	0.6	6.8	Handheld-Class IV	459	1.6	343	1029	2
		Yamaha EF1000is	900	1000	50	0.7	9.1	Handheld-Class V	290	1.3	179	536	2
		Ryobi RYi1000	900	1000	53.5	0.6	8.0	Handheld-Class V	355	1.3	216	647	2
		Power Stroke 2100 inverter	1700	2100	79	1.3	10.5	Handheld-Class V	311	2.3	334	1002	3
		Champion	1700	2000	80	1.0	7.2	Handheld-Class V	347	1.8	292	875	3
		Yamaha EF2000is	1600	2000	79	1.1	8.0	Handheld-Class V	336	2.3	358	1073	3
Generators powered by EPA nonhandheld Class I engines	Class 1 (C1)	Briggs & Stratton P2000	1600	2000	111	1.0	5.0	Nonhandheld-Class I	519	2.1	509	1527	4
		Honda EU2000i	1600	2000	98.5	1.0	6.5	Nonhandheld-Class I	445	2.6	530	1590	3
		Yamaha EF2400iSHC	2000	2400	171	1.6	7.0	Nonhandheld-Class I	343	3.5	561	1682	5
		Briggs & Stratton P3000i	2600	3000	171	1.5	7.6	Nonhandheld-Class I	545	3.9	993	2978	4
		Honda EU3000iS	2800	3000	196	3.4	15.7	Nonhandheld-Class I	331	4.1	634	1901	5
		Generac GP3250	3250	3750	208	3.5	9.7	Nonhandheld-Class I	260	4.5	546	1639	8
		Champion 3400/4000	3400	4000	224	3.4	9.0	Nonhandheld-Class I	285	4.8	639	1917	8
		Generac XP4000	3600	4500	216	4.8	9.5	Nonhandheld-Class I	260	4.5	546	1639	11
		Black Max 3550	3550	4550	208	4.0	11.0	Nonhandheld-Class I	327	4.3	657	1970	8
Generators powered by EPA nonhandheld Class II single cylinder engines	Class 2 single (C2 single)	Yamaha EF4500iSE	4000	4500	357	4.5	12.0	Nonhandheld-Class II	312	7.6	1107	3322	8
		Honda EB5000	4500	5000/7000 for 10 sec	389	6.2	11.2	Nonhandheld-Class II	389	8.7	1580	4741	12
		Briggs & Stratton 3500 watts	3500	4375	250	4.0	8.0	Nonhandheld-Class II	483	5.2	1173	3519	11
		Champion 5000/6250	5000	6250	292	5.7	9.0	Nonhandheld-Class II	431	6.6	1328	3985	14
		Honda EB6500	5500	6500/7000 for 10 sec	389	6.2	10.4	Nonhandheld-Class II	389	8.7	1580	4741	13
		Briggs & Stratton 5500 watts	5500	6875	342	5.0	10.0	Nonhandheld-Class II	396	8.4	1553	4660	11
		Yamaha EF7200DE	6000	7200	358	6.9	11.8	Nonhandheld-Class II	400	7.6	1420	4259	13
		Ryobi 5500	5500	6875	420	6.0	9.0	Nonhandheld-Class II	376	9.4	1651	4952	14
		Champion 7500/9375	7500	9375	439	6.1	8.0	Nonhandheld-Class II	361	11.2	1888	5665	16
		Generac RS7000E	7000	8750	420	7.5	12.0	Nonhandheld-Class II	340	10.0	1588	4763	13
		Briggs & Stratton 7000 watt Elite	7000	8750	420	7.5	9.0	Nonhandheld-Class II	377	10.9	1919	5757	18
		Ridgid 7500	7500	9375	420	8.0	12.0	Nonhandheld-Class II	387	11.0	1988	5964	14
Generators powered by EPA non handheld Class II twin cylinder engines	Class 2 twin (C2 twin)	Honda EB10000	9000	10000	630	8.1	7.2	Nonhandheld-Class II	440	16.5	3390	10171	24
		Generac GP15000E	15000	22500*	992	16.0	10.0	Nonhandheld-Class II	272	23.9	3036	9108	34
		Briggs & Stratton 10000-running watts	10000	12500	570	7.0	7.5	Nonhandheld-Class II	457	13.2	2817	8451	20
		Yamaha EF12000DE	9500	12000	653	11.4	11.8	Nonhandheld-Class II	406	15.3	2901	8703	21

* DF = deterioration factor, explained in US EPA, Nonroad Spark-Ignition Engine Emission Deterioration Factors, EPA-420-R-10-020, NR011-d, July 2010. https://www3.epa.gov/otaq/models/nonrdmdl/nonrdmdl2010/420r10020.pdf

* US EPA's non-road small spark-ignition engine certification database includes several engines with reported Maximum Engine Power > 19kW.

3.2.2 Current Generator CO Emission Rates, Run Times, and Heat-Release Rates

Table 2 presents CO emission rates, run times, and heat-release rates developed by staff for all four generator categories. Ultimately, the CO emission rates, run times, and heat-release rates, were provided to NIST staff for use in modeling of "baseline" CO emissions of carbureted generators when operated in enclosed or semi-enclosed spaces. These values are approximated average values derived from the data shown in Table 1 for each CPSC generator category (see details in Appendix A).

Table 2. Model Input Parameters Used in CONTAM Modeling of Current Carbureted Generators

	Average weighted CO emission rate at 17% O_2 (g/hr)	**Average generator engine run time at 50% load (hrs)**	**Average heat release rate (kW)**
Handheld generators	900	8	2
Class 1 generators	1800	9	6
Class 2 single cylinder generators	4700	10	13
Class 2 twin cylinder generators	9100	9	25

In the CONTAM modeling study, to account for the gradual depletion of oxygen from 20.9 percent to 17 percent, during which time the CO emission rate is expected to be increasing from the ambient rate to the rate shown in Table 2, for the first 2 hours of generator run times, NIST modeled CO emission rates that were two-thirds the rates shown in Table 2. After 2 hours, for each generator category, the respective CO emission rates shown in Table 2 were used to model the respective remaining duration of engine run time.

3.2.3 Reduced Generator CO Emission Rates, Run Times, and Heat Release Rates

Staff selected six reduced weighted[q] CO emission rates for NIST to model so that the benefits associated with each rate for each generator category could then be estimated. These rates are: 50, 125, 250, 500, 1000, and 2000 g/hr. Ultimately, staff limited consideration for each class of generator to those rates staff believes are technically feasible: both handheld and class 1 generator categories (50 g/hr), class 2 single-cylinder category (100 g/hr), and class 2 twin-cylinder category (200 g/hr).[18]

For each generator category, the reduced CO emission rates were modeled as constant rates for the entire respective generator run time shown in Table 2. This is a conservative assumption, as compared to the modeling of current carbureted generator CO emission rates, where, to reflect the gradual decreasing oxygen levels during combustion, CO emission rates were initially only two-thirds of the eventual emission rate at 17 percent oxygen.

For the reduced CO emission rates of each respective generator category, staff used the same values for run times and heat-release rates, as shown in Table 2, for current generators. Staff assumes the run time of a generator that complied with staff's recommended proposed rule could be similar to current generators. Staff reasons that any additional weight and volume of the emission control components

[q] See Appendix A for explanation of "weighted" CO rate.

needed to reduce the CO emission rate could be offset by a smaller fuel tank; and due to the improved fuel efficiency of reduced emissions engines, the smaller tank would still be able to maintain similar run times as carbureted units with larger fuel tanks.

3.3 Structures, Generator Location, and Weather (See Appendix B and E and NIST TN 1925)

3.3.1 Characteristics of Home Models and Detached Structures

Based on patterns of house and detached-structure characteristics evident in CPSC fatal incident data, and staff's use of other information sources,[r] a total of 37 house models (31 detached single family home models, 2 manufactured home models, 4 attached home models) and three detached structures representing detached workshops and similar structures were included in the NIST modeling. These 40 models represent locations involved in 76 percent of generator-related CO deaths in the period 2004 through 2012. Some of the house models were pre-existing plans found in NIST's "Suite of Homes."[23] In other cases, based on CPSC staff input, NIST staff made modifications to existing house plans, or developed new plans, to reflect CPSC staff's findings regarding characteristics of incident structures. Specifics of the structures modeled can be found in Appendix B, and the corresponding NIST report.[24]

When modeling all homes, interior doors were assumed to be open 2 inches (in) during the simulations; and all exterior doors and windows were kept closed, with the following exceptions. Stairways between finished living space levels, other than the first floor door, were modeled with open doorways. Kitchen doors were modeled as open doorways. For cases in which the generator was located in the attached garage, the door from the garage to the house was assumed be open roughly 2 inches, to accommodate an extension cord running from the generator. Exterior garage doors were assumed to be closed.

3.3.2 Portable Generators in Incident Data and Generator Locations Used in Modeling Studies

Staff reviewed incident data to determine the characteristics of generators involved in fatalities. Staff assigned generators to one of four generator categories: handheld, class 1, class 2 single-cylinder generators, and class 2 twin-cylinder generators. To arrive at the number of deaths that occurred by generator category, when the IDI did not report the generator's engine displacement, or it was not obtainable from other information in the IDI, staff considered the reported wattage of the generator, if available. Staff classified generators with a reported wattage of 3.5 kW and larger as a class 2 single-cylinder or class 2 twin-cylinder generator, and those less than 3.5 kW as a handheld or class 1 generator. To distinguish the handheld powered generators from the class 1 powered generators, when there was no information to ascertain the engine displacement, generators with reported wattage of 2 kW and larger, up to 3.5 kW, were considered to have a Class I engine. There was only one generator with reported wattage below 2kW for which the engine displacement could not be ascertained. That was a 1000 watt generator, which staff classified as a handheld generator because staff's review of generators nominally in this size showed almost all as being powered by handheld engines. To distinguish the class 2 single-cylinder generators from the class 2 twin-cylinder generators, staff found from looking at the EPA's website that twin cylinder Class II engines largely have an engine power of 12 kW and higher. Staff then found, from looking at manufacturers' generator specifications, that generators having engines with power equal to, or greater than 12 kW, typically have a rated power of 9 kW and higher.

[r] Such as publicly available property records, real estate website information, and Google Earth.

The majority of fatal incidents and deaths were associated with the use of class 1 and class 2 single-cylinder generators. Table 3 below provides a summary of fatalities and allocated fatalities associated with the different generator categories (see Appendix E, Table. E.2).

Table 3: Distribution of Known Fatalities and Allocated Fatalities by Generator Category

Generator Category	Known Fatalities – Generator Category Known	Allocated Fatalities for Unknown Generators	Total Allocated Fatalities
Handheld	2.0	1.7	3.7
Class 1	90.0	86.2	176.2
Class 2 single-cylinder	167.0	154.3	321.3
Class 2 twin-cylinder	1.0	0.8	1.8
Total	260.0	243.0	503.0

3.3.3 Generator Location (CO Emission Source Location)

For each house type, up to three generator locations were modeled as follows:

1) A first floor room (often the kitchen, or a small bedroom, depending on the house floor plan)
2) An attached closed garage if applicable to the house plan
3) A basement (if applicable to the model house, bedroom or den furthest away from master bedroom or in smallest bedroom or den if master bedroom is on 1st floor) if finished basement OR crawlspace (if applicable) OR a 2nd first floor room if there is no basement (bedroom furthest away from master bedroom or other likely space).

3.3.4 Weather Patterns

According to the incident data, approximately one-half of the generator CO fatalities per year occur during the colder 4 months of the year (November through February) while the other half were somewhat evenly distributed between the transition months of March, April, September, and October and the warmer months (May through August). This distribution of incidents varies year-to-year and is highly dependent on the occurrence of severe weather events because they can result in local and widespread power outages, which increases consumer use of generators. Therefore, for this modeling effort, 14 days of cold weather data (Detroit, MI), seven days of data from transition months (Columbus, OH), and seven days from warmer months (Miami, FL) were chosen,

3.3.5 Indoor Temperatures

Using a starting indoor temperature of 23°C in all interior rooms, temperature distributions within the simulated buildings were calculated using a version of the CONTAM model with heat transfer modeling capability.[25] This model accounts for heat transfer conducted through the building envelopes due to ambient weather conditions and the heat released by the generator heat source, and thus results in realistic spatial and temporal temperature variations in the buildings. CONTAM used each generator category's heat release rate when calculating the temperature changes within the structure. The generator heat-release rate was considered to be the same for carbureted and reduced emissions generators; it varied depending on generator category.

Further details underlying information in Section 3.3 can be found in Appendices A, B, and E, and NIST TN 1925.

3.4 COHb Modeling of CONTAM-Modeled CO Profiles

To conduct this benefits assessment, the nonlinear CFK[26, 27] was used to predict percent COHb levels[s] from the theoretical CO profiles generated by NIST CONTAM modeling of different CO source strengths in a variety of home models. The nonlinear CFK differential equation is a physiologically based, mechanistic model for predicting CO uptake and COHb formation and elimination in humans; it has been validated by empirical data from human studies and is widely regarded by authoritative sources as a reasonably reliable and broadly applicable COHb model for acute CO exposures.[28, 29]

The physiological CFK input values representing average adults[t] were the same as used in the Prototype Report with two exceptions. A minor change was made to the baseline COHb level, which was reduced from 1.2% COHb to 0.27% COHb to reflect improvements in outdoor air quality since reference 27 was published. The second, more significant change, concerns the inhalation rates used to model COHb profiles. Inhalation rates (air volume inspired per unit time) reflect an individual's metabolic energy demand, which is related to their oxygen utilization rate; these rates generally vary as a function of age, sex, and activity level. The respiratory minute volume (RMV), expressed in liters per minute (L/min), is the specific inhalation rate input value used in the CFK. It is one of the key physiological variables affecting the rate of COHb formation (and elimination). In HS staff's Prototype Report memorandum, comparing the CO poisoning risk presented by current portable generator designs with a low CO emissions prototype generator design during individual tests of current and prototype generator designs, the duration of engine operation ranged from 2.5 to 6.25 hours. Therefore, at that time, HS staff used two RMV values to represent sedentary (6 L/min RMV) and light-to-moderate (15 L/min RMV) activity levels that could be expected for average adults in indoor residential settings over these relatively short-duration exposures (few hours). For the current benefits analysis, the theoretical modeling study assumes occupants can remain in exposure scenarios for up to 24 hours. After considering information in recently published authoritative exposure assessment source documents, HS staff judged that an RMV value of 10 L/min was reasonably conservative for modeling average adults presumed to spend 24 hours in indoor residential environments. A 12 L/min RMV was considered a reasonably conservative upper-bound RMV, equivalent approximately to staff's calculated 90th percentile value for adults in indoor residential environments. Finally, a 6 L/min RMV was considered reasonably conservative for modeling baseline, sedentary adult activity levels in indoor residential environments (considered applicable to scenarios where occupants start a generator before retiring to bed or just sitting down). These values were provided to NIST staff to allow automated calculation of COHb profiles from residential CO profiles generated by CONTAM-thermal balanced modeling of different CO source strengths. Full details of how staff decided on the RMV values modeled are documented in Appendix C.

4. Interpretation of Modeled COHb Levels

For this analysis, benefits are considered primarily in terms of the number of deaths that could have been avoided by use of generators with various reduced CO emission rates. To facilitate interpretation of the large modeled COHb data set generated by NIST staff (from their modeling of different CO emission rates inside multiple residential settings), HS staff developed four "COHb Analysis Criteria" to assess whether predicted COHb profiles from modeled residential scenarios were likely indicative of fatal or

[s] % COHb reflects the percentage share of the body's total hemoglobin pool occupied by CO.

[t] CPSC incident data continues to show that adults account for the majority of generator-related CO poisoning fatalities (94% of victims ≥ 15 years, Hnatov 2015).

nonfatal CO exposure in average adults.[u] The criteria are intended to reflect the fact that lethal CO health effects are not simply a function of acute hypoxia resulting from a critical reduction in blood levels of oxygen delivered to tissues, as indicated by attainment of a specific peak COHb level.[v] The criteria include some consideration of the level and duration of the predicted COHb elevation, which recognizes that, in addition to reducing oxygen delivery to tissues, CO can enter the non-vascular body compartment and adversely impact important cellular functions by displacing oxygen from various intracellular heme proteins (particularly myoglobin proteins found predominantly in cardiac and skeletal muscles, and certain cytochrome P-450 enzymes involved is cellular respiration). In some prolonged CO elevations, the additional non-vascular adverse effects of CO can result in death at COHb levels that are not typically lethal.[w] As is detailed in Appendix D, based on review of available data on COHb levels in fatal and nonfatal generator-related CO exposures, and other non-generator, non-fire-related CO deaths and injuries, staff developed the criteria detailed below to distinguish between modeled COHb levels indicative of lethal versus non-lethal outcome.

COHb Analysis Criteria:

As detailed in Appendix D, the likelihood of death is relatively low at levels below 40% COHb, increases as COHb levels transition from 40 to 50% COHb, increases more substantially from 50 to 60% COHb, with death becoming expected once 60% COHb is reached. The generator fatality data show that death is possible between 40 and 59% COHb. Although staff has no precise measures of time to fatal outcome in this transitional COHb range, it reasons that higher COHb levels (greater tissue hypoxia) will take less time to cause lethal outcome than lower levels, whereas extended exposures at lower COHb levels could still prove lethal. Staff also reasons that an exposed individual's COHb exposure profile is influenced by their activity level (RMV) and by the fact that CO levels begin to decay after the expected generator run time on one full tank of gas (approximately 8-10 hours). Staff modeled static CO levels (see Figure D3 in Appendix D) and used professional judgment to derive what it considers "conservative time functions" for generator-related exposures where peak COHb levels are predicted to remain between 40 and 59% COHb. HS staff developed the following criteria to facilitate analysis of NIST staff's modeled data. The criteria enable staff to differentiate between predicted lethal and non-lethal CO exposures in average adults resulting from operation of generators within residential settings:

- If peak level is ≥60% COHb, assume death.
- If peak level is ≤40% COHb, assume survival.
- If peak level is ≥50% COHb, but<60%, assume death, unless: (i) the duration of elevation at ≥ 50% COHb is less than 2 hours, and (ii) the duration of elevation between ≥40% and <50% COHb is less than 4 hours.
- If peak level is ≥40% COHb, but <50% COHb, assume death if the duration of elevation in this range exceeds 6 hours.

Note: HS staff's response to health-related public comments received on 2006 ANPR materials and staff's 2012 Prototype Report regarding the approximate relationship between CO health effects and COHb levels can be found in Appendix F.

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[u] Certain sub-populations are more sensitive to CO exposure, particularly individuals with coronary artery disease; some studies reported adverse health effects in cardiac patients at 2 to 5% COHb, which can result from prolonged exposures to less than 50 ppm CO.

[v] Oxygen binding sites of hemoglobin molecules have more than 200-fold higher affinity for CO than for oxygen.

[w] See Section 3, Summary Information on Carbon Monoxide Pathophysiology, in Inkster, 2012, reference 20.

5. Benefit Analysis Scope and Analysis Methodology Used for NIST Data (See Appendix B and E)

5.1 Scope

The scope of the benefits analysis based on the NIST modeling is limited to a subset of the non-work-related generator-related CO fatalities known to CPSC over the 9-year period 2004 to 2012 that occurred at fixed residential structures or similar structures (*i.e.*, cabins, barns). The subset represents about three-quarters (76%, 503 of 659) of the fatalities known to CPSC staff.[x] It should be noted that CPSC staff believes that the same reduced CO emissions rates modeled in this analysis also have potential to save lives in other reported fatal scenarios that are not specifically addressed in this analysis. These reported scenarios include, but are not limited to, fatal incidents where a generator was placed outdoors, but close enough to a structure or vehicle to allow lethal levels of CO to infiltrate the inside, and scenarios where a generator was used inside a structure not specifically modeled by NIST, such as inside apartment buildings, churches, office buildings, or other non-residential structures.

5.2 Benefits Analysis

The epidemiological benefits analysis is based on the concept of estimating the number of deaths that might have been avoided if consumers had used a lower CO emission generator, as staff recommends in this briefing package, in similar incident scenarios as reported in CPSC's incident data records. Staff concludes that a significant number of lives could have been saved if the CO emission rates had been significantly lower than those produced by carbureted generator models. Staff uses the observed generator-related CO fatalities over the 9-year period 2004 through 2012 as the baseline for the benefits analysis because they provide the best indication of future events and usage patterns. NIST modeling results were used to estimate CO levels and COHb levels for both baseline carbureted CO emission rate levels and those of various proposed reduced CO emission levels.

CPSC Hazard Analysis staff developed a methodology to process NIST staff's modeled CO and COHb data set to estimate the number of deaths that might have been avoided and to derive a percent save rate for each generator category at each reduced CO emission rate. Then, based on reduced CO emission rates identified by ES staff to be appropriate for each generator category when operated in enclosed or semi-enclosed spaces, staff used the modeled data to estimate corresponding percent save rates at these specific CO emission rates. To make this determination, some or all of the following factors, based on actual incident data, were considered (house/structure type and Generator Category dependent):

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[x] CPSC staff's 2015 report cites a total of 751 generator-related CO poisoning fatalities in 562 incidents, which occurred from 2004 through 2014, and were entered into CPSC databases as of 05/21/15 (Hnatov, 2015). Of these, 85 deaths in 64 incidents were reported for the years 2013 to 2014, for which data are considered incomplete and likely to change as new information is received. For the period, 2004 to 2012, where counts are considered relatively stable, staff is aware of 666 deaths in 498 incidents. However, during this time frame, five deaths in three incidents clearly involved a stationary generator product; and two deaths in two incidents involved combination welder-generator products. CPSC's proposed rulemaking is specific to portable generators, (16 CFR Chapter 11, Portable Generators; Advance Notice of Proposed Rulemaking; Request for Comments and Information, Federal Register, 71 FR 74472, December 12, 2006); and staff chose to exclude welder products because they are considered atypical portable generators. Furthermore, welder-generator products are excluded from the scope of two existing U.S. voluntary standards for portable generators (UL 2201 and PGMA G300). Therefore, these seven deaths in five incidents were not included in the benefits analysis described in this report, which is based on starting numbers of 659 deaths in 493 incidents in the 9-year period from 2004 through 2012, of which 503 deaths that occurred in fixed-residential structures or detached structures (*e.g.*, garage, workshop), were used as the basis of modeling studies and benefits analysis (see Appendix B and E).

1) Observed proportion of generator locations within house/structure model
2) Observed proportion of Generator Category involved by location within house/structure model (for example, the incident data shows that larger generators are more likely to be used in a garage while smaller, more portable generators are more often brought into the living spaces)
3) Number of fatalities associated with house/structure model, including the allocation of unknown and non-exact match cases
4) Proportion of fatalities associated with Generator Category (class 1 and class 2 single categories only)
5) The simulated fatality rates by occupied zone: living area (combination of "kitchen" and, if modeled, "bedroom"), garage space (if modeled), and basement (if modeled); and
6) On a per-house/structure basis, the actual fatalities (based on assumed base CO rate for specific Generator Category) minus modeled fatalities with low emission generators.

Staff made determinations of the simulated fatalities on a zone-by-zone basis for each CO emission rate, using the four COHb criteria delineated previously.
Full details of the analysis methodology used and calculation of results can be found in Appendix E.

6. Results

The following tables summarize estimates of potential deaths that might have been avoided over the 2004 to 2012 time span if generators with low CO emission rates, as outlined in this report, were used in place of the high CO output of carbureted generators in use during this period. (Detailed results tables underlying these summary results can be found in Appendix E). The total potential is the summation of all estimated potential deaths that might have been avoided from all structures and all generator categories presented in this analysis. From 2004 through 2012, there were 503 of 659 portable generator-related CO fatalities considered directly addressable by the simulation analysis.

Table 4 presents summary data for all modeled scenarios, where it is assumed that, at each hour of the 24-hour modeling period, there is an equal probability of an exposed individual being removed from the exposure scenario as a result of their own actions, or due to intervention by other co-exposed occupants, or outside parties. This assumes that the generator is run for the full exposure period and is not stopped due to power restoration, lack of fuel, or another reason. At some reduced CO emission rates, in some home locations, the modeling predicted it was possible for exposed individuals to survive, even if they remained in the area for 24 hours, because lethal CO exposure, per CPSC staff criteria, was not predicted.

Table 4

Predicted Benefits at Reduced CO Emission Rates by Generator Category*

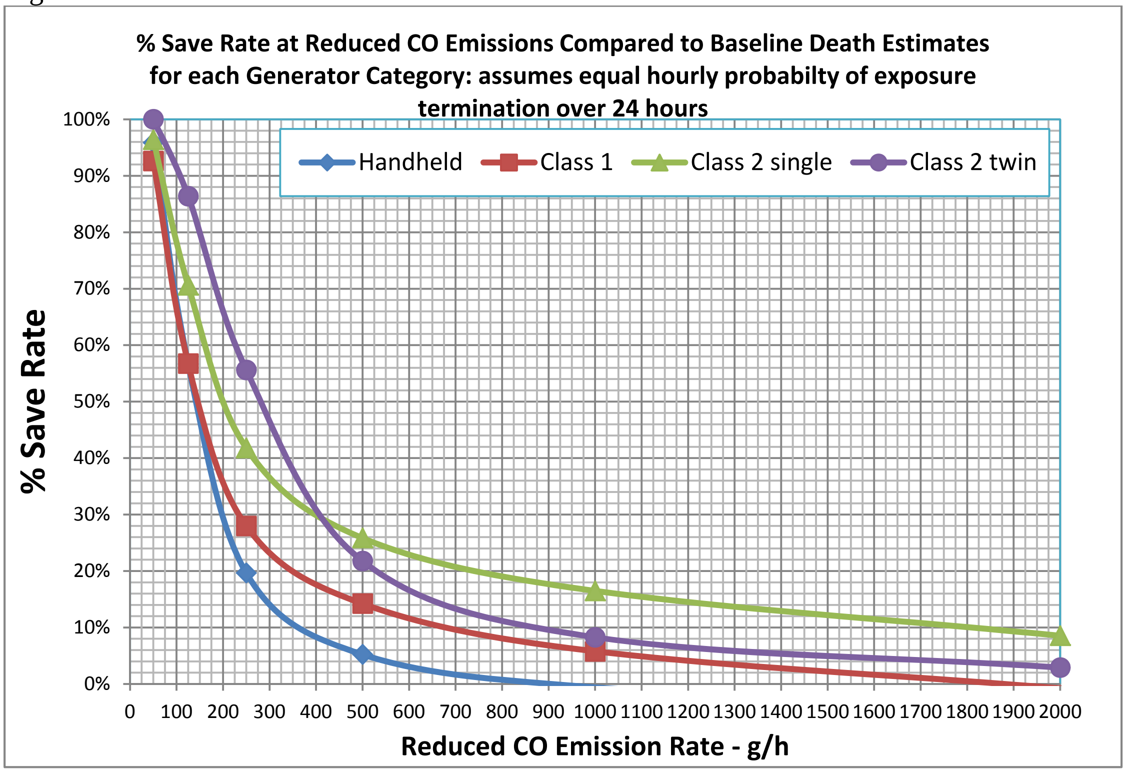
CPSC Generator Category	Handheld	Class 1	Class 2 single cylinder	Class 2 twin cylinder	Total
Baseline CO emission rate (g/hr) reduced oxygen level (~ 3-fold CO emission rate at normal oxygen level	900 g/hr	1800 g/hr	4700 g/hr	9100 g/hr	
CO Emission Rate at Normal Oxygen Level (g/hr)	300 g/hr	600 g/hr	1570 g/hr	3030 g/hr	
Base Rate Deaths	3.7	176.2	321.3	1.8	503
Number of Deaths Avoided by Rate					
50g/hr	3.5	163.2	309.7	1.8	478.3
125g/hr	2.1	100.0	226.8	1.6	330.5
250g/hr	0.7	49.3	134.2	1.0	185.2
500g/hr	0.2	25.1	83.1	0.4	108.7
1000g/hr	0.0	10.2	52.9	0.2	63.2
2000g/hr	NA	NA	27.5	0.1	26.0
% Save Rate					
50g/hr	95.8%	92.6%	96.4%	100.0%	95.1%
125g/hr	56.7%	56.7%	70.6%	86.4%	65.7%
250g/hr	19.6%	28.0%	41.8%	55.6%	36.8%
500g/hr	5.2%	14.2%	25.8%	21.8%	21.6%
1000g/hr	NA	5.8%	16.5%	8.3%	12.6%
2000g/hr	NA	NA	8.5%	2.9%	5.2%

* Assumes CO Exposure is Terminated from 1 to 24 hours Assuming an Equal Hourly Probability of Termination
NA = not applicable

The table shows that the largest safety gains related to reduced CO emissions of generators used in residential settings are expected to come from class 1 and class 2 single-cylinder categories of portable generator products, which are responsible for the majority of reported deaths (they account for 98.9 percent of the 503 deaths covered by the modeled scenarios).

Figure 1 shows the relationship for each generator engine category, between the estimated percentage save rate at reduced CO emissions, relative to the baseline number of deaths when a carbureted generator is operated in reduced oxygen situations.

Figure 1.



The data indicate that for each category of generator, substantial reductions in CO emissions rates will significantly increase the percentage save rate.

As noted earlier in Section 3.2.3, Engineering staff identified the following CO emission rates considered technically feasible for each generator category at normal oxygen levels (20.9%): 50 g/hr for handheld and class 1 generators; 100 g/hr for class 2 single-cylinder generators; and 200 g/hr for class 2 twin-cylinder generators. Since the NIST modeling study was completed, staff conducted tests on generators other than CPSC's low CO prototype generator that were operating with closed-loop fuel control, while the oxygen content of the engine intake air was deliberately reduced to be at or below 18 percent oxygen. In this testing, staff determined that even generators with closed-loop fuel control, when operated in enclosed environments, will cause the oxygen level in that space to drop below normal (~20.9%), and will cause corresponding CO emissions rates to increase above rates seen at normal oxygen levels.[30, 18] Based on staff's testing of these generators, staff believes the factor of increase may be less than 3 for some generators that use closed-loop EFI; nevertheless, staff has based its benefits analysis on reduced CO emission rates that are threefold higher than the reduced emission rate at normal oxygen, which is the same factor of increase used for the current carbureted generators in the modeling. Note that unlike the modeling of the carbureted generator CO emissions, staff did not make any adjustments for the gradual increase to this rate as oxygen levels decline, which is a conservative assumption (*i.e.*, more likely to underestimate than overestimate benefits). Furthermore, staff notes that the empirical findings in the

NIST test house simulations of consumers' use of generators indicate that, when tested in the same scenario, a slower and lesser degree of oxygen depletion occurred with the prototype reduced emissions generator compared to the original carbureted generator. In the most extreme, completely closed, garage scenario, in Test J of the carbureted generator, oxygen levels decreased continuously from a normal 20.9 percent to ~16 percent in just over 2 hours when the test was stopped; whereas, in Test W of the prototype, oxygen levels fell below 19 percent after 90 minutes, then appeared to stabilize, remaining between about 18.2 percent and 18.5 percent for the last 4 hours of the 6-hour run time.[19] This suggests that in field-use conditions, automatic adjustments of the closed-loop EFI engine might prevent oxygen depletion to levels that would cause CO emission rates to triple; it also suggests another reason that use of the threefold increase in CO emissions for the benefits analysis could be overly conservative.

Table 5 summarizes information on CPSC staff-defined generator categories, engine characteristics, approximated rated weighted power ranges, weighted CO emission rates at normal and reduced oxygen levels for current carbureted generators, and corresponding rates for reduced CO emissions generators that staff consider technically feasible. The last four rows of Table 5 provide the estimates of the portion of 503 in-scope deaths that might have been avoided at reduced CO emission rates that CPSC staff considers technically feasible for each generator category at reduced oxygen levels. The estimated deaths are based on interpolation of appropriate values from the curves in Figure 1. It can be seen that the estimated total of 208 deaths or 503 that might have been avoided (overall 41.3% save rate) come primarily from class 2 twin-cylinder (57.6%) and class 1 (41.4 %) generators, which together account for 99 percent of the estimated saves. Staff realizes there is uncertainty associated with this estimate given the assumptions and estimations staff used in developing this estimate. However, staff used conservative values and believes the uncertainty in the estimate is within the range of the sensitivity analysis that staff performed on the effectiveness of the emission rates, as described in staff's regulatory analysis for staff's proposed rule.[31]

Table 5 Summary of CPSC Generator Category Key Properties, and Estimates of Deaths Averted and Potential Lives Saved (%) by Reduced CO Emission Rates

CPSC Defined Generator Category	Handheld	Class 1	Class 2 single cylinder	Class 2 twin Cylinder	Totals
Engine Size (per EPA engine displacement (cc) and/or rated power)	≤80 cc	> 80 cc to < 225 cc	≥ 225 cc up to 19 kW rated engine power		
Carbureted Generator Weighted CO Emission Rate (g/hr) at Normal Oxygen Level (20.9%)	300	600	1570	3330	
Carbureted Generator Weighted CO Emission Rate (g/hr) at ~17% Oxygen (~3-fold increase over rate at normal oxygen level)	900	1800	4700	9100	
Technically Feasible Generator Weighted CO Emission Rate (g/hr) at Normal Oxygen Level (20.9%)	50	50	100	200	
Reduced CO Generator's Weighted CO Emission Rate (g/hr) at ~17% Oxygen (~3 fold Technically Feasible Rate at Normal Oxygen Level)	**150**	**150**	**300**	**600**	
Actual Fatalities Allocated by Generator Category	**3.7**	**176.2**	**321.3**	**1.8**	**503**
Estimated Deaths Averted at 3x Technically Feasible Weighted CO Emission Rate (g/hr) reflecting use at ~17% oxygen	**1.7**	**87.7**	**117.9**	**0.3**	**208**
Potential Lives Saved % at 3x Technically Feasible Weighted CO Emission Rate (g/hr) reflecting use at ~17% oxygen	**47%**	**50%**	**37%**	**17%**	

7. Discussion

Despite efforts by multiple stakeholders[y] to inform and educate consumers about the specific danger of CO poisoning related to use of portable generators, and a mandatory CO warning label, generator-related CO poisoning fatalities and high-severity injuries continue to accumulate, particularly in years when unplanned power outages occur due to extreme weather events. [2]

When operated in recommended outdoor locations, where plentiful oxygen is available, the CO emission rates of current carbureted generator products are very high (approximately 1500 g/h for a typical 5 kW generator (class 2 single-cylinder); and, in fact, depending on generator size, can be several hundred-fold higher than CO emission rates of modern cars.[z] When operated in poorly ventilated locations, the combustion process results in an oxygen-depleted environment that impairs combustion efficiency and is estimated to cause carbureted CO emission rates to increase approximately threefold.[18, Appendix A,] CPSC fatal incident data show that generator-related CO poisoning deaths typically occur when a carbureted generator is operated in a poorly ventilated location, where oxygen depletion is considered likely. It is important to understand that when current carbureted generators are operated in enclosed spaces, CO can build up to extreme lethal levels very rapidly, and can remain at lethal exposure levels for extended durations, after the generator runs out of fuel. This means that anyone who attempts to enter an enclosed area where a current carbureted generator is operating, or has recently operated, could likely lose consciousness near-immediately due to sudden, drastic hypoxia caused by the extreme CO levels. This danger applies to users who enter to attempt to refill a generator or attempt to switch off a generator after a power outage ends, or a task has been completed, or in response to activation of a residential CO alarm. The danger also applies to individuals who attempt to rescue an incapacitated victim in the generator location. Additionally, particularly in the case of small homes, extreme CO levels present in other non-generator locations in the home can present similar, or somewhat reduced dangers to individuals who enter the home to try and rescue occupants.

It is also important to understand that even when a current carbureted generator has an abundant oxygen supply, as when operated outdoors, the CO level in the exhaust can still be deadly. For example, for 2004 through 2014, at least 42 deaths in 30 incidents are also known to have occurred where consumers followed instructions to use a carbureted portable generator outdoors (meaning oxygen depletion was unlikely), but where exhaust infiltrated nearby occupied spaces in homes and other enclosed, or semi-enclosed, structures.[4] Furthermore, staff is aware that multiple victims have reported to NEISS hospital EDs for evaluation of nonfatal CO exposures and injuries associated with, or in several cases clearly related to, a generator that was operated outdoors.[4] Published studies have also documented cases of moderate to serious injuries where a generator was operated outdoors. One study specifies that generators used in an open area were responsible for nine of 30 CO poisoning victims who received hyperbaric oxygen treatment (HBO-T), which suggests that these nine victims sustained relatively serious CO poisoning.[32] Although these outdoor generator cases are not included in the epidemiological benefits modeled here, staff believes that additional benefits would be associated with these cases for low CO emitting generators.

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y Stakeholders include state and local government officials, public health officials, manufacturers, and the medical community.

z CSPC staff estimates CO emissions from a typical 5 kW portable generator are equivalent to 280 to 625 idling cars (late 1990s models)(see staff presentation in 03/17/16 PGMA Technical Summit Report http://www.cpsc.gov/Global/Newsroom/FOIA/Meeting%20Logs/2016/MeetingLogPGMA31716.pdf

Staff believes that the findings in this epidemiological benefits analysis support the view that significant reductions in CO emission rates could help prevent a significant proportion of future deaths and high-severity injuries that are expected to occur without targeted, active intervention efforts. Reduced CO emissions will greatly extend the time taken for CO exposures to result in incapacitation and subsequent death, and in some cases, will actually prevent this from happening if an individual does not leave the exposure location. Staff reasons that in situations where a generator is operated indoors, this extended window of time will allow exposed individuals a much greater chance of terminating their CO exposure or of being found by others before serious injury and/or death can occur. Exposure termination could occur for several reasons, including the following:

- Exposed individuals might leave the exposure location to engage in everyday activities (*e.g*., work, school) without necessarily being aware of any developing CO hazard.
- In some cases, exposure termination might occur without the individual leaving the location, simply because the generator runs out of fuel or power is restored and the generator is shut down in response, allowing CO levels to decay naturally without reaching lethal exposure.
- Exposed individuals might respond to CO alarm activation.
- Exposed individuals might recognize a growing health concern and leave to seek treatment or summon help (call a friend, relative, or 911) even if they do not necessarily recognize CO emissions as the cause of early, nonspecific adverse health effects of CO poisoning.
- Exposed individuals might be found in an impaired state by other, lesser affected, co-exposed individuals who had been in locations further away from the generator.
- Exposed individuals might be found by concerned outside parties conducting welfare checks, or by outside parties simply arriving at their home for other reasons, such as, to co-commute to work, a social or official visit, or the return home from work or school of a co-occupant.

Staff notes that all the reasons noted above for exposure termination have already been reported in incidents where there were survivors of carbureted generator-related CO poisoning.[33,5] More such cases would be expected with reduced CO emissions, due to an overall downward shift in expected CO poisoning severity. Thus, this analysis underestimates potential benefits. Staff recognizes that consumers cannot be relied upon to react appropriately to any indication of a CO exposure, and that even those who recognize a developing CO hazard might decide to enter the area where a generator is located in an attempt to switch it off. This is known to have resulted in lethal outcomes with carbureted generators because CO can accumulate to levels that can cause near-immediate LOC due to hypoxia/anoxia. In NIST IAQ test-house empirical tests, in a totally closed garage where a class 2 single-cylinder carbureted generator was run for just 140 minutes, CO levels exceeded 21,000 ppm. However, with reduced CO emissions, the peak CO levels attained in an unventilated area where the generator is operated will be considerably lower than the level that would cause near-immediate LOC. This could potentially reduce deaths of individuals who enter an unventilated area to turn off a generator by allowing them time to egress the area before being overcome.

7.1 Conservative Basis of Benefits Estimate

Staff was deliberately conservative when developing input values for the modeling study. As such, staff considers that the current combined modeled benefits estimate of about 208 of 503 deaths in 9 years that might have been avoided by reduced CO emission rate limits for each generator class represents a likely underestimate of benefits. The following reasons, in part, explain staff's view:

7.2 *Oxygen Depletion and Increased CO Emission Rates*

As detailed in the Prototype report[17] and results section of this memorandum, testing indicates the rate and degree of oxygen depletion known to occur with carbureted generators operated in enclosed or semi-enclosed environments occurs to a lesser extent with generators having closed-loop EFI-type engines. Staff calculated benefits estimates based on a threefold higher weighted CO emission rate than the reduced weighted CO emission rate considered technically feasible at normal oxygen levels. Unlike the modeling of carbureted generator CO emission rates, no allowance was included for a more gradual increase to the threefold higher CO emission level as oxygen level is expected to decrease. Furthermore, it is not entirely clear that oxygen levels will decrease to 17 percent oxygen in field use of closed-loop EFI type generators, which is the basis of a threefold increase in CO emission rates. Lastly, based on staff's testing of fuel-injected generators with different degrees of closed-loop operation (as discussed in reference 30), staff believes the factor of increase may be less than 3 for some generators that use closed-loop EFI, even if the oxygen does decrease to 17 percent. As such, the benefits estimate is considered to be conservative.

7.3 *Generator Run Times and Fuel Tank Fill Level*

Use of a manufacturer's specified run time at 50 percent load on a full tank of gas, which ranges from 8 to 10 hours, depending upon generator category, is considered conservative because it assumes a full tank of gas was consumed. Although the fill level of fuel tanks was reported infrequently, in some incidents, it is clear that the generator was only needed for, or had only run for, a much shorter duration than expected for a full tank of fuel.

Some victims clearly had intended to use the generator for a short duration at an unpowered location, to complete a specific task, such as painting, cleaning carpets, or moving in or out of a home. In other cases of temporary planned or unplanned power outages, where the need for the generator ended when power was restored after just a few hours, it is reasoned that if victims had not already been incapacitated or killed by high CO levels in exhaust fumes, they would likely have switched off the generator before the fuel was expended. (Staff notes that with reduced emissions generators, entering the location where a generator is, or had recently been running, is less likely to result in victims being near-immediately overcome and incapacitated). In several cases, it was clear that the generator had only been filled and started once, and the generator was still running when the victims were discovered, so clearly it had not consumed a full tank of fuel.

Some fatal incident reports and/or incident scene photos indicate the presence of one or more portable gas container(s). When gas container size was specified, a 5-gallon capacity was commonly reported. For incidents where multiple gas containers were reported to be present (mostly in cases involving prolonged utility shut off for non-payment of bill), it is reasonable to assume that the generator fuel tank was likely filled completely when started. However, in cases where the fuel tank of the involved generator product was known to be larger than 5 gallons, and where the presence of multiple gas cans was not reported, or where only a single gas can was reported, it is possible, if not probable, that the generator was not started with a full tank. In one case of a newly purchased small generator, (categorized by staff as a hand held generator), a new 1-gallon portable gas can had also been purchased to transport fuel to the generator. However, the generator had a much larger 3.8-gallon fuel tank; so it appears that the fuel tank was probably just a ¼-tank full when the engine was started. In just a few incidents, it was specified that the fuel tank had not been full at the time of generator start up.

To be conservative, only results for run times based on manufacturers' specifications for a full fuel tank were used in the epidemiological benefits analysis, even though shorter duration run times, based on half-filled fuel tanks, were modeled and would have resulted in more favorable epidemiological benefits estimates.

7.4 House Size

Compared to the national average, the epidemiological benefits analysis was purposefully weighted heavily towards small and mid-size homes, because these account for a disproportionate number of known fatalities. This approach likely excludes an unknown number of generator-related CO poisoning incidents in larger homes, where high-severity nonfatal injuries, rather than deaths, tend to occur more frequently, due to larger indoor volumes that allow greater dilution of indoor CO levels. Inclusion of additional larger home models would be more representative of national home size distributions and would have resulted in a more favorable benefits estimate considering possible reductions in high-severity nonfatal injuries. However, because this epidemiological benefits estimate analysis is focusing primarily on estimated deaths that might have been avoided by reduced CO emissions, staff considered it more appropriate to focus on small homes where more deaths occurred.

7.5 Occupant Activity Level

Staff's use in this epidemiological benefits analysis of a constant 10 L/min RMV for light activity likely overestimates the breathing rate (and CO uptake rate) of a significant number of victims. In the majority of fatal incidents, where the reason for generator use was reported, victims were at home during an unplanned power outage, or an outage due to utility shut off, and there was no indication that they had engaged in more than sedentary-to-light activity levels for most of the time. In several of these cases, where it was known that a generator was first started in an enclosed space late in the evening/night at a time where victims were clearly preparing for/or retired to bed, a sedentary/resting activity level of 6 L/min RMV is more appropriate. Some cases did clearly indicate that victims were using the generator at an unpowered location to allow them to complete a specific, short-duration task involving a relatively higher activity level (*e.g.*, painting, carpet cleaning, moving, home renovations). In these cases, staff reasoned that, compared to a less active co-exposed individual, an active victim's initially higher breathing rate would cause their COHb levels to rise faster. Accordingly, fatigue, confusion, and then LOC would likely occur earlier than in sedentary individuals. This ultimately would slow the RMV of active individuals. To be conservative, only the 10 L/min results were used in the benefits estimates analysis, even though the 6 L/min sedentary activity-level RMV was modeled and would have slowed the rate of CO uptake and resulted in a more favorable benefits estimate.

7.6 Omission of Other Fatality Data

Approximately 24 percent (156) of the 659 reported in-scope CO fatalities for the period 2004 to 2012, (*i.e.*, not identified as stationary generators or combination generator/welder products) were omitted from the NIST modeling study because they occurred in generator locations considered atypical of most incidents, or in locations that could not be readily modeled using CONTAM. Staff believes that it is highly likely that some hard-to-estimate proportion of these 156 deaths might also have been avoided by use of generators having comparable reduced CO emission rates used in this epidemiological benefits analysis. However, for these 156 deaths, staff can only offer qualitative, reasoned assessments of the scenarios where safety gains are considered most likely.

7.7 Deaths Involving Generators Operated Outdoors

In particular, staff believes that net safety gains could likely be realized with reduced CO emissions for a specific subset of the 156 deaths that were not modeled, *i.e.*, the 42 deaths resulting from incidents where a portable carbureted generator was operated outdoors. Staff reasons that, whereas the modeled benefits estimate pertains to use of generators in enclosed environments where CO emission rates increase as oxygen levels decrease, the CO emission rates at normal oxygen levels are one-third lower. As shown in Table 4, at normal oxygen levels found outdoors, carbureted generator emission rates range from 300 to 3300 g/hr CO for the four generator categories, whereas, the feasible emission rates range from 50 to 200 g/h CO. Staff believes that, in most incidents, these much-reduced technically feasible CO emission rates could prevent lethal exposures from occurring. For 2004 to 2012, CPSC staff is aware of 42 deaths in 30 incidents, where a portable generator was operated outdoors, and where infiltration of exhaust fumes into nearby enclosed occupied spaces caused the death of one or more occupants. Staff believes that it is probable that some, possibly all, of these deaths involving outdoor use of generators, could have been averted by use of generators with reduced CO emission rates. Review of CPSC NEISS injury narratives and CATI findings indicate multiple cases where a current carbureted generator was operated outdoors of residential structures and where patients who were indoors either transported themselves to an ED or initiated actions resulting in their transport to an ED.

7.8 Deaths Involving Generators Operated in Other Large-Volume, Non-Fixed Home Structures

Staff considers some of the additional deaths involving generator use in other enclosed or semi-enclosed locations might also have been avoided, particularly if the location was quite large and other co-exposed victims were known to survive (*e.g*., apartment buildings and commercial building, churches, some large camper trailers, and horse trailers). Staff considers that, at a minimum, the following additional deaths might have been avoided by using generators with reduced CO emission rates:

- Six deaths reported in an incident involving eight co-exposed occupants of the same apartment, where a generator had been run outside, and then brought inside overnight and run in a closet at the foot of the stairs; three of eight occupants were discovered alive and transported to hospital. Of the two victims who ultimately survived, one was a 12-year-old girl who had managed to remove herself from the apartment while the generator was still running. (051026HCC3063)
- Two deaths reported in two incidents where generators were used inside relatively large church buildings and where other co-exposed occupants survived, and in one case, was able to call 911 for help. (070522HCC2504; 070815HCC3690)
- Three deaths in an unpowered commercial building where a generator was being operated; the building owner had asked victims to safeguard the property/his business, while he left to seek medical treatment for adverse health effects involving a cardiac complaint, which quite possibly was related to generator-related CO exposure he sustained while in the building. (061010HNE1504)
- One death that occurred when an exhaust hose connected to a generator running inside a neighboring RV van discharged its exhaust outdoors, but within a few feet of a camper's tent; in this incident, the victim had only been in the tent for a short time and was still alive when found.

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7.9 Caveat

Staff cautions that use of any model to predict CO exposures and COHb levels will give **approximate** estimates, the reliability of which will depend upon how closely the input values represent the population characteristics and environmental exposure conditions, and how well the model correlates to real-world scenarios. In addition to house specifics and CO emission rates, the modeling and interpretations of predicted lethal versus non-lethal outcomes applied here are based on healthy adults. Staff recognizes that certain subpopulations, including those with cardiovascular disease, anemia, compromised lung function, and normal individuals, such as children and pregnant women and developing fetuses, under specific circumstances, are more susceptible to CO poisoning.

8. Conclusions

Staff believes reductions in generator CO emissions rates will reduce the risk of fatal CO poisoning, and high-severity CO poisoning injuries. Staff purposely used conservative input values in the modeling studies conducted for this benefits analysis. The results indicate that in many scenarios where fatalities have been documented with current carbureted generators, staff's conservative estimates of technically feasible reduced CO emission rates might have avoided an estimated 208 of 503 deaths that occurred at fixed home sites during the 9-year period, 2004 through 2012.

The conservative estimates of what staff believes are technically feasible reduced CO emissions are expected to delay and reduce CO exposure and consequent COHb formation to levels that should provide exposed individuals a significant chance of curtailing their exposure, due to either recognition of a developing hazard, or possibly due simply to normal activities (*i.e.*, leaving for work, school), or due to intervention by outside parties. In multiple cases, the COHb modeling predicts that occupants who are not in an enclosed area where a generator is operated are likely to survive without serious injury, even if they remain in the home for 24 hours. In some cases, even individuals who remain in the generator location for 24 hours are predicted to survive, while the same scenario for a carbureted generator would result in death within minutes. At proposed reduced CO emission rates, individuals entering an enclosed area where a generator is being operated/has recently been operated would be much less likely to be at risk of near-immediate incapacitation, as currently occurs with carbureted generators. Furthermore, although not modeled in the current benefits analysis, reduced CO emissions limits are expected to prevent most, perhaps all indoor deaths that occur in situations where users operate a generator outdoors, and some other situations where generators are used inside large non-home buildings such as apartments, churches, and commercial buildings.

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Appendices A through F

A. Generator CO Emission Rates, Run Times, and Heat Release Rates

To determine values for CO emission rates, run times, and heat-release rates representative of current generators involved in the fatal incidents, staff considered the generators manufactured by six large generator manufacturers, all members of the Portable Generator Manufacturers Association (PGMA). These manufacturers (Briggs & Stratton, Champion, Generac, Honda, Techtronic Industries, and Yamaha), per PGMA's website, are the "major manufacturers of portable generators sold in North America and a significant majority of the industry."[1] Staff searched online for these manufacturers' portable generator products, specifically looking for a variety of advertised electrical power output ratings (rated power), ranging from under 1 kW, to possibly as large as 18 kW. Then staff used the manufacturers' reported product specifications to ascertain each generator's defining characteristics. Sections A.1 and A.2 below describe how each was ascertained, and section A.3 describes how that information thereafter was employed to derive the parameters NIST used to model current generators. Section A.4 discusses the range of other CO emission rates used in the modeling, to enable staff to determine whether the CO rates that could be the bases for draft proposed performance requirements provide a reasonable relationship between the costs and the benefits associated with a draft proposed rule.

A.1 Current Generator CO Emission Rates

After compiling a list of various generators with different advertised power ratings made by each manufacturer, staff used the engine specifications provided by the generator manufacturer (model, displacement, and power, if provided) to search the U.S. Environmental Protection Agency's (EPA) non-road, small spark-ignition (NRSI) engine certification data website[2] to find the published CO emission rate, in terms of grams per kilowatt-hour (g/kw-hr), corresponding to each generator's engine. This website lists exhaust emission data reported to the EPA by the engine manufacturer to certify compliance of each engine family with the EPA's emissions regulations for these classes of engines.[a] The reported CO emission rate in terms of g/kW-hr is the sum of six weighted CO rates in grams per hour (g/hr) that the engine emits while installed on a dynamometer test platform and operating with each of six steady-state loads applied (also referred to as modes), divided by the sum of the weighted power for those six modes. The equation representing this is shown in Figure A.1.

[a] The EPA allows engine manufacturers to group engines with similar configurations that are expected to have similar emission rates into a single engine family. The engine configuration in that family, which is expected, but not necessarily known, to have the highest hydrocarbon and oxides of nitrogen (HC+NOx) emission rate, is to be used for certification of the entire family to 40 C.F.R. § 1054. The engine in the generator may not be the same model as the engine on which the certification test was performed.

Figure A.1: Equation for Calculation of the CO Emission Rate in g/kW-hr

CO rate (g/kW-hr) = weighted CO rate (g/hr) / weighted power (kW)

Where
weighted CO rate = $(wf_1 \text{ x } m_1) + (wf_2 \text{ x } m_2) + (wf_3 \text{ x } m_3) + (wf_4 \text{ x } m_4) + (wf_5 \text{ x } m_5) + (wf_6 \text{ x} m_6)$
and
weighted power = $(wf_1 \text{ x } p_1) + (wf_2 \text{ x } p_2) + (wf_3 \text{ x } p_3) + (wf_4 \text{ x } p_4) + (wf_5 \text{ x } p_5) + (wf_6 \text{ x } p_6)$

wf_1 (weighting factor for mode 1) = 0.09
wf_2 (weighting factor for mode 2) = 0.20
wf_3 (weighting factor for mode 3) = 0.29
wf_4 (weighting factor for mode 4) = 0.30
wf_5 (weighting factor for mode 5) = 0.07
wf_6 (weighting factor for mode 6) = 0.05

m_1 through m_6 = CO mass flow rate for modes 1 through 6, in grams per hour (g/hr)

p_1= maximum engine power, in kilowatts (kW)
p_2= power at mode 2 = 0.75 x maximum engine power
p_3= power at mode 3 = 0.50 x maximum engine power
p_4= power at mode 4 = 0.25 x maximum engine power
p_5= power at mode 5 = 0.10 x maximum engine power
p_6= power at mode 6 = no load

Applying the weighting factor for each mode to the power at each mode, then
weighted power = 0.467 x maximum engine power

Therefore, the weighted CO rate (g/hr) = CO rate (g/kW-hr) x 0.467 x max engine power (46.7 percent of maximum engine power)

The EPA's six-mode test cycle was developed with industry to replicate typical in-use operation of small utility engines when used in all types of engine-driven products. Because CPSC staff has been unable to find information that is representative of how consumers typically load their generators, and because the individual modal CO rates measured by the manufacturer are not reported to the EPA, or otherwise publicly available, for this benefits analysis, staff assumes that the typical load profile of a portable generator used by a consumer is the same as the weighted profile. In addition, because staff does not have a reasonable way to estimate the weighted CO emission rate that the consumer could be exposed to, once the engine is installed in a generator, staff assumes the engine's weighted CO rate is the same as the generator's.[b] Staff then calculated the weighted CO emission rate (in g/hr) for each generator's engine, by multiplying the g/kW-hr rate by 46.7 percent of the maximum engine power. Table A1 provides the information staff compiled.[c] The CO rate reported in the third column from the right represents staff's calculated weighted CO emission rate when each generator is operated outdoors, at normal oxygen level.

Considering that 95 percent of the generator-related CO fatalities in CPSC's databases occurred when the generator was operated in an enclosed space, it is important for modeling studies to consider the CO emission rate when a carbureted generator is operating in such enclosed space scenarios. Evidence supporting this view is seen in findings from generator tests conducted by NIST under a prior interagency agreement with CPSC.[3] NIST's testing of generators in a single-zone shed showed that the CO emission rate of current carbureted generators increases threefold as the oxygen drops from normal levels (approximately 20.9 percent oxygen) to approximately 17 to 18 percent oxygen.[4] This finding is supported by the average factor of CO rate increase derived from CPSC staff's tests of three carbureted generators in CPSC's Combustion Laboratory.[5] Additional tests conducted by NIST showed that oxygen depletion is a reasonable expectation when a generator is operated in an enclosed space, such as those reported in the incident data. NIST's tests showed that operation of a current carbureted generator in a 20 x 20 x 8 foot (3,200 cubic feet) garage attached to NIST's test home facility, decreased the garage oxygen level to nearly 16 percent when the exterior garage bay door and interior house connecting door were fully closed, and to approximately 17.2 percent when the bay door was still closed, but the house connecting door was opened approximately 2 inches to simulate the passage into the house of an extension cord connected to the generator. Given that the majority of fatal incidents reported to CPSC occurred when the generator was operated in a garage, or various other enclosed spaces inside the house, where leakage rates and room volumes could likely result in similar oxygen levels as those achieved in NIST's garage, it is reasonable to conclude that oxygen depletion occurred and that the carbureted generator's CO emission rate increased during the fatal exposure. As a result, to reflect more accurately current generator operation under oxygen depletion conditions, staff's calculated weighted CO emission rate when each generator is operated outdoors at normal oxygen was multiplied by a factor of three, as shown in the second column from the right in Table 1.

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[b] Staff believes this is a reasonable assumption, based on results from 6-mode emission testing by The University of Alabama on the baseline generator and the unmodified prototype generator; by CPSC staff on five other generators using the manufacturer's advertised rated power as mode 1; and based on variability in CO emission rates from production line testing required by the EPA in 40 C.F.R. § 1054. Comparing the resulting weighted CO rates from the generators based on rated power to the engines' weighted CO rates from their engine family certification data, the average ratio of the generator's weighted CO rate to that of the engine's certification data for CO was nominally 0.9. However, CO emission rate data provided to staff by a manufacturer, which the manufacturer had measured on an engine they removed from a generator and conducted an emission certification test to 40 C.F.R. § 1065 on it, was 50 percent higher than the engine family's published certification data. The manufacturer stated this was due to production line variation that is allowable per the EPA. In another instance, a manufacturer conducted an emission certification test on a competitor's generator engine and reported to CPSC staff that the engine's CO emission rate was *500* percent greater than the engine family's published certification data. Consequently, staff believes that using the CO rate derived from the published engine family certification data to represent the generator's CO emission rate that consumers could be exposed to is reasonable and can even be considered quite conservative.

[c] For some generators, staff was unable to ascertain the engine's published CO emission rate because the manufacturer-provided engine information was insufficient to ascertain the engine family (*i.e.*, the engine model was listed as "OEM branded) or did not match, or nearly match, the displacement and/or power of an engine on the EPA's NRSI website; therefore, these generators were removed from the list staff compiled. Notably, not all generator manufacturers make generators in the full range of sizes.

Table A1: Summary Information of Representative Portable Generators Produced by Six Major Manufacturers.

		Generator Data						Engine Certification Data from EPA Website			Calculated CO and Heat Release Rates		
Generator Description	**CPSC Generator Category**	**Generator make & model**	**Generator rated power, watts**	**Generator max/surge/starting power, watts**	**Engine displacement, cc**	**Fuel tank capacity, gal**	**Half-load runtime on full tank, hrs**	**Service Class**	**EPA CO emission certification data after DF*, g/kW-hr**	**Max engine power, kW**	**Weighted engine CO rate at normal O2, g/hr**	**Weighted engine CO rate at 17% O2, g/hr**	**Heat release rate, kW**
Generators powered by EPA handheld engines	Handheld	Honda EU1000i	900	1000	49.4	0.6	6.8	Handheld-Class IV	459	1.6	343	1029	2
		Yamaha EF1000is	900	1000	50	0.7	9.1	Handheld-Class V	290	1.3	179	536	2
		Ryobi RYi1000	900	1000	53.5	0.6	8.0	Handheld-Class V	355	1.3	216	647	2
		Power Stroke 2100 inverter	1700	2100	79	1.3	10.5	Handheld-Class V	311	2.3	334	1002	3
		Champion	1700	2000	80	1.0	7.2	Handheld-Class V	347	1.8	292	875	3
		Yamaha EF2000is	1600	2000	79	1.1	8.0	Handheld-Class V	336	2.3	358	1073	3
Generators powered by EPA nonhandheld Class I engines	Class 1 (C1)	Briggs & Stratton P2000	1600	2000	111	1.0	5.0	Nonhandheld-Class I	519	2.1	509	1527	4
		Honda EU2000i	1600	2000	98.5	1.0	6.5	Nonhandheld-Class I	445	2.6	530	1590	3
		Yamaha EF2400iSHC	2000	2400	171	1.6	7.0	Nonhandheld-Class I	343	3.5	561	1682	5
		Briggs & Stratton P3000i	2600	3000	171	1.5	7.6	Nonhandheld-Class I	545	3.9	993	2978	4
		Honda EU3000iS	2800	3000	196	3.4	15.7	Nonhandheld-Class I	331	4.1	634	1901	5
		Generac GP3250	3250	3750	208	3.5	9.7	Nonhandheld-Class I	260	4.5	546	1639	8
		Champion 3400/4000	3400	4000	224	3.4	9.0	Nonhandheld-Class I	285	4.8	639	1917	8
		Generac XP4000	3600	4500	216	4.8	9.5	Nonhandheld-Class I	260	4.5	546	1639	11
		Black Max 3550	3550	4550	208	4.0	11.0	Nonhandheld-Class I	327	4.3	657	1970	8
Generators powered by EPA nonhandheld Class II single cylinder engines	Class 2 single cylinder	Yamaha EF4500iSE	4000	4500	357	4.5	12.0	Nonhandheld-Class II	312	7.6	1107	3322	8
		Honda EB5000	4500	5000/7000 for 10 sec	389	6.2	11.2	Nonhandheld-Class II	389	8.7	1580	4741	12
		Briggs & Stratton 3500 watts	3500	4375	250	4.0	8.0	Nonhandheld-Class II	483	5.2	1173	3519	11
		Champion 5000/6250	5000	6250	292	5.7	9.0	Nonhandheld-Class II	431	6.6	1328	3985	14
		Honda EB6500	5500	6500/7000 for 10 sec	389	6.2	10.4	Nonhandheld-Class II	389	8.7	1580	4741	13
		Briggs & Stratton 5500 watts	5500	6875	342	5.0	10.0	Nonhandheld-Class II	396	8.4	1553	4660	11
		Yamaha EF7200DE	6000	7200	358	6.9	11.8	Nonhandheld-Class II	400	7.6	1420	4259	13
		Ryobi 5500	5500	6875	420	6.0	9.0	Nonhandheld-Class II	376	9.4	1651	4952	14
		Champion 7500/9375	7500	9375	439	6.1	8.0	Nonhandheld-Class II	361	11.2	1888	5665	16
		Generac RS7000E	7000	8750	420	7.5	12.0	Nonhandheld-Class II	340	10.0	1588	4763	13
		Briggs & Stratton 7000 watt Elite	7000	8750	420	7.5	9.0	Nonhandheld-Class II	377	10.9	1919	5757	18
		Ridgid 7500	7500	9375	420	8.0	12.0	Nonhandheld-Class II	387	11.0	1988	5964	14
Generators powered by EPA non handheld Class II twin cylinder engines	Class 2 twin cylinder	Honda EB10000	9000	10000	630	8.1	7.2	Nonhandheld-Class II	440	16.5	3390	10171	24
		Generac GP15000E	15000	22500*	992	16.0	10.0	Nonhandheld-Class II	272	23.9	3036	9108	34
		Briggs & Stratton 10000-running watts	10000	12500	570	7.0	7.5	Nonhandheld-Class II	457	13.2	2817	8451	20
		Yamaha EF12000DE	9500	12000	653	11.4	11.8	Nonhandheld-Class II	406	15.3	2901	8703	21

* DF = deterioration factor, explained in US EPA, Nonroad Spark-Ignition Engine Emission Deterioration Factors, EPA-420-R-10-020, NR011-d, July 2010. https://www3.epa.gov/otaq/models/nonrdmdl/nonrdmdl2010/420r10020.pdf

* US EPA's non-road small spark-ignition engine certification database includes several engines with reported Maximum Engine Power > 19kW.

A.2 Current Generator Run Times and Heat-Release Rates Run Times

The generators' run time on a full tank of gas that was associated with 50 percent of the advertised rated load was used to determine the full-tank run time used in the modeling. Staff used a 50 percent load because, as stated above, 46.7 percent of the engine's maximum power represents the weighted load profile, which is nominally 50 percent. For the majority of the generators in Table A1, the available manufacturer's product specifications included the estimated run time for half load; however, for nine generators, this information was not provided. For four of those generators, the manufacturer specified only the estimated run times for rated load and quarter load; for these, staff assumed a linear relationship between the two values to estimate the run time for half load. For the other five generators, the manufacturer only provided the run time for rated load *or* quarter load; therefore, staff made an estimate of the run time for 50 percent load by considering the tank capacity for each of those generators and the run times of similar units.

Staff also chose to model half-tank run times to simulate scenarios where shorter durations were considered more appropriate. These included scenarios where the generator was being used to allow completion of a specific short duration task at an unpowered location or to provide power in temporary power outage situations where power was restored within a few hours before a full tank of fuel could be consumed, and scenarios where the generator was still running when victims were found, had summoned help, and/or had removed themselves from the area. Although staff has these modeling results, staff only analyzed the modeling results for the full-tank run times to estimate those benefits and to be consistent with a conservative estimate of benefits.

Estimated heat release rates for the representative set of generator engines are shown in the far right column of Table A1. Based on the fuel consumption rate at 50 percent load, staff calculated each generator's heat-release rate using the manufacturer's specification for the generator's tank capacity, a heat of combustion of gasoline of 42.5 MJ/kg[6], and an assumed conservative 35 percent thermal efficiency of the engine.[7]

A.3 Modeled Parameters for Current Carbureted Generators

For the modeling of current generators, and consequently, for the benefits analysis, because almost all the generators involved in consumer incidents were gasoline fueled, staff originally considered the generators in Table A1 as fitting into two categories, depending on the EPA service class of the small spark ignition (SI) engine powering it: (1) a handheld engine or a non-handheld Class I engine, and (2) a non-handheld Class II engine.[d] Staff chose to consider current generators in these two categories, as opposed to separating them into categories based on some other defining characteristic of the generator, such as its advertised rated or maximum power, or considered not separating them into any categories at all, for several reasons. First, there is no standard method used by generator manufacturers to define the rated power, maximum power, or surge power of their generators. Therefore, staff believes that it would be possible for manufacturers to modify assigned wattages of their products to their advantage to avoid the need to comply with a potential regulation that might apply to a restricted range of generator power ratings. Furthermore, staff's understanding is that the EPA classifies engines according to displacement, not power, for the exact same reason: there is no consensus within the industry as to how to rate the

[d] As defined by the EPA, "handheld engines" have a displacement that is 80 cubic centimeters (cc) or smaller, Class I engines have a displacement greater than 80 cc, but less than 225 cc, and Class II non-handheld engines have a displacement equal to, or greater than 225, up to a power rating of 19 kW. Staff's understanding, based on discussions with industry, as well as looking at Table 1, is that generators powered by handheld and Class I engines generally have a nominal rated power of less than 3.5 kW; and portable generators powered by Class II engines generally have a nominal rated power of 3.5 kW and greater, potentially up to nominally 18 kW.

maximum power of an engine. Second, in many of the reports from CPSC's in-depth investigation (IDI) of incidents, based on the limited information, staff is uncertain whether a wattage reported for the incident generator represents its rated power, surge power, or maximum power. In the past, staff understood that the advertised power displayed on the generator and the number used in the generator's model name was its rated power. However, recently, staff has observed that there is no consistent approach among manufacturers; and often, the power the manufacturer displays on the unit and uses in its model designation is its maximum power or surge power. This is apparent in Table A1. Accordingly, staff believes that the power reported in the IDIs is not as reliable as engine class designations to create categories of various generator sizes to estimate the benefits associated with each category. Third, separating the generators into categories allows for the determination of each category's relationship between costs and benefits, and it also allows for the possibility of proposing different performance requirements for each category. Ultimately, staff chose to divide the two categories into four well-defined categories, separating the handheld engine-powered generators from the Class I engine-powered generators and separating the Class II engine-powered generators into separate single-cylinder and twin-cylinder categories, designated as handheld, class 1, class 2 single-cylinder, and class 2 twin-cylinder generators, respectively.[e, f, g] Section A.5 provides photographs of sample products for these four generator categories, which illustrate the point that staff's four generator categories and their related engine characteristics cannot necessarily be determined from the visual appearance of the product (characteristics and/or labeling).

To arrive at CO emission rates, run times, and heat-release rates for all four generator categories for NIST to use in the modeling, staff simply used the average values in those categories in Table A1. These values are shown in Table A2.

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[e] Staff's online review of commercially available handheld generators indicates they have nominal power ratings of less than 2 kW.

[f] Staff found from looking at the EPA's website that twin-cylinder Class II engines largely appear to have a rated maximum engine power of 12 and higher. Staff then found, from an online review of manufacturers' generator specifications, that generators with engines with power equal to or greater 12 kW typically have a rated power of 9kW and higher.

[g] Note that staff describes generators using the categories: handheld generator, class 1 generator, class 2 single-cylinder generator and class 2 twin-cylinder generator, as defined here. Staff describes engines as handheld, Class I and Class II based on their EPA classifications, per 40 C.F.R. part §1054.801.

Table A2: Modeled CO Emission Rates, Run times, and Heat-Release Rates for Baseline Carbureted Generators

Generator Category	Average Weighted CO rate at 17% O2 (g/hr)	Average Run Time (hrs)	Average Heat Release Rate (kW)
Handheld	900	8	2
Class 1	1800 *	9	6
Class 2 Single Cylinder	4700	10	13
Class 2 Twin Cylinder	9100	9	25

* Note: As described above, when the modeling was initiated with NIST, staff had decided upon only two categories of current generators for NIST to model for the benefits analysis: a single category for both the handheld and class 1 generators, referred to as HC1 generators, and another category for all the class 2 generators, consisting of both single-cylinder and two-cylinder generators, referred to as C2 generators. Upon completion of that modeling, staff decided to perform the benefits analysis in four categories, and thus, divided the C2 category into the two separate class 2 single-cylinder and class 2 twin-cylinder categories, and staff divided the HC1 category into the separate handheld and class 1 categories. Because the handheld and class 2 twin-cylinder generators were involved in only 1 percent of the fatalities, each contribute only 1 percent to the incident-weighted average CO emission rate, run time, and heat-release rates that staff calculated for use in the modeling for the original HC1 and C2 categories, respectively. Therefore, separating out the handheld and class 2 twin-cylinder generators resulted in only slight changes to the values used in the modeling that were then used to represent the class1 and class 2 single-cylinder categories. The slight decrease from the modeled CO rate for the class 2 single-cylinder category, after the incident-weighted average class 2 twin-cylinder CO rate was removed, resulted in the same value for the class 2 single-cylinder category, when rounding to the nearest 100 g/hr. The slight increase from the CO rate used in the modeling for the HC1 category after the incident-weighted average handheld CO rate was removed, however, rounded up to 1900 g/hr, not the 1800 g/hr that was modeled to represent the originally-planned HC1 category. Staff considers the difference negligible but notes that the difference errs conservatively (*i.e.*, more likely to underestimate benefits than overestimate). Due to contractual and time constraints with NIST at the time staff made the decision to conduct the benefits analysis in four categories instead of two, the modeling for the handheld and class 2 twin-cylinder categories had to be limited to only three structures, with two of them representing the two homes in which two incidents involving handheld generators occurred and one representing the garage in which the one class 2 twin-cylinder generator incident occurred. (There was another incident involving a class 2 twin-cylinder generator/welding machine, but staff chose to exclude it and another generator/welding machine powered by a Class II single-cylinder engine because these were outside the scope of the proposed rule.)

In the modeling, to simulate the increasing CO emission rate as the oxygen level drops in the space the generator is operating (and thus a lower CO emission rate at the beginning of operation than later), NIST modeled CO rates for the first 2 hours of operation that were two-thirds the rates shown in Table A2. After 2 hours, the CO rates were increased to the rates in Table A2 for the duration of the run time, for models simulating both a full tank, as well as a half tank (although only the more conservative, full-tank models were considered for this analysis, as described earlier).

A.4 Reduced Generator CO Emission Rates, Run Times, and Heat-Release Rates

Staff selected six reduced weighted CO emission rates for NIST to model so that the benefits associated with each rate for each generator category could then be estimated. These rates are: 50, 125, 250, 500, 1,000, and 2,000 g/hr. The three lowest of these approximates the range of CO emission rates that staff believes are technically feasible for both the handheld and class 1 generator categories (50 g/hr), class 2 single-cylinder category (100 g/hr), and class 2 twin-cylinder category (200 g/hr).[8]

For the run times and heat-release rates to correspond with the reduced CO emission rates, staff used the same values as those of current generators. Staff assumes the run time of a draft proposed rule-compliant generator could be similar to current generators – staff reasons that any additional weight and volume of the emission control components needed to reduce the CO emission rate could be offset by a smaller fuel tank, and due to the improved fuel efficiency of reduced emissions engines, the smaller tank would still be able to maintain similar run times to carbureted units with larger fuel tanks.

A.5 Examples of Generator Categories

Sample photos of handheld generators

Sample photos of class 1 generators

Sample photos of class 2 single-cylinder generators

Sample photos of class 2 twin-cylinder generators

References

[1] www.pgmaonline.com

[2] www3.epa.gov/otaq/certdata.htm#smallsi

[3] Emmerich, S. J., A. Persily, and L. Wang, *Modeling and Measuring the Effects of Portable Gasoline Powered Generator Exhaust on Indoor Carbon Monoxide Level* (NIST Technical Note 1781), Feb 2013.

[4] Emmerich, Steven J., B. Polidoro, W. Dols, Simulation of Residential CO Exposure Due to Portable Generator Operation in Enclosed Spaces (NIST Technical Note 1925), 2016.

[5] Brookman, Matthew, P.E., *Development of Test Methods for Determining the Carbon Monoxide Emission Rate of Portable Generators in Normal and Reduced Atmospheric Oxygen*, U.S. Consumer Product Safety Commission, Bethesda, MD, 2016. (TAB J in the NPR briefing package)

[6] SFPE Handbook of Fire Protection Engineering.

[7] http://web.mit.edu/2.61/www/Lecture%20notes/Lec.%2018%20Heat%20transf.pdf

[8] Buyer, Janet, *Rationale for Proposed Performance Requirements, Effective Dates, and Certification for Staff's Proposed Rule for Portable Generators*, U.S. Consumer Product Safety Commission, Bethesda, MD, 2016. (TAB I in the NPR briefing package)

B. Epidemiological Benefits Analysis Scope and Approach

The scope of the epidemiological benefits analysis based on the NIST modeling is limited to a subset of the non-work-related generator-related CO fatalities known to CPSC over the indicated time period that occurred at fixed residential structures or similar structures (*e.g.*, cabins, barns). CPSC staff's 2015 report cites a total of 751 generator-related CO poisoning fatalities in 562 incidents, which occurred from 2004 through 2014, and were entered in CPSC databases as of May 21, 2015 (reference 2, Hnatov, 2015). Of these, 85 deaths in 64 incidents were reported for the years 2013 to 2014, for which data are considered incomplete and likely to change as new information is received. For the period, 2004 to 2012, where counts are considered relatively stable, staff is aware of 666 deaths in 498 incidents. However, during this time frame, five deaths in three incidents clearly involved a stationary generator product, and two deaths in two incidents involved combination welder-generator products. CPSC's proposed rulemaking is specific to portable generators, (71 FR 74472, December 12, 2006), and staff chose to exclude welder products because they are considered atypical portable generators, Furthermore, welder products are also excluded from the scope of two existing U.S. voluntary standards for portable generators (UL 2201 and PGMA G300). Therefore, these seven deaths in five incidents were not included in the benefits analysis described in this report, which is based on starting numbers of 659 deaths in 493 incidents in the 9-year period from 2004 through 2012.

Modeling work for the epidemiological benefits analysis was restricted to fixed residential structures and certain detached structures (*e.g.*, garages, workshops), where existing structure models were available or were easily modified from existing structure models (see Section 3 in the memorandum and Appendix E for details). This subset represents about three quarters (76%, 503 of 659) of in-scope fatalities known to CPSC staff from 2004 through 2012. The remaining 156 in-scope fatalities were not modeled, due to a lack of similarities to existing structure models that adequately represented the enclosed space the victim occupied where the CO exposure occurred (*e.g.*, campers, RVs, tents, churches, boats, apartment complexes), or where the deaths occurred when a generator was used outside, but situated so that CO was allowed to enter an enclosed space and where one or more victims succumbed to fatal CO poisoning.

CPSC staff believes that the same reduced CO emissions rates modeled in this analysis have potential to save lives in other reported fatal scenarios that are not specifically addressed in this analysis. These reported scenarios include, but are not limited to, fatal incidents where a generator was placed outdoors, but close enough to a structure or vehicle for the exhaust to infiltrate inside, and scenarios where a generator was used inside a structure not specifically modeled by NIST, such as inside churches, office buildings, or other non-residential structures.

The epidemiological benefits analysis is based on the concept of estimating the number of deaths that might have been avoided if consumers had used a lower CO emission generator as proposed in this report in similar incident scenarios as reported in CPSC's incident data records. Staff believes that deaths could have been avoided if the CO emission rates had been significantly lower than those produced by current and past generator models. It is impossible to predict future events and usage patterns; so the observed generator-related CO fatalities over the 9-year period from 2004 through 2012, is used as the baseline for the analysis. Staff used NIST modeling results to estimate CO levels and COHb levels for both baseline carbureted CO emission rate levels and those of various possible reduced CO emission levels.

B.1 Characteristics of Home Models and Detached Structures Used in NIST CONTAM Modeling

NIST's modeling estimated CO concentrations over time and predicted corresponding COHb over time for adult individuals in various occupied zones in different structure models. To reduce the scale of the modeling effort, a subset of models was selected from the set of NIST's suite of homes[a] models, based on an initial screening of known generator-related CO fatalities that occurred in structures closely matching the four NIST home classifications shown in Table B.1 below. Specifically, there were four types of structures modeled:

- 31 detached home models, chosen as the most observed exact classification match homes (models match incident data with 3 or more observed fatalities);
- 2 manufactured home models, one representing a mobile home and one representing all other manufactured home designs;
- 4 attached home models, representing the four most common model type observed; and
- 3 garage/external structure models, one representing a single car garage-sized structure, one a two car garage size structure, and one representing a larger or multi-room structure.

A number of the NIST models were either specifically modified, or developed, for this project. Details of the NIST modeling can be found in NIST Technical Note 1925. NIST uses the following classifications to define their CONTAM models. Details of the structure-matching methodology are provided in Appendix E.

Table B. 1: NIST Classification of Homes

Parameter	Classification 1	Classification 2	Classification 3	Classification 4
Number of Floors	1 story above ground	2 stories above ground	- -	- -
Occupied Space Floor Area	less than 148.5 m^2 (1,599ft^2)	148.6 m^2 to 222.9 m^2 (1600 ft^2 to 2399 ft^2)	223.0 m^2 (2400 ft^2) or more	- -
Year Built	before 1940	1940-69	1970-89	1990 and newer
Type of Foundation	concrete slab	crawl space	finished basement	unfinished basement
Presence of a Garage	no garage	attached garage	- -	- -
Heating System Type	Central forced air system	other	- -	- -

[a] The NIST suite of homes is a collection of dwellings that were previously defined by Persily et al. (2006), which includes just over 200 dwellings that together represent 80 percent of the U.S. housing stock.

The NIST classification system also includes information about the heating system in the structure. Nearly all fatal CO generator incidents involved the house or structure not having power due primarily to power outages, power company shut-offs, renovations/new construction, and service not yet turned on for new occupants. So it was assumed that, without power to the house/structure, the heating system in the home would not be running. Therefore, the type of heating system in the home would have a minimal, if any, effect on the modeling results. For this reason, the heating system parameter was not used in the model selection process.

B.2 Classification of structures involved in fatal incidents in NIST CONTAM modeling

Classification of structures involved in fatal incidents was based on CPSC staff review and classification of CPSC's In-Depth Investigations (IDIs) and publically available Internet sources, such as real estate listing sites and news reports.

In the detached home scenarios, many fatal incidents occurred when the generator was run in an enclosed garage. For this benefits analysis, staff modified the classification methodology to represent different garage types because staff believed that CO transport into the home would differ depending on the garage type. "No garage" was used to indicate the home either had no garage attached to the house, although an open carport may be attached, or that, if a garage was at the residence, it was a detached garage. Homes classified as having an "attached garage" were segregated into two subcategories. "Integral garage" indicates that the garage shares its ceiling with the floor of a room of the house and also shares one or more side walls with a room on the same level as the garage, Most commonly, these would be homes where the garage was either in the basement or on ground level, with a room above the garage, in addition to sharing a wall with a room on the same floor. The remaining attached garage homes have a garage that shares a single wall with a room in the house, but has no room above it, although it may also share an attic space. Based on incident data review, some of the existing NIST models were modified to reflect the "integral garage" subcategorization. In 11 of the 31 detached home models, NIST specially modified the designs to represent better some of the home designs found in the incident data (see NIST TN 1925). There were 361 generator-related CO fatalities known to have occurred in detached homes. Of these fatalities, 84 deaths occurred in houses matching all five of NISTs key parameters, plus the specific garage type of the 31 modeled detached homes; an additional 277 deaths were incomplete matches to the modeled houses. These fatalities were allocated to one or more of the structures that were the closest match, based on available information.

During this initial screening phase, CPSC staff did not factor the particular type of attached garage into the assessment. If an attached garage was indicated, then it was considered a match to both an "integral garage" and an "attached garage." Additionally, a basement of unknown type was considered a matched characteristic to any model with similar characteristics, irrespective of whether the house model was designated as having a "finished" basement or an "unfinished" basement. However, in the final allocation of fatalities' step in the analysis (described later), the type of garage and basement were taken into account to provide more accurate results.

More generator-related CO fatalities occurred in homes classified as mobile homes than in any other specific type of home model. There were 80 generator-related deaths known to have occurred in manufactured homes. Of these, 63 deaths occurred in mobile homes, 15 deaths occurred in non-mobile home manufactured houses, and two deaths occurred in manufactured homes of unknown type. For the manufactured home scenarios, NIST designed a new house model to represent a “typical” mobile home. NIST also used an additional manufactured home design to represent the other non-mobile, manufactured home incidents.

Four attached house models were used in the simulation, including one specifically designed to represent a townhouse-type structure with an integral garage on the ground floor/basement level. Attached houses were associated with 16 deaths out of the 503, based on incident data. In matching incident houses, only 4 of the 5 NIST key parameters were used (year built was omitted). Nine deaths occurred in matched houses and another seven deaths occurred in houses that did not exactly match the four NIST parameters, plus garage.

For this project, NIST created a set of three model designs to represent the detached garage-type structures that were associated with 46 fatalities out of the 503 in the incident data. The three designs represent a single car garage size structure, a double car garage size structure, and a structure larger than double car garage size or multiple room structure *(e.g.*, a detached garage with a connected workshop). Based on review of incident data, 40 deaths occurred in detached structures similar to the 3 models developed by NIST and an additional 6 deaths occurred in detached structures where there was insufficient information to determine the best match.

Interior doors were assumed to be open 2 inches (in) during the simulations and all exterior doors and windows were kept closed with the following exceptions: stairways between finished living space levels, other than the first floor door, were modeled with open doorways; kitchen doors were modeled as open doorways. For cases in which the generator was located in the attached garage, the door from the garage to the house was assumed to be open roughly 2 inches (in) to accommodate an extension cord running from to the generator. Garage exterior doors were assumed to be closed.

C. Carboxyhemoglobin Modeling of CONTAM-Modeled CO Profiles

To assess the potential benefits of reduced portable generator CO emission rates, the nonlinear Coburn-Forster-Kane equation (CFK)[1,2] was used to predict percent carboxyhemoglobin (% COHb)[a] levels from the theoretical CO profiles generated by NIST CONTAM modeling of different CO source strengths in a variety of home models. The nonlinear CFK differential equation is a physiologically based, mechanistic model for predicting CO uptake, and COHb formation and elimination in humans. It has been validated by empirical data from human studies, and it is widely regarded by authoritative sources as a reasonably reliable and broadly applicable COHb model for modeling acute CO exposures.[3,4] The physiological CFK input values representing average adults[b] were the same as used in the most recent staff assessment,[5] with two exceptions discussed below.

C.1 Baseline COHb level

First, the nominal average baseline concentration of 1.2% COHb, previously used by HS staff to represent non-smokers ([based on Peterson, Stewart, 1975]) was updated to 0.27% COHb ([based on EPA 2010]). More specifically, the actual CFK time zero input value, expressed in ml CO/ml blood, was decreased from 0.0024 to 0.00056. This more accurately reflects reductions in baseline COHb levels due to improvements in outdoor air quality in the years between the two publications. In terms of CO exposures from generator exhaust, staff considers this change to be of minimal impact, especially regarding the extremely high CO emission rates of current generator engine designs.

C.2 Inhalation Rates (Respiratory Minute Volumes, RMVs)

The second more significant change concerns the inhalation rates used to model COHb profiles. Inhalation rates (air volume inspired per unit time) reflect an individual's metabolic energy demand, which is related to their oxygen utilization rate; these rates generally vary as a function of age, sex, and activity level. The respiratory minute volume (RMV), expressed in liters per minute (L/min), is the specific inhalation rate input value used in the CFK. It is one of the key physiological variables affecting the rate of COHb formation (and elimination). In HS staff's 2012 memorandum, comparing the CO poisoning risk presented by current portable generator designs with a low CO emissions prototype generator design (Inkster 2012), during individual tests of current and prototype generator designs, the duration of engine operation ranged from 2.5 to 6.25 hours. Therefore, HS staff used two RMV values to represent sedentary (6 L/min RMV) and light-to-moderate (15 L/min RMV) activity levels that could be expected for average adults in indoor residential settings over these relatively short duration exposures (few hours). The rates were selected based on information for (1) expected amount of time an average person spends indoors during a 24-hour period; and (2) expected inhalation rates relevant to indoor settings, by age and sex, and activity level, as documented in tables 5.17 and 5.16 of the 1997 version of US EPA's Exposure Factors Handbook[6] (US EPA, 1997). The EPA reported

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[a] % COHb reflects the percentage share of the body's total hemoglobin pool occupied by CO.
[b] CPSC incident data continue to show that adults account for the majority of generator-related CO poisoning fatalities (94% of victims ≥ 15 years, Hnatov 2015.

that an average person spends 20.4 hours/day indoors, with 19.64 hours (96 percent of estimated indoor time) being spent at resting or light activity levels (9.82 hours at each level), and only 0.76 hours at higher activity levels. For these estimates, the EPA defined "light activity" as: *"Includes most domestic work, attending to personal needs and care, hobbies, and conducting minor indoor repairs and home improvements,"* and it defined "resting activity" as: *"Includes watching television, reading, and sleeping."*

For this current benefits analysis of modeled CO levels, CO emission source durations ranged from 9 to 10 hours (assuming generators operated continuously at 50 percent load, starting with a full fuel tank). Theoretical adult occupants were assumed to remain inside homes for up to 24 hours. The extended 24-hour modeling period includes any impact on predicted COHb levels after a generator engine stops running, which allows for continued infiltration of CO from the source area to the more remote home locations during progressive decay of indoor CO levels. To reevaluate the RMV values considered appropriate for 24-hour modeling of sedentary (minimal) activity and mixed activity patterns expected in residential settings, HS staff reviewed recommended inhalation rates in two recently published authoritative exposure assessment documents.[7, 8,]

C.2.1 U.S. Environmental Protection Agency (EPA). (2011) Exposure Factors Handbook: Chapter 6 – Inhalation Rates

To estimate adult RMVs appropriate for indoor residential settings over 24 hours, staff relied on reported durations for different activity levels spent in an indoor microenvironment which totaled 20.4 hours[c] (Table 5.17 in EPA EFH 1997; Table 6-30 in EPA EFH 2011). To derive a 24-hour distribution for indoor activity levels, the additional 3.6 hours attributed to outdoor activity (1.8 hours) and transportation in a vehicle (1.8 hours) were divided among the four indoor activity levels, according to each activity level's percentage share of the 20.4 hour time indoors (see Table C1).

Table C1. Estimated Time Spent at Different Activity Levels by Average Adults Assumed to Be Inside Residential Settings

Activity Level	Average Hours Per Day in Indoor Microenvironment at Each Activity Level*	% of Total 20.448h Spent Indoors at Each Activity Level	Average Hours Per Day in Indoor Microenvironment at Each Activity Level Assuming 24 Hours Spent Indoors	Average Minutes Per Day in Indoor Microenvironment at Each Activity Level Assuming 24 Hours Spent Indoors
Resting	9.820	48.02%	11.526	691.5
Light	9.820	48.02%	11.526	691.5
Moderate	0.710	3.47%	0.833	50.0
Heavy	0.098	0.48%	0.115	6.9
Total	**20.448**	**100.00%**	**24.000**	**1440.0**

**From US EPA Exposure Factors Handbook (Table 5.17, in 1997 edition; Table 6-30 in 2011 Edition)*

[c] Although EPA's updated EFH has new data on daily durations at different activity levels as a function of age and sex, it does not differentiate between time spent in different microenvironments (*i.e*., indoors, outdoors, and in transportation vehicles). Therefore, HS staff relied on EPA's earlier age-specific data on indoor activity duration.

Recommended mean average and 95th percentile short-term inhalation rates (combined for males and females) are reported in m^3/day, as a function of age and activity level, in Table 6.2, EPA EFH 2011. Table C-4 of the cited data source, EPA 2009, provides a more detailed breakdown of the data by age and sex, and additional percentiles; furthermore, data are expressed as L/min, which is a more convenient format for use with the CFK.[d] HS staff used the EPA 2009 published data for men and women to calculate adult RMVs (combined sex, ages 21 through 80 years of age) for each activity level, then applied its calculated durations for time spent indoors at each activity level (from Table 1 above) to derive RMVs for adults over a 24-hour period spent in indoor residential settings (Table C2).

Table C2. Activity Specific RMV(L/min) Inhalation Rates for Adults (Males and Females) Ages 21 to 80 Years and Calculated Average RMV for 24 h Spent Indoors (Based on EPA 2009, 2011)

	Sedentary/ Passive	Light Intensity	Moderate Intensity	High Intensity	RMV (L/day*)	Average RMV (L/min) for 24 h spent indoors
Average minutes/day at each activity level assuming 24 h spent indoors	691.5	691.5	50.0	6.9		
	RMV (L/min)					
EPA 2009						
mean average	5.36	12.55	26.73	49.63	14065.0	**9.77**
50th percentile	5.26	12.31	25.88	47.66	13775.6	**9.57**
75th percentile	5.87	13.61	29.66	56.34	15341.4	**10.65**
90th percentile	6.53	15.10	33.77	65.46	17097.7	**11.87**
95th percentile	6.98	16.01	36.74	71.90	18228.9	**12.66**

**calculated by summing product of each activity level L/min RMV x respective average minutes per day duration*

HS staff also looked at the EPA's recommended long-term inhalation rates, which are typically used for assessing exposure risks lasting several days to years. As shown in Table C1, age-specific, combined-sex, mean average long-term daily inhalation rates (m^3/day) recommended in 2011 by US EPA were used to calculate an average RMV of 10.5 L/min for adults ages 21-80 years (Table C3). Notably, the activity patterns in the sample underlying the EPA source data incorporate time spent away from a home, and that time spent outdoors is more likely to involve above-average activity levels, which explains why the average 10.5 L/min RMV is higher than the mean average 9.77 L/min RMV calculated above.

[d] Essentially the same data can be found in Tables 6-17 (males) and Table 6-19 (females) of EPA EFH 2011, where it is expressed as m^3/min; however, due to rounding of values that were over 0.01 m^3/min (10 L/min), the 2011 tables have some of loss of detail, compared to the original source data in EPA's 2009 report on metabolically derived human ventilation rates.

Table C3. Recommended Mean Average Long-Term Inhalation Rates (RMV*) for Adults (males and females combined) (*based on Table 6.1 US EPA EFH, 2011)*

Age Group (years)	Mean RMV (m^3/day)	Mean RMV (L/min)
21 to <31	15.7	10.9
31 to <41	16.0	11.1
41 to <51	16.0	11.1
51 to <61	15.7	10.9
61 to <71	14.2	9.9
71 to <81	12.9	9.0
Average adult 21-80	**15.1**	**10.5**

** Respiratory Minute Volume*

C.2.2 California Environmental Protection Agency, (2012) - Revised Technical Support Document for Exposure Assessment and Stochastic Analysis [08/27/12], Chapter 3 – Daily Breathing Rates

California EPA (2012) reports recommended average and 95th percentile, age-specific, 1 hour and 8 hour short-term inhalation rates (m^3/duration) for different activity levels, in Tables 3.4b and 3.3 b, respectively. HS staff used the 1 hour and 8 hour inhalation rates to calculate average adult breathing rates (L/min) at each activity level, and again applied its calculated duration of time spent indoors at each activity level (Table C1) to derive L/min RMVs for adults over a 24-hour period indoors (Table C4). California EPA does not report an 8-hour high-intensity activity level because high intensity activity cannot be sustained for 8-hour durations. Therefore, HS staff used the 1 hour high-intensity RMV when calculating a 24-hour indoor RMV based on California EPA's 8 hour RMVs. (Note that California only has one age group for adults, which covers individuals from ages 16 to 70 years).

Table C4. Activity Specific RMV (L/min) Inhalation Rates for Adults (Males and Females) Ages 16 to 70 Years and Calculated Average RMV for 24 h Spent Indoors (Based on California EPA, 2012)

	Sedentary/ Passive	Light Intensity	Moderate Intensity	High Intensity#	RMV (L/day*)	Average RMV (L/min) for 24 h spent indoors
Average minutes/day at each activity level assuming 24 h indoors	691.5	691.5	50.0	6.9		
	RMV (L/min)					
California EPA (2012)						
Based on 1 hour values						
mean average	5.33	12.50	27.00	50.17	14026.6	**9.74**
95th percentile	7.00	16.17	37.67	73.17	18411.7	**12.79**
Based on 8 hour values						
mean average	5.27	12.56	26.96	***50.17***	14024.6	**9.74**
95th percentile	6.96	16.25	37.65	***73.17***	18438.3	**12.80**

**calculated by summing product of each activity level L/min RMV x respective average minutes per day duration*
 # 8 hour values used the 1 hour RMV value for high-intensity activity since no 8 hour activity RMV is reported because high activity cannot be sustained for 8 hours.

HS staff also reviewed California EPA's recommended RMVs for long-term exposures of individuals 16 to 70 years of age, reported as mean average and 95th percentile point estimates in Table 3.1, and as distributions with percentile values in Table 3.2b (see Table C5).

Table C5. Recommended Long-Term Inhalation Rates (RMVs) for Individuals Ages 16 to 70 years (*based on Table 3.2b, California EPA, 2012)*

Age 16 to 70 years	Inhalation Rate (m^3/day)	RMV (L/min)
mean average*	13.9	9.7
50th percentile	13.6	9.4
75th percentile	16.8	11.7
90th percentile	20.1	14.0
95th percentile*	22.9	15.9

* *Mean average and 95th percentile values are also recommended for use as point estimates.*

C.3 Selected RMVs used for Modeling Generator CO Emissions in Residential Settings

After considering the collective information above, HS staff judged that an RMV value of 10 L/min was reasonably conservative for modeling average adults presumed to spend 24 hours in indoor residential environments. A 12 L/min RMV was considered a reasonably conservative upper bound RMV, equivalent approximately to staff's calculated 90th percentile value for adults in indoor residential environments. Finally, a 6 L/min RMV was considered reasonably conservative for modeling baseline, sedentary adult activity levels in indoor residential environments (considered applicable to scenarios where occupants start a generator before retiring to bed). CPSC staff provided these values to NIST staff to allow automated calculation of COHb profiles from residential CO profiles generated by CONTAM-thermal balanced modeling of different CO source strengths.

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[5] Inkster SE, (August 13, 2012) CPSC Health Sciences Memorandum. A comparison of the carbon monoxide (CO) poisoning risk presented by a commercially available portable gasoline-powered generator versus a prototype "reduced CO emissions" generator, based on modeling of carboxyhemoglobin (COHb) levels from empirical CO data.

[6] U.S. Environmental Protection Agency (EPA) (1997) Exposure Factors Handbook EPA/600/P-95/002Fa August 1997, Chapter 5 - Inhalation Route http://www.epa.gov/oppt/exposure/presentations/efast/usepa_1997_efh.pdf

[7] U.S. Environmental Protection Agency (EPA). (2011) Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/052F, Chapter 6 – Inhalation Rates (link to document at EPA site http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252).

[8] California Environmental Protection Agency EPA, Office of Environmental Health Hazard Assessment (OEHHA) (2012) - Revised Technical Support Document for Exposure Assessment And Stochastic Analysis [08/27/12], Chapter 3 – Daily Breathing Rates http://www.oehha.ca.gov/air/hot_spots/pdf/2012tsd/Chapter3_2012.pdf

D. Interpretation of Modeled Carboxyhemoglobin Levels

For staff's analysis of the potential benefits from reducing portable generator CO emission rates, staff considered benefits primarily in terms of the number of deaths that could have been avoided by use of generators with various reduced CO emission rates. Interpretation of the enormous modeled carboxyhemoglobin data set generated by NIST staff (from their modeling of different CO emission rates inside multiple residential settings) required a simplified approach to allow Hazard Analysis staff to automate some data extraction and analysis steps and to facilitate the process for making benefits estimates. To that end, HS staff developed four "COHb Analysis Criteria" to assess whether predicted COHb profiles from modeled residential scenarios were likely indicative of fatal versus nonfatal CO exposure in average adults.[a] Where fatal outcome is predicted, the criteria can be used to assess the predicted time to reach fatal exposure during a 24-hour modeling period for each simulated CO exposure. The criteria are intended to reflect the fact that lethal CO health effects are not simply a function of acute hypoxia resulting from a critical reduction in blood levels of oxygen delivered to tissues, as indicated by attainment of a specific peak COHb level.[b] The criteria include some consideration of the level and duration of the predicted COHb elevation, which recognizes that, in addition to reducing oxygen delivery to tissues, CO can enter the non-vascular body compartment and adversely impact important cellular functions by displacing oxygen from various intracellular heme proteins (particularly myoglobin proteins found predominantly in cardiac and skeletal muscles, and certain cytochrome P-450 enzymes involved is cellular respiration). In some prolonged CO elevations, the additional non-vascular adverse effects of CO can result in death at COHb levels that are not typically lethal.[c]

D.1 Overview of the COHb Criteria Basis

Although the relationship is not absolute, physiological, epidemiological, and clinical studies provide evidence that acute CO poisoning health effects in healthy adults tend to follow toxicological dose-response principles, and that risk of more serious adverse CO poisoning effects worsens progressively as blood levels of COHb increase.[d] However, it is clear that lethal CO exposures cannot be defined simply by attainment of a single COHb level. Staff used several information sources to develop COHb assessment criteria to facilitate calculation of benefits estimates predicted for generators with reduced CO emissions. A recent authoritative review of CO toxicity by the Agency for Toxic Substances and Disease Registry indicates that there is a high risk of lethal outcome once COHb levels have reached a critical window, which, for healthy individuals, is generally considered to lie between 40% and 60% COHb (see Fig. 2-1,

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[a] It is recognized that certain sub-populations are more sensitive to CO exposure, particularly individuals with coronary artery disease; some studies reported adverse health effects in cardiac patients at 2 to 5% COHb, which can result from prolonged exposures to less than 50 ppm CO.

[b] The oxygen binding sites of hemoglobin molecules have more than 200-fold higher affinity for CO than for oxygen.

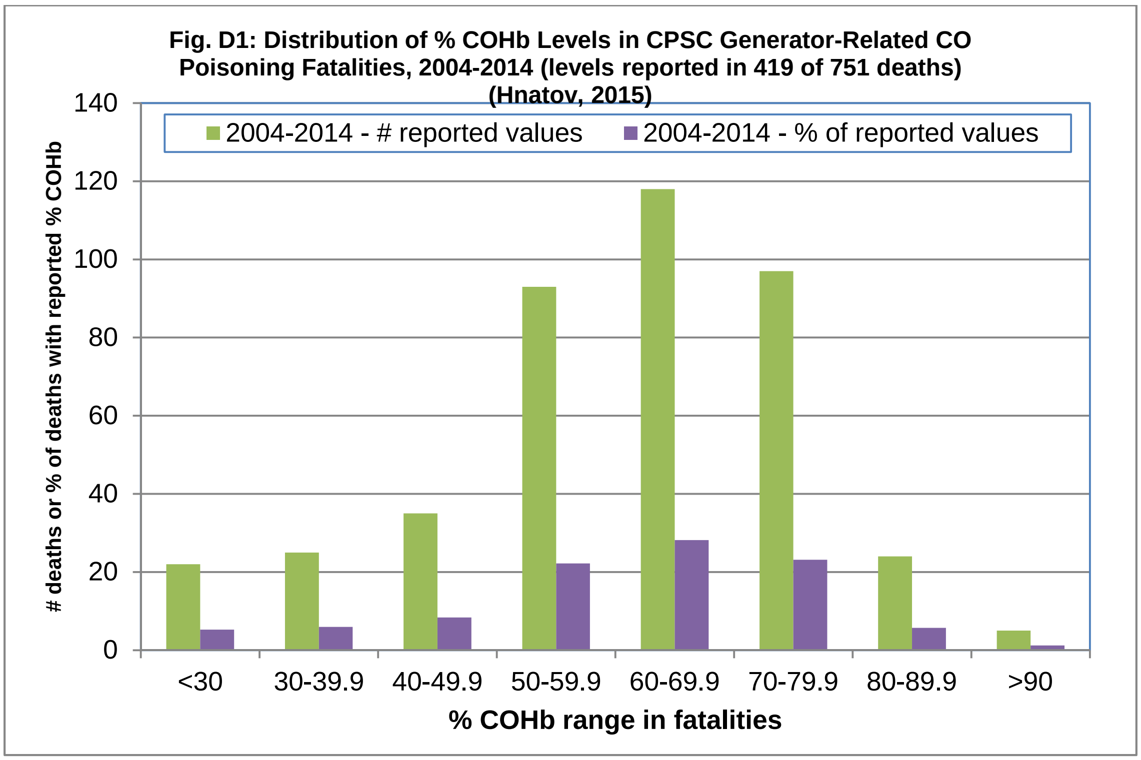
[c] See Section 3, Summary Information on Carbon Monoxide Pathophysiology, in Inkster, 2012.

[d] For example, loss of consciousness is not generally expected in average adults if peak COHb levels remain below 20 percent, but becomes increasingly more likely as levels approach, and exceed, 40% COHb. (Note: staff is referring to the acute COHb blood levels actually reached, or predicted by modeling, which is not necessarily the same as the highest measured COHb levels reported in clinical cases, where initial COHb measurements are typically reduced from peak levels attained, primarily due to the time lag between the end of CO exposure and blood sampling, plus use of supplemental oxygen during this interval).

ATSDR, 2012).[1] HS staff reviewed information on COHb levels of victims who experienced acute, generator-related CO poisoning. COHb levels documented in fatal CO poisoning cases reported to CPSC were compared with COHb levels reported for a select group of survivors who received hyperbaric oxygen treatment (HBO-T) for generator-related CO poisoning injuries considered to be of high severity. Staff also considered information on fatal and nonfatal COHb levels reported in non-fire-related CO poisoning cases that did not specifically involve generator -related CO exposures. To guide selection of appropriate exposure time functions for the COHb criteria, staff used the non-linear CFK equation to model 24-hour COHb profiles predicted for average adults, over a range of static CO levels, at two different activity levels representative of indoor residential behaviors.

D.2 Generator-Specific COHb Data

Deaths: Appendix B of CPSC Epidemiology staff's most recent report on generator-specific CO poisoning incidents provides information on 419 of the 751 CO poisoning fatalities that occurred from 2004 to 2014 where COHb levels are reported (Hnatov, 2015).[2] The same data are presented below as a frequency distribution (Figure D1), followed by some summary key findings.



Key Findings:

- In 244 deaths (58.2%), levels were ≥ 60% COHb.
- In 337 deaths (80.4%), levels were ≥ 50% COHb.
- In 47 deaths (11.3%), levels were ≤40% COHb.
- In 128 deaths (30.5%), levels ranged from 40 to 59.9% COHb.
- In 36 deaths (8.4%), levels ranged from 40 to 49.9% COHb.

Most generator-related CO poisoning deaths reported to CPSC occurred at the scene of exposure. A small fraction of victims died during transport to, or minutes-to-days after arrival at a medical facility. In some cases, autopsy findings revealed factors recognized to increase risk of death (*e.g.*, preexisting health conditions, such as coronary artery/cardiovascular disease) and/or evidence of recent drug use (*e.g.*, methamphetamine, cocaine, and/or alcohol). However, unless victims also had relatively low COHb levels (<40% COHb), medical examiners and/or coroners often omitted these additional autopsy findings from death certificates. Most frequently, death certificates reported the underlying cause of death simply as CO poisoning/asphyxia caused by CO intoxication, with the exposure source identified as a portable generator being operated inside an enclosed or poorly ventilated space.

Injuries: A recently published study provides information on characteristics of generator-related CO poisoning victims who did not die at the exposure scene, and who received subsequent hyperbaric oxygen treatment (HBO-T).[3] HBO-T is not without risk, and is generally reserved for a relatively small fraction of CO poisoning victims who have evidence of high severity injury.[e,4,5] The study's 264 subjects are a subset of a large, convenience sample of 1,912 CO poisoning victims (1604 with unintentional CO exposures) who received HBO-T from August 1, 2008 through July 31, 2011.[f,6,7] The lead author, Dr. Neil Hampson, provided HS staff with some additional details of the generator-specific HBO-T patient population that were not included in the published report.[8] Therefore, HS staff is aware that only one of the 264 patients died. The COHb levels reported for survivors of generator-related CO poisoning averaged 22.7% ± 9% (mean ± SD), and ranged from 2.3 % to 48.3 % COHb. Although a frequency distribution for the COHb levels was not provided, if the data are assumed to be normally distributed, the standard deviation can be used to estimate that 95 percent of the patients had initial measured levels below 40.7% COHb.[g] It is important to understand that COHb levels reported for victims found alive are more variable than COHb levels reported for victims who die at the scene, and are more likely to underestimate peak COHb attained primarily because: (1) COHb levels of those found alive will decrease during the interval between the end of the CO exposure and measurement of CO and duration of this interval is highly variable; and (2), victims found alive are very likely to have received supplemental normobaric oxygen before blood COHb determinations, especially if transported to a medical facility by emergency responders or taken directly to an HBO-T facility (driven or airlifted).

D.3 Other Non-Generator Specific COHb Data

US data: Several chapters in one authoritative book, Carbon Monoxide and Human Lethality; Fire and Non-Fire Studies (Hirschler et al., 1993, [2005])[9] include detailed comparative information on COHb levels reported in fire and non-fire-related CO fatalities.

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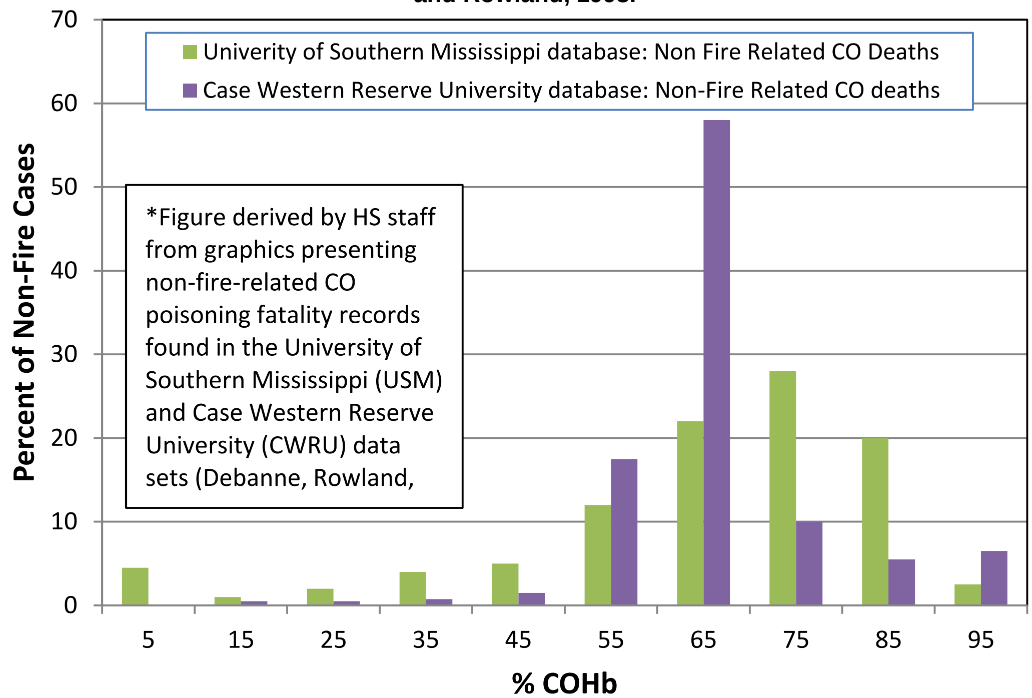
[e] The medical literature contains several proposed screening systems for identifying CO poisoning victims considered most likely to benefit from HBO-T, but universally applied criteria have not been developed, and long term benefits of HBO-T are still considered controversial. (Wolfe, Lavonas. et al., 2008).

[f] Case details for 1,912 anonymous victims were submitted voluntarily by participating US-base HBO facilities during a prospective, 3-year survey. The survey data represents the largest single data collection describing exposure scenarios and characteristics of CO poisoning survivors who received HBO-T (see Clower, Hampson, et al., 2012 and Hampson, Dunn, et al., 2012).

[g] In a normal distribution, 95 percent of the population lies between two standard deviations of the mean average. Thus, staff estimated that 95 percent of the study's 264 patients might be assumed to have less than 40.7% COHb (22.7% COHb + [2 x 9% COHb]).

Chapters 6[10] and 7[11] report details of fire and non-fire-related CO deaths for two large data sets, developed by the University of Southern Mississippi (USM, n = 2241)[h] and Case Western Reserve University (CWRU, n = 2637 records)[i], respectively. Most of the non-fire-related CO deaths in each data set were caused by exposure to vehicle exhaust (85% of USM cases; 82.2% of CWRU cases). Furthermore, the majority of the CWRU deaths occurred before 1975, and for both data sets, it seems probable that a significant fraction (perhaps most) of the vehicle exhaust-related deaths that occurred later (from 1976 to 1979 [CWRU]) or (1976-1985 [USM]), involved vehicles manufactured before 1975, *i.e.*, when U.S. EPA first required new vehicles to have catalytic converters.[12] The CO emission rates of pre-1975 vehicle engines are comparable to the extremely high CO emission rates of current generator engine designs. As such, findings from the USM and CWRU non-fire related data are considered particularly relevant to generator-related CO exposures. For each data set, Debanne and Rowland (1993b)[13] provide graphs showing comparative frequency distributions of COHb levels reported for fire- and non-fire-related deaths. HS staff combined the data points for USM and CWRU non-fire-related deaths into a single graph (Figure D2). This clearly shows that, for either data set, very few deaths occurred below 40% COHb and most occurred at levels above 50% COHb.

Fig. D2 % Frequency Distributions of COHb Levels in Non-Fire-Related CO Poisoning Deaths: Based on Analysis of Data Sets Reported by Debanne and Rowland, 1993.*



[h] The USM data base contains details submitted by 37 forensic laboratories (36 in the USA-36; one in Canada) for 2241 CO poisoning deaths that occurred in the years 1976 through 1985; 85 percent of the non-fire related deaths were caused by automobile exhaust (see Nelson, Canfield, Larsen, 1993, Chapter 6, in Hirschler et al., 1993/2005).

[i] The CWRU database contains records on 2637 CO poisoning deaths that occurred in Cuyahoga County, OH, from 01/02/38 through 12/28/79, during a term served by a single County Coroner, Samuel R. Gerber, M.D. Most of the 1,693 non-fire-related deaths were caused by automobile exhaust, and the percentage of automobile exhaust-related deaths increased over time (72.0% of 339 deaths for 1938-1949; 72.8% of 338 deaths for 1950-1959; 86.0% of 473 deaths for 1960-1969; and 91.2% of 543 deaths for 1970-1979. (Debanne, Rowland, 1993a, Chapter 7, in Hirschler et al., 1993 [/2005]).

Foreign Data: A sizeable Polish study,[14] (and subsequent English language summary version)[15] cited in Hirschler et al. (1993), and the National Research Council's (NRC) Acute Exposure Guideline Levels (AEGLs) for Carbon Monoxide (NRC, 2010),[16] provides comparative information on COHb levels reported in lethal and non-lethal exposures that occurred in Poland from 1975 to 1976. According to NRC's reporting of the full study, the Polish investigators tried to address the variability in lethal and non-lethal COHb levels introduced by delayed measurement of COHb levels in victims who were still alive when removed from the exposure location. They did this by restricting: (1) the lethal data set to COHb levels measured in post-mortem blood samples obtained from ***CO poisoning victims who died at the exposure scene;*** and (2) the non-lethal data set to COHb levels measured in ***survivors of CO poisoning within 2 hours of their removal from the CO environment.*** According to figures in Pach et al., 1979, COHb levels for 101 CO poisoning fatalities averaged 62.3% ± 10.1% COHb (mean ± SD) and more than 90 percent of deaths exceeded 50% COHb; approximately 5 percent of deaths ranged from 40 to <50% COHb, approximately 2 percent of deaths ranged from 30 to<40% COHb, and no deaths were reported under 30% COHb. In contrast, in 158 of 220 survivors of CO poisoning who met the study inclusion criteria, COHb levels averaged 28.1% ± 14.1% COHb (mean ± SD) and more than 80 percent of survivors had less than 40% COHb; approximately 13 percent had 40 to <50% COHb, and less than 4 percent had more than 50%COHb. Although the specific CO exposure sources are not reported in the summary report, the lethal and non-lethal % COHb frequency distributions in this Polish study are in general accordance with lethal and non-lethal COHb levels summarized for generators and other combustion engine-related CO sources (mainly pre-1975 vehicle engines lacking emission controls).

D.4 COHb Formation at Static CO Exposure Levels

Figures D3 a-d illustrate the modeling of static CO levels over 24 hours using the non-linear CFK and RMVs for sedentary (6 L/min) and average daily indoor residential (10 L/min) activity levels of average adults described in Appendix C. Results are presented in two formats: curves in Figures D3-a and D3-b show timing of progression to expected equilibrium COHb levels; and bars in Figures D3-c and D3-d present a readily obvious visual comparison of how quickly levels progress through each percentile COHb level at each CO exposure level. These figures show that approximately 900 ppm CO is required to reach 60% COHb; whereas, less than about 400 ppm CO would keep levels below 40% COHb, regardless of RMV value. However, the RMV value significantly affects the rate of COHb formation, with attainment of equilibrium levels being reached faster at the higher RMV. The generator fatality data show that death is possible between 40 and 59% COHb. Although staff has no precise measures of time to fatal outcome in this transitional COHb range, it reasons that higher COHb levels (greater tissue hypoxia) will take less time to cause lethal outcome than lower levels, whereas extended exposures at lower COHb levels could still prove lethal. Considering that CO levels would begin to decay after the estimated run times of generators on one full tank of gas (approximately 9-10 hours), HS staff used the modeled data and professional judgment to derive conservative time functions detailed below for COHb levels predicted to remain between 40 and 59% COHb.

D.5 COHb Analysis Criteria

HS staff considers that the collective information above provides persuasive evidence that the likelihood of death is relatively low at levels below 40% COHb, increases as COHb levels transition from 40 to 50% COHb, increases more substantially from 50 to 60% COHb, with death becoming expected once 60% COHb is reached. The following criteria were developed by HS staff to facilitate analysis of NIST staff's modeled data. The following criteria enable staff to differentiate between predicted lethal and non-lethal CO exposures in average adults resulting from operation of generators within residential settings:

- If peak level is ≥60% COHb, assume death.
- If peak level is ≤40% COHb, assume survival.
- If peak level is ≥50% COHb but<60%, assume death, unless (i) the duration of elevation at ≥ 50% COHb is less than 2 hours, and (ii) the duration of elevation between ≥40% and <50% COHb is less than 4 hours.
- If peak level is ≥40% COHb, but <50% COHb, assume death, if the duration of elevation in this range exceeds 6 hours.

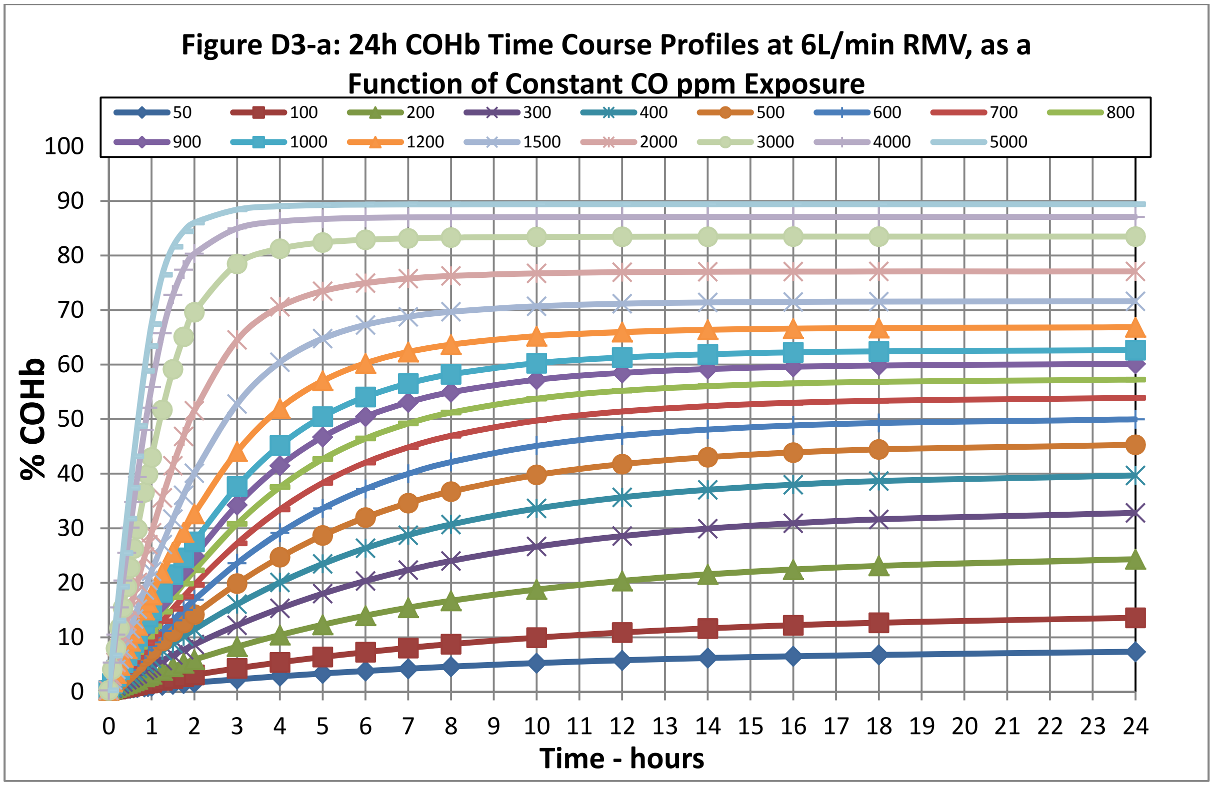


Figure D3-a: 24h COHb Time Course Profiles at 6L/min RMV, as a Function of Constant CO ppm Exposure
50
100
200
300
400
500
600
700
800
900
1000
1200
1500
2000
3000
4000
5000
% COHb
0 10 20 30 40 50 60 70 80 90 100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time - hours

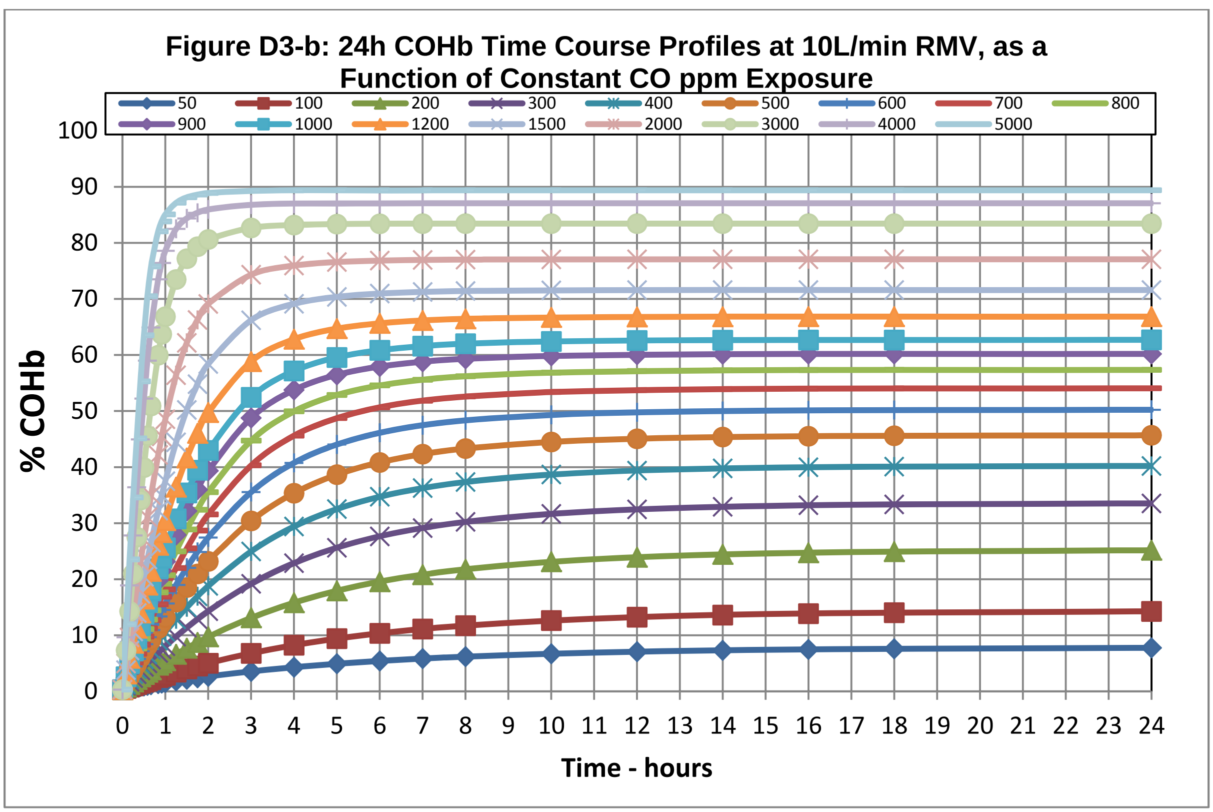


Figure D3-b: 24h COHb Time Course Profiles at 10L/min RMV, as a Function of Constant CO ppm Exposure
50
100
200
300
400
500
600
700
800
900
1000
1200
1500
2000
3000
4000
5000
% COHb
0 10 20 30 40 50 60 70 80 90 100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time - hours

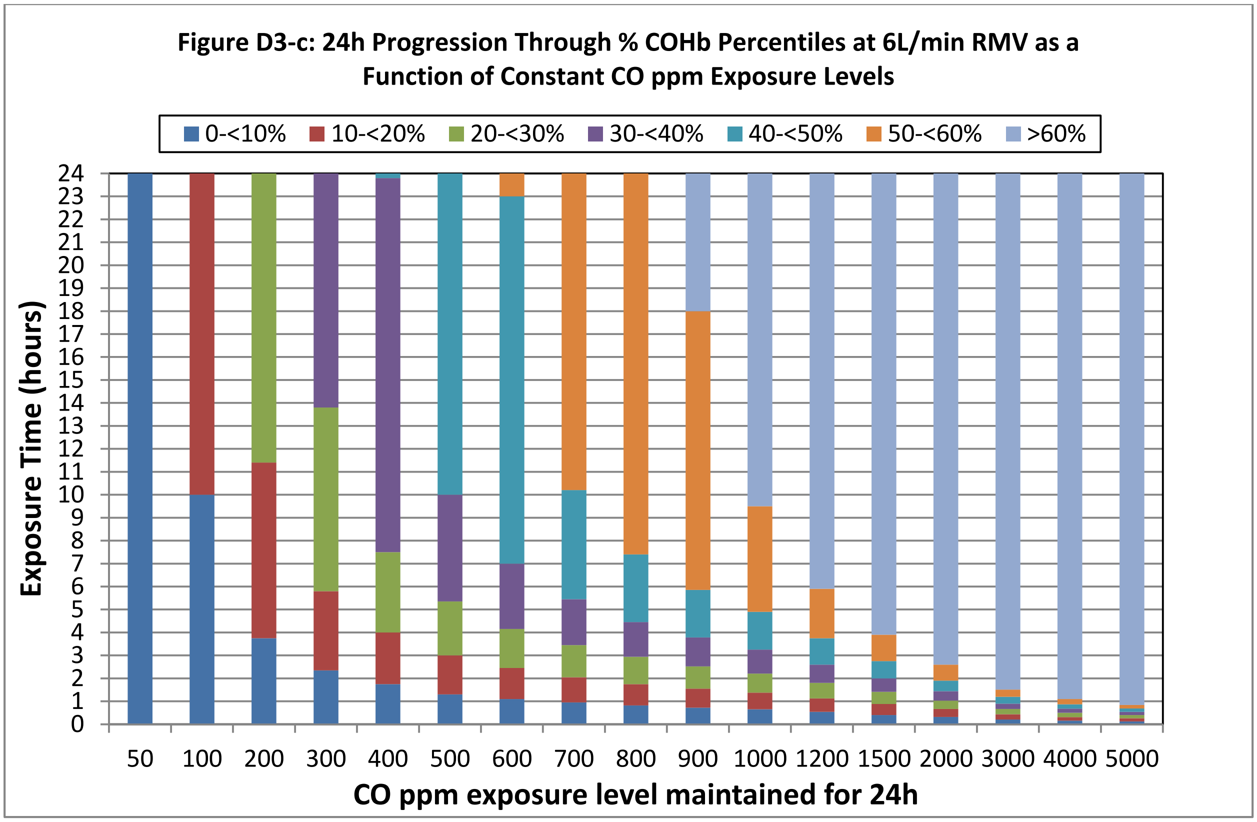


Figure D3-c: 24h Progression Through % COHb Percentiles at 6L/min RMV as a Function of Constant CO ppm Exposure Levels
0-<10%
10-<20%
20-<30%
30-<40%
40-<50%
50-<60%
>60%
Exposure Time (hours)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
50 100 200 300 400 500 600 700 800 900 1000 1200 1500 2000 3000 4000 5000
CO ppm exposure level maintained for 24h

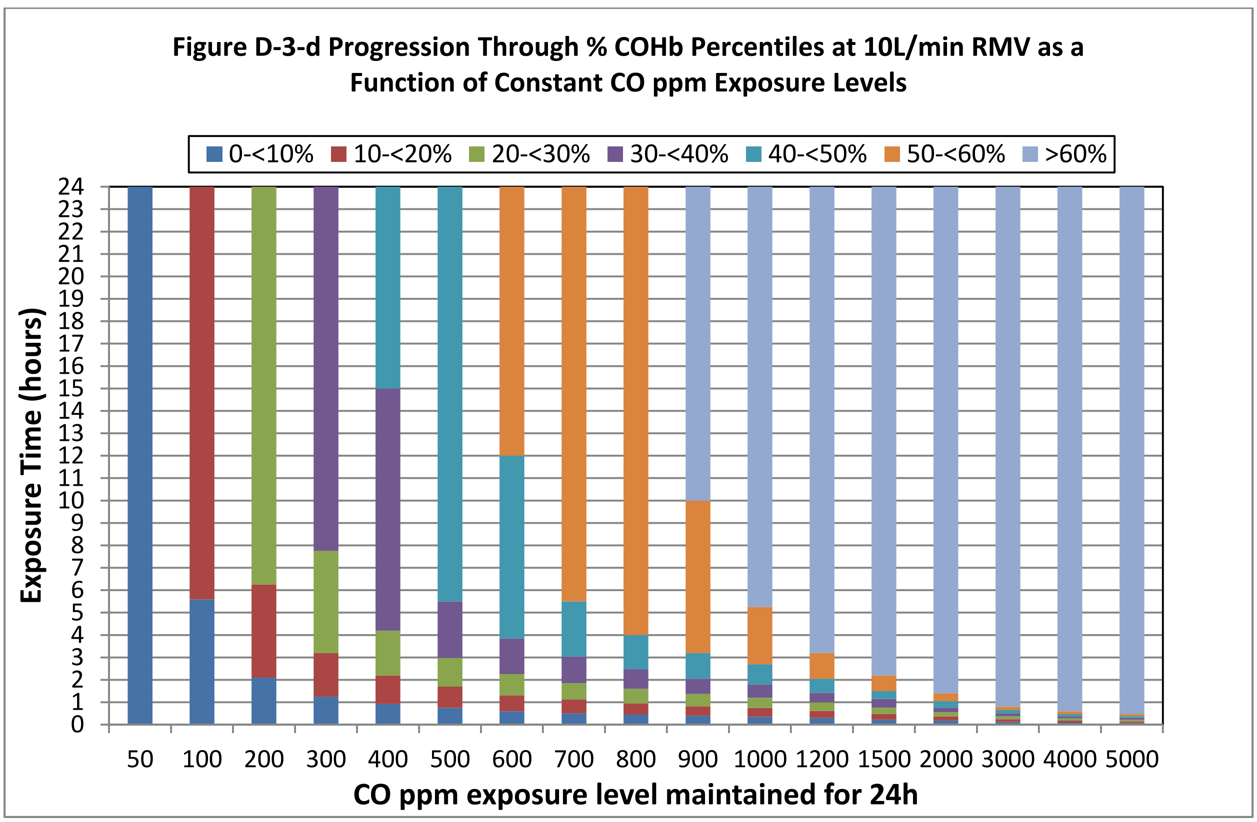


Figure D-3-d Progression Through % COHb Percentiles at 10L/min RMV as a Function of Constant CO ppm Exposure Levels
0-<10%
10-<20%
20-<30%
30-<40%
40-<50%
50-<60%
>60%
Exposure Time (hours)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
50 100 200 300 400 500 600 700 800 900 1000 1200 1500 2000 3000 4000 5000
CO ppm exposure level maintained for 24h

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E. Modeling Output and Analysis Methodology

The benefits analysis is defined as potential lives saved for a given reduced CO emission rate. To make this determination, some or all of the following factors were taken into account (house/structure type and Generator Category dependent):

1) Observed proportion of generator locations within house/structure model
2) Observed proportion of Generator Category involved by location within house/structure model (for example, the incident data shows that larger generators are more likely to be used in a garage while smaller, more portable generators are more often brought into the living spaces)
3) Number of fatalities associated with house/structure model, including the allocation of unknown and non-exact match cases
4) Proportion of fatalities associated with Generator Category (class 1 and class 2 single categories only)
5) The simulated fatality rates by occupied zone: living area (combination of "kitchen" and, if modeled, "bedroom"), garage space (if modeled), and basement (if modeled)
6) And, on a per-house/structure basis, the actual fatalities (based on assumed base CO rate for specific Generator Category) minus modeled fatalities with low emission generators.

In 48 percent of the fatalities, the specific details of the generator involved were not obtainable. CPSC made the assumption that the same proportions in unknown generator category fatalities would be the same proportion where the generator type could be obtained. Therefore, the unknown generator category incident fatalities were allocated proportionately to the known case.

Table E.1: Distribution of Known Fatalities and Allocated Fatalities by Generator Category

Generator Category	Known Fatalities – Generator Category Known	Allocated Fatalities for Unknown Generators	Total Allocated Fatalities
Handheld	2.0	1.7	3.7
Class 1	90.0	86.2	176.2
Class 2 single cylinder	167.0	154.3	321.3
Class 2 twin cylinder	1.0	0.8	1.8
Total	260.0	243.0	503.0

The methodology steps and the general equations used to determine the deaths averted benefits analysis are as follows:

A_j = Allotted Fatalities for j^{th} Structure

B_k = % by k^{th} generator category (*structure specific considerations*)

C_j = Allotted Fatalities for j^{th} Structure by Generator Category ($A_j * B_k$)

$D_{i,j}$ = % Gen Used in i^{th} Zone ("living space", "basement", "garage," or "crawlspace") in j^{th} Structure

$E_{i,j}$ = Modeled Fatality Rate for Respective Current Carbureted Generator Placed in i^{th} Zone in j^{th} Structure

$F_{i,j}$ = Modeled Fatality Rate for Respective Proposed Lower Emission Generator Placed in i^{th} Zone in j^{th} Structure

$G_{i,j}$ = Relative % Difference - Modeled Fatality Rates Base Rate to Lower Emission in i^{th} Zone in j^{th} Structure
$[(E_{i,j} - F_{i,j})/E_{i,j}]$

H_j = Deaths Averted for j^{th} structure = $[(G_{1,j} * D_{1,j}) + (G_{2,j} * D_{2,j}) + \ldots + (G_{n,j} * D_{n,j})] * C_j$
where n = the number of generator location zones modeled for the j^{th} structure.

H = Sum of Deaths averted for All structures = Sum of All $H_{j.}$

Details for each step in the process and rationale are given below.

E.1 Allotted Fatalities to Each Structure

A_j = Allotted Fatalities for j^{th} Structure (Class 1 and Class 2 single cylinder Generators only)

To account for all 503 generator-related fatalities in the modeling simulation, all fatalities needed to be assigned or allocated to the different modeled structures. Fatalities that occurred in structures that exactly matched the parameters of one of the NIST models were assigned to that specific corresponding model only. Fatal incidents that occurred in structures that did not exactly match a modeled structure, or in situations where there was not sufficient information to completely characterize the structure, were allocated to one or more of the structures that were the closest matched based on available information. The methodology of allocation differed slightly by structure type, which will be explained.

E.1.1 Allocation of Incident Data Fatalities with Unmatched or Incomplete Information Methodology

As a general rule, for all incidents that occurred in structures that do not exactly match the characteristic parameters of a modeled structure, the deaths were allocated between the closest matched structures. "Closest matched structure" is defined as the structure or structures that match the greatest number of characteristic parameters in the same type category (*e.g.*, incidents in detached houses were only matched to other detached houses). If more than one structure was identified as a closest match, then the deaths were allocated among the closest match structures proportional to the numbers of exact match cases. This resulted in numerous fractional allocations, rather than allocations of whole numbers. The allocations ensure that the observed proportions remain constant. A key assumption for using this strategy is that the proportion of unknown characteristics closely matches the distribution of the known characteristics. Raking procedures for allocating unknowns based on observed proportions of knowns is a common statistical practice. The approach was simplified and modified somewhat to account for the great variation that exists in real-world structures and the somewhat limited available selection of modeled scenarios. For example, if two deaths needed to be allocated to two equally closest-matched structures, where structure A had six exact match deaths and structure B had two deaths, the allocation would be of the proportion 6:2 (A:B) or 3:1. Therefore, 75 percent of the two deaths to be allocated (1.5 deaths) would be allocated to structure A, and 25 percent of the deaths (0.5) would be allocated to structure B.

If a characteristic parameter for a structure involved in an incident is unknown, this parameter is automatically assumed to be unmatched. A few of the modeled structures did not have any exact match incidents. These were allocated across all like structures proportionally to the matched counts.

If non-exact match incidents are closest matched to structures with exact matches and structures with no exact matches, then all incident deaths were allocated to the structures with exact matches only. If incidents were closest matched to only structures with no exact match fatalities, then all the deaths are allocated evenly among all of the closest match structures.

E.1.2 Structure Type Specific Considerations for Allocation of Incident Deaths

<u>Detached Houses – All Characteristic Parameters Known and Exact Match to Modeled Houses</u>
For detached house incidents, an exact match is where the five incident structure characteristic parameters match exactly with one of the NIST modeled houses. Additionally, the garage type ("integral," "attached," or "none") must match. In these cases, all the incident fatalities are allotted to the exact match house.

<u>Detached Houses – All Characteristic Parameters Known But No Direct Match</u>
If non-exact match house incidents have all known characteristic parameters, then the fatalities were distributed proportionately among all modeled houses that are closest matched, as described above.

Detached Houses – One or More Characteristic Parameters Unknown

Characteristic parameters that could not be determined were considered unknown and a non-matched parameter. An exception to this rule is when it is known that there was a basement at the incident location, but whether it was a finished or unfinished basement is not known. In these cases, it was considered to be a match to both finished and unfinished basements, but not to concrete slab or crawlspaces; allocation of the incident fatalities were performed as described. So, if there were both finished and unfinished basement closest match models, the deaths would be allocated proportionately between the two. If there was only one closest matched model, then the allocation would go to that model. If neither a matching finished or unfinished basement model were in the exact match set, then this parameter would be consider unmatched.

Table E.1.2.1: Allocated CO Fatalities – Detached House

Matched Model	Exact Match Allocations	Partial Match Allocations from "No Basement" Subset*	Partial Match Allocations from "Basement" Subset*	Total Allocated Fatalities
DH-1	3.0	6.7	0.0	9.7
DH-2	2.0	3.6	7.1	12.7
DH-2mod	0.0	1.0	1.5	2.5
DH-3	7.0	11.3	0.0	18.3
DH-5	3.0	6.7	0.0	9.7
DH-7	5.0	7.5	10.5	23.0
DH-8	6.0	9.5	0.0	15.5
DH-10	0.0	2.5	1.5	4.0
DH-12	1.0	2.4	2.3	5.6
DH-19mod	1.0	2.3	14.4	17.7
DH-21	17.0	14.4	0.0	31.4
DH-21mod	3.0	2.9	0.0	5.9
DH-24mod	4.0	1.2	0.0	5.2
DH-27	0.0	2.0	0.0	2.0
DH-32	0.0	6.0	0.0	6.0
DH-33mod	3.0	3.8	0.3	7.1
DH-34	9.0	10.8	1.8	21.6
DH-41	0.0	0.5	5.5	6.0
DH-44	0.0	0.0	1.0	1.0
DH-45	0.0	1.5	1.5	3.0
DH-45mod	1.0	13.8	18.6	33.4
DH-52mod	1.0	1.6	4.4	7.0
DH-56	0.0	0.5	7.0	7.5
DH-60	1.0	2.0	6.2	9.2
DH-60mod	0.0	2.0	1.5	3.5
DH-61	3.0	3.0	10.7	16.7
DH-61mod	8.0	6.6	13.4	28.0
DH-63mod1	2.0	5.6	16.7	24.3
DH-63mod2	0.0	0.0	7.0	7.0
DH-64	4.0	5.4	1.6	11.1
DH-81	0.0	0.0	5.5	5.5
Total	84.0	137.0	140.0	361.0

* In many cases, a basement was known to be part of a house, but it was unknown if the basement was a "finished basement' or an "unfinished basement." To allocate "unknown basement type" incidents to only modeled houses that had basements, the allocations were handled separately for "no basement" houses and "with basement" houses. Rows and column counts may not add to totals due to rounding.

<u>Manufactured Houses</u>

NIST modeled two manufactured houses. One specially designed model to represent mobile homes (MH1mod) and an existing house model (MH1) that represents other manufactured homes. When the type of manufactured house was known, mobile home incidents were allotted to the mobile home model and all others to the other manufactured home model. Cases where it was known that the house was a manufactured home, but the specific type was not known, were proportionately allocated between the two models.

Table E.1.2.2: Allocated CO Fatalities – Manufactured House

Matched Model	Exact Match Allocations	Allocations for Partial Matches	Total Allocated Fatalities
MH1	15.0	0.5	15.5
MH1mod	63.0	1.5	64.5
Total	78.0	2.0	80.0

Attached Houses – All Characteristic Parameters Known and Direct Match to Model

Attached house incidents were handled similarly to detached houses, with the exception that the year built parameter was not used due to the small number of models.

Table E.1.2.3: Allocated CO Fatalities – Attached House

Matched Model	Exact Match Allocations	Partial Match Allocations from "No Basement" Subset	Partial Match Allocations from "Basement" Subset	Total Allocated Fatalities
AH3	3.0	4.0	0.5	7.5
AH10	3.0	1.0	0.5	4.5
AH21	1.0	0.0	0.0	1.0
AH34mod	2.0	0.0	1.0	3.0
Total	9.0	5.0	2.0	16.0

Detached Garages / External Structures

For this project, NIST developed three structures to represent various detached garages and other non-house external structures. When the size and/or configuration of the external structures were known, each incident was assigned to the most appropriate model. In the few cases where there was no information regarding size or configuration of the external structure, the incident fatalities were allocated proportionately to the three models, based on the proportion assigned to the models.

Table E.1.2.4: Allocated CO Fatalities – Detached Structures

Matched Model	Exact Match Allocations	Allocations for Partial Matches	Total Allocated Fatalities
GAR1	11.0	1.9	12.9
GAR2	12.0	1.7	13.7
GAR3	17.0	2.4	19.4
Total	40.0	6.0	46.0

E.2 Proportion of Generators Involved in Fatal CO Poisoning Incidents & Allotted Fatalities for by Structure by Generator Class/Type

B_k = % by k^{th} Generator Category (structure specific considerations)
*C_j = Allotted Fatalities for j^{th} Structure by Gen Class (A_j * B_k)*

The CPSC incident database contains reports of fatal carbon monoxide poisoning incidents involving many different types and sizes of generators. The generators involved have been classified into one of four categories: handheld, class 1, class 2 single cylinder, and class 2 twin cylinder.[a] The majority of fatal incidents and deaths were associated

[a] To arrive at the number of deaths that occurred by generator category, when the IDI did not report the generator's engine displacement, or it was not obtainable from other information in the IDI, staff then considered the reported wattage of the generator, if that was available in the IDI. Staff classified generators with a reported wattage of 3.5 kW and larger as either a class 2 single-cylinder or class 2 twin-cylinder generator and those less than 3.5 kW as either a handheld or class 2 generator. To

with the use of class 1 and class 2 single cylinder generators. Because the number of fatalities associated with handheld and class 2 twin cylinder generators was small in relation to the class 1 and class 2 single cylinder generators and were only observed in three structures in the incident data, these structures were modeled independently. A handheld incident occurred in the detached house DH8; DH8 was thus handled independently of the other detached houses. A handheld incident also occurred in the manufactured home MH1mod (mobile home). Therefore, MH1mod and MH1 (the non-mobile home manufactured home) were handled independently. One fatal incident related to a lass 2 twin cylinder generator occurred in a detached structure best described as GAR3. Since there were only three detached structure models, it was decided that each model (GAR1, GAR2 & GAR3) would be handled separately. Table E.2.1 below provides a summary of fatalities and allocated fatalities associated with the different Generator Categories by structure type.

Table E.2.1: Proportions of Generators Observed in Incident Data by Generator Category and Structure Type

	Generator Category (% Generator Category by Structure Type)				
	Handheld	**Class 1**	**Class 2 Single Cylinder**	**Class 2 Twin Cylinder**	**Total by Structure Type**
Detached Houses (except DH8)	0.0 (0.0%)	116.4 (33.7%)	229.1 (66.3%)	0.0 (0.0%)	345.5 (100.0%)
Detached Houses – DH8 only	1.9 (12.4%)	4.6 (29.5%)	9.0 (58.1%)	0.0 (0.0%)	15.5 (100.0%)
Manufactured Houses – MH1	0.0 (0.0%)	8.8 (57.1%)	6.6 (42.9%)	0.0 (0.0%)	15.5 (100.0%)
Manufactured Houses – MH1mod	1.7 (2.7%)	22.7 (35.1%)	40.1 (62.2%)	0.0 (0.0%)	64.5 (100.0%)
Attached Houses	0.0 (0.0%)	6.9 (42.9%)	9.1 (57.1%)	0.0 (0.0%)	16.0 (100.0%)
External Structures – GAR1	0.0 (0.0%)	6.2 (48.0%)	6.7 (52.0%)	0.0 (0.0%)	12.9 (100.0%)
External Structures – GAR2	0.0 (0.0%)	8.9 (64.9%)	4.8 (35.1%)	0.0 (0.0%)	13.7 (100.0%)
External *Structures* – GAR3	0.0 (0.0%)	1.8 (9.4%)	15.8 (81.3%)	1.8 (9.4%)	19.4 (100.0%)
Total by Generator Category	**3.7 (0.7%)**	**176.2 (35.0%)**	**321.3 (63.9%)**	**1.8 (0.4%)**	**503.0 (100.0%)**

distinguish the handheld generators from the class 1 generators when there was no information to ascertain the engine displacement, generators with wattage 2 kW and larger, up to 3.5 kW, were considered to have a Class I engine. There was only one generator with wattage below 2kW in which the engine displacement could not be ascertained. That was a 1,000 watt generator, which staff classified as a handheld generator because staff's review of generators nominally in this size showed almost all to be powered by handheld engines. To distinguish the class 2 single-cylinder generators from the class 2 twin-cylinder generators, staff found from looking at the EPA's website that twin-cylinder Class II engines largely have a maximum engine power of 12 to13 kW and higher. Staff then found, from looking at manufacturers' generator specifications, that generators having engines with power equal to, or greater than 12, typically have a rated power of 9kW and higher. Rows and column counts may not add to totals due to rounding.

E.3 *Proportion of Incidents by Location of the Generator*

$D_{i,j}$ = % Gen Used in i^{th} Zone (“living space,” “basement,” or “garage”) in j^{th} Structure

A review of the incident data indicates that the location where consumers placed the generator within the home in fatal CO incidents was dependent upon two main factors: (1) the presence of a basement/crawlspace and/or a garage, and (2) the size of the generator itself. The incident data indicate that consumers who use generators indoors do so for a number of reasons, including: lack of knowledge of the dangers of CO and/or incomplete understanding of how rapidly CO in engine exhaust can accumulate and rise to lethal exposure levels (often a window will be left “cracked open” in an attempt to ventilate the house); fear of theft (especially in urban areas); concerns about bothering the neighbors with the noise produced by the generator; desire to hide the use of the generator from neighbors due to embarrassment at being unable to pay utility bills; and attempts to comply with electrocution hazard warnings cautioning against use of the generator in wet weather. Obviously, if the house has neither a basement/crawlspace, nor a garage, and if the consumer decides to use a generator inside their house, the living space is the only location available. Consumers using larger generators tend to use them more in an attached garage, presumably because of the difficulty moving one into the basement due to weight and size. Smaller generators are more often brought into the living space or the basement/crawlspace.

The simulation run by NIST assumes the generator was operated in a number of modeled locations within the modeled structure – dependent on structure type and configuration. The table below shows the generator locations based on the structure configurations.

Table E.3.1: Modeled Generator Locations Based on Structure Parameters

Detached houses, manufactured houses, attached houses			
House Attributes	Modeled Space 1	Modeled Space 2	Modeled Space 3
No basement/crawl space and no attached garage	Kitchen (living space)	Bedroom farthest from Master Bedroom (living space)	
No basement/crawlspace, but, attached garage	Kitchen (living space)	Bedroom farthest from Master Bedroom (living space)	Attached Garage
Basement or crawlspace, but, no attached garage	Kitchen (living space)	Basement or Crawlspace	
If basement or crawlspace, and, attached garage	Kitchen (living space)	Attached Garage	Basement or Crawlspace
External Structures (Detached garages, etc.)			
House Attributes	Modeled Space 1	Modeled Space 2	Modeled Space 3
Single room/space	Garage Area (single zone)		
Two or more rooms/spaces	Garage Area (larger zone)	Workshop (smaller zone)	

An in-depth review of the CPSC incident data indicates that there appear to be differences in where consumers place the generator given the type of structure, the characteristics of the structure, and the size (category) of the generator. It is intuitively obvious that if a generator were used indoors in a house that has neither garage, nor basement, then the location of the generator would be in the living space. But differences about where consumers tend to use a generator seem to arise when the consumer has different choices to locate the generator, basement and/or garage/crawlspace, in addition to the living space. This choice may also be dependent upon the generator category, possibly due to the physical size of the generator. For example, in houses with a garage and no basement, for class 1 generators, 76.9 of the fatalities occurred with generator used in the living space and 23.1 percent when used in the garage. Conversely, in houses with a garage and no basement, for (physically larger) class 2 single cylinder generators, only 26.4 percent of the fatalities occurred with generator used in the living space, while 73.6 percent occurred when used in the garage.

The following tables present a summary of proportions of fatalities that occurred with generator locations based on structure type and Generator Category. Note that due to the limited number of attached house cases, for purposes of generator locations, generators were treated together. This was the same for the detached structures GAR1 and GAR2.

Table E.3.2: Proportions of Fatalities Based on Generator Locations - Detached House – Class 1 Generators – By Structure Type (121.0 allocated fatalities)

Foundation	Garage	Living space	Basement	Crawlspace	Attached Garage
No basement	No garage	100.0%	n/a	n/a	n/a
No basement	Garage	76.9%	n/a	n/a	23.1%
Crawlspace	No garage	73.4%	n/a	26.6%	n/a
Crawlspace+	Garage	- -	n/a	- -	- -
Basement	No garage	39.3%	60.7%	n/a	n/a
Basement	Garage	29.5%	44.0%	n/a	26.5%

"n/a" indicates this location is not applicable to the structure configuration.
+ There were no instances in the incident data of a Class 1 generator used in a detached house with a crawlspace and a garage.

Table E.3.3: Proportions of Fatalities Based on Generator Locations - Detached House – Class 2 Single Cylinder Generators – by Structure Type (238.1 allocated fatalities)

Foundation	Garage	Living space	Basement	Crawlspace	Attached Garage
No basement	No garage	100.0%	n/a	n/a	n/a
No basement	Garage	26.4%	n/a	n/a	73.6%
Crawlspace	No garage	100.0%	n/a	0.0%	n/a
Crawlspace	Garage	0.0%	n/a	40.0%	60.0%
Basement	No garage	27.3%	72.7%	n/a	n/a
Basement	Garage	0.0%	20.6%	n/a	79.4%

Table E.3.4: Proportions of Fatalities Based on Generator Locations - Detached House (DH8 only) – Handheld Generators (1.9 allocated fatalities)

Foundation	Garage	Living space	Basement	Crawlspace	Attached Garage
No basement	Garage	26.4%	n/a	n/a	73.6%

Table E.3.5: Allocated Fatalities and Proportions of Fatalities Based on Generator Locations - Manufactured Homes – Handheld Generators - by Structure Type

Structure Type	Allocated Fatalities	Living space	Basement/crawlspace
Mobile Home	1.7	100.0%	n/a
Other Manufactured Homes	0	n/a	n/a

Table E.3.6: Allocated Fatalities and Proportions of Fatalities Based on Generator Locations - Manufactured Homes – Class 1 Generators - by Structure Type

Structure Type	Allocated Fatalities	Living space	Basement/crawlspace
Mobile Home	22.7	100.0%	n/a
Other Manufactured Homes	8.8	100.0%	n/a

Table E.3.7: Allocated Fatalities and Proportions of Fatalities Based on Generator Locations - Manufactured Homes – Class 2 Single Cylinder Generators - by Structure Type

Structure Type	Allocated Fatalities	Living space	Basement/crawlspace
Mobile Home	40.1	97.5%	2.5%
Other Manufactured Homes	6.6	66.7%	33.3%

Table E.3.8: Allocated Fatalities and Proportions of Fatalities Based on Generator Locations, Structure Model and Generator Category - Attached House – All Generator Categories

Structure Model	Allocated Fatalities	Living Space	Basement	Attached Garage
AH10	4.5	66.7%	33.3%	n/a
AH21	1.0	0.0%	20.0%	80.0%
AH3	7.5	100.0%	n/a	n/a
AH34mod	3.0	0.0%	20.0%	80.0%

Table E.3.9: Allocated Fatalities and Proportions of Fatalities Based on Generator Locations, Structure Type and Generator Type - Detached Structure – All Generator Categories – GAR1 and GAR2

Structure Model	Allocated Fatalities	Garage Area/Larger Room	Workshop/Smaller Room
GAR1	12.9	100.0%	n/a
GAR2	13.7	100.0%	n/a

Table E.3.10: Proportions of Fatalities Based on Generator Locations and Generator Type - Detached Structure – GAR3 (19.4 fatalities)

Generator Type	Garage Area/Larger Room	Workshop/Smaller Room
Class 1	12.5%	87.5%
Class 2	51.6%	48.4%
Twin-Cylinder	75.0%	25.0%

E.4 Benefits Analysis (Potential Deaths Averted) Determinations

NIST modeled the estimated baseline CO emission levels, as well as a series of lower emission rates using CONTAM based on a number of factors including:

- Structure design,
- Location of the generator in the structure (structure design dependent),
- Generator runtime (generator type specific, assumed full tank, no refill),
- Exposure duration of up to 24 hours, estimated on a minute-by-minute resolution, starting at 12:00am,
- The simulations were run for 28 individual days using historic weather data recorded at three different geographic locations and three different temperature ranges to approximate the distribution of incidents observed in the CPSC incident data at a generalized level,
- Although the weather file data was chosen from consecutive days for the different seasons/locations, each simulated day was treated as a standalone event with no carryover effect from the previous day (*i.e.*, each of the day's simulation is not affected by the previous day's results.)

NIST staff programmed CONTAM output files for 24-hour CO profiles in different home locations to be used automatically as input values in the non-linear form of the Coburn Forster Kane equation (CFK-E) to model corresponding predicted COHb profiles for average adults, assuming activity levels expected in indoor residential settings (see Appendix C).

See NIST Tech Note 1925 for details.

E.4.1 CPSC Staff Epidemiological Benefits Analysis

CPSC staff developed a custom computer program to read NIST's coupled CONTAM-modeled CO profiles and CFK-E modeled COHb output files. The program automatically determined if, and when, a fatal scenario was predicted based on four criteria developed by CPSC HS staff for interpretation of modeled COHb values, (see Appendix D). Determination was made on a zone-by-zone basis for each CO emission rate. The four criteria used to interpret predicted COHb profiles are:

1) If peak level is ≥60% COHb, assume death.
2) If peak level is ≥50% COHb but<60%, assume death unless average duration of elevation > 50% COHb is less than 2 hours, and average duration of elevation between ≥40% and <50% COHb is less than 4 hours.
3) If peak level is ≥40% COHb, but <50% COHb, assume death if duration of the average in this range exceeds 6 hours.
4) If peak level is ≤40% COHb, assume survival.

In order to estimate the proportion of fatalities for a given scenario, the following assumptions regarding exposure to generator produced CO were used:

1) Each of the 28 simulated days was treated as a separate event with no carry-over effect from previous runs since each modeled day is assumed to be an independent event. The possible outcome at any given point in time the victim would be a binary variable, either survival (0) or death (1). Therefore, the average of the outcomes at any given time over all 28 simulated days would be the probability of survival for the purposes of this analysis.
2) Generator locations within the house/structure are proportionately equal to incident data.
3) Intervention probabilities are assumed to have equal probability over the 24-hour period. This assumption was used because, frequently, it was unknown from the incident data how long an interval passed between when the generator was started and when the victim died or some other type of intervention occurred.
4) The victim's location in the house is assumed to have equal probability of occurring in any room in the living space. This assumption was made for two reasons. In multi-fatality incidents, victims were often found in different locations within a house. Additionally, it was frequently unclear whether victims were located the entire time in the area they were found.

The following four tables present the summary of the simulated proportion of fatalities associated with the location of the generator, based on the incident data. For class 1 and class 2 single-cylinder generators, the proportions are based on all structures of similar configurations. For handheld and class 2 twin-cylinder generators, the proportions are based on the few actual incidents as reported in the CPSC incident data.

Table E.4.1.1: Class 1 Generator Placement Location Proportions

Class 1 Generators				Generator Location				
NIST Model	Allocated Deaths - All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	4.5	42.9%	1.9	66.7%	33.3%			
AH21	1.0	42.9%	0.4	0.0%	20.0%		80.0%	
AH3	7.5	42.9%	3.2	100.0%				
AH34mod	3.0	42.9%	1.3	0.0%	20.0%		80.0%	
DH-1	9.7	33.7%	3.3	76.9%			23.1%	
DH-10	4.0	33.7%	1.3	29.5%	44.0%		26.5%	
DH-12	5.6	33.7%	1.9	29.5%	44.0%		26.5%	
DH-19mod	17.7	33.7%	6.0	29.5%	44.0%		26.5%	
DH-2	12.7	33.7%	4.3	29.5%	44.0%		26.5%	
DH-21	31.4	33.7%	10.6	100.0%				
DH-21mod	5.9	33.7%	2.0	100.0%				
DH-24mod	5.2	33.7%	1.7	100.0%				
DH-27	2.0	33.7%	0.7	39.3%	60.7%			
DH-2mod	2.5	33.7%	0.8	29.5%	44.0%		26.5%	
DH-3	18.3	33.7%	6.2	73.4%		26.6%		
DH-32	6.0	33.7%	2.0	76.9%			23.1%	
DH-33mod	7.1	33.7%	2.4	76.9%			23.1%	
DH-34	21.6	33.7%	7.3	100.0%				
DH-41	6.0	33.7%	2.0	39.3%	60.7%			
DH-44	1.0	33.7%	0.3	29.5%	44.0%		26.5%	
DH-45	3.0	33.7%	1.0	29.5%	44.0%		26.5%	
DH-45mod	33.4	33.7%	11.3	29.5%	44.0%		26.5%	
DH-5	9.7	33.7%	3.3	76.9%			23.1%	
DH-52mod	7.0	33.7%	2.4	29.5%	44.0%		26.5%	
DH-56	7.5	33.7%	2.5	39.3%	60.7%			
DH-60	9.2	33.7%	3.1	29.5%	44.0%		26.5%	
DH-60mod	3.5	33.7%	1.2	29.5%	44.0%		26.5%	
DH-61	16.7	33.7%	5.6	39.3%	60.7%			
DH-61mod	28.0	33.7%	9.4	39.3%	60.7%			
DH-63mod1	24.3	33.7%	8.2	39.3%	60.7%			
DH-63mod2	7.0	33.7%	2.4	39.3%	60.7%			
DH-64	11.1	33.7%	3.7	76.9%			23.1%	
DH-7	23.0	33.7%	7.8	29.5%	44.0%		26.5%	
DH-8	15.5	29.5%	4.6	76.9%			23.1%	
DH-81	5.5	33.7%	1.9	39.3%	60.7%			
GAR1	12.9	48.0%	6.2				100.0%	
GAR2	13.7	64.9%	8.9				100.0%	
GAR3	19.4	9.4%	1.8				12.5%	87.5%
MH1	15.5	57.1%	8.8	100.0%		0.0%		
MH1mod	64.5	35.1%	22.7	100.0%		0.0%		
Total			176.2					

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.

Table E.4.1.2: Class 2 Generator Placement Location Proportions

Single-Cylinder Class 2 Generators				Generator Location				
NIST Model	Allocated Deaths - All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawlspace	Attached Garage/Garage Area	Workshop
AH10	4.5	57.1%	2.6	66.7%	33.3%			
AH21	1.0	57.1%	0.6	0.0%	20.0%		80.0%	
AH3	7.5	57.1%	4.3	100.0%				
AH34mod	3.0	57.1%	1.7	0.0%	20.0%		80.0%	
DH-1	9.7	66.3%	6.4	26.4%			73.6%	
DH-10	4.0	66.3%	2.7	0.0%	20.6%		79.4%	
DH-12	5.6	66.3%	3.7	0.0%	20.6%		79.4%	
DH-19mod	17.7	66.3%	11.7	0.0%	20.6%		79.4%	
DH-2	12.7	66.3%	8.4	0.0%	20.6%		79.4%	
DH-21	31.4	66.3%	20.8	100.0%				
DH-21mod	5.9	66.3%	3.9	100.0%				
DH-24mod	5.2	66.3%	3.4	100.0%				
DH-27	2.0	66.3%	1.3	27.3%	72.7%			
DH-2mod	2.5	66.3%	1.7	0.0%	20.6%		79.4%	
DH-3	18.3	66.3%	12.2	100.0%		0.0%		
DH-32	6.0	66.3%	4.0	26.4%			73.6%	
DH-33mod	7.1	66.3%	4.7	26.4%			73.6%	
DH-34	21.6	66.3%	14.3	100.0%				
DH-41	6.0	66.3%	4.0	27.3%	72.7%			
DH-44	1.0	66.3%	0.7	0.0%	20.6%		79.4%	
DH-45	3.0	66.3%	2.0	0.0%	20.6%		79.4%	
DH-45mod	33.4	66.3%	22.1	0.0%	20.6%		79.4%	
DH-5	9.7	66.3%	6.5	26.4%			73.6%	
DH-52mod	7.0	66.3%	4.6	0.0%	20.6%		79.4%	
DH-56	7.5	66.3%	5.0	27.3%	72.7%			
DH-60	9.2	66.3%	6.1	0.0%	20.6%		79.4%	
DH-60mod	3.5	66.3%	2.3	0.0%	20.6%		79.4%	
DH-61	16.7	66.3%	11.1	27.3%	72.7%			
DH-61mod	28.0	66.3%	18.5	27.3%	72.7%			
DH-63mod1	24.3	66.3%	16.1	27.3%	72.7%			
DH-63mod2	7.0	66.3%	4.6	27.3%	72.7%			
DH-64	11.1	66.3%	7.3	26.4%			73.6%	
DH-7	23.0	66.3%	15.3	0.0%	20.6%		79.4%	
DH-8	15.5	58.1%	9.0	26.4%			73.6%	
DH-81	5.5	66.3%	3.6	27.3%	72.7%			
GAR1	12.9	52.0%	6.7				100.0%	
GAR2	13.7	35.1%	4.8				100.0%	
GAR3	19.4	81.3%	15.8				51.6%	48.4%
MH1	15.5	42.9%	6.6	66.7%		33.3%		
MH1mod	64.5	62.2%	40.1	100.0%		0.0%		
Total			321.3					

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.

Table E.4.1.3: Handheld Generator Placement Location Proportions

Handheld Generators				Generator Location				
NIST Model	Allocated Deaths - All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawlspace	Attached Garage	Workshop
MH1mod	64.5	2.7%	1.7	100.0%		0.0%		
DH-8	15.5	12.4%	1.9	100.0%			0.0%	
Total			3.7					

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.

Table E.4.1.4: Twin-Cylinder Generator Placement Location Proportions

Twin-Cylinder Class 2 Generators				Generator Location				
NIST Model	Allocated Deaths - All Gens	% TC	Allocated Deaths	Living Space	Basement	Crawlspace	Garage Area	Workshop
GAR3	19.4	9.4%	1.8				75.0%	25.0%
Total			1.8					

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.

E.4.2 Modeled Fatality Rates for Current Carbureted Model Generators

$E_{i,j}$ = Modeled Fatality Rate for Respective Base Generator Placed in i^{th} Zone in j^{th} Structure

The tables presented below provide the fatality rates with the modeled location of the generator in various locations in the structure, depending on structure configuration. Note that for models that did not have a basement, two living space zones were modeled (the kitchen and the bedroom farthest from the master bedroom). The average of these two zones was used to represent the "living space" generator location scenarios.

- Class 1 generators – 1800 g/hr
- Class 2 single-cylinder generators – 4700 g/hr
- Handheld generators – 900 g/hr
- Class 2 twin cylinder generators – 9100 g/hr

NIST ran the simulations for both class 1 and class 2 single-cylinder generators for all 40 structures. Because CPSC only knew of a small number of incidents in which a handheld or a class 2 twin-cylinder generator was used in fatal incidents, the decision was made to model only the types of structures that were involved.

Table E.4.2.1: Base Rate Fatality Rate by Generator Location – Class 1 Generators

Model	Living Space*	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	68.3%	68.3%		88.0%			
AH21	87.2%	87.2%		77.9%		80.8%	
AH3	96.6%	97.5%	95.6%				
AH34mod	74.8%	74.8%		88.6%		72.1%	
DH-1	89.0%	91.3%	86.7%			63.8%	
DH-10	79.9%	79.9%		89.2%		39.1%	
DH-12	71.6%	71.6%		80.0%		40.1%	
DH-19mod	51.9%	51.9%		89.8%		95.9%	
DH-2	53.3%	53.3%		92.4%		14.9%	
DH-21	94.4%	95.6%	93.1%				
DH-21mod	93.3%	94.7%	91.9%				
DH-24mod	93.4%	93.5%	93.3%				
DH-27	53.4%	53.4%		92.1%			
DH-2mod	50.8%	50.8%		89.3%		95.2%	
DH-3	79.5%	79.9%	79.0%		79.0%		
DH-32	97.2%	97.3%	97.0%				
DH-33mod	87.3%	88.2%	86.4%			69.9%	
DH-34	95.5%	96.8%	94.1%				
DH-41	90.3%	90.3%		92.6%			
DH-44	42.4%	42.4%		89.6%		14.3%	
DH-45	86.2%	86.2%		68.6%		53.1%	
DH-45mod	85.7%	85.7%		78.7%		81.4%	
DH-5	92.9%	95.3%	90.5%			40.6%	
DH-52mod	84.5%	84.5%		56.7%		52.7%	
DH-56	80.1%	80.1%		93.7%			
DH-60	84.8%	84.8%		71.7%		68.3%	
DH-60mod	81.3%	81.3%		92.0%		92.8%	
DH-61	83.6%	83.6%		73.0%			
DH-61mod	85.1%	85.1%		73.2%			
DH-63mod1	86.8%	86.8%		76.4%			
DH-63mod2	88.4%	88.4%		76.1%			
DH-64	89.4%	91.5%	87.2%			70.8%	
DH-7	53.2%	53.2%		90.5%		20.8%	
DH-8	91.5%	95.0%	87.9%			30.4%	
DH-81	89.0%	89.7%	88.3%	69.2%			
GAR1						100.0%	
GAR2						100.0%	
GAR3						95.6%	86.2%
MH1	80.7%	81.3%	80.2%		81.3%		
MH1mod	96.4%	97.0%	95.8%		83.5%		

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.
* - For some structure models, two zone locations were modeled to represent generator placement in the "living space" of a structure: "kitchen" and the bedroom farthest from the master (largest) bedroom. In these cases, the "living space" percentage is the average of the two locations; otherwise, it is the single modeled location ("kitchen").

Table E.4.2.2: Base Rate Fatality Rate by Generator Location –Class 2 Single-Cylinder Generators

Model	Living Space*	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	69.7%	69.7%		96.8%			
AH21	89.4%	89.4%		87.0%		91.1%	
AH3	98.8%	99.2%	98.3%				
AH34mod	88.7%	88.7%		94.4%		72.7%	
DH-1	94.3%	95.7%	92.9%			78.9%	
DH-10	86.6%	86.6%		94.4%		49.1%	
DH-12	87.1%	87.1%		90.2%		50.6%	
DH-19mod	51.6%	51.6%		92.3%		98.3%	
DH-2	54.7%	54.7%		97.2%		23.2%	
DH-21	97.7%	97.9%	97.4%				
DH-21mod	97.2%	97.7%	96.6%				
DH-24mod	95.6%	94.4%	96.8%				
DH-27	34.4%	34.4%		55.7%			
DH-2mod	51.7%	51.7%		92.1%		98.1%	
DH-3	87.5%	81.9%	93.0%		93.0%		
DH-32	99.4%	99.4%	99.4%				
DH-33mod	92.0%	93.8%	90.1%			82.9%	
DH-34	98.2%	98.7%	97.7%				
DH-41	92.3%	92.3%		93.9%			
DH-44	44.4%	44.4%		95.7%		21.3%	
DH-45	86.4%	86.4%		81.5%		63.8%	
DH-45mod	84.7%	84.7%		88.3%		90.6%	
DH-5	97.0%	98.4%	95.6%			60.9%	
DH-52mod	90.7%	90.7%		66.5%		64.2%	
DH-56	87.2%	87.2%		97.2%			
DH-60	89.5%	89.5%		86.3%		70.1%	
DH-60mod	91.9%	91.9%		95.7%		96.6%	
DH-61	87.4%	87.4%		91.2%			
DH-61mod	87.5%	87.5%		90.5%			
DH-63mod1	90.5%	90.5%		90.3%			
DH-63mod2	90.6%	90.6%		89.9%			
DH-64	94.4%	95.8%	93.0%			84.6%	
DH-7	75.0%	75.0%		95.4%		37.1%	
DH-8	96.7%	98.1%	95.4%			58.7%	
DH-81	86.5%	81.3%	91.6%	86.4%			
GAR1						100.0%	
GAR2						100.0%	
GAR3						97.8%	92.9%
MH1	83.0%	83.3%	82.6%		93.0%		
MH1mod	99.2%	99.1%	99.2%		94.4%		

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.
* - For some structure models, two zone locations were modeled to represent generator placement in the "living space" of a structure: "kitchen" and the bedroom farthest from the master (largest) bedroom. In these cases, the "living space" percentage is the average of the two locations; otherwise, it is the single modeled location ("kitchen").

Table E.4.2.3: Base Rate Fatality Rate by Generator Location – Handheld Generators

Model	Living Space*	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage	Workshop
MH1mod	92.0%	92.0%					
DH-8	92.8%	92.8%					

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.
* - For some structure models, two zone locations were modeled to represent generator placement in the "living space" of a structure: "kitchen" and the bedroom farthest from the master (largest) bedroom. In these cases, the "living space" percentage is the average of the two locations; otherwise, it is the single modeled location ("kitchen").

Table E.4.2.4: Base Rate Fatality Rate by Generator Location Class 2 Twin Cylinder Generators

Model	Living Space*	Kitchen	Bedroom	Basement	Crawlspace	Garage Area	Workshop
GAR3						98.8%	99.9%

Note: No value in the Generator Location field indicates that this zone is not present in the specific model.
* - For some structure models, two zone locations were modeled to represent generator placement in the "living space" of a structure: "kitchen" and the bedroom farthest from the master (largest) bedroom. In these cases, the "living space" percentage is the average of the two locations; otherwise, it is the single modeled location ("kitchen").

E.4.3 Modeled Fatality Rates for Low CO Emission Model Generators

$F_{i,j}$ = Modeled Fatality Rate for Respective Lower Emission Generator Placed in i^{th} Zone in j^{th} Structure

NIST modeled a series of CO emission scenarios for use in estimating the benefits of potential low emission generators. The modeled emission levels were:

- 50 g/hr
- 125 g/hr
- 250 g/hr
- 500 g/hr
- 1000 g/hr, and
- 2000 g/hr

Staff selected these CO emission rates for NIST to model so that the benefits associated with each reduced rate for each of the four generator categories could then be estimated to determine which rate yields a reasonable relationship between the costs and the benefits. The lowest of these rates cover the range of CO emission rates that staff believes are technically feasible for the handheld and Class1 generator categories (50 g/hr), Class 2 single-cylinder category (100 g/hr), and Class 2 twin-cylinder category (200 g/hr). For more details on staff's rationale on the feasibility of these rates, refer to reference.[1]

At the time of the NIST modeling work, staff had not finalized its assessment of the technically feasible rates for the proposed rule. To estimate the potential deaths averted by use of a reduced CO emission generator, staff had to interpolate the data from the modeled results because the CO emission rates for generators expected to meet the performance requirement increased by a conservative factor of 3[b], which was used with the current carbureted generators, did not line-up precisely with the modeled values. Although all of the modeled CO emission level results were used in the curve-fit interpolation, only the two bounding Fatality Rate tables (the closed lower rate and the closed higher rate) are presented here for each generator class.

[b] As noted in the Epidemiological Benefits Analysis memorandum's Results section, staff believes that using a factor of 3 for reduced CO emission generators is conservative because NIST testing of UA's prototype generator showed that the generator did not reduce the oxygen nearly as much as the carbureted generator in four matched pair tests that had identical house and garage configurations. Additionally, from staff's testing of fuel-injected generators with different degrees of closed-loop operation (discussed in reference 5), staff believes that a threefold factor of increase in diminished oxygen may be conservative for some generators that use closed-loop EFI.

Class 1 Generators

Table E.4.3.1: Class 1 Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (125 g/hr) Fatality Rate by Generator Location

NIST Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	23.3%	23.3%		32.5%			
AH21	34.3%	34.3%		21.7%		28.4%	
AH3	76.7%	77.5%	75.9%				
AH34mod	24.0%	24.0%		33.1%		22.2%	
DH-1	55.1%	58.1%	52.1%			8.4%	
DH-10	40.9%	40.9%		52.2%		4.3%	
DH-12	25.9%	25.9%		29.8%		3.9%	
DH-19mod	24.4%	24.4%		56.1%		41.8%	
DH-2	17.3%	17.3%		45.9%		1.3%	
DH-21	30.8%	36.5%	25.0%				
DH-21mod	21.9%	23.6%	20.3%				
DH-24mod	18.6%	17.8%	19.5%				
DH-27	16.4%	16.4%		45.8%			
DH-2mod	10.3%	10.3%		33.3%		23.9%	
DH-3	10.7%	21.4%	0.0%		0.0%		
DH-32	80.2%	80.6%	79.9%				
DH-33mod	53.1%	55.9%	50.3%			6.7%	
DH-34	58.9%	63.3%	54.5%				
DH-41	28.4%	28.4%		28.9%			
DH-44	8.3%	8.3%		37.6%		0.0%	
DH-45	52.4%	52.4%		24.2%		6.7%	
DH-45mod	54.9%	54.9%		47.1%		39.2%	
DH-5	61.2%	63.9%	58.6%			6.8%	
DH-52mod	49.1%	49.1%		6.9%		3.0%	
DH-56	22.1%	22.1%		31.6%			
DH-60	38.7%	38.7%		30.0%		8.2%	
DH-60mod	9.5%	9.5%		26.1%		18.0%	
DH-61	9.3%	9.3%		17.9%			
DH-61mod	38.6%	38.6%		25.7%			
DH-63mod1	15.7%	15.7%		11.5%			
DH-63mod2	19.0%	19.0%		12.4%			
DH-64	62.3%	63.0%	61.7%			8.4%	
DH-7	18.6%	18.6%		46.8%		3.6%	
DH-8	31.7%	37.5%	25.9%			6.1%	
DH-81	15.0%	10.6%	19.4%	10.5%			
GAR1						85.3%	
GAR2						77.4%	
GAR3						38.8%	17.1%
MH1	58.0%	61.2%	54.8%		0.8%		
MH1mod	28.1%	25.9%	30.2%	32.5%	0.0%		

Table E.4.3.2: Class 1 Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Fatality Rate by Generator Location

Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	48.3%	48.3%		64.5%			
AH21	72.5%	72.5%		59.3%		64.9%	
AH3	86.5%	87.1%	86.0%				
AH34mod	49.0%	49.0%		60.2%		47.4%	
DH-1	70.1%	71.8%	68.5%			12.1%	
DH-10	53.2%	53.2%		73.0%		10.3%	
DH-12	51.6%	51.6%		61.7%		5.1%	
DH-19mod	33.9%	33.9%		76.5%		79.7%	
DH-2	25.7%	25.7%		74.3%		6.0%	
DH-21	66.8%	73.2%	60.4%				
DH-21mod	54.7%	60.0%	49.4%				
DH-24mod	63.7%	65.2%	62.3%				
DH-27	28.2%	28.2%		69.2%			
DH-2mod	29.0%	29.0%		65.8%		69.7%	
DH-3	64.8%	72.1%	57.5%		4.8%		
DH-32	88.7%	88.9%	88.5%				
DH-33mod	68.9%	70.0%	67.8%			13.9%	
DH-34	80.6%	82.5%	78.8%				
DH-41	53.2%	53.2%		64.5%			
DH-44	27.2%	27.2%		66.3%		5.2%	
DH-45	71.5%	71.5%		44.2%		12.7%	
DH-45mod	72.9%	72.9%		62.9%		62.0%	
DH-5	75.1%	76.1%	74.2%			9.5%	
DH-52mod	68.2%	68.2%		27.4%		6.8%	
DH-56	52.1%	52.1%		69.9%			
DH-60	64.1%	64.1%		48.5%		20.1%	
DH-60mod	45.6%	45.6%		67.9%		67.8%	
DH-61	41.8%	41.8%		42.5%			
DH-61mod	68.2%	68.2%		52.8%			
DH-63mod1	59.0%	59.0%		47.4%			
DH-63mod2	65.3%	65.3%		50.8%			
DH-64	72.7%	74.0%	71.5%			19.0%	
DH-7	31.8%	31.8%		71.8%		6.5%	
DH-8	67.7%	70.8%	64.6%			9.5%	
DH-81	62.4%	62.0%	62.9%	44.7%			
GAR1						92.6%	
GAR2						88.4%	
GAR3						69.1%	46.3%
MH1	71.1%	71.8%	70.5%		6.4%		
MH1mod	69.7%	70.7%	68.8%		8.0%		

Class 2 Single-Cylinder Generators

Table E.4.3.3: Class 2 Single-Cylinder Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Fatality Rate by Generator Location

Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	47.3%	47.3%		70.5%			
AH21	72.0%	72.0%		64.5%		65.9%	
AH3	85.9%	86.3%	85.4%				
AH34mod	48.8%	48.8%		64.3%		49.3%	
DH-1	69.7%	71.5%	68.0%			9.6%	
DH-10	49.7%	49.7%		75.7%		7.2%	
DH-12	49.8%	49.8%		63.7%		4.9%	
DH-19mod	30.3%	30.3%		77.7%		79.9%	
DH-2	25.3%	25.3%		74.8%		4.9%	
DH-21	61.9%	67.0%	56.7%				
DH-21mod	48.0%	51.4%	44.6%				
DH-24mod	63.5%	63.0%	64.0%				
DH-27	20.9%	20.9%		35.5%			
DH-2mod	26.7%	26.7%		67.4%		69.9%	
DH-3	58.8%	66.5%	51.0%		5.5%		
DH-32	89.1%	89.2%	89.0%				
DH-33mod	69.0%	69.9%	68.0%			10.0%	
DH-34	78.3%	81.4%	75.3%				
DH-41	56.2%	56.2%		66.9%			
DH-44	24.0%	24.0%		66.7%		2.4%	
DH-45	71.3%	71.3%		52.6%		10.7%	
DH-45mod	72.2%	72.2%		70.5%		63.7%	
DH-5	74.8%	76.1%	73.6%			9.1%	
DH-52mod	68.2%	68.2%		28.2%		4.7%	
DH-56	51.6%	51.6%		76.9%			
DH-60	62.4%	62.4%		60.1%		10.4%	
DH-60mod	37.7%	37.7%		68.5%		66.4%	
DH-61	36.6%	36.6%		48.0%			
DH-61mod	67.9%	67.9%		58.1%			
DH-63mod1	56.5%	56.5%		55.8%			
DH-63mod2	64.3%	64.3%		59.5%			
DH-64	73.1%	74.4%	71.7%			12.0%	
DH-7	31.2%	31.2%		72.7%		6.1%	
DH-8	66.4%	70.2%	62.6%			9.0%	
DH-81	62.1%	59.2%	65.1%	52.7%			
GAR1						91.4%	
GAR2						87.8%	
GAR3						55.2%	45.8%
MH1	70.7%	71.2%	70.1%		8.9%		
MH1mod	65.1%	65.1%	65.1%		20.6%		

Table E.4.3.4: Class 2 Single Cylinder Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (500 g/hr) Fatality Rate by Generator Location

Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop
AH10	56.4%	56.4%		78.2%			
AH21	80.2%	80.2%		75.0%		74.0%	
AH3	91.7%	92.0%	91.4%				
AH34mod	60.4%	60.4%		78.0%		60.2%	
DH-1	78.9%	81.6%	76.2%			27.1%	
DH-10	56.3%	56.3%		83.0%		19.0%	
DH-12	57.2%	57.2%		72.6%		10.5%	
DH-19mod	37.7%	37.7%		84.3%		89.3%	
DH-2	30.6%	30.6%		82.8%		7.8%	
DH-21	82.3%	85.9%	78.7%				
DH-21mod	75.0%	81.5%	68.6%				
DH-24mod	82.6%	81.1%	84.0%				
DH-27	27.6%	27.6%		48.3%			
DH-2mod	31.8%	31.8%		81.5%		87.1%	
DH-3	83.6%	86.7%	80.6%		44.6%		
DH-32	93.7%	93.9%	93.4%				
DH-33mod	77.7%	78.4%	77.0%			40.5%	
DH-34	88.4%	88.9%	87.9%				
DH-41	64.3%	64.3%		77.3%			
DH-44	30.7%	30.7%		78.1%		8.2%	
DH-45	78.3%	78.3%		63.0%		19.5%	
DH-45mod	78.7%	78.7%		78.3%		72.9%	
DH-5	82.5%	84.9%	80.1%			10.2%	
DH-52mod	77.3%	77.3%		42.8%		16.9%	
DH-56	59.7%	59.7%		87.7%			
DH-60	73.0%	73.0%		71.0%		18.4%	
DH-60mod	62.3%	62.3%		83.0%		83.9%	
DH-61	66.9%	66.9%		70.7%			
DH-61mod	76.3%	76.3%		75.3%			
DH-63mod1	74.7%	74.7%		71.1%			
DH-63mod2	79.2%	79.2%		71.7%			
DH-64	80.4%	83.0%	77.8%			40.1%	
DH-7	34.8%	34.8%		81.3%		7.0%	
DH-8	79.6%	82.1%	77.0%			10.2%	
DH-81	74.6%	70.1%	79.1%	67.1%			
GAR1						95.8%	
GAR2						93.0%	
GAR3						83.9%	60.1%
MH1	76.3%	76.3%	76.2%		43.0%		
MH1mod	87.3%	87.7%	86.9%		55.8%		

Handheld Generators

Table E.4.3.5: Handheld Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (125 g/hr) Fatality Rate by Generator Location

NIST Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage	Workshop
MH1mod	32.5%	32.5%					
DH-8	47.0%	47.0%					

Table E.4.3.6: Handheld Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Fatality Rate by Generator Location

NIST Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Attached Garage	Workshop
MH1mod	68.8%	68.8%					
DH-8	79.3%	79.3%					

Class 2 Twin-Cylinder Generator

Table E.4.3.7: Class 2 Twin-Cylinder Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (500 g/hr) Fatality Rate by Generator Location

NIST Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Garage Area	Workshop
GAR3						74.9%	85.4%

Table E.4.3.8: Class 2 Twin-Cylinder Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (1000 g/hr) Fatality Rate by Generator Location

NIST Model	Living Space	Kitchen	Bedroom	Basement	Crawlspace	Garage Area	Workshop
GAR3						90.3%	92.6%

E.4.4 Determination of the Potential Deaths Averted with the Use of Low-Emission Generators by Structure by Generator Category

$G_{i,j}$ = Relative % Difference - Modeled Fatality Rates Base Rate to Lower Emission in i^{th} Zone in j^{th} Structure = $[(E_{i,j} – F_{i,j})/E_{i,j}]$

H_j = Deaths Averted for j^{th} structure = $[(G_{1,j} * D_{1,j}) + (G_{2,j} * D_{2,j}) +…+ (G_{n,j} * D_{n,j})] * C_j$

The tables below summarize the potential deaths that might have been averted had the consumers used a lower CO emission generator than the types currently available. The estimates are presented by generator type and by structure model. The middle section of the tables (directly under “Percentage of Potential Deaths Averted”) gives the relative percent difference between the modeled fatality rate for current model generators and low-emission generators. Relative percent difference is used to estimate the percentage of deaths averted because the estimates must be scaled to the actual number of fatalities. Accordingly, the modeled fatality rates of the current generators must be counted. As a simple example, suppose the low-emission generator model yields an estimated 20 percent fatality rate, while the current generator is modeled at a 40 percent fatality rate. The deaths averted proportion needs to be scaled to the current generator to properly compare the two. A 20 percent fatality rate, when compared to 40 percent fatality rate is an estimated 50 percent of deaths averted (20% is half of 40%).

The deaths averted estimate per structure is simply the sum of the proportion of times the generator was located in a specific zone (*e.g.*, living space, basement) times the relative percent difference for the given zone. times the number of allocated deaths for the specific structure and generator type.

Class 1 Generators

Table E.4.4.1: Class 1 Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (125 g/hr) Percentage of Potential Deaths Averted

Model	Allocated Deaths - All Generators	Proportion	Class 1 Deaths	Living Space	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
AH10	4.5	42.9%	1.9	65.8%	63.0%	0.0%	0.0%	0.0%	1.3	64.9%
AH21	1.0	42.9%	0.4	60.6%	72.1%	0.0%	64.9%	0.0%	0.3	66.4%
AH3	7.5	42.9%	3.2	20.6%	0.0%	0.0%	0.0%	0.0%	0.7	20.6%
AH34mod	3.0	42.9%	1.3	67.9%	62.6%	0.0%	69.2%	0.0%	0.9	67.9%
DH-1	9.7	33.7%	3.3	38.1%	0.0%	0.0%	86.8%	0.0%	1.6	49.4%
DH-10	4.0	33.7%	1.3	48.8%	41.4%	0.0%	88.9%	0.0%	0.8	56.2%
DH-12	5.6	33.7%	1.9	63.8%	62.8%	0.0%	90.3%	0.0%	1.3	70.4%
DH-19mod	17.7	33.7%	6.0	53.0%	37.5%	0.0%	56.4%	0.0%	2.8	47.0%
DH-2	12.7	33.7%	4.3	67.5%	50.3%	0.0%	91.5%	0.0%	2.8	66.3%
DH-21	31.4	33.7%	10.6	67.4%	0.0%	0.0%	0.0%	0.0%	7.1	67.4%
DH-21mod	5.9	33.7%	2.0	76.5%	0.0%	0.0%	0.0%	0.0%	1.5	76.5%
DH-24mod	5.2	33.7%	1.7	80.0%	0.0%	0.0%	0.0%	0.0%	1.4	80.0%
DH-27	2.0	33.7%	0.7	0.0%	50.3%	0.0%	0.0%	0.0%	0.2	30.5%
DH-2mod	2.5	33.7%	0.8	79.8%	62.6%	0.0%	74.9%	0.0%	0.6	70.9%
DH-3	18.3	33.7%	6.2	71.3%	0.0%	100.0%	0.0%	0.0%	4.9	78.9%
DH-32	6.0	33.7%	2.0	17.4%	0.0%	0.0%	0.0%	0.0%	0.3	13.4%
DH-33mod	7.1	33.7%	2.4	39.2%	0.0%	0.0%	90.5%	0.0%	1.2	51.0%
DH-34	21.6	33.7%	7.3	38.3%	0.0%	0.0%	0.0%	0.0%	2.8	38.3%
DH-41	6.0	33.7%	2.0	68.6%	68.8%	0.0%	0.0%	0.0%	1.4	68.7%
DH-44	1.0	33.7%	0.3	80.3%	58.0%	0.0%	100.0%	0.0%	0.3	75.7%
DH-45	3.0	33.7%	1.0	39.3%	64.7%	0.0%	87.4%	0.0%	0.6	63.2%
DH-45mod	33.4	33.7%	11.3	36.0%	40.1%	0.0%	51.8%	0.0%	4.7	42.0%
DH-5	9.7	33.7%	3.3	34.1%	0.0%	0.0%	83.3%	0.0%	1.5	45.4%
DH-52mod	7.0	33.7%	2.4	41.8%	87.9%	0.0%	94.3%	0.0%	1.8	76.0%
DH-56	7.5	33.7%	2.5	72.4%	66.2%	0.0%	0.0%	0.0%	1.7	68.7%
DH-60	9.2	33.7%	3.1	54.3%	58.1%	0.0%	88.0%	0.0%	2.0	64.9%
DH-60mod	3.5	33.7%	1.2	88.3%	71.6%	0.0%	80.6%	0.0%	0.9	78.9%
DH-61	16.7	33.7%	5.6	88.9%	75.5%	0.0%	0.0%	0.0%	4.5	80.7%
DH-61mod	28.0	33.7%	9.4	54.7%	64.9%	0.0%	0.0%	0.0%	5.7	60.9%
DH-63mod1	24.3	33.7%	8.2	81.9%	84.9%	0.0%	0.0%	0.0%	6.9	83.7%
DH-63mod2	7.0	33.7%	2.4	78.4%	83.7%	0.0%	0.0%	0.0%	1.9	81.6%
DH-64	11.1	33.7%	3.7	30.2%	0.0%	0.0%	88.1%	0.0%	1.6	43.6%
DH-7	23.0	33.7%	7.8	65.0%	48.3%	0.0%	82.9%	0.0%	4.8	62.4%
DH-8	15.5	29.5%	4.6	65.3%	0.0%	0.0%	80.0%	0.0%	3.1	68.7%
DH-81	5.5	33.7%	1.9	83.2%	84.9%	0.0%	0.0%	0.0%	1.6	84.2%
GAR1	12.9	48.0%	6.2		0.0%	0.0%	14.7%	0.0%	0.9	14.7%
GAR2	13.7	64.9%	8.9		0.0%	0.0%	22.6%	0.0%	2.0	22.6%
GAR3	19.4	9.4%	1.8		0.0%	0.0%	59.5%	50.1%	0.9	51.3%
MH1	15.5	57.1%	8.8	28.2%	0.0%	99.0%	0.0%	0.0%	2.5	28.2%
MH1mod	64.5	35.1%	22.7	70.9%	0.0%	100.0%	0.0%	0.0%	16.1	70.9%
Total	**503.0**		**176.2**						**100.0**	**56.7%**

Table E.4.4.2: Class 1 Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Percentage of Potential Deaths Averted

Model	Alloc Deaths - All Gens	% Class 1	Class 1 Deaths	Living Space	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
AH10	4.5	42.9%	1.9	29.2%	26.6%	0.0%	0.0%	0.0%	0.5	28.4%
AH21	1.0	42.9%	0.4	16.9%	23.9%	0.0%	19.7%	0.0%	0.1	20.5%
AH3	7.5	42.9%	3.2	10.4%	0.0%	0.0%	0.0%	0.0%	0.3	10.4%
AH34mod	3.0	42.9%	1.3	34.5%	32.1%	0.0%	34.3%	0.0%	0.4	33.8%
DH-1	9.7	33.7%	3.3	21.2%	0.0%	0.0%	81.1%	0.0%	1.1	35.0%
DH-10	4.0	33.7%	1.3	33.5%	18.1%	0.0%	73.7%	0.0%	0.5	37.4%
DH-12	5.6	33.7%	1.9	27.9%	22.9%	0.0%	87.4%	0.0%	0.8	41.5%
DH-19mod	17.7	33.7%	6.0	34.7%	14.8%	0.0%	16.9%	0.0%	1.3	21.2%
DH-2	12.7	33.7%	4.3	51.7%	19.6%	0.0%	59.6%	0.0%	1.7	39.6%
DH-21	31.4	33.7%	10.6	29.2%	0.0%	0.0%	0.0%	0.0%	3.1	29.2%
DH-21mod	5.9	33.7%	2.0	41.4%	0.0%	0.0%	0.0%	0.0%	0.8	41.4%
DH-24mod	5.2	33.7%	1.7	31.6%	0.0%	0.0%	0.0%	0.0%	0.5	31.6%
DH-27	2.0	33.7%	0.7	0.0%	24.9%	0.0%	0.0%	0.0%	0.1	15.1%
DH-2mod	2.5	33.7%	0.8	42.8%	26.3%	0.0%	26.8%	0.0%	0.3	31.3%
DH-3	18.3	33.7%	6.2	31.9%	0.0%	93.7%	0.0%	0.0%	3.0	48.3%
DH-32	6.0	33.7%	2.0	8.7%	0.0%	0.0%	0.0%	0.0%	0.1	6.7%
DH-33mod	7.1	33.7%	2.4	21.1%	0.0%	0.0%	80.1%	0.0%	0.8	34.7%
DH-34	21.6	33.7%	7.3	15.5%	0.0%	0.0%	0.0%	0.0%	1.1	15.5%
DH-41	6.0	33.7%	2.0	41.0%	30.4%	0.0%	0.0%	0.0%	0.7	34.6%
DH-44	1.0	33.7%	0.3	35.7%	26.0%	0.0%	63.8%	0.0%	0.1	38.9%
DH-45	3.0	33.7%	1.0	17.1%	35.5%	0.0%	76.0%	0.0%	0.4	40.8%
DH-45mod	33.4	33.7%	11.3	15.0%	20.1%	0.0%	23.8%	0.0%	2.2	19.6%
DH-5	9.7	33.7%	3.3	19.1%	0.0%	0.0%	76.6%	0.0%	1.1	32.4%
DH-52mod	7.0	33.7%	2.4	19.2%	51.7%	0.0%	87.0%	0.0%	1.2	51.5%
DH-56	7.5	33.7%	2.5	34.9%	25.4%	0.0%	0.0%	0.0%	0.7	29.1%
DH-60	9.2	33.7%	3.1	24.4%	32.4%	0.0%	70.5%	0.0%	1.2	40.2%
DH-60mod	3.5	33.7%	1.2	44.0%	26.1%	0.0%	26.9%	0.0%	0.4	31.6%
DH-61	16.7	33.7%	5.6	50.0%	41.7%	0.0%	0.0%	0.0%	2.5	45.0%
DH-61mod	28.0	33.7%	9.4	19.8%	27.8%	0.0%	0.0%	0.0%	2.3	24.7%
DH-63mod1	24.3	33.7%	8.2	32.0%	37.9%	0.0%	0.0%	0.0%	2.9	35.6%
DH-63mod2	7.0	33.7%	2.4	26.1%	33.3%	0.0%	0.0%	0.0%	0.7	30.4%
DH-64	11.1	33.7%	3.7	18.6%	0.0%	0.0%	73.1%	0.0%	1.2	31.2%
DH-7	23.0	33.7%	7.8	40.1%	20.6%	0.0%	69.0%	0.0%	3.0	39.2%
DH-8	15.5	29.5%	4.6	26.0%	0.0%	0.0%	68.9%	0.0%	1.6	35.9%
DH-81	5.5	33.7%	1.9	29.8%	35.5%	0.0%	0.0%	0.0%	0.6	33.2%
GAR1	12.9	48.0%	6.2		0.0%	0.0%	7.4%	0.0%	0.5	7.4%
GAR2	13.7	64.9%	8.9		0.0%	0.0%	11.6%	0.0%	1.0	11.6%
GAR3	19.4	9.4%	1.8		0.0%	0.0%	27.7%	46.3%	0.8	44.0%
MH1	15.5	57.1%	8.8	11.9%	0.0%	90.1%	0.0%	0.0%	1.0	11.9%
MH1mod	64.5	35.1%	22.7	27.7%	0.0%	90.4%	0.0%	0.0%	6.3	27.7%
Total			**176.2**						**49.3**	**28.0%**

Class 2 Single Cylinder Generators

Table E.4.4.3: Class 2 Single-Cylinder Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Percentage of Potential Deaths Averted

Model	Alloc Deaths - All Gens	% Class 2	Class 2 Deaths	Living Space	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
AH10	4.5	57.1%	2.6	32.1%	27.2%	0.0%	0.0%	0.0%	0.8	30.5%
AH21	1.0	57.1%	0.6	19.5%	25.8%	0.0%	27.6%	0.0%	0.2	27.3%
AH3	7.5	57.1%	4.3	13.0%	0.0%	0.0%	0.0%	0.0%	0.6	13.0%
AH34mod	3.0	57.1%	1.7	45.0%	31.9%	0.0%	32.2%	0.0%	0.6	32.2%
DH-1	9.7	66.3%	6.4	26.1%	0.0%	0.0%	87.8%	0.0%	4.6	71.5%
DH-10	4.0	66.3%	2.7	42.6%	19.8%	0.0%	85.4%	0.0%	1.9	71.9%
DH-12	5.6	66.3%	3.7	42.8%	29.4%	0.0%	90.3%	0.0%	2.9	77.8%
DH-19mod	17.7	66.3%	11.7	41.3%	15.8%	0.0%	18.8%	0.0%	2.1	18.2%
DH-2	12.7	66.3%	8.4	53.8%	23.1%	0.0%	78.8%	0.0%	5.6	67.3%
DH-21	31.4	66.3%	20.8	36.7%	0.0%	0.0%	0.0%	0.0%	7.6	36.7%
DH-21mod	5.9	66.3%	3.9	50.6%	0.0%	0.0%	0.0%	0.0%	2.0	50.6%
DH-24mod	5.2	66.3%	3.4	33.4%	0.0%	0.0%	0.0%	0.0%	1.1	33.4%
DH-27	2.0	66.3%	1.3	39.4%	36.4%	0.0%	0.0%	0.0%	0.5	37.2%
DH-2mod	2.5	66.3%	1.7	48.3%	26.8%	0.0%	28.8%	0.0%	0.5	28.4%
DH-3	18.3	66.3%	12.2	40.0%	0.0%	94.0%	0.0%	0.0%	4.9	40.0%
DH-32	6.0	66.3%	4.0	10.3%	0.0%	0.0%	0.0%	0.0%	0.1	2.7%
DH-33mod	7.1	66.3%	4.7	25.0%	0.0%	0.0%	87.9%	0.0%	3.4	71.3%
DH-34	21.6	66.3%	14.3	20.2%	0.0%	0.0%	0.0%	0.0%	2.9	20.2%
DH-41	6.0	66.3%	4.0	39.2%	28.7%	0.0%	0.0%	0.0%	1.3	31.6%
DH-44	1.0	66.3%	0.7	46.0%	30.3%	0.0%	88.7%	0.0%	0.5	76.6%
DH-45	3.0	66.3%	2.0	17.5%	35.4%	0.0%	83.3%	0.0%	1.5	73.4%
DH-45mod	33.4	66.3%	22.1	14.7%	20.2%	0.0%	29.7%	0.0%	6.1	27.7%
DH-5	9.7	66.3%	6.5	22.9%	0.0%	0.0%	85.1%	0.0%	4.4	68.7%
DH-52mod	7.0	66.3%	4.6	24.8%	57.6%	0.0%	92.7%	0.0%	4.0	85.5%
DH-56	7.5	66.3%	5.0	40.8%	20.9%	0.0%	0.0%	0.0%	1.3	26.3%
DH-60	9.2	66.3%	6.1	30.3%	30.4%	0.0%	85.1%	0.0%	4.5	73.9%
DH-60mod	3.5	66.3%	2.3	59.0%	28.4%	0.0%	31.3%	0.0%	0.7	30.7%
DH-61	16.7	66.3%	11.1	58.1%	47.4%	0.0%	0.0%	0.0%	5.6	50.3%
DH-61mod	28.0	66.3%	18.5	22.4%	35.8%	0.0%	0.0%	0.0%	6.0	32.1%
DH-63mod1	24.3	66.3%	16.1	37.5%	38.2%	0.0%	0.0%	0.0%	6.1	38.0%
DH-63mod2	7.0	66.3%	4.6	29.0%	33.8%	0.0%	0.0%	0.0%	1.5	32.5%
DH-64	11.1	66.3%	7.3	22.6%	0.0%	0.0%	85.8%	0.0%	5.1	69.1%
DH-7	23.0	66.3%	15.3	58.4%	23.7%	0.0%	83.6%	0.0%	10.9	71.3%
DH-8	15.5	58.1%	9.0	31.3%	0.0%	0.0%	84.7%	0.0%	6.4	70.6%
DH-81	5.5	66.3%	3.6	28.1%	39.0%	0.0%	0.0%	0.0%	1.3	36.1%
GAR1	12.9	52.0%	6.7		0.0%	0.0%	8.6%	0.0%	0.6	8.6%
GAR2	13.7	35.1%	4.8		0.0%	0.0%	12.2%	0.0%	0.6	12.2%
GAR3	19.4	81.3%	15.8		0.0%	0.0%	43.6%	50.7%	7.4	47.0%
MH1	15.5	42.9%	6.6	14.8%	0.0%	88.3%	0.0%	0.0%	2.6	39.3%
MH1mod	64.5	62.2%	40.1	34.3%	0.0%	78.2%	0.0%	0.0%	13.8	34.3%
			321.3						**134.2**	**41.8%**

Table E.4.4.4: Class 2 Single-Cylinder Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (500 g/hr) Percentage of Potential Deaths Averted

Model	Alloc Deaths - All Gens	% Class 2	Class 2 Deaths	Living Space	Basement	Crawlspace	Attached Garage/ Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
AH10	4.5	57.1%	2.6	19.1%	19.2%	0.0%	0.0%	0.0%	0.5	19.1%
AH21	1.0	57.1%	0.6	10.3%	13.7%	0.0%	18.7%	0.0%	0.1	17.7%
AH3	7.5	57.1%	4.3	7.2%	0.0%	0.0%	0.0%	0.0%	0.3	7.2%
AH34mod	3.0	57.1%	1.7	31.9%	17.4%	0.0%	17.3%	0.0%	0.3	17.3%
DH-1	9.7	66.3%	6.4	16.3%	0.0%	0.0%	65.6%	0.0%	3.4	52.6%
DH-10	4.0	66.3%	2.7	35.0%	12.1%	0.0%	61.3%	0.0%	1.4	51.2%
DH-12	5.6	66.3%	3.7	34.3%	19.5%	0.0%	79.2%	0.0%	2.5	66.9%
DH-19mod	17.7	66.3%	11.7	27.0%	8.7%	0.0%	9.2%	0.0%	1.1	9.1%
DH-2	12.7	66.3%	8.4	44.1%	14.8%	0.0%	66.5%	0.0%	4.7	55.8%
DH-21	31.4	66.3%	20.8	15.7%	0.0%	0.0%	0.0%	0.0%	3.3	15.7%
DH-21mod	5.9	66.3%	3.9	22.8%	0.0%	0.0%	0.0%	0.0%	0.9	22.8%
DH-24mod	5.2	66.3%	3.4	13.5%	0.0%	0.0%	0.0%	0.0%	0.5	13.5%
DH-27	2.0	66.3%	1.3	19.7%	13.4%	0.0%	0.0%	0.0%	0.2	15.1%
DH-2mod	2.5	66.3%	1.7	38.5%	11.5%	0.0%	11.2%	0.0%	0.2	11.3%
DH-3	18.3	66.3%	12.2	14.6%	0.0%	51.3%	0.0%	0.0%	1.8	14.6%
DH-32	6.0	66.3%	4.0	5.8%	0.0%	0.0%	0.0%	0.0%	0.1	1.5%
DH-33mod	7.1	66.3%	4.7	15.5%	0.0%	0.0%	51.1%	0.0%	2.0	41.7%
DH-34	21.6	66.3%	14.3	10.0%	0.0%	0.0%	0.0%	0.0%	1.4	10.0%
DH-41	6.0	66.3%	4.0	30.4%	17.6%	0.0%	0.0%	0.0%	0.8	21.1%
DH-44	1.0	66.3%	0.7	30.7%	18.3%	0.0%	61.3%	0.0%	0.3	52.5%
DH-45	3.0	66.3%	2.0	9.4%	22.7%	0.0%	69.5%	0.0%	1.2	59.8%
DH-45mod	33.4	66.3%	22.1	7.1%	11.3%	0.0%	19.6%	0.0%	4.0	17.9%
DH-5	9.7	66.3%	6.5	15.0%	0.0%	0.0%	83.3%	0.0%	4.2	65.3%
DH-52mod	7.0	66.3%	4.6	14.7%	35.6%	0.0%	73.7%	0.0%	3.0	65.8%
DH-56	7.5	66.3%	5.0	31.5%	9.8%	0.0%	0.0%	0.0%	0.8	15.7%
DH-60	9.2	66.3%	6.1	18.5%	17.8%	0.0%	73.8%	0.0%	3.8	62.3%
DH-60mod	3.5	66.3%	2.3	32.2%	13.3%	0.0%	13.2%	0.0%	0.3	13.2%
DH-61	16.7	66.3%	11.1	23.5%	22.4%	0.0%	0.0%	0.0%	2.5	22.7%
DH-61mod	28.0	66.3%	18.5	12.8%	16.7%	0.0%	0.0%	0.0%	2.9	15.7%
DH-63mod1	24.3	66.3%	16.1	17.5%	21.3%	0.0%	0.0%	0.0%	3.3	20.2%
DH-63mod2	7.0	66.3%	4.6	12.6%	20.3%	0.0%	0.0%	0.0%	0.8	18.2%
DH-64	11.1	66.3%	7.3	14.9%	0.0%	0.0%	52.6%	0.0%	3.1	42.6%
DH-7	23.0	66.3%	15.3	53.6%	14.8%	0.0%	81.2%	0.0%	10.3	67.5%
DH-8	15.5	58.1%	9.0	17.8%	0.0%	0.0%	82.7%	0.0%	5.9	65.5%
DH-81	5.5	66.3%	3.6	13.7%	22.3%	0.0%	0.0%	0.0%	0.7	20.0%
GAR1	12.9	52.0%	6.7		0.0%	0.0%	4.2%	0.0%	0.3	4.2%
GAR2	13.7	35.1%	4.8		0.0%	0.0%	7.0%	0.0%	0.3	7.0%
GAR3	19.4	81.3%	15.8		0.0%	0.0%	14.3%	35.3%	3.9	24.4%
MH1	15.5	42.9%	6.6	8.1%	0.0%	43.7%	0.0%	0.0%	1.3	19.9%
MH1mod	64.5	62.2%	40.1	11.9%	0.0%	40.9%	0.0%	0.0%	4.8	11.9%
			321.3						**83.1**	**25.8%**

Handheld Generators

Table E.4.4.5: Handheld Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (125 g/hr) Percentage of Potential Deaths Averted

Model	Allocated Deaths - All Generators	Proportion	Handheld Generator Deaths	Living Space	Basement	Crawlspace	Attached Garage	Workshop	Deaths Avoided	% Deaths Avoided
MH1mod	64.5	2.7%	1.7	64.7%					1.1	64.7%
DH-8	15.5	12.4%	1.9	49.4%					0.9	49.4%
Total			**3.7**						**2.1**	**56.7%**

Table E.4.4.6: Handheld Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (250 g/hr) Percentage of Potential Deaths Averted

Model	Allocated Deaths - All Generators	Proportion	Handheld Generator Deaths	Living Space	Basement	Crawlspace	Attached Garage	Workshop	Deaths Avoided	% Deaths Avoided
MH1mod	64.5	2.7%	1.7	25.2%					0.4	25.2%
DH-8	15.5	12.4%	1.9	14.6%					0.3	14.6%
Total			**3.7**						**0.7**	**19.6%**

Class 2 Twin Cylinder Generators

Table E.4.4.7: Class 2 Twin-Cylinder Generators – Lower-Bound Reduced CO Emission Model Generators Estimate (500 g/hr) Percentage of Potential Deaths Averted

Model	Allocated Deaths - All Generators	Proportion	Twin Cylinder Generator Deaths	Living Space	Basement	Crawlspace	Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
GAR3	19.4	9.4%	1.8				24.2%	14.5%	0.4	21.8%
Total			**1.8**						**0.4**	**21.8%**

Table E.4.4.8: Class 2 Twin-Cylinder Generators – Upper-Bound Reduced CO Emission Model Generators Estimate (1000 g/hr) Percentage of Potential Deaths Averted

Model	Allocated Deaths - All Generators	Proportion	Twin Cylinder Generator Deaths	Living Space	Basement	Crawlspace	Garage Area	Workshop	Deaths Avoided	% Deaths Avoided
GAR3	19.4	9.4%	1.8				8.6%	7.3%	0.2	8.3%
Total			**1.8**						**0.2**	**8.3%**

E.4.5 Estimated Deaths Averted from Low Emission Generators

H = Sum of Deaths Averted for All structures = Sum of All H_j

Table E.4.5.1 below provides a summary of the modeling results for potential deaths averted and the associated percentage reduction from the actual fatalities allocated by class (Base Rate estimates. Results are presented for all six CO emission levels modeled.

Table E.4.5.1: Summary of Potential Deaths Averted Based on Modeling Results and Associated Save Rates for Each Generator Category and Modeled CO Emission Rate

	Handheld	Class 1	Class 2 Single Cylinder	Class 2 Twin Cylinder
Base Rate Deaths	3.7	176.2	321.3	1.8
Potential Deaths Averted				
50g/hr	3.5	163.2	309.7	1.8
125g/hr	2.1	100.0	226.8	1.6
250g/hr	0.7	49.3	134.2	1.0
500g/hr	0.2	25.1	83.1	0.4
1000g/hr	n/a	10.2	52.9	0.2
2000g/hr	n/a	n/a	27.5	0.1
Potential Lives Saved Rate				
50g/hr	95.8%	92.6%	96.4%	100.0%
125g/hr	56.7%	56.7%	70.6%	86.4%
250g/hr	19.6%	28.0%	41.8%	55.6%
500g/hr	5.2%	14.2%	25.8%	21.8%
1000g/hr	n/a	5.8%	16.5%	8.3%
2000g/hr	n/a	n/a	8.5%	2.9%

Engineering staff identified the following CO emission rates staff considers to be technically feasible for each generator category (see reference 1 for details).

Table E.4.5.2: Technically Feasible CO Emission Rates

Generator Category	Technically Feasible CO Emission Rate (g/hr)
Handheld	50
Class 1	50
Class 2 Single Cylinder	100
Class 2 Twin Cylinder	200

The final table presents a summary of the number of deaths that potentially could have been averted over the 2004 to 2012 time span, if low-emission generators, as outlined in this report, were used in place of the high CO output generators use during this period. The numbers are based on the conservative assumption of CO emission rates tripling from technically feasible rates in normal oxygen for each generator category when operating in theorized oxygen depletion. This factor of 3 is based on testing conducted by NIST[2] and CPSC staff[3] on carbureted generators. However, from staff's testing of fuel-injected generators with different degrees of closed-loop operation (discussed in reference 3), staff believes that a threefold factor of increase for some generators using closed-loop EFI when operated in 17 percent oxygen, may be conservative. Furthermore, test results from NIST[4] indicate that the EFI generator depleted the oxygen significantly less than the carbureted generator in each matched pair identical test scenario. Nevertheless, staff has based its benefits analysis on reduced CO emission rates that are threefold higher than the reduced emission rate at normal oxygen, which is the same factor of increase used for the current carbureted generators in the modeling. Therefore, the factor of 3 could likely overstate the weighted CO emission rates for EFI-generators when operated indoors, and the factor of 3 could understate the reduction in deaths and injuries resulting from the draft standard. Because the reduced oxygen, technically feasible CO emission rate values do not match up exactly with the modeled CO rates, the values presented in this table are curve-fit interpolated values based on the summary values shown in Table E.4.5.2. Staff realizes there is uncertainty associated with this estimate given the assumptions and estimations staff used in developing this estimate. However, staff used conservative values and believes the uncertainty in the estimate is within the range of the sensitivity analysis that staff performed on the effectiveness of the emission rates, as described in staff's regulatory analysis for staff's proposed rule.

Table E.4.5.3: Summary of Potential Deaths Averted at Technically Feasible CO Emission Rates When a Generator is Operating in an Enclosed Space at Reduced Oxygen, 2004-2012

Generator Category	CO Emission Rate* Simulating Generator Operation in an Enclosed Space	Actual Fatalities Allocated by Class	Potential Deaths Averted	Potential Lives Saved Rate
Handheld	150	3.7	1.7	46.6%
Class 1	150	176.2	87.7	49.7%
Class 2 Single Cylinder	300	321.3	117.9	36.7%
Class 2 Twin Cylinder	600	1.8	0.3	17.2%
Total	**- -**	**503.0**	**207.6 = ~208**	**41.3%**

*- These rates are 3 times the technically feasible rates at normal ambient oxygen (~20.9%) to account for CO emission rate increase in reduced oxygen. To account for production variation, the CO emission rates in the proposed requirement are 1.5 times the technically feasible rate in normal oxygen.

References

[1] Buyer, Janet, *Rationale for Proposed Performance Requirements, Effective Dates, and Certification for Staff's Proposed Rule for Portable Generators*, U.S. Consumer Product Safety Commission, Bethesda, MD, 2016. (TAB I in the NPR briefing package)

[2] Emmerich SJ, Polidoro, B, Dols WS, *Simulation of Residential CO Exposure Due to Indoor Portable Generator Operation*, NIST Technical Note 1925, 2016.

[3] Brookman, Matthew, P.E., *Development of Test Methods for Determining the Carbon Monoxide Emission Rate of Portable Generators in Normal and Reduced Atmospheric Oxygen*, U.S. Consumer Product Safety Commission, Bethesda, MD, 2016. (TAB J in the NPR briefing package).

[4] Buyer J. *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator.* U.S. Consumer Product Safety Commission, Bethesda, MD, September 2012.

F. HS Staff Response to COHb-Related Public Comments on the ANPR and the Prototype Report

This section presents HS staff's response to public comments related to interpretation of COHb levels as presented in: (A) the 2006 Portable Generators - Advanced Notice of Proposed Rulemaking (ANPR)[a,b] and (B) staff's 2012 research report titled, "Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator."[c]

[a] See 71 FR 238, pp74472-74474, December 12, 2006, https://www.cpsc.gov/PageFiles/95179/pganpr.pdf
[b] See https://www.cpsc.gov//PageFiles/87714/PortableGenerators.pdf
[c] See http://www.cpsc.gov/PageFiles/129846/portgen.pdf

F1 Comments on 2006 ANPR and related 2006 Generator Safety Briefing Package.
Comment #CC-07-3-9, dated 02-07-07, from Mr. Albert Donnay.

Comment*:* The commenter considers that CPSC staff assumes COHb levels below 10 percent are not harmful. He notes that there is no scientific basis for such an assumption and also notes that, in many studies, COHb levels do not correlate consistently with symptoms.

Staff Response**:** CPSC staff does not assume that a CO exposure resulting in less than 10% COHb is incapable of causing adverse health effects. Staff has long recognized the existence of populations especially sensitive to CO health effects (fetuses, asthmatics, and individuals with cardiovascular diseases.)[1] Most authorities, including CPSC, consider individuals with coronary artery disease [CAD] to be the population most sensitive to potential adverse health effects of CO at the lowest exposure levels.[2,3,4] Some studies report individuals with CAD might perceive adverse health effects, and/or tests show that they may experience adverse health effects that they are unaware of, at about 2 to 5 % COHb. HS staff understands that the pathophysiological effects of CO are complex and strongly influenced by multiple factors, particularly CO level, exposure duration, and exposed individual's inhalation rate and health status. In ANPR and Prototype Report documents, staff focused on extremely high level, acutely lethal, CO exposures caused by generator exhaust. Therefore, rather than provide an exhaustive review of all studies, including equivocal findings in some low-level exposure studies,[5] staff endeavored to provide an overview of the complex interactions between multiple variables that influence the end effects of acute, high-severity CO exposures in humans. Staff emphasized that CO poisoning effects should be understood to be a continuum of effects of the exposure, rather than be viewed as discrete health effects tightly tied to specific CO levels or COHb levels.

F2 Comments on 2012 Staff Research Report - Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator (aka, Prototype Report).
Comment 9, dated September 24, 2012 from Dr. Neil B. Hampson, MD

Comment*:* Dr. Hampson considers that a low CO emissions generator *"would undoubtedly save lives if widely applied,"* but he has expressed concern that *"prediction of confusion and incapacitation from COHb levels is not possible."* He provided his recent publication reporting that "*symptoms of CO poisoning do not correlate well with COHb levels.*"[6] Based on his findings and other clinical reports, Dr. Hampson questions the validity and/or concept of a table relating COHb levels to particular symptoms, as used by CPSC staff[d]; his research findings attribute the likely source of all such tables to a 1920s Bureau of Mines staff report.[7] Dr. Hampson believes that it is *"not correct"* to use COHb levels to calculate egress times from a CO-containing environment; he notes: "there are no data to support the method."

NOTE: The first commenter, Mr. Donnay, has also questioned the validity of an approximate relationship between COHb levels and severity of CO poisoning symptoms/health effects.[8]

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[d] See Table 4, *The Approximate Correlation Between Acute %COHb Levels and Symptoms in Healthy Adults*, in the HS staff support memorandum, Tab G of the CPSC staff research report, *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator*, (Buyer, 2012).

Staff Response: Staff's use of predicted COHb levels was not intended to calculate an actual egress time from a CO exposure; and staff noted that a reduced emissions generator would not guarantee egress by exposed individuals. Rather, staff considers that reduced generator CO emissions, as achieved with its prototype unit, will substantially delay the rate at which CO levels rise in poorly ventilated spaces, and therefore, will delay the rate at which COHb levels of exposed individuals rise (in some cases reducing the peak COHb level attained). Staff reasons that this will provide significantly increased time available for individuals to remove themselves from the exposure environment,[e] or be rescued by an outside party. Supporting evidence that some individuals will react appropriately to slower onset of CO poisoning effects has been reported (111 of 167 patients with CO poisoning presented to Florida hospital emergency departments (ED) between 5 a.m. and 10 a.m., after waking and feeling ill consequent to overnight use of a generator during hurricane-related power outages).[9] CPSC data indicate that in 69 of 93 cases where it was known how and why a patient with generator-related CO exposure presented to an ED, the patient had either transported themselves or contacted others (911, family, friends) to arrange for their transport to the ED. In the remaining cases, individuals were found in distress by others (either a lesser affected co-exposed individual or an outside party).[10]

Staff recognizes that even healthy individuals can exhibit variability in individual susceptibility to CO health effects under identical exposure scenarios. Staff understands that, in *clinical* situations, CO poisoning symptoms and health effects do not necessarily correlate well with a patient's initial COHb measurement, which is often confounded (generally reduced by factors such as time interval relative to cessation of CO exposure and provision of supplemental oxygen). Clearly, COHb measurements can be of limited value to physicians when determining appropriate treatment plans for individual patients.[f]

Rather than make clinical decisions, staff needed to provide controlled, systematic comparisons of how CPSC's reduced CO emissions prototype generator could be expected to reduce the lethal CO hazard presented by the unmodified original generator. Therefore, staff used identical physiological input parameters for a healthy adult to model COHb formation and elimination from empirical generator CO time course exposure data. Predicted times taken to rise to, and progress through, three convenience benchmark percentile COHb values were used to compare the relative CO poisoning hazard presented by a generator before and after design modifications to reduce its CO emission rate. Staff considered these benchmark values to *approximate* relatively mild (20% COHb), potentially incapacitating (40% COHb) and likely lethal (60% COHb) exposure levels. Although indicating health effects generally first reported at these benchmark COHb levels, staff did not intend to convey that they represented precise measures when appearance of symptoms and adverse health effects would be expected in all individuals. Staff noted that rapidly rising, high-level CO exposures of several thousand ppm (as can occur with current carbureted generators) would result in extreme oxygen deprivation and fast-rising COHb levels, causing rapid incapacitation, loss of consciousness and death, without

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[e] Individuals may leave the exposure location for a variety of reasons, including onset of progressively worsening non-specific symptoms resulting in general concern that something is not right or clear awareness of a developing CO hazard; activation of a CO alarm; or simply leaving the location to go about daily activities (*e.g.*, work, school) before being incapacitated.

[f] Although a measurement $\geq$ 25% COHb is one factor typically used as a selection criterion for HBO-T, a lower measured COHb level does not necessarily exclude a patient from consideration for HBO-T if other clinical signs indicate high severity poisoning.

individuals necessarily experiencing milder, progressively worsening CO poisoning symptoms typically manifested in slowly rising or lower-level CO exposures.

Staff respectfully opines that modern clinical findings do not negate the existence of a fundamental **approximate** dose-response relationship for CO, long reported in other clinical reports, research studies, and authoritative textbooks, whereby severity of adverse health effects experienced is related to highest COHb levels attained (or CO time-weighted exposures). Staff considers that the available physiological research data and clinical findings in the scientific literature do support staff's use of "COHb benchmarks," for approximate estimation and comparison of CO-related health effects expected during generator-related exposures (see Appendices C and D). Staff notes some key early literature reports detailing controlled physiological studies of CO exposure in human subjects and unintentional high-level CO exposures.[g, 11, 12,h, 13, 14, 15, 16, 17] Staff welcomes suggestions on alternative health-based approaches to compare the reduced CO emissions generators with current products for improved safety benefits.

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TAB L

Draft Proposed Rule Establishing a Safety Standard for Portable Generators: Preliminary Regulatory Analysis

Charles L. Smith
Directorate for Economic Analysis
Consumer Product Safety Commission
October 2016

Executive Summary

This preliminary regulatory analysis presents an initial evaluation of the benefits and costs of the staff's draft proposed standard to address the risks of carbon monoxide (CO) poisoning from portable generators powered by small spark-ignition (SI) engines. About 80 manufacturers and importers have supplied gasoline-powered portable generators for the U.S. market in recent years. The top 10 manufacturers account for about 84 percent of unit sales of generators in power ranges likely to be purchased by consumers. Although annual sales fluctuate, yearly shipments from 2010 through 2014 ranged from about 1.2 million to 1.6 million units.

During 2004–2012, there was an average of about 73 portable generator-related CO poisoning deaths and at least 2,800 generator-related nonfatal injuries annually. The societal costs of these deaths and injuries averaged about $820 million annually. During the same period, there was an average of about 11.1 million portable generators in use, suggesting about 0.66 deaths and at least 25.2 nonfatal CO poisonings per 100,000 portable generators in use.

The draft proposed standard seeks to reduce deaths and injuries by limiting the grams of CO that may be emitted per hour, with different limits based on engine class (determined by displacement) and other characteristics (such as number of cylinders). The draft proposed standard distinguishes among four primary categories of portable generators, including:

- Generators with handheld engines (displacement of 80 cc or less);
- Generators with Class I engines (displacement less than 225 cc);
- Generators with one-cylinder Class II engines (displacement of 225 cc and more); and
- Generators with two-cylinder Class II engines (displacement of 225 cc and more).

Generators with Class I engines and one-cylinder Class II engines accounted for an estimated 92.2 percent of portable generators in use during 2004–2012. Generators with handheld and two-cylinder Class II engines are estimated to have comprised 0.7 percent and 7.1 percent of portable generators in use, respectively.

The draft proposed standard would require portable generators powered by handheld engines and Class I engines to emit CO at a weighted rate of no more than 75 grams per hour (g/h); those with one-cylinder Class II engines may not exceed a weighted emission rate of 150 g/h; and those with two-cylinder Class II engines may not exceed 300 g/h.

The base case analysis suggests substantial gross benefits for most generators. The estimated *gross* benefits per generator ranged from about $215 to $255 for generators with hand-held, Class I, and one-cylinder Class II engines. However, the expected gross benefits for generators with two-cylinder Class II engines amounted to only about $4 per unit.

The estimated costs of the draft proposed standard were generally similar across generator types, ranging from about $110 to $120 per generator for the models with handheld, Class I, and one-cylinder Class II engines, to about $140 for the models with two-cylinder Class II engines. The retail price increases likely to result from increases in manufacturing costs could reduce portable generator sales by roughly 50,000 units annually, an overall sales reduction of about 3 to 4 percent.

Given these findings, and with the exception of the models with two-cylinder Class II engines, *net benefits* (*i.e.*, benefits minus costs) ranged from about $100 to about $140 per generators with handheld, Class I, and one-cylinder Class II engines. However, net benefits were a *negative* $135 for the models with two-cylinder Class II engines (*i.e.*, benefits of $4 per generator minus costs of $139 per generator).

The estimated per-unit benefits and costs can be converted to aggregate annual estimates, given information on the production and sale of portable generators. Based on sales estimates, the aggregate annual benefits and costs of the staff's draft proposed rule would amount to about $297.6 million and $153.0 million, respectively. Therefore, aggregate net benefits would amount to about $144.6 million annually. However, because the costs of the draft proposed rule for generators with two-cylinder Class II engines ($139 per unit) substantially exceeded the benefits (about $4 per unit), excluding the generators with two-cylinder Class II engines from the draft proposed rule would increase aggregate net benefits to $153.2 million.

The main findings of the base analysis were not altered by the results of the sensitivity analysis, which considered variations in the products' expected product life; the discount rate; compliance costs; the value of statistical life applied; and the estimated effectiveness in reducing CO emissions for each engine class. For each variation analyzed, the overall estimated net-benefits of the draft proposed standard were positive; and, as with the base analysis, generators with two-cylinder engines were found to have estimated costs that are greater than the present value of projected benefits.

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1. Introduction

The U.S. Consumer Product Safety Commission (CPSC or Commission) for many years has established as a strategic goal the reduction in the rate of non-fire-related carbon monoxide (CO) poisoning deaths associated with consumer products. In 2002 the Commission initiated the Portable Generator Project to look specifically at the CO poisoning hazard associated with this product because the estimated number of CO poisoning deaths related to generators annually appeared to be increasing. In 2006 concerns with the safety of portable generators prompted the Commission to approve an advance notice of proposed rulemaking (ANPR) and direct staff to investigate potential technologies to reduce the hazard of CO poisoning from generators.[1]

CPSC staff created a technology development and demonstration program to see if a portable generator powered by an engine with a substantially reduced CO emission rate could be developed to reduce the risk of fatal and severe CO poisonings when the generator is used in an attached garage (an indoor location that is frequently reported in generator-related consumer fatalities, despite warnings against use in this location). Based in part on the results of staff's technology demonstration of a prototype low CO emission portable generator (Buyer, 2012), CPSC staff has concluded that reducing the CO emission rates of generator engines would be the most reliable strategy to address the CO hazard associated with this product. This memorandum provides a preliminary regulatory analysis of staff's draft proposed standard that is intended to achieve significant reductions in CO emissions from portable generators.

2. The Draft Proposed Standard

2.1. Need for the Draft Proposed Rule

2.1.1. Deaths and Injuries from CO Poisoning

From 2004 through 2014, the Commission is aware of reports of at least 751 fatalities that were associated with CO emissions from consumer use of generators, either alone (702) or in combination with the operation of other fuel-burning appliances (49) (Hnatov, 2015). Deaths can occur when CO enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood's capacity to carry oxygen to organs and tissues (Inkster, 2012). Deaths resulted when generators were operated in indoor locations, as well as in some outdoor locations. From 2004 through 2012 (the most recent year for which the Hazard Analysis Division considers incident reporting to be essentially complete), the number of CO poisoning deaths associated with portable generators reported to the CPSC averaged about 73 annually.[2]

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[1] 16 CFR Chapter 11, *Portable Generators; Advance Notice of Proposed Rulemaking; Request for Comments and Information*, Federal Register, 71 FR 74472, December 12, 2006.

[2] For the purpose of staff's epidemiological benefits analysis (Hnatov, Inkster & Buyer, 2016) and the preliminary regulatory analysis, the data reported to CPSC as of May 21, 2015 for years 2013 and 2014, which amounted to 85 (of the 751) deaths in 64 incidents, are not included. Also excluded from staff analyses are 5 deaths in 3 incidents that occurred in the years 2004 through 2012 that were known to involve a stationary generator and 2 deaths in 2 incidents that occurred in those years that were known to involve a generator that was part of a welding machine, because these types of generators are excluded from the scope of the draft proposed rule (discussed in Section 2.2.1., below). Therefore, staff's analyses are based on 659 deaths in 493 incidents that occurred from 2004 through 2012. It should be noted that reporting of generator-related deaths is not a statistical sample or a complete census of incidents.

In addition to fatalities from CO exposure, portable generators are responsible for many nonfatal injuries each year. The Hazard Analysis Division of the CPSC Directorate for Epidemiology provided analysis of data from a search of CPSC's National Electronic Injury Surveillance System (NEISS) for portable generator-related CO injuries seen in emergency departments in recent years. Estimated nonfatal CO poisoning emergency department-treated injuries related to the use of portable generators during 2004 ─ 2012 totaled a minimum of 8,703 (Hanway, 2015), a minimum annual average of 967 during this period. The Directorate for Health Sciences (HS) reports that for some individuals who survive serious, prolonged COHb elevations, the resulting brain hypoxia, and any consequent associated damage, may result in the phenomenon of delayed neurological sequelae (DNS), including symptoms of emotional instability, memory loss, dementia, psychosis, Parkinsonism, incontinence, blindness, hearing loss, paralysis, and peripheral neuropathy (Inkster, 2012). Some of the more severe symptoms are often permanent. HS staff believes that survivors of generator-related CO poisoning incidents can be at significant risk of developing DNS, particularly if the incident is known also to involve a death.

Staff's draft proposed standard will reduce the risk of CO poisoning resulting from operating a generator in an indoor location, and in some outdoor locations as well. Portable generators that comply with the draft proposed standard are expected to expose consumers to lower levels of CO, and the resulting lower COHb levels will lead to reduced fatality rates. Staff believes that a significant reduction in the rate of progression of CO poisoning symptoms would make it more likely that occupants: recognize that their CO poisoning symptoms are indicative of a developing hazardous situation; are provided with a longer period of awareness to allow consumers to remove themselves from the exposure before being incapacitated; or might simply be able to leave the home for other everyday reasons, such as going to work and shopping (Hnatov, Inkster & Buyer, 2016). Reduced CO emission rates will also increase the likelihood that some individuals would be removed from the exposure to CO through interventions, such as welfare checks by other persons. Additionally, in some exposure scenarios, it is possible that reduced CO emissions will prevent the development of lethal CO exposures; so individuals might survive, with varying levels of CO health effects, even if they do not take any specific actions. Staff of CPSC Division of Human Factors, Directorate for Engineering Sciences, believes that performance requirements that reduce CO emissions from portable generators "should increase the chances of survival by providing consumers with more time to detect and correctly diagnose their symptoms, and to escape or perform other actions that might reduce CO exposure" (T. Smith, 2016). The high CO emission rates of current generators can result in the exposed person experiencing the onset of confusion extremely quickly, along with loss of muscular coordination, loss of consciousness and death, with little or no time experiencing the milder CO poisoning symptoms. Without adequate warning provided by milder symptoms, victims have very little time, if any, to recognize that an imminent life-threatening environmental hazard is occurring and be able to seek safety or take other actions that could help their situation after being exposed.

2.1.2. Market Failure

A market failure can exist when the private markets fail to adequately protect or improve the health and safety of the public. Such market failures can justify regulatory intervention. The major types of market failure, as described in the Office of Management and Budget's (OMB) Circular A-4 (2003), concern: (1) inadequate or asymmetric information, (2) externalities, and (3) market power. In the case of portable generators, arguably, many of the generator-related CO deaths and injuries result from inadequate information. Inadequate information exists when consumers do not have sufficient knowledge to understand fully the risks associated with a product and how to use the product safely.

The continued occurrence of CO poisoning from the improper placement of generators suggests that some consumers do not understand the risks of using portable generators in enclosed or semi-enclosed spaces or how rapidly CO poisoning can progress when generators are used in or near enclosed areas. When it is determined that consumers *do not* have adequate information to use a product safely, one response is to provide the consumer with the information required to use the product safely. Toward that end, most portable generators include cautionary information on product labels and operating instructions regarding risks of CO poisoning. Moreover, the Commission required mandatory warning labels starting in in 2007. Nevertheless, deaths and injuries from the improper placement of newly purchased generators suggest that at least some consumers poorly understand and process the information contained in the operating instructions and warning labels and continue to put themselves and others at risk through the improper placement of generators in enclosed areas. Consequently, additional regulatory interventions may be warranted.

2.1.3. CPSC Staff Assessment of the Adequacy of Voluntary Standards for Portable Generators in Addressing CO Deaths and Injuries

Two organizations, Underwriters' Laboratories, Inc. (UL) and the Portable Generator Manufacturers Association (PGMA) have been accredited by the American National Standards Institute (ANSI) to develop U.S. safety standards for portable generators. Although each organization has developed a standard (designated as UL 2201 and PGMA G300, respectively), only PGMA's standard has achieved the consensus needed to be recognized by ANSI (as ANSI/PGMA G300-2015). A UL 2201 task group has been working on developing proposals to address CO hazards of portable generators. However, the task group has not yet sent a proposal to the standards technical panel established by UL to consider for adoption into UL 2201. The current version of UL 2201 includes the same requirements as the mandatory CPSC label, but UL 2201 does not otherwise address the risks related to CO poisoning. Staff believes that the label alone is insufficient to address the risk of injury from CO poisoning. Staff is unaware of any portable generator that has been certified to UL 2201. Therefore, it is unlikely that there would be substantial compliance with UL 2201 if the standard were to incorporate CO emissions requirements (Buyer, 2016b).

PGMA G300 also includes the same requirements as the mandatory CPSC label for portable generators, but does not otherwise address the risks related to CO poisoning. In a letter dated September 16, 2016 to CPSC Chairman, Elliot Kaye, PGMA announced its intention to reopen G300 to develop a "performance strategy focused on CO concentrations" [which will provide] … companies flexibility in meeting a standard [by allowing them to either] reduce CO emissions as a whole, or demonstrate that products will not exceed a CO threshold in an enclosed space" (Orenga, 2016). As discussed in the briefing memorandum (Buyer, 2016b), staff does not have an adequate basis to determine that PGMA's modification to G300 would likely eliminate or reduce the risk of injury or that there will likely be substantial compliance with the voluntary standard, once modified. In addition, based on the complex nature of setting CO limits and the fact that G300 is just now being re-opened, staff is not convinced that a modification to the voluntary standard adequately addressing the risk of injury identified in the rulemaking would be accomplished within a reasonable period of time. Staff believes that significant technical work, requiring significant time, would be required in order to develop appropriate requirements and test methods within the broad framework identified in the PGMA letter and at a September 6, 2016, public meeting between PGMA and staff. Specifically, as discussed at the meeting and in the NPR briefing memorandum, there are several technical concerns that would need to be investigated about shutoff criteria and testing (Buyer, 2016a). Staff is concerned whether the test methodologies would be accurate, dependable and practicable and sufficient to ensure that the generators would shut off quickly enough in a sufficient number of common scenarios seen in portable generator incidents to result in an adequate reduction in the risk of injury and death. Staff expects that significant periods of time will be needed to evaluate each of these factors. For example, determining the expected epidemiological benefits for the draft proposed rule required nearly a year for NIST to conduct a modelling study and for staff to evaluate the study. For the PGMA to develop an effective voluntary standard, similar efforts will be required to assess the standard after the technical details have been established.

2.2. Scope and Description of the Draft Proposed Standard

2.2.1. Products within the Scope of the Draft Proposed Rule

The draft proposed standard applies to portable generators powered by small handheld[3] and non-handheld (as defined by the Environmental Protection Agency (EPA) at 40 C.F.R. § 1054.801), spark-ignition (SI) engines. Handheld engines have total engine displacement of 80 cubic centimeters (cc) or less; non-handheld engines include EPA Class I engines, with total engine displacement of less than 225cc, and Class II engines with displacement of 225cc and more. Class II engines have an upper limit determined by rated engine power, 19 kilowatts (kW), which is equivalent to 25 horsepower. Generators within the scope of the draft proposed rule provide receptacle outlets for AC output circuits and are intended to be moved, although not necessarily with wheels. Products that would not be covered by the draft proposed rule include permanently installed stationary generators, 50 hertz generators, marine generators, generators installed in recreational vehicles, generators intended to be pulled by vehicles, generators intended to be mounted in truck beds, and generators that are part of welding machines. Generators powered by compression-ignition (CI) engines fueled by diesel also are excluded from the scope of the draft rule.[4]

Portable generators that are the subject of the draft proposed standard and staff analyses commonly are purchased by household consumers to provide electrical power during emergencies (such as power outages caused by storms); when electrical power to the home has been shut off; when power is needed at locations around the home that lack access to electricity; and for recreational activities (such as camping or recreational vehicle trips). Rated power outputs for these units generally range from under 1 kW to about 15 kW. Built-in wheels or optional wheel kits are often available for heavier, more powerful units (*e.g.*, those with 3 kW power ratings and

[3] Although handheld engines generally are used in equipment which is held or supported by an operator during use, they may also be used to power non-handheld equipment such as smaller portable generators.
[4] The current EPA standard for CO emissions is 8.0 g/kW-hr for CI engines rated below 8 kW, which is significantly lower than the EPA standard of 610 g/kW-hr applicable to small SI engine classes used in portable generators.

more). The great majority of the units that fall within the scope of the draft proposed standard are gasoline-fueled; but portable generators powered by engines fueled by liquid propane (LP) present similar risks of CO poisoning; and, therefore, these units also would be covered by the draft proposed standard. Some portable generators can operate fueled by gasoline, LP or natural gas.

2.2.2. CO Emission Limits

The draft proposed standard includes provisions intended to reduce hazards identified by CPSC staff by limiting CO emissions from operating generators. Staff has drafted a performance standard that requires portable generators powered by handheld engines and Class I engines to emit CO at a weighted rate that is no more than 75 grams per hour (g/h); generators powered by one-cylinder Class II engines must not exceed a weighted CO emission rate of 150 g/h; and generators powered by Class II engines with two cylinders would be required to emit CO at a weighted rate of no more than 300 g/h. The weighted emission rates are based on the weighting of six modes of generator operation, ranging from maximum generator load capability (mode 1) to no load (mode 6), similar to a procedure used by EPA to certify compliance with its emission standards for small SI engines. A detailed description of the determination of weighted CO emission rates can be found in Appendix A3 of staff's report on the testing of generators (Brookman, 2016). Staff's analyses, along with the rationale for the standard's CO limits and expected reductions in CO poisoning deaths from the standard are explained in analyses by Buyer (2016a) and Hnatov, Inkster & Buyer (2016), respectively.

The draft proposed standard specifies different limits on weighted emission rates for generators in recognition of the effects of factors such as engine size and other engine characteristics on CO emissions, as well as the different challenges that would be faced in meeting CO emission rates expressed in grams per hour. The draft performance standard applies different criteria to generators, based on EPA's classification of engines (and on the number of engine cylinders), rather than on power ratings of either the generators or the engines. This determination was based primarily on the more direct linkage between the engine size and emissions, than the link between the generator rating and emissions, and the absence of standard methods for defining the rated power, maximum power, or surge power of generators. Furthermore, staff notes that there is uncertainty in many of the in-depth investigation reports when the wattage reported for the portable generator involved in incidents was referring to the generator's rated power, surge power, or maximum power (Hnatov, Inkster & Buyer, 2016).

2.2.3. Draft Anti-Stockpiling Provision

In accordance with Section 9 of the CPSA, the draft proposed standard contains a provision that prohibits a manufacturer from "stockpiling" or substantially increasing the manufacture or importation of noncomplying generators between the date that the draft proposed rule may be promulgated and its effective date (or compliance date, in the case of generators with handheld and Class I engines). The rule would prohibit the manufacture or importation of noncomplying portable generators by engine class in any period of 12 consecutive months between the date of the promulgation of the rule and the effective/compliance date at a rate that is greater than 125% of the rate at which they manufactured or imported portable generators with engines of the same class during the base period for the manufacturer. The base period is any period of 365 consecutive days, chosen by the manufacturer or importer, in the 5-year period immediately preceding the promulgation of the rule.

As discussed in the following section of this analysis, generator sales can vary substantially from year to year, depending upon factors such as widespread power outages caused by hurricanes and winter storms. Annual unit shipment and import data obtained from Power Systems Research, Inc. (PSR), the U.S. International Trade Commission (ITC) and individual manufacturers show that it has not been uncommon for shipments to have varied by 40 percent or more from year-to-year, at least once in recent years. The anti-stockpiling provision is intended to allow manufacturers and importers sufficient flexibility to meet normal changes in demand that may occur in the period between promulgation of a rule and its effective/compliance date and limit their ability to stockpile noncomplying generators for sale after that date. The draft notice of proposed rulemaking requests comments on the proposed product manufacture or import limits and the base period.

3. Market Information

3.1. Manufacturers

Data obtained from PSR (2012, 2013) indicate that a total of 78 domestic or foreign manufacturers produced or exported gasoline-powered portable generators for the U.S. market in recent years. However, most of these manufacturers were based in other countries. Staff has identified 20 domestic manufacturers of gasoline-powered portable generators; 13 would be considered small businesses based on U.S. Small Business Administration (SBA) size guidelines for North American Industry Classification System (NAICS) category 335312 (Motor and Generator Manufacturing). SBA categorizes these manufacturers as small if they have fewer than 1,250 employees.

Few of the 78 firms involved in production for the U.S. market in recent years have held significant market shares: less than half of these firms reportedly have had annual shipments of 1,000 units or more; and only 6 firms have had annual shipments of 50,000 units or more. From 2009 through 2013 the top 5 manufacturers combined for an estimated 62 percent of the U.S. market for portable generators with power ranges more likely to be in consumer use and the top 10 manufacturers combined for about 84 percent of unit sales during that period. Under the CPSA, the firms that import generators from foreign producers would be considered manufacturers of the products. A review of import records for portable generators found that the annual number of individual importers of record has ranged from about 25 to 30 in recent years (Zepol, 2015). These firms would be responsible for certifying that the products they import comply with the rule, should it be adopted by the Commission.

3.2. Annual Shipments/Sales of Portable Generators

CPSC Directorate for Economic Analysis staff has acquired information on annual unit sales of portable generators through contract purchases from market research firms, from federal data sources (*e.g.*, the ITC and Bureau of the Census), and other sources.[5] Chart 1 presents information on sales of portable generators for 1995 through 2014. Sales estimates are based on estimated portable generator shipments and projected shipments to U.S. retailers for the years 1998─2002 and 2007─2013 (RTI International, 2006; Power Systems Research, 2012, 2013), and estimated U.S. consumer purchases of portable generators for 1995─1997 and 2004─2008 (Synovate, 2006a, 2006b, 2008 & 2009).

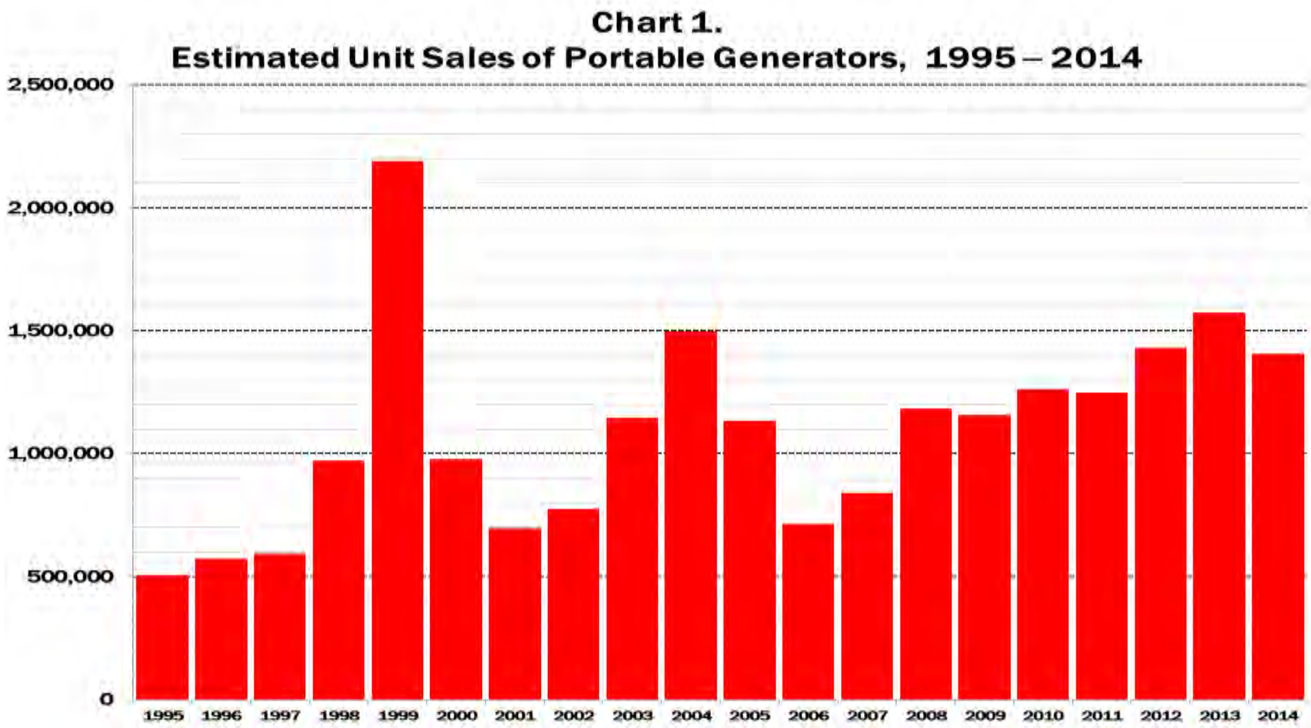


Chart 1 presents estimated unit sales of portable generators from 1995 through 2014. As shown by the chart, consumer demand for portable generators from year-to-year fluctuates with power outages, such as outages caused by hurricanes and other storms along the Gulf and Atlantic coasts and by winter storms in other areas. Periods of increased demand for portable generators may be followed by reduced demand because a larger percentage of households had made recent purchases. Evidence of the importance of weather-related power outages in driving the demand for portable generators, the fiscal 2007 annual report issued by Briggs & Stratton, a leading manufacturer of engines used in the production of generators (its own and others), noted that for

[5] Power Systems Research compiled information on domestic production and imports of portable generators from its OE Link™ market intelligence database of original equipment and original equipment manufacturer (OEM) production & forecast data. Synovate (which was purchased by another market research firm, Ipsos, in 2011), based on analysis of surveys of the firm's Continuing Consumer Survey panel and the firm's Multi-Client Research Group (SMRG) sample.

2007, the company had "a 66% reduction of engine shipments for portable generators caused by a lack of events, such as hurricanes, that cause power outages" (Briggs & Stratton, 2007). Additionally, spurred by widespread concerns over the possible impact of Y2K in disrupting power supplies, estimated portable generator shipments rose to about 2.2 million in 1999, still the highest year for estimated sales (RTI, 2006).

3.3. Product Characteristics of Portable Generators Shipped in Recent Years

This section presents information on the characteristics of portable generators marketed for consumer use. A summary of these characteristics, by engine class, including images of typical generators, can be seen in Appendix A. Additionally, selected characteristics of products found in an informal market survey of generators offered for sale at retail in 2015 and 2016 are shown below in Table 2 for the generator engine classes and types that would be subject to the standard.

3.3.1. Power Ratings

Data obtained by CPSC staff in recent years show that portable generators purchased by consumers and in household use generally range from under 1 kW of rated power up to perhaps 15 kW of rated power. Staff believes that the most powerful portable generators are purchased mainly for construction or commercial use, although some also end up in household use.[6] In Table 1, we present information on generator power ratings for shipments of portable generators powered by Class I or Class II engines for the U.S. market for the years 2010 through 2014, based on staff analysis of data obtained from PSR, import data from the U.S. International Trade Commission, and information provided by individual firms. The generators are separated into six power-rating categories. Over this 5-year period for shipments, about 6.9 million gasoline-powered portable generators were shipped for consumer use, or an average of about 1.4 million units per year. Shipments of nearly 1.6 million units in 2013 made it the peak year for sales during this period.

Data on recent portable generator shipments shown in Table 1, compared to information on consumer purchases before 2010, indicate that the U.S. market has shifted toward smaller, less powerful units. Synovate surveys on generators purchased by consumers from 2004 ─ 2006 found that about 9 percent of units likely purchased for consumer use (< 15kW) had continuous electrical outputs of under 2 kW and about 12 percent had ratings of 2 ─ 3.49 kW (Synovate, 2008). Data acquired from PSR and individual manufacturers on portable generator shipments in more recent years show that units with power ratings of under 2 kW comprised an estimated 21 percent of the market, and units with power ratings of 2 ─ 3.49 kW have held an estimated market share of about 36 percent over the period 2010 ─ 2014. The market share of larger units, with outputs of 6.5 kW or more, fell from about 22 percent of the market in 2004 ─ 2006 to about 9 percent over the period 2010 ─ 2014.[7]

[6] Although generator power ratings are only known for about 48% of the units involved in death reports as of May 21, 2015 for the period of 2004 through 2012, fewer than 3% of these units had power ratings of 8 kW or greater, and the most powerful unit involved was 10 kW (Hnatov. 2014).
[7] Some of the demand for generators with greater power has been met by the reported increase in sales and installations of stationary stand-by generators.

Table 1.
Shipments of Portable Generators, 2004—2006 & 2010—2014, by Rated Generator Power, in Kilowatts (kW)

Generator kW Range	2004 — 2006 Annual Average	2010 — 2014 Annual Average
Under 2 kW	**100,900**	**283,923**
percent	9.1%	20.5%
2 to 3.49 kW	**136,245**	**496,684**
percent	12.2%	35.9%
3.5 to 4.99 kW	**196,552**	**184,874**
percent	17.6%	13.4%
5 to 6.49 kW	**437,669**	**289,669**
percent	39.3%	20.9%
6.5 to 7.99 kW	**142,277**	**46,938**
percent	12.8%	3.4%
8 kW & Greater*	**100,893**	**81,808**
percent	9.1%	5.9%
All Portable Generators	**1,114,536**	**1,383,896**

Source: Power Systems Research, Inc. data; market estimates for individual firms; analysis by Directorate for Economic Analysis, CPSC.

* Limited to generators powered by Class II engines (*i.e*., under 19 kW).

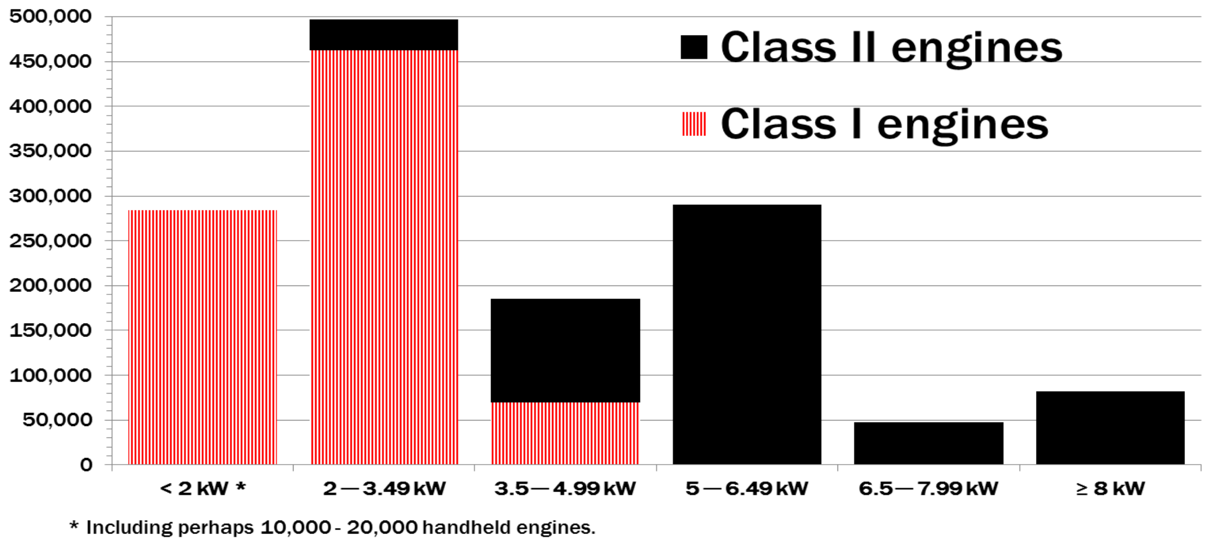
3.3.2. Engine Classes

Small SI engines used in the manufacture of portable generators are classified (by EPA and for the draft CPSC rule) according to their total cylinder displacement, in cubic centimeters (cc). Staff obtained data on this engine characteristic from PSR and individual firms for recent shipments of portable generators. This information enabled us to estimate numbers by engine classes for the kilowatt ranges discussed above. Data on shipments of portable generators for 2010 through 2014 show that portable generators with handheld engines (those with displacement of 80 cc and less) and Class I engines (those with a total cylinder displacement of < 225 cc) combined for about 59 percent of units shipped; and those with Class II engines (those with total displacement ≥ 225 cc) comprised about 41 percent. We estimate that total annual shipments of portable generators from 2010 – 2014 averaged almost 1.4 million units, of which about 816,000 had handheld or Class I engines, and about 568,000 had Class II engines.

Although sometimes used in non-handled equipment (such as portable generators), engines are classified by EPA as handheld if they have total displacement of less than or equal to 80 cc. Based on information provided by PSR and individual firms, we estimate that generators with handheld engines account for an average of about 10,000 to 20,000 units sold annually; about 1 percent of the overall consumer market for portable generators and perhaps 2 percent of the units with smaller (< 225 cc) engines.

Chart 2 shows the relationship between rated kilowatt power of portable generators and their engine classes for 2010 through 2014. As may be seen, generators with rated power of under 2 kW were made with handheld or Class I engines, and virtually all of those with rated power of 5 kW or greater were made with Class II engines. For units with 2 – 3.49 kW (which was the largest single kW category, accounting for 36 percent of units in 2010 – 2014), the great majority (93%) were made with Class I engines, while a majority (63%) of units with rated power in the range of 3.5 – 5 kW were made with Class II engines.

Chart 2.
Average Annual Unit Sales, 2010 – 2014, By Kilowatt Range & Engine Class



Source: Power Systems Research, Directorate for Economic Analysis

3.3.3. Engine Cylinders

Engines used in the manufacture of portable generators intended for consumer use have either one or two cylinders for combustion of fuel. Based on information on engine characteristics gathered and reported by PSR, virtually all of the portable generators with sustained power ratings below 6.5 kW that were sold from 2010 – 2014 were powered with one-cylinder engines. These power categories comprised about 91 percent of all units purchased by consumers during that period, as shown in Table 1. PSR data reveal that one-cylinder engines powered about 91 percent of the generators with 6.5 – 7.99 kW, and about 58 percent of units with power ratings from 8 – 9.99 kW. Two-cylinder engines are more common in more powerful generators, with sustained power ratings of 10 kW and greater, accounting for about 93 percent of units sold from 2010 – 2014. Overall, the data indicate that one-cylinder engines were used in the manufacture of at least 95 percent of total unit sales of portable generators to consumers and in about 89 percent of the Class II engines used to produce portable generators.

3.3.4. Fuel Distribution Systems

According to ES staff, OEM manufacturers of portable generators are likely to comply with the CO emission requirements of the draft proposed standard by selecting engines that have fuel distribution systems that are more capable of controlling air-to-fuel ratios than traditional carbureted systems (Buyer, 2016a). Specifically, staff expects that manufacturers will switch to electronic fuel injection (EFI), instead of conventional carburetors, to control the delivery of gasoline to the pistons of generator engines. CPSC staff is aware of at least five portable generator manufacturers that have either developed models with EFI for evaluation, or that have actually marketed such models within the last 2 years. Some of these models have been evaluated by ES staff at the National Product Test and Evaluation Center (Brookman, 2016). However, virtually all generators currently in consumer use have carbureted fuel distribution systems.

3.3.5. Engine Valve Configurations

One engine characteristic that varies somewhat by engine class is valve location. This is an engine characteristic that could affect manufacturers' strategies for complying with the draft proposed standard. Until recent years, Class I engines were predominantly manufactured with side valve configurations, with valves placed in the engine block beside the piston. In contrast, Class II engines were much more likely to have overhead valve configurations, in which the valves are placed over the cylinder head. However, as a result of more stringent requirements adopted by the California Air Resources Board and EPA for hydrocarbons plus nitrogen oxides (HC+NOx) emissions from small SI engines (used in all non-road applications), the percentage of Class I engines used for portable generators (and other uses) with side valves has fallen dramatically.[8] EPA estimated that 66 percent of Class I engines sold in 2005 had side valve configurations (EPA, 2008). On the other hand, PSR data show that Class I engines used in generators for the U.S. market from 2010 – 2014 were only slightly more likely than Class II engines to have side valves instead of overhead valves (about 4% of Class I engines and 1% of Class II engines).

3.3.6. Engine Cycles

SI engines used in portable generators have either two or four piston strokes per combustion cycle. Two-stroke engines have simpler designs with fewer moving parts, making them easier to maintain and lighter in weight at a given displacement than four-stroke engines. Two-stroke engines also reportedly can produce up to 40 percent more power than four-stroke engines with the same displacement (MECA, 2009). These characteristics, and the ability to operate in many directions without flooding, make two-stroke engines attractive for use in handheld equipment, such as chainsaws, trimmers and leaf-blowers. Portable generators and other larger non-handheld equipment, such as lawn & garden equipment and pressure-washers, typically have four-stroke engines. Although all of the portable generators reported in PSR's database of recent shipments had four-stroke engines, EC staff found portable units with small (< 80 cc) two-stroke engines advertised for sale on Internet websites. These units likely comprise an extremely small share of the market for portable generators.

[8] More stringent CARB requirements became effective in 2008, and the equivalent requirements of EPA's Phase 3 regulations became effective in 2011, for Class II engines and in 2012, for Class I engines.

3.3.7. Retail Prices

With the wide range of engine power and other features available on portable generators shipped in recent years, these products also have been offered at a wide range of retail prices to consumers. The most recent survey data on retail prices in staff's possession were obtained from Synovate for the years 2004 through 2006. Consumer survey data developed by Synovate found that the average retail price consumers paid for portable generators intended primarily for backup power during electric power outages (the primary stated purpose for the purchase by about 75% of consumers) was about $1,040 in 2006.

More recent pricing information was gained through an informal survey of advertised prices for portable generators by CPSC staff in October 2015 (which included units available in stores and via the Internet). This survey found that retail prices generally vary by kW rating of the units, engine class, and number of cylinders. Regarding rated generator power, average prices were $393 for units under 2 kW; $606 for 2 to 3.49 kW generators; $640 for 3.5 to 4.99 kW units; $936 for those with 5 to 6.49 kW ratings; $1,002 for units with 6.5 to 7.99 kW ratings; and $1,745 for units with power ratings of 8 kW or more. Generator characteristics other than power ratings also affect price. For example, "inverter generators" have electronic and magnetic components that convert the AC power to DC power, which is then "inverted" back to clean AC power that maintains a single-phase, pure sine wave at the required voltage and frequency suitable for powering sensitive equipment, such as computers. These additional components add to the manufacturing cost, resulting in significantly higher retail prices than units with similar power outputs. For example, our limited retail price survey found that the average retail prices of generators with power ratings of under 2 kW were $242 for units not identified as inverters, and $710 for units identified as inverters.

Regarding retail price information by engine class and number of cylinders, our informal survey of prices found that generators with handheld engines ranged in price from $133 to $799, with an average price of about $324. Generators with non-handheld Class I engines had a wide price range, from $190 to more than $2,000, with an average price of $534. Generators with one-cylinder Class II engines ranged from $329 to $3,999, with an average price of $1,009. Generators with two-cylinder Class II engines ranged in price from $1,600 to $4,999, and the average price of these units was $2,550.

Table 2 shows selected characteristics (displacement, power rating, price and weight) for generators found in an informal retail market survey of generators, by engine class and type.

Table 2.
Sample Characteristics of Portable Generators Recently Marketed, by Engine Class/Type

Product Characteristic		Handheld	Class I	One-Cylinder, Class II	Two-Cylinder, Class II
	Sample size (n)[1]	(43)	(261)	(412)	(35)
Engine Displacement (cc)	Range	31 to 80	87 to 224	250 to 459	530 to 992
	Average	67.7	185.6	389.2	703.9
	Median	79	206	389	680
Power Ratings (watts)	Range	450 to 1,700	1000 to 4,375	3,500 to 9,200	9,000 to 17,500
	Average	1,094	2,968	6,230	11,771
	Median	1,050	3,250	6,200	10,500
Retail Prices	Range	$133 to $799	$190 to $2,324	$329 to $3,999	$1,600 to $4,999
	Average	$324 (24)	$534 (151)	$1,009 (226)	$2,550 (20)
	Median	$225 (24)	$439 (151)	$899 (226)	$2,439 (20)
Weight (lbs.)	Range	19 to 62	45.6 to 140	115 to 320	278 to 471
	Average	44.6 (22)	101.8 (124)	204.3 (174)	333.8 (14)
	Median	46.0 (22)	105.5 (124)	204.0 (174)	330.0 (14)

Source: Directorate for Economic Analysis, CPSC, informal market survey of portable generators offered for sale by selected major retailers in 2015 and 2016 (price information limited to 2015).

[1] Sample size pertains to engine displacement and power rating. Smaller sample sizes for retail prices and weights are reported with the averages and medians for those product characteristics.

4. Portable Generators in Use

In this section, we estimate the population of portable generators in use, averaged over the 2004 – 2012 time period for which benefits were analyzed by the Directorate for Epidemiology, Division of Hazard Analysis (Hnatov, 2015). Estimation of the number of generators in use represents a measure of risk exposure and constitutes the necessary first step in calculating product-related risks (*e.g.*, generator-related deaths and injuries divided by the population of generators in use) in determining the per-unit societal costs of deaths and injuries that would be addressed by the proposed standard, and finally, in estimating the possible benefits of the draft proposed rule.

We estimated the population of portable generators in use with the CPSC's Product Population Model (PPM), a computer model that projects the number of products in use, given estimates of annual product sales and their expected product life (Lahr and Gordon, 1980). The expected useful life of generators, in years, is largely a function of engine size, loads placed upon the unit, and hours of use. Portable generators purchased primarily for household backup power, and mainly used during occasional or rare power outages, could have useful lives much longer than 10 years if they are properly maintained. An evaluation of data on historical sales in relation to surveys of product ownership suggests an expected useful product life of about 11 years. An assumption of a considerably shorter expected useful life, using data on historical annual unit shipments, would yield estimated numbers of units in use and saturation rates that are well below those indicated by Synovate survey data from 2005, as well as industry estimates of ownership in recent years.[9]

Table 3 presents the product population estimates for the years 2004 through 2012; estimated totals have increased from about 9.9 million in 2004 to about 12.5 million in 2012. The average for the years 2004–2012 was about 11.1 million units in use. Table 3 also presents estimates of numbers of portable generators in use by ranges of kW ratings. These estimates were based on: (1) portable generator shipment and purchase data provided by PSR and Synovate for the years 2004 through 2013, augmented by estimates of annual sales developed by and for some individual manufacturers; and (2) estimates of aggregate annual sales for prior years, in combination with Synovate estimates of market shares for the various power categories for previous years. The PPM was then used to estimate the product population for each power category, assuming an 11-year average product life. According to population estimates, the largest power category was generators 5 to 6.49 kW, accounting for an average of 3.6 million units in use, or about 33 percent of the total, followed by generators 3.5 to 4.99 kW (averaging about 2 million units and 18.2% of the total).

Table 3. Estimated Units of Portable Generators in Use, by Generator kW Ratings, 2004 - 2012

Year	< 2 kW	%	2—3.49 kW	%	3.5—4.99 kW	%	5—6.49 kW	%	6.5—7.99 kW	%	8 kW +	%	Total
2004	1,164,937	11.8%	1,514,418	15.3%	2,003,691	20.2%	3,307,573	33.4%	1,125,797	11.4%	785,440	7.9%	9,901,855
2005	1,169,828	11.2%	1,507,610	14.5%	2,052,923	19.7%	3,620,229	34.8%	1,218,983	11.7%	843,880	8.1%	10,413,454
2006	1,138,111	10.9%	1,494,780	14.3%	2,026,543	19.4%	3,684,521	35.3%	1,234,027	11.8%	865,844	8.3%	10,443,826
2007	1,138,122	10.8%	1,507,516	14.3%	2,019,291	19.2%	3,721,225	35.3%	1,246,975	11.8%	908,152	8.6%	10,541,281
2008	1,225,495	11.2%	1,657,508	15.2%	2,029,573	18.6%	3,804,931	34.8%	1,246,355	11.4%	965,614	8.8%	10,929,475
2009	1,382,555	12.3%	1,945,110	17.3%	2,006,405	17.8%	3,755,195	33.4%	1,189,234	10.6%	966,810	8.6%	11,245,308
2010	1,565,789	13.5%	2,278,780	19.6%	2,001,427	17.2%	3,686,827	31.7%	1,133,894	9.8%	962,137	8.3%	11,628,854
2011	1,724,038	14.4%	2,579,743	21.6%	1,988,252	16.6%	3,641,605	30.4%	1,071,810	9.0%	961,550	8.0%	11,966,999
2012	1,906,637	15.3%	2,943,773	23.6%	2,001,557	16.1%	3,626,361	29.1%	1,012,496	8.1%	968,748	7.8%	12,459,571
9-Year Average	1,379,501	12.5%	1,936,582	17.5%	2,014,407	18.2%	3,649,830	33.0%	1,164,397	10.5%	914,242	8.3%	11,058,958

Source: CPSC Directorate for Economic Analysis, based on Product Population Model evaluation of estimated historical sales.

[9] For example, portable and stationary generator manufacturer, Generac, reportedly estimated that about 12 percent of households had portable generators in 2013, up from 10 percent in 2010 (Hill, 2013).

Note that the estimates provided in Table 3 assume uniform expected product lives across engine sizes and power ratings; that is, the generators with smaller engine sizes are assumed to last as long as the larger engine sizes. Larger engines usually are rated for more hours of operation than smaller engines. Assuming the hour ratings reflect the relative differences in total hours of actual use, our estimates imply fewer hours of use per year for smaller generators versus larger units over their useful lives.

As noted in Section 2.2.2., the draft proposed standard specifies different requirements for CO emission rates, depending on generator engine class and other objective characteristics, rather than engine or generator power ratings. The Directorate for Economic Analysis has estimated historical sales of generators by engine class from estimated sales by kW ratings, using data from PSR reporting both generator power and engine displacement. Table 4 presents estimated units in use for 2004 – 2012, by engine class. Based on our analysis, the proportion of generators with smaller engines (handheld and Class I) has increased over the 9-year period. This is consistent with estimates of the increasing share of generators in use with power ratings of under 3.5 kW (see Table 3). This follows from the information presented in Section 3.3.1., regarding the apparent shift in the U.S. market towards smaller, less powerful units.

Table 4.

Estimated Units of Portable Generators in Use, by Generator Engine Class, 2004 – 2012

Year	Handheld Engines		Class I Engines		Class II Engines				All Units
					1-Cylinder		2-Cylinders		
	Units	Percent	Units	Percent	Units	Percent	Units	Percent	
2004	67,418	0.7%	3,317,468	33.5%	5,826,761	58.8%	690,209	7.0%	9,901,855
2005	67,701	0.7%	3,335,886	32.0%	6,266,611	60.2%	743,256	7.1%	10,413,454
2006	65,866	0.6%	3,283,911	31.4%	6,333,338	60.6%	760,711	7.3%	10,443,826
2007	65,866	0.6%	3,293,317	31.2%	6,390,317	60.6%	791,781	7.5%	10,541,281
2008	70,923	0.6%	3,521,657	32.2%	6,504,141	59.5%	832,755	7.6%	10,929,475
2009	80,012	0.7%	3,932,257	35.0%	6,405,261	57.0%	827,778	7.4%	11,245,308
2010	90,616	0.8%	4,418,072	38.0%	6,301,520	54.2%	818,646	7.0%	11,628,854
2011	99,775	0.8%	4,846,279	40.5%	6,208,911	51.9%	812,035	6.8%	11,966,999
2012	110,342	0.9%	5,367,384	43.1%	6,170,376	49.5%	811,468	6.5%	12,459,571
9-Year Average	79,835	0.7%	3,924,026	35.5%	6,267,471	56.7%	787,626	7.1%	11,058,958

Source: CPSC Directorate for Economic Analysis, based on Product Population Model evaluation of estimated historical sales.

5. Benefit–Cost Analysis

This section of the analysis consists of a comparison of the benefits and costs of the proposed rule. The analysis is conducted from a societal perspective, considering all of the significant costs and health outcomes. Benefits and costs are calculated on a per-product-in-use basis, an approach that has been found useful at the CPSC (Rodgers and Rubin, 1989; Tohamy, 2006; Smith, 2007; Franklin, 2014). The benefits are based on the reduced risk of fatal and nonfatal injury due to CO poisoning involving portable generators. The costs are defined as the added costs of making the portable generators conform to the draft proposed rule.

Our primary outcome measure is the expected net benefits (*i.e.*, benefits minus costs) of the rule. As noted above, our primary analysis calculates the benefits and costs of the rule on a per-product-in-use basis. However, aggregated estimates of the benefits and costs on an annual basis can be readily calculated, given projections of annual generator sales.

5.1. Societal Costs of Portable Generator Deaths and Injuries

As discussed in Section 2.1 above, the Directorate for Epidemiology, Division of Hazard Analysis (EPHA) reports that there were 659 deaths involving portable generators from 2004–2012, an average of about 73 annually (Hnatov, 2015).[10] The average annual societal costs of these CO deaths are estimated to be about $637 million in 2014 dollars, based on a value of a statistical life (VSL) of $8.7 million.[11]

EPHA also provided an estimate of CO-related injuries involving portable generators, based on estimates from the National Electronic Injury Surveillance System (NEISS) during the years 2004 through 2012 (Hanway, 2015). According to EP, there was a minimum of 8,703 nonfatal CO poisonings involving portable generators that were treated in hospital emergency departments from 2004 through 2012, or a minimum of about 967 annually (Hanway, 2015). This NEISS estimate is considered a minimum because it only included injuries that were explicitly attributed to CO poisoning injuries in the NEISS narrative.

The NEISS injury estimates are limited to individuals initially treated in hospital emergency departments. However, the CPSC's Injury Cost Model (ICM) uses empirical relationships between the characteristics of injuries and victims in cases initially treated in hospital emergency departments and injuries initially treated in other medical settings (*e.g*., physicians' offices, ambulatory care centers, emergency medical clinics), based primarily on data from the Medical Expenditure Panel Survey, to estimate the number of non-hospitalized medically-attended injuries that were treated outside of hospital emergency departments. The ICM also analyzes data from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project to project the number of direct hospital admissions bypassing hospital emergency departments. According to the ICM estimates, there were an additional 16,660 medically-attended injuries during 2004–2012, or

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[10] The Division of Hazard Analysis does not consider reports of incidents and deaths for the years 2013 and 2014 to be complete.

[11] The estimated value of a statistical life (VSL) of $8.7 million (in 2014 dollars) for the annual average of 73 CO related deaths is a revision of the VSL estimated by the Environmental Protection Agency (EPA, 2010) and is generally consistent with other estimates based on willingness-to-pay. Kneiser et al. (2012), suggested that a reasonable range of values for VSL was between $4 million and $10 million (in 2001 dollars), or about $5.3 million to $13.3 million in 2014 dollars (BLS 2015).

about 1,851 annually. Consequently, based on NEISS and ICM estimates, there was a minimum of about 2,818 medically attended injuries (967 ED + 1,851 non-ED-treated) annually during 2004 through 2012.

The ICM is fully integrated with NEISS and provides estimates of the societal costs of injuries reported through NEISS, as well as the costs associated with the estimated medically attended injuries treated outside of hospital emergency departments. The major aggregated societal cost components provided by the ICM include medical costs, work losses, and the intangible costs associated with lost quality of life or pain and suffering.[12]

Medical costs include three categories of expenditures: (1) medical and hospital costs associated with treating the injury victim during the initial recovery period, and in the long run, the costs associated with corrective surgery, the treatment of chronic injuries, and rehabilitation services; (2) ancillary costs, such as costs for prescriptions, medical equipment, and ambulance transport; and (3) costs of health insurance claims processing. Cost estimates for these expenditure categories were derived from a number of national and state databases, including the Medical Expenditure Panel Survey, the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project, the Nationwide Emergency Department Sample, the National Nursing Home Survey, MarketScan® claims data, and a variety of other federal, state, and private data.

Work-loss estimates are based on information from the Nationwide Inpatient Sample of the Healthcare Cost and Utilization Project, the Nationwide Emergency Department Sample, Detailed Claims Information (a workers' compensation database), the National Health Interview Survey, the U.S. Bureau of Labor Statistics, and other sources. These estimates include: (1) forgone earnings of the victim, including lost wage work and household work; (2) forgone earnings of parents and visitors, including lost wage work and household work; (3) imputed long-term work losses of the victim that would be associated with permanent impairment; and (4) employer productivity losses, such as the costs incurred when employers spend time juggling schedules or training replacements.

Intangible or non-economic costs of injury reflect the physical and emotional trauma of injury, as well as the mental anguish of victims and caregivers. Intangible costs are difficult to quantify because they do not represent products or resources traded in the marketplace. Nevertheless, they typically represent the largest component of injury cost, and they need to be accounted for in any benefit-cost analysis involving health outcomes (Rice et al., 1989). The ICM develops a monetary estimate of these intangible costs from jury awards for pain and suffering. Although these awards can vary widely on a case-by-case basis, studies have shown them to be systematically related to a number of factors, including economic losses, the type and severity of injury, and the age of the victim (Viscusi, 1988; Rodgers, 1993). Estimates for the ICM were derived from regression analysis of jury awards in nonfatal product liability cases involving consumer products compiled by Jury Verdicts Research, Inc.

According to the ICM, the estimated injury costs of the approximately 2,818 medically attended portable generator CO injuries annually amounted to about $184 million (in 2014 dollars), an estimated average of $65,400 per injury. Medical costs and work losses accounted for

[12] A detailed description of the cost components, the general methodology and data sources used to develop the CPSC's Injury Cost Model, as well as Injury Cost Model Updates, can be found in Miller et al. (2000), Bhattacharya and Lawrence (2012), Lawrence (2008), Lawrence (2013), Lawrence (2014), and Lawrence (2015a, 2015b, 2015c).

about 53 percent of the total, while the non-economic losses associated with pain and suffering accounted for about 47 percent. The societal costs of both fatal and nonfatal CO poisoning injuries involving portable generators amounted to about $821 million ($637 million for fatal injuries + $184 million for nonfatal injuries) annually.

The average annual societal cost estimates for generators in use in 2004 through 2012, by engine class, are presented in more detail in Table 5. Row 1 provides the annual estimates of fatal CO poisoning injuries by engine class, and the estimated percent of all deaths involving each category. Note that information on engine class for generators involved in the deaths was available on only about 48 percent of the cases. The cases in which the engine classes were not known were distributed proportionally to the cases in which the classes were known.

Row 2 shows estimated annual nonfatal injuries by engine class; the nonfatal CO injuries were distributed proportionally to the deaths because very little information is available on the displacement of engines of generators involved in these injuries. Row 3 provides estimates of the aggregate annual societal costs of the deaths and injuries. Societal costs were based on a VSL of $8.7 million per death, and the nonfatal injury costs are from the ICM modeling. Row 4 provides the annual estimates of portable generators in use by engine class, as well as the estimated percent of all units in use for each category. Row 5 provides annual per-unit societal costs of deaths and injuries, which is based on the Row 3 estimates divided by the estimated numbers of portable generators in use (shown in Row 4).

Table 5.
Estimated Units of Portable Generators in Use and Expected Societal Costs of CO Poisoning, by Generator Engine Class, 2004 – 2012

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinder	
Estimated Deaths / Year (Percent)	0.5 0.7%	25.6 35.0%	46.2 63.0%	0.9 1.2%	73.2 100.0%
Estimated Nonfatal Injuries / Year	21	986	1,776	34	2,818
Aggregate Annual Societal Costs of Deaths and Injuries (million $)	$6.0	$287.6	$517.8	$10.0	$821.3
Estimated Number of Units in Use (Average, 2004 – 2012) (Percent)	79,835 0.7%	3,924,026 35.5%	6,267,471 56.7%	787,626 7.1%	11,058,958 100.0%
Annual Societal Costs of CO Poisonings / Unit	$74.90	$73.29	$82.62	$12.66	$74.27
Total Present Value of Expected Societal Costs of Deaths and Injuries / Unit	$687	$672	$758	$116	$682

Finally, Row 6 provides per-unit estimates of the present value of the expected societal costs (at a 3% discount rate[13]) over the expected product life of a generator. This figure is useful in benefit-cost analysis because it represents the maximum per-unit benefits that might be derived from a product safety standard, if the standard prevented all deaths and injuries. The present value of expected societal costs is $687 per unit for portable generators with handheld engines (which are estimated to have accounted for less than 1 percent of units in use during the period 2004 through 2012); $672 per unit for generators with Class I engines (35.5% of units in use); $758 per unit for generators with one-cylinder Class II engines (56.7% of units in use); and $116 per unit for generators with two-cylinder Class II engines (7.1% of units in use). The societal costs associated with the two-cylinder Class II generators are substantially lower than for the other generator categories because of the small relative risk for the two-cylinder models. Because the two-cylinder models accounted for about 7.1 percent of generators in use, but only about 1.2 percent of the deaths, the risk of death with two-cylinder generators was only about 16 percent of the risk associated with generators with one-cylinder engines (*i.e.*, handheld, Class I, and one-cylinder Class II generators).

These Row 6 calculations of the present value of societal costs also represent baseline estimates of the societal costs associated with portable generators, by engine class, and other characteristics: estimates of what per-unit societal costs would be in the absence of regulatory action. Therefore, benefits of the draft regulation can be estimated as the expected reduction in the baseline societal costs.

5.2. Estimated Benefits of the Draft Proposed Standard

As described above in Section 2.2.2., the draft performance standard requires portable generators powered by handheld engines and Class I engines to emit CO at a weighted rate that is no more than 75 grams per hour (g/h); generators powered by one-cylinder Class II engines to emit CO at a weighted rate that is no more than 150 g/h; and generators powered by two-cylinder Class II engines are required to emit CO at a weighted rate that is no more than 300 g/h. As noted in staff's analysis that provides the rationale for the performance requirements, these emission requirements reflect a factor of 1.5 over the expected technically feasible emission rates for each engine classification: 50 g/h for those with handheld and Class I engines; 100 g/h for those with one-cylinder Class II engines; and 200 g/h for those with two-cylinder Class II engines (Buyer, 2016a).

To estimate the expected reduction in societal costs, and hence, the benefits from a draft proposed standard for portable generators, an interdisciplinary analysis by CPSC staff provided estimates of generator-related consumer CO poisoning deaths reported in the agency's databases that could have been avoided by reduced CO emission rates from generators. An important part of the analysis was indoor air quality modeling by the National Institutes of Standards and Technology (NIST) under an interagency agreement with the CPSC (IAG No. CPSC-I-15-0024) to estimate the transport of CO emitted from generators and predicted health effects for scenarios and house characteristics found in CPSC's incident data. CPSC staff then compared the health effects

[13] Our base analysis discount rate is consistent with research suggesting that a real rate of 3 percent is an appropriate discount rate for interventions involving public health (see Gold, Siegel, Russell & Weinstein, 1996); a 3 percent discount rate (along with a 7 percent discount rate) is also recommended for regulatory analyses by the Office of Management and Budget (OMB, 2003).

resulting from emission rates from current generators to a range of lower CO emission rates to estimate deaths that could have been avoided for each emission rate (Hnatov, Inkster & Buyer, 2016).

The NIST modeling and CPSC staff analysis considered scenarios associated with 503 CO poisoning deaths from 2004 ─ 2012, or about 76 percent of the 659 CO poisoning deaths in CPSC records over the 9-year period. These deaths occurred at various fixed-structure residential settings, including traditional houses, mobile homes, townhomes, and structures attached to a home, in addition to residential sites where generators were operated in separate structures, such as cabins used for temporary (non-residential) shelters and detached garages. For our analysis, deaths and injuries occurring in these settings are considered to be most addressable by the draft proposed standard. However, we note that an unquantified number of the 156 deaths not modeled by NIST might be addressed and prevented by the draft proposed rule (Hnatov, Inkster & Buyer, 2016).

Chart 3 presents the results of CPSC staff analyses of estimated reductions in CO poisoning fatalities that would result from lower-weighted emission rates for modeled scenarios under various weighted CO emission rates. At each reduced emission rate, the estimated percentage reduction in fatalities is greater for generators powered with larger engines because of their higher average estimated base rate for CO emissions (4700 g/h for one-cylinder and 9100 g/h for two-cylinder Class II engines versus 1,800 g/h for Class I non-handheld engines and 900 g/h for handheld engines).[14] Based on CPSC engineering staff's judgment, the technically feasible weighted-CO emission rates are 50 g/h for generators powered by handheld and Class I engines, 100 g/h for generators powered by one-cylinder Class II engines, and 200 g/h for generators with two-cylinder Class II engines (Buyer, 2016a).

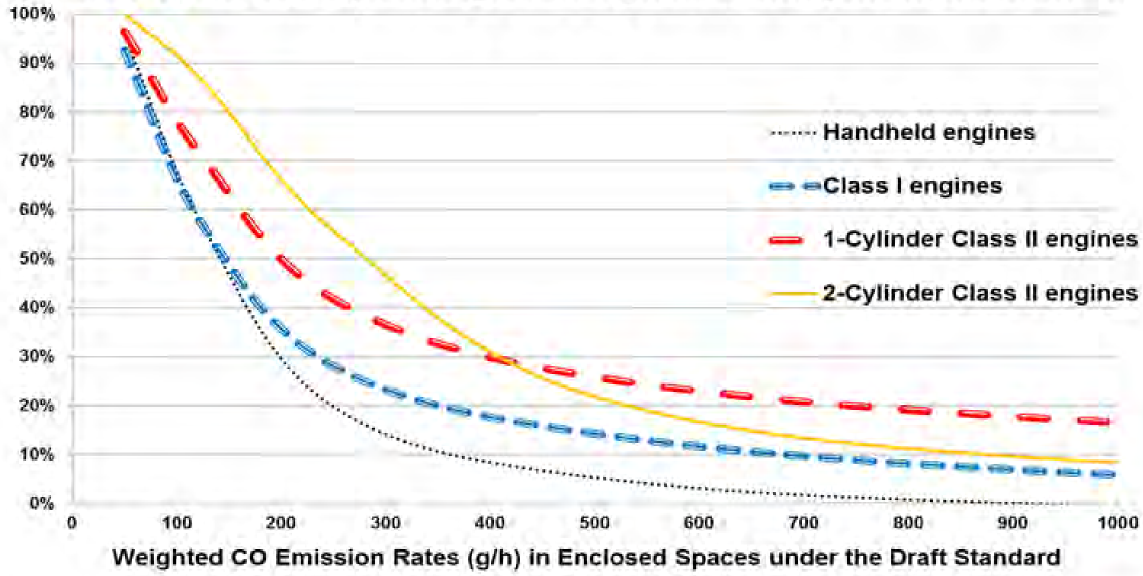
Emission rates from generators meeting the proposed performance requirements are expected to be higher while operating indoors (at reduced oxygen levels of approximately 17%) than the feasible rates under ambient conditions of approximately 20.9 percent oxygen; perhaps 150 g/h for generators with handheld engines and Class I engines; 300 g/h for generators with one-cylinder Class II engines; and 600 g/h for generators with two-cylinder Class II engines[15] (three times the technically feasible rate for each generator category) (Hnatov, Inkster & Buyer, 2016). Based on staff's analysis of 503 deaths (76 percent of all deaths) modeled by NIST (and generally deemed to be addressable by the draft proposed standard), these emission rates are expected to result in about a 47 percent reduction in (addressable) fatalities involving generators with handheld engines; about a 50 percent reduction in fatalities involving generators with Class I engines; a reduction of about 37 percent for generators with one-cylinder Class II engines; and a reduction of about 17 percent for generators with two-cylinder Class II engines. The average expected

[14] These rates assume a factor of 3 in the increase in CO emission rates of a generator operating in an enclosed space, compared to operation outdoors in normal oxygen. This factor of 3 is based on testing of carbureted generators conducted by NIST (Emmerich, 2016) and CPSC staff (Brookman, 2016).

[15] Based on staff's testing of three generators with fuel-injected engines with different degrees of closed-loop operation (Brookman, 2016), staff believes the factor of increase when the oxygen is 17 percent may be less than 3 for some generators that use closed-loop EFI. Furthermore, test results from NIST (Buyer, 2012) indicate that the prototype EFI generator depleted the oxygen significantly less than the carbureted generator, when tested in each of four matched-pair, identical test scenarios. Therefore, the factor of 3 likely overstates the weighted CO emission rates for EFI generators when operated indoors, and it likely understates the reduction in deaths and injuries resulting from the draft standard.

reduction in CO poisoning fatalities across generators of all engine types is about 44 percent of the addressable deaths, or about 33 percent of all generator-related deaths (44% × 76%).

Chart 3.
Estimated Reduction (%) in CO Poisoning Fatalities for Scenarios Modeled by NIST, Depending on CO g/h Resulting from the Standard*



* Estimated base CO emission rates at reduced O_2 average about 900 g/h for generators with handheld engines; 1800 g/h for generators with non-handheld Class I engines; 4700 g/h for generators with one-cylinder Class II engines and 9100 g/h for generators with two-cylinder Class II engines.

Table 6 presents estimated reductions in societal costs, and hence, benefits of the reduced CO emissions predicted to result from the draft proposed standard. The societal costs per generator from Table 5 are included at row 1. However, as noted above, not all of these costs will be addressed by the proposed standard or were not included among the major residential scenarios modeled by NIST.[16] The present value of expected societal costs of CO poisoning that would be addressed by an emission standard are shown in row 2, and the costs average about $514 for generators with Class I engines and about $586 for generators with one-cylinder Class II engines; engine categories that combine for an estimated 92 percent of portable generators in use. Generators with handheld engines, estimated to account for less than 1 percent of units in use, are estimated to average $525 in societal costs. Generators with two-cylinder Class II engines are estimated to average $26 in societal costs for CO poisoning over their useful lives. These larger generators are estimated to account for about 7 percent of all units in use.

Row 3 of Table 6 shows the staff estimates of weighted CO emissions from complying generators for the different engine categories that would result from operation in conditions of reduced oxygen. Row 4 shows the estimated reduction in addressable societal costs resulting from the weighted emission rates, based upon CPSC staff's estimate of the reduction in CO poisoning deaths (Hnatov, Inkster & Buyer, 2016). CPSC's estimate of the reduction in societal costs of CO poisoning deaths and injuries assumes that projected injury costs from annual production of

[16] About 76 percent of all CO poisoning deaths from 2004 – 2012 involved scenarios that were modeled by NIST. Among the scenarios not modeled were incidents involving CO poisoning deaths in apartments, vehicles and trailers (non-mobile homes), and other structures, such as a church, a sea-land container, and tents.

generators will fall in proportion to the estimated reduction in deaths, with a minor adjustment to account for the possibility that deaths avoided by reduced CO emissions would still occur as injuries.[17] With projected reductions in deaths and injuries under the draft proposed standard, the present value of benefits (shown in row 5 of Table 6) are estimated to average about $243 for generators with handheld engines; $254 per unit for generators with Class I engines; $214 per unit for generators with one-cylinder Class II engines; and $4 for generators with two-cylinder Class II engines.

Multiplying the present value of expected benefits per unit, by estimated annual unit sales (in row 6), yields the estimated aggregate present value of benefits from annual sales of portable generators that would comply with the draft proposed standard. The estimated present value of benefits of reduced CO poisoning from complying portable generators sold in a year totals about $315 million. Nearly 99 percent of the total benefits are attributable to expected sales of generators with Class I engines and one-cylinder Class II engines. These two types of engines are expected to comprise about 94 percent of annual unit sales under the standard.

Table 6.
Estimated Present Value of Societal Costs from CO Poisoning Involving Portable Generators and Expected Benefits Under the Draft Standard, by Generator Engine Class & Characteristics

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinders	
Total Present Value of Expected Societal Costs of Deaths and Injuries / Unit	$687	$672	$758	$116	$682
Estimated Present Value of Societal Costs per Unit Addressed by The Draft Standard	$525	$514	$586	$26	$520
Estimated Weighted CO Emission Rate Under the Draft Standard in Conditions of Reduced Oxygen	150	150	300	600	
Estimated Reduction in Addressable Societal Costs of CO Poisoning*	47%	50%	37%	17%	44%
Expected Benefits per Unit: Present Value of Expected Reduction in Societal Costs	$243	$254	$214	$4	$227
Estimated Annual Unit Sales	15,000	800,502	503,576	64,818	1,383,896
(Percent)	1.1%	57.8%	36.4%	4.7%	100.0%
Present Value of Expected Reduction in Societal Costs from Units Sold Annually (Millions $)	$3.6	$203.1	$107.5	$0.3	$314.5

* Based on estimated reduction in CO poisoning deaths by CPSC staff (Hnatov, Inkster & Buyer, 2016)

Projections of benefits of the draft proposed standard should account for recent changes and reasonably expected changes in the market that will affect societal costs and the costs of compliance by manufacturers. One consideration expected to reduce the addressable societal costs

[17] We have assumed that avoided deaths under the draft proposed standard would still occur as non-fatal CO injuries of average severity and cost.

of the rule, from the costs estimated for the period of 2004 – 2012, is the relatively recent introduction of units with EFI. Increased use of EFI would also reduce the costs of compliance with a standard based on reduced CO emissions. However, portable generators with EFI have not gained a significant share of the consumer market for portable generators; moreover, we have little basis for incorporating projected sales of EFI units into the analysis. Regarding the introduction of EFI on expected hazard costs, most of the EFI-equipped portable generators reportedly have not specifically targeted reductions in CO emissions. Therefore, a relatively small share of the generator market would not be expected to contribute to substantial reduction in the overall hazard. However, costs of compliance with a mandatory standard would be greatly reduced for units with EFI systems.

In addition to reducing societal costs related to CO poisoning deaths and injuries, product modifications to achieve greatly reduced CO emissions could also result in improved fuel efficiency and other benefits, including easier starting, altitude compensation, fuel adaptability, improved power, better reliability and longer useful product life.

5.3. **Estimated Costs of Compliance with the Draft Proposed Standard**

5.3.1. Costs of Compliance per Unit

Based on CPSC engineering sciences staff's judgment, the most likely technical means of compliance with the requirements of the draft proposed standard would be the use of closed-loop electronic fuel-injection systems to achieve and maintain the needed air-to-fuel ratios under different loads and ambient conditions (Buyer, 2012). Another element expected to be part of the industry's technical response to the draft proposed standard is the addition of three-way catalysts in the muffler systems of portable generator engines. Besides achieving further reductions in CO emissions, these catalysts would likely serve to reduce HC+NOx emissions for continued compliance with EPA emission standards for small SI engines.

More detailed discussions of the expected product modifications and other factors leading to cost increases appear below. All cost estimates are expressed in 2014 dollars, for comparison with estimated benefits of the draft proposed standard.[18]

5.3.1.1. Electronic Fuel Injection (EFI)

The likely industry switch from engines with carburetors as the means of fuel delivery to closed-loop EFI is expected to be the most significant factor in determining cost increases under the draft proposed standard. This technology has been used for a number of years on the small SI engines in small motorcycles and scooters, as well as in more recent years in a variety of other product applications, including lawnmowers/tractors and golf carts. Although some firms have introduced portable generators with EFI for the consumer market in the last couple of years, generators with this fuel delivery system currently account for a very small fraction of sales. Associated components for closed-loop EFI could include the electronic control unit, fuel pump, injector(s), pressure regulator, throttle body, and a variety of sensors, such as the manifold air pressure sensor or throttle position sensor, intake air temperature sensor, oil temperature sensor,

[18] Cost estimates are adjusted to 2014 dollars by applying changes in the producer price index for riding lawn & garden equipment, a product group with similarities to portable generators.

crank position sensor, and related wiring and hardware, and an oxygen sensor for closed-loop feedback. Based on an analysis of EFI-related costs of potential revisions to EPA emission standards (EPA, 2006), the combined costs of these elements for one-cylinder engines (which dominate the market for residential generators) are estimated to be about $90 per unit in 2014 dollars.[19] Cost savings of about $20 per unit are estimated for elimination of the carburetor, yielding estimated net costs of about $70 for the EFI components.

The effectiveness of EFI in controlling the air-fuel ratio with resulting improved engine combustion efficiency and reduced CO emissions was demonstrated by CPSC staff's technology demonstration project (Buyer, 2012), as well as by the EPA (McDonald, *et al*, 2009). The EPA's demonstration work, which formed the basis of EPA's 2008 analysis of more stringent requirements for HC+NOx emissions of small non-road SI engines, provides a basis for our evaluation of this technology, specific to portable generators. The EPA estimates are largely consistent with other confidential estimates of costs provided by manufacturers of generators, as well as by a manufacturer of fuel control components, during discussions with CPSC staff.

Most CO poisoning deaths from portable generators occur when generators are used in enclosed spaces, such as a closed garage, basement, or room in the living space of a house, or in a partially enclosed space, such as a garage with the garage door partially open (Hnatov, 2014). In such scenarios, the SI engines are likely to be operating in conditions of decreasing oxygen concentrations in the ambient air. As noted above, these conditions can make combustion less efficient, thereby increasing CO emission rates as the generators continue to operate. Staff's benefits analysis considers this, noting that both carbureted and closed-loop fuel injected generators' CO emission rates increase, as the oxygen in the intake air to the generator decreases (Hnatov, Inkster, Buyer, 2016) and (Buyer, 2016a). In staff's view, manufacturers are likely to choose to meet these performance requirements by using an oxygen sensor placed in the engine's exhaust stream to provide closed-loop feedback to the fuel control system. The oxygen sensor sends a voltage signal to the electronic control unit (ECU) that varies with the amount of oxygen in the engine exhaust. The ECU uses this signal to check that the correct amount of fuel is being metered through the fuel injector, to maintain the air/fuel ratio at or near stoichiometry, which is the theoretical point for near-complete combustion and minimized CO emissions. The ECU uses the other sensors to determine how much fuel to provide, and the oxygen sensor provides feedback on whether the fuel mixture is correct. In this closed-loop operation, the ECU would continually adjust the fuel mixture to maintain complying CO emission rates. Based on information developed for EPA when its staff considered more stringent requirements for HC+NOx emissions, engine manufacturers that incorporate oxygen sensors into the exhaust streams of portable generator engines could incur variable costs of about $10 per engine (adjusted to 2014 dollars) (EPA, 2008, p. 6-22).[20]

In assessing the costs of this feature for small SI engines, the EPA (2006) projected that Class I engines would also require batteries and alternators/regulators at additional costs estimated to total about $17 (including original equipment manufacturer and warranty markups). As in Table 6 above, data on shipments of portable generators for 2010 through 2014 show that portable

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[19] These cost estimates include original equipment manufacturer markups and warranty markups totaling an estimated 34 percent. Such markups were also included in EPA's cost estimates (2006).

[20] As with EFI cost estimates, this per-unit cost estimate related to oxygen sensors includes original equipment manufacturer and warranty markups totaling 34 percent.

generators with handheld and Class I engines comprised about 59 percent of units shipped; and generators with Class II engines accounted for about 41 percent of units. Therefore, the estimated cost increase per unit for the EFI-related components identified in this section would be about $94 for generators with handheld and Class I engines; about $79 for generators with one-cylinder Class II engines; and about $85 for generators with two-cylinder Class II engines.[21]

We note that it may be technically feasible, and perhaps eventually less costly, for manufacturers to incorporate EFI systems that power-up the fuel pump and electronic components by magnetos when starter cords are pulled. Battery-less EFI systems have been available for several years in consumer products, such as snowmobiles, outboard motors and motorcycles. However, we are not aware of the current use of this technology in applications with Class I engines. Comments would be welcome on prospective use (*e.g.*, costs, applicability and challenges) of battery-less EFI for portable generators.

5.3.1.2. Catalysts in Mufflers

Generator manufacturers also are likely to include three-way catalysts[22] in the mufflers of generator engines to achieve the low CO emission rates that would be required by the draft proposed standard, and to still allow compliance with EPA's Phase 3 emissions standard for other pollutants. This is based on the judgment of ES staff (Buyer, 2016a). Catalysts assist in chemical reactions to convert harmful components of the engine's exhaust stream (hydrocarbons [HC] and oxides of nitrogen [NOx] in addition to CO) to less harmful gases. According to the Manufacturers of Emission Controls Association (MECA), the catalysts perform this function without being changed or consumed by the reactions that take place. In particular, when installed in the exhaust stream, the catalyst promotes the reaction of HC and CO with oxygen to form carbon dioxide and water, and the chemical reduction of NOx to nitrogen is caused by reaction with CO over a suitable catalyst (MECA, 2009).

In its assessment of the costs of the Phase 3 emission standards for small SI engines, EPA (2008) estimated that 3-way catalysts in mufflers of one-cylinder engines of portable generators could add about $10 to $20 in additional hardware costs to the manufacturing costs per engine, depending on capacity, power and useful life. These estimates were based on assumptions regarding precious metal use (principally platinum and rhodium), which were not formulated to oxidize CO and also based their prices in 2005. Based on our analysis of costs, including heat shields or double-walled mufflers that could be necessary, catalytic mufflers could add about $14 to the manufacturing cost of a Class I engine and about $30 to the cost of a Class II engine. These costs could vary, depending on choices and assumed loadings of precious metals. Recent evaluations of non-precious metal catalysts by MECA have found that these less-costly catalysts perform well in the oxidization of CO (Hallstrom, 2016). Application of this technology could lead to a reduction in costs of compliance related to catalytic after-treatment.

Although EPA assumed that Class I and Class II engines would include catalytic mufflers under Phase 3 emission requirements, a majority of small SI engines submitted for EPA

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[21] Two-cylinder engines would require two fuel injectors, which increases costs compared to one-cylinder Class II engines.

[22] Three-way catalysts are designed to convert three pollutants to harmless emissions simultaneously: Carbon Monoxide → Carbon Dioxide; Hydrocarbons → Water; and Oxides of Nitrogen → Nitrogen.

certification in recent years have not included after-treatment devices, such as catalysts. Current engines produced with catalytic after-treatment would incur smaller costs for this feature. CPSC engineering staff believes that portable generators powered by 4-stroke handheld engines might not require catalysts to comply with the draft proposed standard because the catalyst in both CPSC's and EPA's demonstration programs was primarily for NOx reduction; and handheld engines have less stringent HC+NOx emission requirements under current EPA emission standards (Buyer, 2016a). In estimating costs, we assume that catalyst-related costs for generators with handheld engines would average 50 percent of estimated costs for units with Class I engines, or about $7 per generator.

5.3.1.3. Design & Development/Other Reengineering

In an analysis of small SI engine technologies and costs for EPA, ICF International estimated that costs of conversion to EFI from carburetors would require 4 months of design time (engineers) and 6 months for development (by engineers and technicians) for Class I engines, and 2 months for design and 2 months for development for Class II engines (EPA, 2006). Based on estimated labor costs for engineering/technical staff, EPA estimated that these design and development costs totaled about $175,000 for Class I engines and about $64,000 for Class II engines, for each engine family (pp. 5-7). Design and development costs for three-way catalysts in mufflers were estimated by EPA to be about $135,000 per engine line for 2 months of design time (engineers) and 5 months of development time (engineers and technicians) (pp. 5-11). Adjusting for changes in an appropriate producer price index, the total design and development costs for engines to incorporate EFI and catalysts are estimated to be about $316,000 for a Class I engine family and $203,000 for a Class II engine family. We assume (as did EPA) that these costs are recovered over 5 years. If average annual production per engine family ranges from 10,000 to 50,000 units, per-unit design and development costs could range from about $1 to $6 for Class I engines and under $1 to about $4 for Class II engines.

These estimated costs could be applicable for portable generator manufacturers that supply their own engines. Engine manufacturers that supply engines to independent generator manufacturers might successfully pass along research and development costs with markups. EPA estimated that manufacturing and warranty markups by suppliers of EFI and catalytic components total 34 percent. Similar markups of design and development costs by suppliers of complying engines could increase generator manufacturing costs by about $2 to $8 for generators with Class I engines and by about $3 to $5 for generators with Class II engines. Manufacturers of approximately 80 percent of generators supply their own engines. Therefore, average generator manufacturing costs for design and development could be about $4.05 for generators with Class I engines and $2.60 for generators with Class II engines.[23]

Costs of design and development for generators powered by handheld engines were not specifically addressed by EPA. For the purposes of this preliminary analysis, we assume that these costs will be similar to those estimated for units with Class I engines. However, we assume that costs per engine family would be apportioned over perhaps 5,000 to 10,000 units annually. This assumption leads to average generator manufacturing costs for design and development of about $10 per unit for generators with handheld engines. We also acknowledge that models with handheld engines often are valued and promoted for their compactness and light weight.

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[23] Midpoint estimates for annual engine family production ranging from 10,000 to 50,000 units.

Accommodating new features that might be necessary for compliance with the draft rule and still provide these desired product characteristics could present greater challenges and costs for product engineers and firms. Staff welcomes comments on this issue, as well as on components and technologies that might be available to meet these challenges and moderate the impacts of the draft rule on these models.

Costs of new designs and tooling may also be required for generator frames and housings to accommodate additional components, such as batteries for generators with Class I engines, and to address reported concerns with heat dissipation. Modifications could be minimal for many larger generators with open-frame designs, but some smaller units with housings that enclose engines and other components could require larger, redesigned housings, at greater cost. We have assumed that per-unit tooling costs for generators with handheld engines would be twice as much as other generators, but costs may be underestimated for small generators. Staff welcomes comments on this issue from firms that would be affected by the rule.

The modifications to small SI engines to comply with the CO emission requirements of the CPSC standard would likely require engine manufacturers to seek certifications (as new engine families) under EPA requirements for HC+NOx and CO, with the attendant costs for fees and testing. These costs could be passed on to generator manufacturers that purchase the engines to power their products. Some of the larger manufacturers of portable generators are vertically integrated firms that also manufacture the engines that power their products. It is possible that engine modifications by engine manufacturers (including firms that also manufacture generators) to comply with the CPSC emission standards for CO could result in emissions of HC+NOx that are consistently lower than the EPA emission requirements. This potential effect of the use of EFI and catalysts was shown by demonstration programs sponsored by CPSC (conducted by the University of Alabama) and EPA, as detailed in the staff's technical rationale for the draft proposed standard (Buyer, 2016a). Consistently lower emission rates for HC+NOx could result in "engine credits" for engine families under EPA's program for averaging, banking and trading (ABT) of emission credits. If manufacturers of engines participate in the ABT program, they could partially offset increased manufacturing costs of compliance with the draft CPSC standard; and some of these savings could moderate the engine cost increases incurred by generator manufacturers that do not make their own engines. The impact of this potential offset is not included in the estimates presented in this preliminary analysis.

5.3.1.4. Testing and Certification

The draft proposed rule does not prescribe a particular technology or design that portable generators must incorporate to meet the emission limits. Nor does the draft proposed rule specify a test that manufacturers must use to assess compliance with the performance requirements. Instead, the draft proposed rule describes the test procedure and equipment that CPSC staff would use to assess compliance with the applicable performance requirements of the standard.[24] Manufacturers need not use the particular test referenced by the draft rule. However, whatever test is used must effectively assess compliance with the standard. We have assigned minor costs per unit for this element in Table 7, but we welcome comments on this issue.

[24] *i.e.,* Weighted CO emission rates emitted from the generator when operating in normal oxygen: 75 g/h for generators with handheld and Class I engines; 150 g/h for generators powered by one-cylinder Class II engines, and; 300 g/h for generators powered by two-cylinder Class II engines.

5.3.2. Other Potential Costs

EPA's evaluation of more stringent potential emission requirements than they ultimately included in their rule found that pressurized oil lubrication systems for engines would be among the possible engine design changes that might be needed for operation closer to stoichiometry. EPA's assessment of this engine feature is that it results in "enhanced performance and decreased emissions" because it allows better calibrations and improved cooling potential (EPA, 2006). Based on estimates made for EPA, estimated variable costs for a pressurized oil system would be about $19 for small SI engines that lack this feature. Directorate for Engineering Sciences staff believes that pressurized lubrication systems would not be necessary to comply with the draft proposed standard. We welcome comments on this issue.

5.3.3. Total Costs, per Unit

Cost elements by engine class and characteristics are shown in Table 7. Per-unit costs range from about $110 to $115 for portable generators with handheld, Class I, and one-cylinder Class II portable generators, and are about $140 dollars for the portable generators with two-cylinder Class II engines.

Table 7.
Net Estimated Manufacturing Costs[1] per Unit to Comply with the Draft Proposed Standard CO Emission Requirements[2]

Cost Elements	Handheld Engines	Class I Engines	Class II Engines	
			1-Cylinder	2-Cylinder
EFI-Related Costs[3]	$67	$67	$69	$75
Oxygen Sensor for Closed-Loop	$10	$10	$10	$10
Battery and Alternator/Regulator[4]	$17	$17	n/a	n/a
Catalyst-Related Costs	$7	$14	$27	$49
Research and Development	$10	$4	$3	$3
Tooling Costs	$4	$2	$2	$2
Testing and Certification	< $1	< $1	< $1	< $1
Combined Compliance Costs	$114	$113	$110	$138

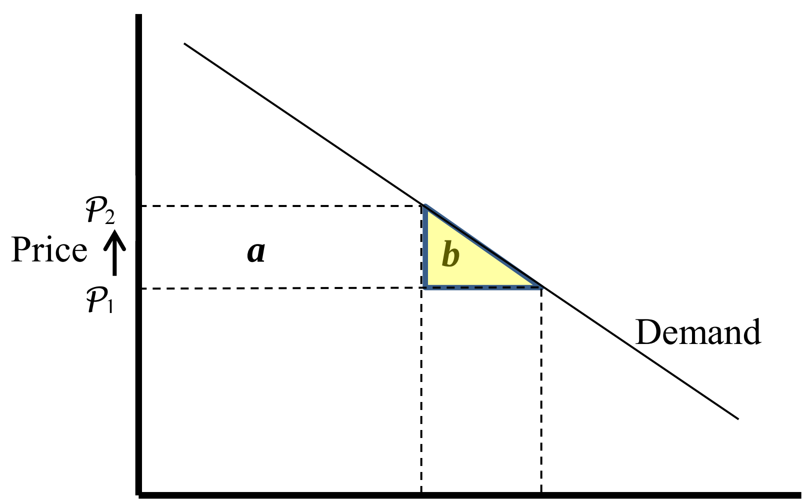
[1] Costs expressed in 2014 dollars, rounded to the nearest dollar.
[2] Estimates are for overhead valve (OHV) engines, which comprise nearly all engines used in the manufacture of portable generators
[3] Net, less costs related to carburetors.
[4] For those generators with handheld and Class I engines which currently do not have batteries.

5.3.3.1. Implications for Retail Prices and Consumer Demand

In addition to the direct costs of the rule, increases in the retail price of portable generators (as costs are passed forward to consumers) are likely to reduce sales. Additionally, consumers who no longer purchase portable generators because of the higher prices will experience a loss in utility that is referred to as consumer surplus but is not included in the direct cost estimates described in the last section. These impacts are illustrated conceptually in Chart 4 below. For purposes of this analysis, we assume that cost increases are pushed forward to consumers.

The downward sloping curve in Chart 4 represents the demand for generators; p_1 and q_1 represent the pre-regulatory price and quantity of generators demanded. After the regulation becomes effective, generator prices rise to p_2, and the quantity of generators demanded declines to q_2. The value of $p_2 - p_1$ represents the direct costs of the rule per generator (*e.g.*, \$113 for those with Class I engines and \$138 for those with two-cylinder Class II engines). The area given by the rectangle ***a*** represents the aggregate annual direct costs of the rule, which is equal to the product of the increase in portable generator price ($p_2 - p_1$) and the post-regulatory quantity demanded (*i.e.*, q_2). The triangle ***b*** represents additional costs of the rule in the form of a loss in consumer surplus: a value over and above what consumers paid for the product before the regulation, but which is lost to the consumers who do not purchase a generator at the higher price, p_2.

Chart 4.
Demand for Portable Generators



Given information on the pre-regulatory price (p_1) and quantity demanded (q_1), the impact of the rule on product prices, and information on the elasticity of demand for portable generators (*i.e.*, the percentage change in quantity demanded given a percentage change in price), we can estimate the expected reduction in sales ($q_1 - q_2$), and the lost consumer surplus represented by triangle ***b*** in Chart 4. Based on information presented earlier, estimated pre-regulatory (current) sales (*i.e.*, q_1) consist of about 15,000 generators with handheld engines; about 801,000 generators with non-handheld Class I engines; about 504,000 generators with one-cylinder Class II engines; and about 65,000 generators with two-cylinder Class II engines. Pre-regulatory retail prices of portable generators (p_1) average about $324 for generators with handheld engines; $534 for generators with non-handheld Class I engines; $1,009 for generators with one-cylinder Class II engines; and $2,550 for generators with two-cylinder Class II engines.[25]

We are not aware of precise estimates of the price elasticity of demand for portable generators; however, the nature of the product could argue for a relatively inelastic demand: sales of the product often peak when consumers need or anticipate the need for backup power for small and major appliances (*e.g.,* during weather-related outages, anticipated Y2K outages). In these circumstances, price may not be a significant determinant of many purchasing decisions. Based on available estimates of the price elasticity of demand for household appliances (for example: – 0.23, by Houthakker & Taylor, 2010 and – 0.35, for refrigerators, clothes washers and dishwashers, by Dale & Fujita, 2008), the price elasticity for portable generators could be approximately – 0.3. If this relationship between price increase and consumer demand holds true for complying portable generators marketed under the standard drafted by CPSC staff, a 1.0 percent increase in price for generators would result in a 0.3 percent reduction in unit demand.

Given these parameters, the quantity demanded might decline by about 11 percent ($114/$324 × – 0.3), on average, for generators with handheld engines (reducing sales from about 15,000 to about 13,400 annually); by an average of about 6 percent ($113/$534 × – 0.3) for generators with non-handheld Class I engines (projected to reduce sales from about 801,000 to about 750,000 annually); by about 3 percent ($110/$1,009 × – 0.3) for generators with one-cylinder Class II engines (projected to reduce sales from about 504,000 to about 487,000); and by about 2 percent ($138/$2,550 × – 0.3) for generators with two-cylinder Class II engines (projected to reduce sales from about 65,000 to 64,000). As noted in our discussion of retail price information (section 3.3.7.), factors other than engine capacity or generator power affect retail prices; and lower-priced generators with each engine class/category would be expected to face a relatively greater price increase under the draft proposed standard, and a correspondingly greater decrease in consumer demand. In general, we would anticipate that generators without features that increase price, such as inverter technology (described in section 3.3.7.), would realize a more significant percentage impact on manufacturing costs, retail prices, and consumer demand, at least initially. Price increases for new generators that would comply with the standard could lead more consumers to repair their older units or to purchase used units on the secondary market. Additionally, price increases for larger portable generators could lead more consumers to purchase stationary, standby generators to use during power outages.

The value of lost consumer surplus resulting from increased prices under the draft proposed standard (represented by the area of triangle **b** in Chart 4) could be about $4 million annually. This would be comprised of about $90,000 for generators with handheld engines; $2.9 million for generators with Class I engines; about $910,000 for generators with one-cylinder Class II engines; and about $70,000 for generators with two-cylinder Class II engines.

[25] Based on a survey of retail prices conducted in October 2015 of more than 350 portable generators, as reported on Internet sites of six retailers.

5.3.3.2. Combined Direct Costs and Lost Consumer Surplus per Unit

If the estimate of lost consumer surplus is spread over the remaining units sold, the estimated costs, per product sold, might average about $6.78 for generators with handheld engines ($91,000 ÷ 13,400 units); $3.85 for generators with Class I engines ($2,889,000 ÷ 750,000 units); $1.88 for generators with one-cylinder Class II engines ($914,000 ÷ 487,000 units); and $1.14 for generators with two-cylinder Class II engines ($73,000 ÷ 64,000 units). If these per-unit costs of lost consumer surplus are combined with the direct manufacturing costs estimated previously in this section, the total estimated per-unit costs would amount to about $121 for generators with handheld engines; $117 for generators with Class I engines; $112 for generators with one-cylinder Class II engines; and about $139 for generators with two-cylinder Class II engines. These are the cost figures that will be compared to the expected benefits of the rule.

Perhaps some consumers might perceive greater value for complying generators, in terms of fuel efficiency, greater ease of starting, product quality and safety. These perceptions could moderate the adverse impact on demand (*i.e.*, reduced sales) resulting from price increases.

5.4. Comparison of Benefits and Costs

Table 8 presents both the estimated benefits (Row 1) and the estimated costs (Row 2) of the draft proposed rule. The expected per-unit benefits were derived in Table 6. They average about $243 for generators with handheld engines; $254 for generators with Class I engines; $214 per unit for generators with one-cylinder Class II engines; and $4 for generators with two-cylinder Class II engines. The estimated $4 in benefits for the two-cylinder Class II engines reflect that very few consumer deaths have involved these generators in the scenarios modeled by NIST and analyzed by CPSC staff. This is perhaps because these types of generators may be less likely to be brought indoors because of their size and weight or loudness during operation. Additionally, given the limits on CO emissions for those generators, only about 17 percent of the addressable societal costs are projected to be prevented by the draft proposed standard.

The costs, including both manufacturing compliance costs (from Table 7) and the costs associated with lost consumer surplus (from the previous section) amount to $121 for generators with handheld engines; $117 for generators with Class I engines; $112 for generators with one-cylinder Class II engines; and about $139 for generators with two-cylinder Class II engines.

As shown in Row 3, the draft CO emission standard is estimated to result in net benefits (*i.e.*, benefits minus costs) of about $122 per unit for generators with handheld engines ($243 - $121); $137 per unit for generators with Class I engines ($254 - $117); about $101 for generators with one-cylinder Class II engines ($214 - $112); and approximately −$135 for generators with two-cylinder Class II engines ($4 - $139).

The estimated per-unit benefits and costs can be converted into annual aggregate estimates, given information on the production and sale of portable generators. Based on annual sales estimates shown in Row 4 of Table 8, the aggregate annual benefits and costs of the staff's draft proposed rule would amount to about $297.6 million and $153.0 million, respectively. Aggregate *net benefits* therefore, would amount to about $144.6 million annually, as shown in Row 5 of Table 8.

Because the costs of the draft proposed rule for generators with two-cylinder Class II engines ($139 per unit) substantially exceeded the benefits (about $4 per unit), aggregate net benefits would be maximized if the two-cylinder Class II engines were excluded from the rule. As shown in Row 5, excluding the two-cylinder Class II engines from the draft proposed rule would increase aggregate net benefits to $153.2 million.

We note that these larger and more powerful generators with two-cylinder Class II engines accounted for just 0.4 percent of the 503 consumer CO poisoning deaths addressed by the simulation analysis performed by NIST and the benefits analysis performed by CPSC staff (Hnatov, Inkster & Buyer, 2016). Portable generators with two-cylinder engines are estimated to have comprised about 7 percent of units in use over 2004 – 2012 (as shown in Tables 4 & 5) and about 5 percent of unit sales in recent years (Table 6).

Table 8.
Aggregate Estimated Present Value of Benefits and Expected Costs Resulting from the Draft Proposed Standard, for Annual Unit Shipments, by Generator Engine Class

	Handheld Engines	Class I Engines	Class II Engines		All Units
			1-Cylinder	2-Cylinders	
Present Value of Expected Benefits / Unit	$243	$254	$214	$4	$227
Costs to Manufacturers + Lost Consumer Surplus / Unit	$121	$117	$112	$139	$116
Net Benefits / Unit	$122	$137	$101	-$135	$110
Projected Annual Unit Sales Under the Standard	13,410	749,504	487,026	63,765	1,313,705
Aggregate Net Benefits from Annual Sales (Million $)	$1.6	$102.3	$49.3	-$8.6	$144.6

As discussed, the analysis was limited to the 503 out of 659 CO poisoning deaths during 2004 through 2012. Hnatov, Inkster & Buyer (2016) report that there could be some unquantified benefits associated with 156 deaths not modeled by NIST. However, this would not change the main findings of our analysis. If there were some additional deaths involving generators with handheld, Class I, or one-cylinder Class II engines that would have been prevented, our estimated net benefits for these generator classes would increase somewhat. On the other hand, even if all of the deaths involving generators with two-cylinder Class II engines would have been prevented, the costs for this class of generators would have exceeded the benefits.

Additionally, one underlying assumption for the benefits estimate is that there would be no behavioral adaptations by consumers in response to the reduced rate of CO emissions from portable generators. Knowledge about reduced CO emissions from generators produced under the draft rule could reduce consumers' perceptions of injury likelihood and susceptibility. This, in turn, could affect consumer behavior (Evans, 1985). In economic terms, the proposed rule could reduce what we might call the "cost" or "risk-price" of unsafe behavior, and implicitly provide an incentive for consumers to increase that behavior. If consumers are aware of the reduced CO poisoning risk and the rule does not make it more difficult to operate generators indoors, it seems likely that there would be some increase in warned-against practices. For example, some consumers might reduce the distance of the generator from their house because they think closer proximity will reduce the likelihood that the generator will be stolen. For the same reason, or to keep the generator out of the elements, some consumers who had run their generator outside might decide to bring it into the garage. Additionally, some consumers might even decide to run the generator inside their home. Behavioral adaptation as a potential effect of the rule is discussed by CPSC's Division of Human Factors (HF) (Smith, T., 2016). We cannot quantify this impact, and for reasons cited by HF, it could be small. However, although the proposed rule will significantly increase the safety of generators from an engineering standpoint, it seems likely that the increased technical safety predicted by modeling under the assumption of no behavioral adaptation will be partially offset by the behavioral adaptations of some users.

6. Sensitivity Analysis

The benefit-cost analysis presented in Section 5 compares benefits and costs of our base-case analysis. In Section 6, we present a sensitivity analysis to evaluate the impact of variations in some of the important parameters and assumptions used in the base-case analysis. Alternative inputs for the sensitivity analysis included:

- Shorter (8 years) and longer (15 years) expected product-life estimates than the 11 years used in the base analysis;
- A discount rate of 7 percent, rather than 3 percent, to express societal costs and benefits in their present value;
- Compliance costs and lost consumer surplus per-unit that are 25 percent higher than the base analysis;
- Lower ($5.3 million) and higher ($13.3 million) values of a statistical life (VSL) than the $8.7 million value for the base analysis; and
- Lower (by 25%) and higher (by 25%) effectiveness for each engine class and characteristic at reducing societal costs of CO poisoning.

The results of the sensitivity analysis are presented in Table 9, with Part A showing estimated net benefits per unit for generators in our base-case analysis (from Table 8) for each engine class and type, and Part B presenting the estimated net benefits per unit, using the alternative input values.

Variations in the expected product life had a relatively small impact on net benefits. A reduced expected product life decreased expected net benefits slightly, while an increased expected product life increased net benefits (rows a & b).

OMB (2003) recommends conducting a regulatory analysis using a 3 percent and a 7 percent discount rate. We presented base-case calculations using a 3 percent discount rate because research suggests it as an appropriate discount rate for interventions involving public health (Gold, et al., 1996). OMB justifies using a 7 percent discount rate because it is an estimate of the average before-tax rate of return to private capital in the U.S. economy. Because of the relatively long product life of generators, using a 7 percent discount rate substantially reduced the estimates of net benefits for the first three generator categories, but they remained positive (row c). However, because benefits were so small for the units with 2-cylinder Class II engines, the impact of the 7 percent discount rate on this category was negligible.

Variations in cost estimates would impact our estimates of net benefits directly. Discussions with generator and engine manufacturers suggest that the EPA cost estimates, upon which our analysis was based, may have led to underestimates of the incremental costs of EFI and other components that would be needed for the proposed rule. However, the results of this sensitivity analysis show that even if we had systematically underestimated the costs of the proposed rule by 50 percent, the findings of the analysis would have remained unaltered. Accordingly, generators with handheld, Class I, and one-cylinder Class II engines would continue to exhibit positive net benefits.

Finally, we considered the impact of variations in the value of statistical life (VSL) on the results of the analysis. Kniesner et al. (2012) suggested that a reasonable range of values for VSL was between $4 million and $10 million (in 2001 dollars), or about $5.3 million to $13.3 million in 2014 dollars. Consequently, we evaluated the sensitivity of our results to variations in the VSL by applying these alternative VSLs (rows e and f). This variation had a substantial impact on the estimated net benefits (as would be expected because deaths account for the great majority of generator-related societal costs). Nevertheless, the variations in VSL did not affect the results of the analysis.

In summary, for each variation analyzed, the overall estimated net-benefits of the draft proposed standard were found to remain positive for the first three categories of generators. However, as with the base-case analysis, the sensitivity analysis showed that generators with two-cylinder Class II engines had estimated costs that remained substantially greater than the present value of projected benefits.

Table 9. Sensitivity Analysis:
Expected Net Benefits Associated with Variations in Inputs
Part A: Base-Case Results*

Row	Input Value	Net Benefits per Generator, by Portable Generator Engine Class/Type			
		Handheld	Class I	1-cylinder Class II	2-cylinder class II
a	**Base-Case Analysis**	**$122**	**$137**	**$101**	**−$135**

* Base-Case Inputs:

- 3% discount rate;
- Portable Generators in Use: 10.3 million.
- VSL = $8.7 million per statistical life
- Expected product life: (years), 11 years
- Compliance Costs & Lost Consumer Surplus per unit ranging from $112–$139
- Estimated reduction in addressable deaths (and injuries) ranging from ≈ 17% for 2-cylinder Class II engines to ≈ 49% for Class I engines.

Table 9. Part B: Alternative Inputs for Sensitivity Analysis

Row	Input Variable and Value(s) Used in Sensitivity Analysis	Net Benefits per Generator, by Portable Generator Engine Class/Type			
		Handheld	Class I	1-cylinder Class II	2-cylinder Class II
	Base-Case Analysis:	**$122**	**$137**	**$101**	**−$135**
	Expected Product Life				
a	Shorter Expected Product Life: 8 years	$107	$121	$88	−$135
b	Longer Expected Product Life: 15 years	$144	$161	$124	−$134
	Discount Rate				
c	7% discount rate	$66	$78	$52	−$136
	Costs Estimates				
d	50% higher than base-case for each engine class/type	$61	$78	$45	−$204
	Value of a Statistical Life				
e	Lower VSL: $5.3 million	$48	$60	$36	−$136
f	Higher VSL: $13.3 million	$221	$241	$189	−$133
	Effectiveness at Reducing Deaths & Injuries				
g	Lower Effectiveness: 25% lower than estimated	$62	$75	$49	−$136
h	Higher Effectiveness: 25% higher than estimated	$185	$202	$157	−$134

7. Regulatory Alternatives

In accordance with OMB (2003) guidelines to federal agencies on preparation of regulatory impact analyses, CPSC staff considered several regulatory alternatives available to the Commission that could address the risks of CO poisoning from consumer use of portable generators. The alternatives considered included: (A) establishing less stringent (higher allowable) CO emission rates; (B) excluding generators with Class II, two-cylinder engines from the scope of the rule; (C) including an option that would allow compliance by means of automatic shutoff systems; (D) establishing a later effective/compliance date; (E) relying upon informational measures only; and (F) taking no regulatory action.

7.1. Less-Stringent (Higher Allowable) CO Emission Rates

Consistent with OMB Circular A-4 guidance on the preparation of regulatory analyses, CPSC staff considered establishing less stringent emission rates. This alternative could increase net benefits if it decreased the costs associated with the standard by a greater amount than it decreased the benefits. CO emission standards that were high enough to allow many generators to meet the requirements without the use of catalysts could reduce the cost of the standard by $14 per unit for generators with Class I engines and $30 per unit for engines with Class II engines.

If we assume that allowable emission rates under the draft proposed standard were increased by one-third (resulting in actual rates in enclosed operation of 200 g/h for generators with handheld and Class I engines, 400 g/h for generators with one-cylinder Class II engines, and 800 g/h for generators with two-cylinder Class II engines), expected reductions in societal costs from CO poisoning in scenarios analyzed by the staff could be about 30 percent for units with handheld engines; about 36 percent for units with Class I engines; about 30 percent for generators with one-cylinder Class II engines; and about 11 percent for generators with two-cylinder Class II engines. We estimate that these reductions in societal costs would be reflected in decreased present value of benefits per-unit of nearly $90 for generators with handheld engines; about $70 for generators with Class I engines; and about $40 for units with one-cylinder Class II engines. Thus, it seems likely that cost savings from less-stringent CO emission requirements that eliminated the need for catalysts would be less than the expected reductions in benefits. Therefore, net benefits of the rule would probably fall under this regulatory alternative.

CPSC staff did not consider a more stringent alternative because CPSC engineering staff believes that the rates in the draft proposed standard are based on the lowest rates that are technically feasible. Comments providing information on the benefits and costs that would be associated with different CO emission rates are welcome.

7.2. Alternative Scope: Limit Coverage to Generators with One-Cylinder Engines, Exempting Portable Generators with Two-Cylinder Class II Engines from the Rule

The Commission could exempt portable generators with two-cylinder Class II engines from the requirements of the draft proposed rule. As shown in the base-case analysis, the gross benefits that would be derived from including this class of portable generators within the requirements of the standard would only amount to about $4 per unit. There are two reasons for the small per-unit benefit estimate. First, although the two-cylinder generators accounted for 7.1 percent of generators in use during the 2004 through 2012 study period, they accounted for only about 1.2 percent of deaths. Consequently, the relative risk for two-cylinder generators was only about 16 percent of the risk for the handheld and one-cylinder models. Second, analysis of the benefits of the proposed emission limits for generators with two-cylinder Class II engines (300 g/h at unreduced ambient oxygen levels) suggests that the draft proposed rule would only prevent about 17 percent of the addressable deaths for this class of generators (Hnatov, Inkster & Buyer, 2016).

The costs of the draft rule are estimated to be $139 per two-cylinder, Class II generator, which yields *negative* net benefits of about $135 ($4 in benefits – $139 in costs) per unit. Given annual sales of about 64,000 units, the aggregate net benefits associated with this class of generators would amount to about −$8.6 million (64,000 generators × $135 per generator) annually. In other words, excluding this class of generators from the requirements of the draft proposed rule would increase the net benefits of the rule by about $8.6 million annually, to approximately $153 million. We also note that the total estimated value of expected societal costs of CO poisoning deaths and injuries per unit, including those <u>not</u> addressed by the staff's epidemiological benefits analysis, is $116 per unit (as shown in Tables 4 & 5). Hence, even if all of the deaths attributed to generators with two-cylinder Class II engines were to be prevented by the draft proposed standard, the costs would exceed the benefits for these generators.

Exclusion of generators with two-cylinder engines from the scope of the rule could create an economic incentive for manufacturers of generators with larger one-cylinder engines to either switch to two-cylinder engines for those models, or if they already have two-cylinder models in their product lines, they might be more likely to drop larger one-cylinder models from their product lines. The precise impacts of such business decisions on aggregate net benefits of the rule are not known at this time.

However, because of differences in characteristics between one- and two- cylinder models, the economic incentive to shift production to two-cylinder engines would likely be of marginal significance. As shown in Table 2, the Class II generators with two cylinders are heavier, more powerful, and generally, much more expensive than the Class II generators with one cylinder. Moreover, there appears to be a clear demarcation in the engine displacement for these two categories of generators. All identified two-cylinder generators have an engine displacement of 530 cc or more. In contrast, all identified one-cylinder models have an engine displacement of 459 cc or less. We have no evidence that any of the one-cylinder models would be converted into two-cylinder models to avoid the costs associated with the draft proposed rule. On the other hand, even if such conversion did occur in some cases, we have no evidence that the impact would be significant. Moreover, it seems unlikely that the higher cost of manufacturing the two-cylinder generators could be offset by any cost advantage that would result from avoiding the requirements of the proposed rule.

If it would be technologically feasible and cost-effective for manufacturers to use smaller two-cylinder engines for generators in lower power-ratings that are associated with greater per-unit societal costs, the reduction in scope of the rule might also specify a minimum engine displacement. For example, if this issue were a concern to the Commission, the Commission could exempt generators with two-cylinder engines, but only if the two-cylinder models had a displacement above a specified value of total engine displacement.

7.3. Alternate Means of Limiting Consumer Exposure: Automatic Shutoff Systems

CPSC staff considered options for reducing the risk of CO poisoning that would require portable generators to automatically shut off if they sensed that a potentially hazardous situation was developing or if they were used in locations that are more likely to result in elevated COHb levels in users. Four shutoff strategies/technologies were evaluated by CPSC engineering staff: (1) a generator-mounted CO-sensing system, which would (ideally) sense higher CO levels during operation indoors and shut off the engine before dangerous levels build up; (2) a CO-sensing system located away from the generator (*e.g.,* inside the dwelling) that relies on the user to properly place the sensing unit in a location where it can communicate with the generator, and send a signal remotely, causing the engine to shut down; (3) a generator-mounted global-positioning (GPS) system intended to infer operation of the generator indoors (from detection of reduced satellite signal strength) and automatically shut down the engine; and (4) applicable to generators equipped with EFI, an algorithm programmed into the engine control unit (ECU) that relies on system sensors to infer indoor operation, signaling the ECU to shut down the engine. The findings of the CPSC engineering evaluation reports on each of the shutoff strategies are summarized in detail in the briefing memorandum for the draft proposed standard (Buyer, 2016b).

An automatic shutoff option could be incorporated into a portable generator standard, either as an alternative to a standard that limited CO production per hour, or as an additional option for complying with a standard (*i.e.*, manufacturers could comply either by limiting the grams of CO produced per hour, or by ensuring that the generator automatically shut off if used in conditions that could lead to accumulation of hazardous levels of CO). In the latter case, the costs of complying with the rule could be reduced because manufacturers could choose the option for compliance that was less costly or more advantageous for them. In the former case, the cost of compliance would be reduced if the cost to manufacturers of incorporating an automatic shutoff technology was lower than for the cost of limiting the amount of CO produced.

However, CPSC staff does not believe that an automatic shutoff standard or option is feasible at this time. As noted above, CPSC engineering staff investigated four different approaches for an automatic shutoff system, and staff was not able to demonstrate how any of the shutoff systems could be implemented satisfactorily. Unresolved concerns with the automatic shutoff technologies studied by CPSC staff include: (1) possibly creating a false sense of safety, which could lead to increased use of portable generators indoors; (2) alternatives that require CO sensors that could falsely identify hazards, which would detrimentally affect the utility of the generator when used in proper locations and could lead to consumers overriding the mechanism; (3) the system would have to be shown to be durable and be capable of functioning after being stored for long periods and being used under widely different conditions; and (4) use of algorithms to shut off engines with ECUs would have to be engine-specific and tailored to how each engine functions, requiring a significant amount of additional testing on this system. These concerns would have to be resolved before a standard incorporating an automatic shutoff option could be developed.

Of the four shutoff technologies evaluated by the staff, the one staff judged to be potentially effective without negatively impacting the proper use of the generator is the use of programmed algorithms to shut down engines. Staff notes: "the concept is supplementary to the low CO rate emitted by the prototype [studied by the University of Alabama] because the shutoff algorithm only existed by virtue of the closed loop fuel injection system" (Buyer, 2016b). Therefore, this approach might have little impact on the cost of the draft standard because EFI-related costs would still be incurred without the algorithm programming. However, incorporation of programmed engine shut-down could potentially increase the net benefits, by combining a requirement for low emissions, with an option for automatic shutoff at minimal additional cost.

7.4. Different (Longer) Effective/Compliance Dates

As noted in the staff's technical rationale for the draft proposed standard, staff believes that 1 year is sufficient lead time for manufacturers to implement the necessary modifications on both one-cylinder and two-cylinder Class II engines powering generators (Buyer, 2016a). This assessment is based partly on industry experience in manufacturing small engines with closed-loop EFI for a variety of applications, including portable generators since 2006. At that time, the EPA estimated that manufacturers would need 3 to 5 years to implement closed-loop EFI and make necessary engine improvements if the agency were to adopt more stringent requirements for its HC+NOx emission standard for small SI engines. Because of the experience gained by engine manufacturers in recent years, staff thinks that 1 year from the date of publication of the final rule would provide an appropriate lead-time for manufacturers of generators powered by Class II engines. Staff is recommending a later compliance date that would take effect 3 years from the date of publication of the final rule for generators powered by smaller engines (handheld and Class I engines). This longer period to become compliant addresses manufacturers' concerns that there may be different challenges associated with accommodating the necessary emission control technologies on these smaller engines (even though industry has also gained some limited experience with incorporating fuel-injection on handheld and Class I engines).

The Commission could decide that the recent industry experience in manufacturing small engines with EFI, cited in the staff's technical rationale (Buyer, 2016a), although it facilitates compliance for some manufacturers of engines and generators, might not shorten the time needed by other manufacturers that have not gained relevant experience in application of EFI technology to their products. Based on recent discussions with generator manufacturers, a longer time frame before requiring compliance would allow firms additional time to design and build parts in-house, which could be more cost-effective than outsourcing. Lack of relevant recent experience with incorporating EFI into engine manufacturing could be more common for small manufacturers of generators. As noted in the staff's initial regulatory flexibility analysis, a longer period before the rule becomes effective (or before compliance is required for generators with smaller engines) would provide small engine manufacturers more time to develop engines that would meet the requirements of draft proposed rule; and in the case of small manufacturers of generators that do not also manufacture their own engines, "it would provide them with additional time to find a supplier for compliant engines so that their production of generators would not be interrupted [and . . .] for small importers, a later effective date would provide them with additional time to locate a supplier of compliant generators" (Krishnan & Squibb, 2016).

7.5. Informational Measures

OMB (2003) notes that informational measures are often preferable when agencies are considering regulatory action to address a market failure arising from inadequate information. As discussed in Section 2.1. ("Need for the Rule"), the Commission issued a rule requiring mandatory warning labels for generators in 2007, but deaths and injuries from the improper placement of newly purchased generators suggest that some consumers still poorly understand and process the information provided with generators and continue to put themselves and others at risk through the improper placement of generators in enclosed areas. Additionally, a review of injury and market data since warning labels have been required found insufficient evidence to conclude that the “Danger” label required in the current labeling standard has reduced the CO fatality risks associated with portable generators. Moreover, findings of other general studies on the effectiveness of labels “make it seem unlikely that any major reductions in fatalities should be anticipated due to the introduction of these labels” (Hanway, 2016).

Other informational measures that could be taken by the Commission include increased provision of information through means such as government publications, telephone hotlines, or public interest broadcast announcements. CPSC has previously taken actions to alert consumers to the dangers of CO poisoning from portable generators. Continued involvement in these activities, in cooperation with other interested stakeholders, is warranted. However, evidence of problems in processing information, and continued occurrence of deaths and injuries from improper use of portable generators, suggest that informational measures would not adequately address the risks presented by these products.

7.6. No Action to Establish a Mandatory Standard

The Commission could take no further regulatory action to establish a mandatory standard on portable generators. Given that some generator manufacturers have demonstrated that it is technologically feasible to produce generators that emit significantly lower levels of CO, taking no regulatory action to establish a mandatory standard would allow manufacturers to market low CO-emitting generators if they believe that there would be a market for such products. In addition, it would allow fully informed consumers to purchase low CO-emitting generators if they value the reduced risk. However, staff does not expect that a significant number of generators with CO emission rates proposed by the draft proposed standard would be marketed voluntarily, at least in the short run.

8. Conclusions from the Preliminary Regulatory Analysis

During 2004 through 2012, there was an average of about 73 portable generator-related deaths and at least 2,800 generator-related nonfatal injuries annually. The societal costs of these injuries, as described above, totaled about $820 million annually. During the same period, there was an average of about 11.1 million portable generators in use, suggesting about 0.66 deaths and at least 25.2 nonfatal CO poisonings per 100,000 portable generators in use. Based on indoor air quality modeling by NIST, and a staff technical evaluation of the predicted health effects for scenarios and housing characteristics found in the CPSC incident data (Hnatov, Inkster & Buyer, 2016), staff estimated that the draft proposed standard would prevent about one-third of these deaths and injuries.

The preliminary regulatory analysis evaluated the benefits and costs of staff’s draft proposed standard. The analysis distinguished between four categories of portable generators by engine class and type: (1) generators with handheld engines with displacement of 80 cc or less; (2) generators with Class I engines with engine displacement of less than 225 cc; (3) generators with one-cylinder Class II engines with engine displacement of 225 cc or more; and (4) generators with two-cylinder class II engines with engine displacement of 225 cc or more.

Generators with Class I and one-cylinder Class II engines accounted for about 92.2 percent of portable generators in use from 2004 through 2012. Generators with handheld engines (with engine displacement of 80 cc or less) and two-cylinder Class II engines (with displacement of 225 cc or more) accounted for 0.7 percent and 7.1 percent of portable generators in use, respectively, from 2004 through 2012.

The preliminary regulatory analysis suggests that the draft proposed rule could have substantial benefits for most generators. The estimated gross benefits per generator (over the product's expected life) ranged from about $215 to $255 for models with hand-held, Class I, and one-cylinder Class II engines. However, gross benefits for the units with two-cylinder Class II engines amounted to only about $4 per unit.

Staff's analysis shows the estimated costs of the draft proposed rule are generally similar across generator types, ranging from about $110 to $120 per generator for the models with handheld, Class I, and one-cylinder Class II engines, to about $140 for the models with two-cylinder Class II engines. The retail price increases likely to result from these higher costs could reduce portable generator sales by roughly 50,000 units annually, an overall sales reduction of about 3 to 4 percent. The relative impact on handheld generator sales could be greater because of the lower base price of these models.

Given these benefit and cost estimates, net benefits (*i.e.*, benefits minus costs) ranged from about $100 to about $140 per generator for the models with *handheld, Class I, and one-cylinder Class II engines*. However, net benefits were a *negative $135 for the models with two-cylinder Class II engines* (*i.e.*, benefits of $4 per generator minus costs of $139 per generator).

Estimated net benefits can be converted to aggregate annual estimates, given estimates of the annual sales of portable generators. The estimated aggregate net benefits, based on 1 year's sales of the generators with handheld, Class I, and one-cylinder Class II engines amounted to $153 million (see Table 8). Including the models with two-cylinder Class II engines (which account for only about 5 percent of portable generators sold in recent years) under the requirements of the draft proposed rule, would reduce aggregate net benefits to about $145 million annually.

The sensitivity analysis supported the findings of the base analysis. None of the inputs used in the sensitivity analysis altered our main findings that there would be positive net benefits for the generators with handheld, Class I, and one-cylinder Class II engines, but negative net benefits for the generators with two-cylinder Class II engines.

Additionally, we note that benefits of the draft proposed rule were estimated based on an assumption that consumer behavior would not change in response to knowledge of the reductions in CO emissions from generators. However, a perceived reduction in the risk associated with using the generators in unsafe environments may increase the likelihood that some consumers will use their generators in the house, in the garage, or in outside locations that are near openings to the house – behaviors that the CPSC recommends against. Although this is likely to be a secondary impact, it could, to some extent, offset the expected benefits from the proposed rule. On the other hand, our benefits estimates were based on 503 of the 659 CO-related deaths during 2004 through 2012. These were the deaths occurring in fixed-residential or similar structures (*e.g.*, detached and attached houses, and fixed mobile homes) that could be modeled by NIST. CPSC staff believes that some unquantified proportion of the remaining 156 deaths that were not modeled by NIST, because they occurred at non-fixed home locations (*e.g.*, temporary structures, such as trailers, horse trailers, recreational vehicles, church, sea-land container or tents), and some that occurred when portable carbureted generators were operated outdoors, would have been prevented (Hnatov, Inkster, & Buyer, 2016). If so, our benefits estimates would have been somewhat higher than presented in this analysis.

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Appendix A.
Representative Characteristics of Portable Generators by Engine Type

Handheld Engines

≈ 30 — 80 cc
≈ 20 — 60 lbs.
450 — 1700 watts
$130 (2-stroke)
to $800 (inverters)

Class I Engines

80 — 225 cc
1,000 — 4,400 watts
$190 to $2,300+

One-Cylinder Class II Engines

250 — 460 cc
3.5 — 9 kW
$330 — $4,000
115 — 320 lbs.

Two-Cylinder Class II Engines

≈ 530 — 990 cc
≈ 9 — 17.5 kW
$1,600 — $5,000
280 — 400+ pounds

Appendix B

Response to Previous Public Comments on Economic Issues

The Commission received comments on economic issues in response to the publication of the ANPR in 2006 and the CPSC report on the technology demonstration of a prototype low carbon monoxide emission portable generator in 2012.

1. On February 12, 2007, counsel for American Honda Motor Co., Inc., Briggs & Stratton Company and Yamaha Motor Corporation, USA ("the companies") submitted comments jointly on the December 12, 2006, Advance Notice of Proposed Rulemaking (ANPR) concerning portable generators. The companies made the following comments on economic issues:

   a) *The vast majority of consumers use their portable generators properly and safely. CPSC should give proper weight to the benefits and widespread uses of portable generators, as well as the affordability of current models.*

   While the great majority of consumers might always exercise proper safety precautions, improper use of the product can and does have disastrous consequences. CPSC engineering staff evaluated different technologies to address the risk, and has concluded that a performance standard that sets requirements that reduce CO emissions from generators is the most reliable regulatory alternative to address the risks of CO poisoning associated with portable generators. Manufacturing cost increases under the draft proposed standard would generally have a relatively greater impact on percentage price increases (and consumer demand) for low-price units, such as units lacking inverter technology (as discussed in section 5.3.3.1 of the preliminary regulatory analysis for the draft proposed standard). However, the analysis finds that the estimated benefits outweigh the costs to comply with staff's draft proposed standard.

   b) *Staff has not provided consumer exposure data to support risk analysis of CO deaths associated with consumer use of generators.*

   Since the comment was filed, additional information and analysis has greatly improved the analysis of risks associated with consumer use of portable generators. Staff's preliminary regulatory analysis has analyzed historical shipment information acquired from market research firms (Power Systems Research and Synovate), from federal data sources (the International Trade Commission and Bureau of the Census) and from individual manufacturers to estimate the numbers of portable generators in use, by engine class and other characteristics, during the period covered by the staff's epidemiological benefits analysis (Hnatov, Inkster & Buyer, 2016). The new information and analysis has enabled the staff to estimate CO poisoning risks (and societal costs) per generator in use. Additional information on product sales and use, which the industry would be encouraged to provide in subsequent comments, could further refine these estimates.

2. Roger Gault, Technical Director, The Truck and Engine Manufacturers Association (EMA), submitted the following comment on November 13, 2012, in response to the technology demonstration report:

Engine designs that incorporate the report's design changes[26] *are possible, but may not be suitable for all engines, including many utilized to power portable generators. This is especially true when considering the price point and reliability considerations associated with portable generators designed and sold to consumers for emergency or infrequent use.*

As noted in the response to the first comment, we agree that some types of generators (and engines) will be more severely affected by a draft performance requirement that is likely to require EFI and catalysts (although some generators with handheld engines might not require catalysts) in terms of relative price increases that would result from incorporation of the technologies. The impact on demand for these products could affect their future availability to consumers.

[26] Mr. Gault is referring to the incorporation of electronic control unit, manifold air pressure sensor, fuel pump, fuel injector… exhaust oxygen sensor, catalyst after-treatment and other components used on the prototype generator.

TAB M

Draft Proposed Rule Establishing a Safety Standard for Portable Generators: Initial Regulatory Flexibility Analysis

Charu Krishnan
Robert Squibb
Directorate for Economic Analysis
October 2016

Proposed Safety Standard for Portable Generators: Draft Initial Regulatory Flexibility Analysis

Background

On December 12, 2006, the Commission published an advance notice of proposed rulemaking (ANPR) seeking information on potential technologies or standards that would reduce the hazard of CO poisoning associated with portable generators. CPSC staff now recommends that the Commission issue a notice of proposed rulemaking (NPR) that would mandate a standard, based in part on the results of the staff's technology demonstration of a prototype low CO emission portable generator (Buyer, 2012), that would limit the CO emissions from portable generators.

Whenever an agency is required to publish an NPR, the Regulatory Flexibility Act (5 U.S.C. 601–612) requires the agency to prepare an initial regulatory flexibility analysis (IRFA) that describes the impact that the rule would have on small businesses and other entities. The IRFA must contain –

(1) a description of why action by the agency is being considered;
(2) a succinct statement of the objectives of, and legal basis for, the proposed rule;
(3) a description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;
(4) a description of the projected reporting, recordkeeping and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record; and
(5) an identification to the extent practicable, of all relevant Federal rules which may duplicate, overlap or conflict with the proposed rule.

The IRFA should also describe any significant alternatives to the proposed rule that would accomplish the stated objectives and would minimize any significant economic impact of the proposed rule on small entities. This report provides the IRFA of the draft proposed rule.

Why the Commission Is Considering this Rule

The draft proposed rule would strictly limit the rate of CO emitted by portable generators and is intended to reduce the risk of death or injury resulting from the use of a portable generator in or near an enclosed space or semi-enclosed space. The Directorate for Epidemiology, Division of Hazard Analysis (EPHA), reports that there were 659 deaths involving portable generators from 2004 through 2012 (which is a subset of 751 deaths that occurred in 2004 through 2014), an average of about 73 annually (Hnatov, 2015). Furthermore, there was a minimum of 8,703 nonfatal CO poisonings involving portable generators that were treated in hospital emergency departments from 2004 through 2012, or a minimum of about 967 annually (Hanway, 2015) and, as discussed in the preliminary regulatory analysis, there were an additional 16,600 medically-attended injuries treated in other settings, or an estimated 1,851 per year. The societal costs of both fatal and nonfatal CO poisoning injuries involving portable generators amounted to about $821 million ($637 million for fatal injuries + $184 million for nonfatal injuries) on an annual basis. The draft proposed standard is expected to significantly reduce generator-related injuries and deaths and the associated societal costs.

Objectives and Legal Basis of the Draft Proposed Rule

The objective of the draft proposed rule is to reduce deaths and injuries resulting from exposure to CO associated with portable generators being used in or near confined spaces. The Commission published an ANPR in December 2006, which initiated this proceeding to evaluate regulatory options and potentially develop a mandatory standard to address the risks of CO poisoning associated with the use of portable generators. The draft proposed rule would be issued under the authority of the Consumer Product Safety Act (CPSA).

Small Entities to Which the Draft Proposed Rule Would Apply

The draft proposed rule would apply to small entities that manufacture or import spark-ignited (SI) portable generators. Based on data collected by Power Systems Research, Trade IQ, and general market research, staff has identified more than 70 manufacturers of generators that at some time have supplied portable generators to the U.S. market. However, most of these manufacturers were based in other countries. Staff has identified 20 domestic manufacturers of gasoline-powered portable generators; 13 of these manufacturers would be considered “small” based on the U.S. Small Business Administration (SBA) size guidelines for North American Industry Classification System (NAICS) category 335312 (Motor and Generator Manufacturing), which categorizes manufacturers as “small” if they have fewer than 1,250 employees. Four of the small manufacturers are primarily engaged in the manufacture or supply of larger, commercial, industrial, or backup generators, or other products, such as electric motors, that would not be subject to the draft standard. For the other nine small manufacturers, portable generators could account for a significant portion of the firms’ total sales. Of these nine small, domestic manufacturers, six have fewer than 99 employees, one has between 100 and 199 employees, another has between 200 and 299 employees, and one has between 300 and 399 employees, based on firm size data from Hoovers, Inc., and interviews with several manufacturers.

In some cases, a small manufacturer may be responsible for designing its own brand of generators, but will outsource the actual production of the generators to other manufacturers, which are often based in China. Other small manufacturers may assemble generators using components (including engines) purchased from other suppliers. There may be some small manufacturers that manufacture or fabricate some components of the generators in addition to assembling them.

Using the same sources of data described above, staff identified more than 50 firms that have imported gasoline-powered portable generators. However, in some cases, the firms have not imported generators regularly, and generators appear to account for an insignificant portion of these firm’s sales. Of these firms, staff believes that 20 may be small importers of gasoline-powered portable generators that could be affected by the draft proposed rule. Importers were considered to be small businesses if they had fewer than 200 employees, based on the SBA guidelines for NAICS category 423610 (Electrical Apparatus and Equipment, Wiring Supplies, and Related Equipment Merchant Wholesalers) or $11.0 million dollars in average annual receipts, based on the SBA guidelines for NAICS category 443141 (Household Appliance Stores). Of the 20 small, potential importers staff identified, all have 50 or fewer employees based on firm size data from Hoovers, Inc.

Compliance Requirements of the Draft Proposed Rule, Including Reporting and Recordkeeping Requirements

The draft proposed rule would establish a performance standard that would limit the rate of CO that could be produced by portable generators that are typically used by consumers for electrical power in emergencies or other circumstances in which the electrical power has been shut off or is not available. The performance standard would be based on the generator's weighted CO emissions rate and is stated in terms of grams/hour (g/h), depending upon the class[1] of the engine powering the generator. Generators powered by handheld engines and Class I engines would be required to emit CO at a weighted rate that is no more than 75 grams per hour (g/h). Generators powered by Class II engines with a single cylinder would be required to emit CO at a weighted rate that is no more than 150 g/h. Class II engines with two (or twin) cylinders, which are generally larger than others in the class, and are believed to comprise a very small share of the consumer market, would be required to emit CO at a weighted rate of no more than 300 g/h.

Section 14 of the CPSA requires that manufacturers, importers, or private labelers of a consumer product subject to a consumer product safety rule to certify, based on a test of each product or a reasonable testing program, that the product complies with all rules, bans or standards applicable to the product. The draft proposed rule states the test procedure and equipment that CPSC staff proposes to use to determine whether a generator complies with the requirements (also stated in Appendix A3 of staff's test report (Brookman, 2016). However, the draft proposed rule would not require manufacturers to use any particular test procedure to certify that the product conforms to the standard; they could use any reasonable method to demonstrate compliance with the requirements of the standard. For products that manufacturers certify, manufacturers would issue a general certificate of conformity (GCC).

[1] Because most of the generators that were associated with fatal CO poisonings reported to CPSC were gasoline-fueled, staff has chosen to set the performance standard based on the U.S. Environmental Protection Agency's (EPA) classification of the small SI engine powering the generator and the number of cylinders the engine has. The EPA broadly categorizes small SI engines as either non-handheld or handheld, and within each of those categories EPA further distinguishes them into different classes based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cc up to 225 cc and Class II having displacement at or above 225 cc but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Staff chose to divide non-handheld Class II engines according to whether the engine had a single cylinder or twin cylinders.

The requirements for the GCC are stated in Section 14 of the CPSA. Among other requirements, each certificate must identify the manufacturer or private labeler issuing the certificate and any third party conformity assessment body on whose testing the certificate depends, the place of manufacture, the date and place where the product was tested, each party's name, full mailing address, telephone number, and contact information for the individual responsible for maintaining records of test results. The certificates must be in English. The certificates must be furnished to each distributor or retailer of the product and to the CPSC, if requested.

Costs of Draft Rule that Would Be Incurred by Small Manufacturers

The most likely method for manufacturers of portable generators to comply with the proposed CO emissions requirement are converting to the use of closed-loop electronic fuel-injection (EFI) systems, instead of conventional carburetors, to control the delivery of gasoline to the pistons of generator engines (Buyer, 2016a). Manufacturers are also likely to use catalytic converters in the mufflers of the generator engines. As discussed in the preliminary regulatory analysis of the draft proposed rule (Smith, 2016), the cost to manufacturers for complying with the draft proposed rule is expected to be, on average, about $114 per unit for handheld engines (1.1% of unit sales between 2010 and 2014), $113 per unit for generators with Class I engines (57.8% of unit sales between 2010 and 2014), $110 for those with single cylinder Class II engines (36.4% of unit sales between 2010 and 2014), and $138 for those with twin cylinder Class II engines (4.7% of unit sales between 2010 and 2014).

The above estimates include the variable costs related to EFI, including an oxygen sensor for a closed-loop system, a battery and alternator or regulator, and 3-way catalysts. They also include the fixed costs associated with the research and development required to redesign the generators, tooling costs, and the costs associated with testing and certification that the redesigned engines to comply with the U.S. Environmental Protection Agency (EPA) requirements for exhaust constituents they regulate, namely hydrocarbons and oxides of nitrogen (HC + NOx) and CO emissions.[2]

Manufacturers would likely incur some additional costs to certify that their portable generators meet the requirements of the draft proposed rule as required by Section 14 of the CPSA. The certification must be based on a test of each product or a reasonable testing program. Manufacturers may use any testing method that they believe is reasonable and are not required to use the same test method that would be used by CPSC to test for compliance. Based on information from a testing laboratory, the cost of the testing might be more than $6,000 per generator model. However, it may be possible to use the results from other tests that

[2] The modifications to small SI engines to comply with the CO emission requirements would likely require engine manufacturers to seek certifications (as new engine families) under EPA requirements for HC + NOx and CO, with the attendant costs for fees and testing, which could be passed on to generator manufacturers that purchase the engines to power their products. Some of the larger manufacturers of portable generators are vertically-integrated firms that also manufacture the engines that power their products. These testing and certification requirements are to meet EPA requirements and are in addition to the testing and certification requirements of Section 14 of the CPSA.

manufacturers may already be conducting, such as testing to ensure that the engines comply with EPA requirements, per 40 C.F.R. part 1054, for HC + NOx and CO emissions, to certify that the generator meets the requirements of the draft proposed rule. Manufacturers and importers may also rely upon testing completed by other parties, such as their foreign suppliers, in the case of importers, or the engine suppliers in the case of manufacturers, if those tests provide sufficient information for the manufacturers or importers to certify that the generators comply with the draft proposed rule.

CPSC staff welcomes comments from the public regarding the cost or other impacts of the certification requirements under Section 14 of the CPSA and whether it would be feasible to use the results of tests conducted for certifying compliance with EPA requirements to certify compliance with the draft proposed rule.

Impact on Small Businesses

Manufacturers

In order to comply with the draft proposed rule, small manufacturers would incur the costs described above to redesign and manufacture their generators to comply with the CO emissions requirements. However, to the extent that the volume of generators produced by small manufacturers is lower than that of the larger manufacturers, the costs incurred by smaller manufacturers may be higher than the average costs reported above. One reason to expect that costs for lower-volume manufacturers could be higher than average is that some of the costs are fixed. For example, research and development costs were estimated to be about $203,000, on average, for Class II engines and about $316,000 for Class I engines. On a per-unit basis, the preliminary regulatory analysis estimated that these costs would average about $4 for Class I engines and $3 for Class II engines. However, for manufacturers with a production volume only one-half the average production volume, the per-unit costs would be twice the average.

For lower-volume producers, the per-unit costs of the components necessary to modify their engines might also be higher than the costs for higher-volume producers. As discussed in the preliminary regulatory analysis (Smith, 2016), generators that meet the requirements of the draft proposed rule would probably use closed-loop electronic fuel-injection, instead of conventional carburetors. Therefore, manufacturers would incur the costs of adding components associated with EFI to the generator, including injectors, pressure regulators, sensors, fuel pumps, and batteries. Based on information obtained from a generator manufacturer, the cost of these components might be as much as 35 percent higher for a manufacturer that purchased only a few thousand units at a time, as opposed to a manufacturer that purchased more than 100,000 units at once.

Although the cost for small, low-volume manufacturers that manufacture their own engines might be higher than for high-volume manufacturers, small portable generator manufacturers often do not manufacture the engines used in their generators, but obtain them from engine manufacturers, such as Honda, Briggs and Stratton, and Kohler, as well as several engine manufacturers based in China. These engine manufacturers often supply the same engines to other generator or engine-driven tool manufacturers. Because these engine manufacturers would be expected to have higher production volumes and can spread the fixed research and development and tooling costs over a higher volume of production, the potential disproportionate impact on lower-volume generator producers might be mitigated to some extent.

As discussed in the regulatory analysis (Smith, 2016), the retail prices staff observed for portable generators from manufacturers and importers of all sizes ranged from a low of $133 to $4,399, depending upon the characteristics of the generator. On a per-unit basis, staff expects the draft proposed rule to increase the costs of generators by an average of $110 to $140. Generally, staff considers impacts that exceed 1 percent of a firm's revenue to be potentially significant. Because the estimated average cost per generator would be between about 3 percent and 80 percent of the retail prices (or average revenue) of generators, staff believes that the draft proposed rule could have a significant impact on manufacturers and importers that receive a significant portion of their revenue from the sale of portable generators.

Based on a conversation with a small manufacturer, staff believes that the draft proposed rule may have a disproportionate impact on generator manufacturers that compete largely on the basis of price rather than on brand name or reputation. CPSC cannot currently identify how many of the nine domestic, small manufacturers of engines compete on the basis of price. One reason for the disproportionate impact is that consumers of the lower-priced generators are probably more price sensitive than consumers of the brand name generators and may be more likely to reduce or delay their purchases of generators in response to the cost increases that would be expected to result from the draft proposed rule. A second reason that manufacturers that compete largely on the basis of price could be disproportionately impacted is that brand name generator manufacturers might have more options for absorbing the cost increases that result from the draft proposed rule. For example, a high-end generator manufacturer might be able to substitute a less expensive, but still adequate engine for a name brand engine that they might currently be using. On the other hand, manufacturers that have been competing primarily on the basis of price are more likely to have already made such substitutions and will have fewer options for absorbing any cost increases. As a result, the price differential between generators aimed at the low-end or price conscious market segments and the name brand generators will be reduced, which could affect the ability of the manufacturers of generators aimed at the price conscious market to compete with the manufacturers of name brand products.

Importers

For many small importers, the impact of the draft proposed rule would be expected to be similar to the impact on small manufacturers. One would expect that the foreign suppliers would pass much of the costs of redesigning and manufacturing portable generators that comply with the draft proposed rule to their domestic distributors. Therefore, the cost increases experienced by small importers would be similar to those experienced by small manufacturers. As with small manufacturers, the impact of the draft proposed rule might be greater for importers that primarily compete on the basis of price. CPSC cannot currently identify how many of the 20 domestic, small importers of engines compete on the basis of price.

In some cases, the foreign suppliers might opt to withdraw from the U.S. market, rather than incur the costs of redesigning their generators to comply with the draft proposed rule. If this occurs, the domestic importers would have to find other suppliers of portable generators or exit the portable generator market. Exiting the portable generator market could be considered a significant impact if portable generators accounted for a significant percentage of the firm's revenue.

Small importers will be responsible for issuing a GCC certifying that their portable generators comply with the draft proposed rule should the rule become final. However, importers may rely upon testing performed and GCCs issued by their suppliers to comply with this requirement.

Federal Rules Which May Duplicate, Overlap or Conflict with the Draft Proposed Rule

We have not identified any Federal rules that duplicate or conflict with the draft proposed rule. The EPA promulgated a standard in 2008 for small spark-ignited engines that set a maximum rate for CO emissions. However, the maximum level set by the EPA is higher than the draft proposed CPSC standard for portable generators.

Alternatives Considered to Reduce the Burden on Small Entities

Under section 603(c) of the Regulatory Flexibility Act, an initial regulatory flexibility analysis should "contain a description of any significant alternatives to the proposed rule which accomplish the stated objectives of the applicable statutes and which minimize any significant impact of the proposed rule on small entities." CPSC staff examined several alternatives to the draft proposed rule which could reduce the impact on small entities. These are discussed below and include: (1) less stringent CO emission rates, (2) limiting coverage to one-cylinder engines, (3) using an automatic shutoff device as an option for reducing consumer exposure to CO, (4) establishing alternative compliance dates, (5) employing informational measures, or (6) taking no action. Each of these alternatives is discussed in more detail below.

Less Stringent (Higher Allowable) CO Emission Rates

Cost savings for small entities from higher allowable CO emission rates might result if rates were set high enough so that many generators could meet the requirements without the use of catalysts. While catalysts may not be necessary to meet higher allowable CO emissions, the use of EFI would likely still be required to meet even these higher allowable emissions. The cost savings for generators that do not require catalysts to meet the standard could range from $7 to $49 per unit, depending on the class of engine (Smith, 2016). However, if the emission rates under the draft proposed standard were increased by one-third, the expected reductions in societal costs from CO poisoning in scenarios analyzed by the staff could be about 30 percent for units with handheld engines; about 36 percent for units with Class I engines; about 30 percent for generators with one-cylinder Class II engines; and about 11 percent for generators with two-cylinder Class II engines. We estimate that these reductions in societal costs would be reflected in decreased present value of benefits per unit of nearly $90 for generators with handheld engines; about $70 for generators with Class I engines; and about $40 for units with one-cylinder, Class II engines (Smith, 2016). It seems likely that cost savings from less-stringent CO emission requirements, and therefore, the reduced burden on small businesses would be less than expected reductions in benefits. Therefore, net benefits of the rule would probably decrease under this regulatory alternative.

Alternative Scope: Limit Coverage to One-Cylinder Engines, Exempting Portable Generators with Two-Cylinder, Class II Engines from the Draft Proposed Rule

Staff considered limiting the scope of the rule to generators with one-cylinder engines. Generators with two-cylinder, Class II engines have been associated with relatively few deaths: only about 1.2 percent of portable generator deaths. Because of this, the estimated net benefits that would be associated with generators with two-cylinder, Class II engines are negative $135 per unit. Thus, excluding generators with two-cylinder, Class II engines could increase the net benefits of the draft proposed rule and reduce the burden on any small manufacturer or importer of these portable generators.

Alternate Means of Limiting Consumer Exposure: Automatic Shutoff Systems

CPSC staff considered options for reducing the risk of CO poisoning that would require portable generators to shut off automatically if the generator sensed that a potentially hazardous situation was developing or if the generator were used in locations that are more likely to result in elevated COHb levels in users. CPSC engineering staff evaluated four shutoff strategies/technologies: (1) a generator-mounted CO-sensing system, which would (ideally) sense higher CO levels during operation indoors and shut off the engine before dangerous levels build up; (2) a CO-sensing system located away from the generator (*e.g.*, inside the dwelling) that relies on the user to properly place the sensing unit in a location where it can communicate with the generator and send a signal remotely, causing the engine to shut down; (3) a generator-mounted global-positioning (GPS) system intended to infer operation of the generator indoors (from detection of reduced satellite signal strength) and automatically shut down the engine; and (4) applicable to generators equipped with EFI, an algorithm programmed into the engine control unit (ECU) that relies on system sensors to infer indoor operation, signaling the ECU to shut down the engine. The findings of the CPSC engineering evaluation reports on each of the shutoff strategies are summarized in the briefing memorandum for the draft proposed standard (Buyer, 2016b).

An automatic shutoff option could be incorporated into a portable generator standard either as an alternative to a standard that limited CO production per hour or as an additional option for complying with a standard (*i.e.*, manufacturers could comply either by limiting the grams of CO produced per hour or by ensuring that the generator automatically shut off if used in conditions that could lead to accumulation of hazardous levels of CO). In the latter case, the costs of complying with the rule could be reduced because manufacturers could choose the option for compliance that was less costly or more advantageous for them. In the former case, the cost of compliance would be reduced if the cost to manufacturers of incorporating an automatic shutoff technology was lower than the cost of limiting the amount of CO produced.

However, CPSC staff does not believe that an automatic shutoff standard or option is feasible at this time. As noted above, CPSC engineering staff investigated four different approaches for an automatic shutoff system and was not able to demonstrate how any of the shutoff systems could be implemented satisfactorily. Unresolved concerns with the automatic shutoff technologies studied by CPSC staff include: (1) possibly creating a false sense of safety, which could lead to increased use of portable generators indoors; (2) alternatives that require CO sensors might falsely identify hazards, which would detrimentally affect the utility of the generator when used in proper locations and could lead to consumers overriding the mechanism; (3) demonstrating that the system is durable and capable of functioning after being stored for long periods and being used under widely different conditions; and (4) using algorithms to shut off engines with ECUs would have to be engine-specific and tailored to each engine functions, requiring a significant amount of additional testing on this system. These concerns would have to be resolved before a standard incorporating an automatic shutoff option could be developed.

Of the four shutoff technologies evaluated by staff, the one staff judged to be potentially effective without negatively impacting the proper use of the generator is the use of programmed algorithms to shut down engines. Staff notes that "the concept is supplementary to the low CO rate emitted by the prototype [studied by the University of Alabama] because the shutoff algorithm only existed by virtue of the closed loop fuel injection system" (Buyer, 2016b). Therefore, this approach might have little impact on the cost of the draft standard because EFI-related costs would still be incurred without the algorithm programming. However, this option potentially could increase the net benefits by combining a requirement for low emissions with an option for automatic shutoff at minimal additional cost.

Different (Longer) Compliance Dates

CPSC staff recommends that the Commission propose that the draft proposed rule take effect 1 year after a final rule is published in the Federal Register. Staff also recommends proposing that generators powered by Class II engines would have to comply at that time and that generators powered by handheld and Class I engines would have to comply with the requirements 3 years after publication of a final rule. Staff considered later compliance dates than these that could potentially reduce the impact on manufacturers of generators, including small manufacturers, by providing them with more time to develop engines that would meet the requirements of the draft proposed rule; or in the case of small manufacturers that do not manufacture the engines used in their generators, by providing them with additional time to find a supplier of compliant engines so that their production of generators would not be interrupted. Later compliance dates would also provide small importers with additional time to locate a supplier of compliant generators. On the other hand, later compliance dates could delay the introduction of complying generators, thereby reducing the expected benefits of the proposed rule.

Staff believes that the compliance dates suggested in the draft proposed rule provide sufficient time for small manufacturers and importers to bring their products into compliance. Because of the experience gained by engine manufacturers in recent years, staff thinks that 1 year is an appropriate lead-time for generators powered by Class II engines to comply (Buyer, 2016a). Staff is recommending a compliance date of 3 years after the publication of a final rule for generators powered by handheld and Class I engines to address manufacturers' concerns that there might be different challenges associated with accommodating the necessary emission-control technologies on these smaller engines (even though industry has also gained some limited experience with incorporating fuel injection on handheld and Class I engines).

Informational Measures

CPSC staff considered focusing on informational measures as an option. This would reduce the burden on small manufacturers and importers because they would not incur the costs of developing a new technology. OMB (2003) notes that informational measures will often be preferable when agencies are considering regulatory action to address a market failure arising from inadequate information. However, although the Commission required mandatory labels for generators starting in 2007, deaths and injuries from the improper placement of newly purchased generators suggest that some consumers still poorly understand and process the information contained in the operating instructions and warning labels and continue to put themselves and others at risk through the improper placement of generators in enclosed areas. The findings of other studies on the effectiveness of labels also "make it seem unlikely that any major reductions in fatalities should be anticipated due to the introduction of these labels" (Hanway, 2016).

Other informational measures that the Commission could take include increased provision of information, through means such as government publications, telephone hotlines, or public interest broadcast announcements. CPSC has previously taken, and continues to take, actions to alert consumers to the dangers of CO poisoning by portable generators, and believes that continued involvement in these activities is warranted. However, evidence of problems in processing information, and the continued occurrence of deaths and injuries from improper use of portable generators, indicate that informational measures do not adequately address the risks presented by these products.

Taking No Action to Establish a Mandatory Standard

CPSC staff considered the alternative of taking no action to establish a mandatory safety standard for portable generators. This alternative could be accompanied by increased public information and education efforts to warn consumers of the dangers of using portable generators in and near enclosed areas. Given that some generator manufacturers have demonstrated that it is technologically feasible to produce generators that emit significantly lower levels of CO, taking no action to establish a mandatory standard would allow manufacturers to market low CO-emitting generators if they believe that there would be a market for such products and it would allow fully informed consumers to purchase such generators if they valued the reduced risk. However, the purpose of the draft proposed rule is to reduce the hazard for consumers who are not adequately informed about the hazards of using generators in and near enclosed spaces. Given that there have already been efforts to warn consumers of these risks and yet there are still some consumers who continue to use generators inappropriately and suffer serious consequences from doing so, CPSC staff does not have confidence that increased public information and education efforts would reach the targeted consumers. Therefore, although the option of not taking any action to establish a mandatory standard would minimize the impact on small portable generator suppliers, it is unlikely to accomplish the purpose of the draft proposed rule, which is to reduce or mitigate deaths and injuries associated with CO poisoning resulting from the use of portable generators in or near enclosed spaces or semi-enclosed spaces.

Summary and Request for Comments

Staff has identified about nine small generator manufacturers and about 20 small generator importers that would be impacted by the draft proposed rule. Staff believes that the draft proposed rule could have a significant impact on small manufacturers and importers that receive a significant portion of their revenue from the sale of portable generators.

The most likely means of complying with the draft proposed rule would be to use closed-loop EFI systems, instead of conventional carburetors, to control the delivery of gasoline to the pistons of generator engines and to use catalytic converters in the mufflers of the generator engines to be able to meet the EPA's HC+NOx emission standards. CPSC staff estimates that, on average, the requirements will increase the costs of generator manufacturers by about $110 and $140, depending upon engine type. The costs might be higher than average for lower-volume manufacturers, which could include several small manufacturers.

Small manufacturers and importers that serve the low-end of the market and compete mostly on the basis of price might be more severely impacted by the draft proposed rule because their customers may be more price sensitive; and compared with larger manufacturers, small manufacturers and importers may not have the same options of reducing other costs to mitigate the impact of the draft proposed rule on the price of generators. Suppliers of name brand generators, or suppliers that compete on a basis other than price, might be able to make other adjustments, such as using less expensive engines, to mitigate the impact of the draft proposed rule on the price of their generators. CPSC cannot currently identify how many of the nine domestic, small manufacturers or the 20 domestic, small importers of engines compete on the basis of price.

Generator manufacturers and importers will be responsible for certifying that their products comply with the requirements of the draft proposed rule. Testing and certification costs can have a disproportionate impact on small manufacturers, depending upon the cost of the tests and volume of production relative to larger manufacturers. However, some of these testing costs might be mitigated if manufacturers could use the results of testing already being conducted (such as, for example, testing to certify compliance with EPA requirements), to offset some of the testing costs required for certification with the draft proposed rule.

CPSC staff invites comments on this initial regulatory flexibility analysis and the potential impact of the draft proposed rule on small entities, especially small businesses. In particular, CPSC staff seeks comment on:

- the types and magnitude of manufacturing costs that might disproportionately impact small businesses or that were not considered in this analysis;

- the costs of the testing and certification requirements of the draft proposed rule, including whether EPA testing can be used to meet the certification requirements for the draft proposed rule;

- whether other factors not considered in this analysis could be significant, such as EPA's Averaging, Banking and Trading (ABT) program, which could allow manufacturers of engine families that do have low CO emissions to meet the draft proposed rule and also have very low HC+NOx emissions to "buy credits" in the ABT program, thus allowing their other engine families to exceed HC+NOx limits;

- differential impacts of the draft proposed rule on small manufacturers or suppliers that compete in different segments of the portable generator market; and finally,

- alternatives that would minimize the impact on small businesses, but would still reduce the risk of CO poisoning associated with generators.

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