Briefing Package on Assessment of Portable Generator Voluntary Standards' Effectiveness in Addressing CO Hazard, and Information on Availability of Compliant Portable Generators

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EXECUTIVE SUMMARY

Engine-driven portable generators are useful products to provide consumers with electrical power when utility power is interrupted or not available. However, almost all generator engines emit very high rates of carbon monoxide (CO), and when consumers use portable generators in or near enclosed areas, the immediate and surrounding environment can quickly become fatal for occupants. The U.S. Consumer Product Safety Commission's (CPSC) databases contain many records of fatal incidents that commonly involved a generator being used at home, in the living space, an attached garage, a basement, or a crawlspace. The average fatality rate over the 11-year period 2010 through 2020 is 64 deaths per year, when only a generator was involved, and 68 deaths per year when a generator and another CO-producing consumer product was involved. Three-quarters of the CO deaths are single-fatality incidents; the remaining one-quarter are multiple-fatality incidents, some involving entire families. A relatively small number of reported incidents involved a generator being used outdoors. Reducing CO deaths and injuries from generators is critical to making a significant reduction in consumer CO deaths caused by consumer products under CPSC's jurisdiction.

In November 2016, the Commission issued a notice of proposed rulemaking (NPR) to limit the CO emission rates of portable generators to address the CO poisoning hazard associated with this product. In 2018, two voluntary standards for portable generators, ANSI-approved *ANSI/PGMA G300-2018 Safety and Performance of Portable Generators*, and ANSI-approved *UL 2201, Standard for Safety for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition* (referred to as PGMA G300 and UL 2201, respectively), adopted CO poisoning hazard-mitigation requirements. Both standards require generators to shut off when certain concentrations of CO are present around the generator. UL 2201 also requires a specific, relatively lower CO emission rate, compared to current generators.

The Consumer Product Safety Act (CPSA) prohibits issuing a final rule under section 9 of the Act if a voluntary standard exists whose requirements will eliminate or adequately reduce the risk of injury, and there is likely to be substantial compliance with that voluntary standard. This briefing package describes staff's assessment of the effectiveness of the voluntary standards' CO hazard-mitigation requirements in reducing consumer CO deaths and injuries. The briefing package also includes information on the availability of compliant generators in the marketplace.

Staff's approach to evaluating the effectiveness of the voluntary standards was like that we used to evaluate the effectiveness of the proposed rule. CPSC staff worked with staff of the National Institute for Standards and Technology (NIST) to simulate a subset of fatal incident data from CPSC's databases using an indoor air quality (IAQ) modeling program called "CONTAM." CONTAM simulated a 24-hour period during which a noncompliant generator, referred to as a "baseline generator," emitted CO at a specified rate, representing a baseline generator, at a specified location inside a house, for a specified number of hours, which represented the generator's run time associated with that CO emission rate on a full tank of fuel. CONTAM simulated the accumulation and transport of CO throughout the house while the generator was emitting CO, and the continued transport of CO for the remainder of the 24-hour period after the generator ran out of fuel. For each of the voluntary standard-compliant generators, CONTAM also simulated a 24-hour period that started with the generator operating in the same location inside the house as the baseline generator, emitting CO at a specified rate, representative of a voluntary standard-compliant generator. However, if the CO concentration in that location reached the voluntary standard's criteria for shutting off the generator, the CO emission stopped. The simulation then continued in one of a variety of ways for the remainder of the 24-hour period, *i.e.*, with the generator either not restarted, or restarted 10 minutes later in the same location, or in a new location, that was either indoors or outdoors. If indoors and it stopped again, it was restarted a second time outdoors. In every simulation in which the generator was restarted, the voluntary standard-compliant generator operated until the full fuel tank was empty, just as the baseline generator operated. Every simulation yielded CO concentrations in each room of the house as a function of time over the 24-hour analysis interval. These concentrations were then used to calculate carboxyhemoglobin (COHb) levels for the house's theoretical occupants. The COHb level serves as a useful measure of expected CO poisoning severity. Comparing the occupants' health effects from the simulation of a baseline generator to a voluntary standard-compliant generator provides staff's assessment of the benefits offered by the compliant generators for deaths averted and level of injury, if any, the survivors sustained. Staff completed approximately 140,000 simulations for 37 different house models and three detached garages, with various generator locations and generator sizes in 28 different weather conditions.

The simulations replicated 511 fatalities in CPSC's databases. Staff's analysis found that generators compliant with the PGMA G300 standard would avert nearly 87 percent of deaths that occurred with baseline generators, with 55 survivors requiring hospitalization, and 34 survivors seeking medical treatment and being released. Staff's analysis found that generators compliant with the UL 2201 standard would avert nearly 100 percent of the deaths, with three survivors requiring hospitalization, and 22 survivors seeking medical treatment and being released.

Staff found that portable generator models with CO detection and shutoff features, and other generators with those features, plus reduced CO emissions, are available for consumers to purchase. When staff asked manufacturers about their production of compliant generators, three manufacturers replied that all their models now comply with PGMA G300, UL 2201, or both. Four other firms reported that their compliance with PGMA G300 is expected to increase substantially in the next year. Firms cited sourcing of adequate supplies of CO sensor modules as contributing factors delaying their compliance. Staff reviewed generators advertised online via manufacturers' websites, brand names' websites, and retailer websites and found 19 brands that offered one or more models with CO protection, in the form of a CO sensor or shutoff feature, plus some of these models also had reduced CO emissions. However, only four brands stated that they were compliant with one of the voluntary standards. Based on staff's current review, compliance with UL 2201 appears to be minimal; compliance with PGMA G300, although greater, is still lacking for most models or units currently being sold.

Staff intends to propose that the Fiscal Year 2023 Operating Plan include the delivery of a rulemaking briefing package on portable generators to the Commission.

TABS

TAB A Hnatov, Matthew, *Modeling Output and Analysis Methodology*, U.S. Consumer Product Safety Commission, Bethesda, MD, February 2022.

TAB B Smith, Charles, *Portable Generator Voluntary Standards Addressing CO Hazard: Information on Voluntary Standard-Compliant Product Availability*, U.S. Consumer Product Safety Commission, Bethesda, MD, February 2022.

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Memorandum

TO : The Commission
Alberta E. Mills, Division of the Secretariat

DATE: February 16, 2022

THROUGH: Austin C. Schlick, General Counsel
Mary T. Boyle, Executive Director
DeWane Ray, Deputy Executive Director for Operations

FROM : Duane Boniface, Assistant Executive Director
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Directorate for Engineering Sciences

SUBJECT : Briefing Package on Assessment of Portable Generator Voluntary Standards' Effectiveness in Addressing CO Hazard, and Information on Availability of Compliant Portable Generators

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1. Introduction

This briefing package, prepared by staff of the U.S. Consumer Product Safety Commission (CPSC), describes staff's assessment of the effectiveness of voluntary standards for portable generators in addressing this product category's carbon monoxide (CO) poisoning hazard.[a] The package also describes staff's observations of compliance from an online review of products in the marketplace and responses staff has received from several manufacturers on their production of compliant products.

2. Background

2.1 Generator 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 (LP), or diesel fuel. The generator has a receptacle panel for connecting appliances, power tools, or other electrical loads to the generator via a plug connection. These generators are designed for portability, to be carried, pulled, or pushed by a person. Portable generators that are installed in a recreational vehicle or boat are

[a] In this memorandum, superscripted letters refer to footnotes and superscripted numbers refer to references listed in section 5.

outside of CPSC's jurisdiction, even though the models may be the same as those falling within the scope of this project. Stationary generators have use patterns that differ from portable generators and are covered by a different voluntary standard. Accordingly, they too are outside the scope of this project.

Manufacturers and retailers advertise portable generators by many different features, but one of the primary features is the amount of electrical power the generator can provide continuously. The industry commonly refers to this as "rated power" or "running wattage," which ranges from less than 1,000 watts (1 kilowatt or 1 kW) to approximately 15 kW.[b] Consumers often choose the generator they wish to purchase or rent by its rated power, to make sure the generator can supply enough power to the appliances and other items they intend to plug into it, *e.g*., heating/lighting/refrigeration, if utility power is interrupted or lost, or connect to power tools they want to operate when they are away from available utility power.

To assist with characterizing hazard patterns, staff developed a size categorization for portable generators, based largely on the U.S. Environmental Protection Agency's (EPA) classification of the nonroad small spark ignition (SI) engines that power generators. Most of the generators involved in fatal CO poisonings in CPSC's databases were gasoline-fueled, which means they are SI engines. These EPA engine classifications are handheld, non-handheld Class I, and non-handheld Class II, and they are distinguished by engine displacement (in terms of cubic centimeter (cc)). Staff further divided the non-handheld Class II engine classification according to whether the engine has a single cylinder or twin cylinders. Staff refers to these four generator categories as handheld (HH), class 1 (C1), class 2 single cylinder (C2S), and class 2 twin cylinder (C2T). For a frame of reference, staff observes that, based on a review of specifications of generators on the market, in general, HH generators have an advertised rated power below 2 kW; C1 generators are rated 2 kW up to 3.5 kW; C2S generators are rated 3.5 kW up to 9 kW; and C2T generators are rated 9 kW and higher. Figure 1 shows examples of portable generators, with two in each of the four categories. Table 1 summarizes the categories.

[b] The generator's rated power is generally a function of the horsepower rating of the engine, but there is no industry standard that relates 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."

Figure 1. Examples of Gasoline-Fueled Portable Generators

Generator 1 (HH)

Generator 2 (HH)

Generator 3 (C1)

Generator 4 (C1)

Generator 5 (C2S)

Generator 6 (C2S)

Generator 7 (C2T)

Generator 8 (C2T)

Table 1. CPSC Staff's Generator Size Category Descriptions

CPSC Staff's Genator Size Categories	EPA Nonroad Small SI Engine Classification	Generator's Rated Power (approximated)
HH*	Handheld (≤80cc)	< 2 kW
C1	Nonhandheld Class I (>80 cc and <225 cc)	2 kW to < 3.5 kW
C2S (single cylinder)	Nonhandheld Class II (≥225 cc)	3.5 kW to < 9 kW
C2T (twin cylinder)	Nonhandheld Class II (≥225 cc)	9 kW and greater
* Although handheld is somewhat misleading as applied to portable generators, because generators are unattended products when in use, and because both handheld and smaller C1 generators may be fairly easily carried by hand by one adult, staff chose to use the EPA nomenclature for this size category.		

2.2 Carbon Monoxide Poisoning and Fatalities due to Portable Generators

2.2.1 Physiology and Health Impacts of CO Poisoning

CO is a colorless, odorless, poisonous gas, formed during incomplete combustion of fossil fuels, such as gasoline and LP gas used to power portable generator engines. These combustion engines also often emit noxious odors of other exhaust gas constituents, in addition to CO. 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). The COHb level reflects the percentage share of the body's total hemoglobin pool occupied by

CO.[c] In modeled acute exposure scenarios, it serves as a useful measure of expected poisoning severity in a reference individual.[1] See Table 2.[2]

Table 2. Approximate Correlation Between Acute %COHb Levels and Symptoms in Healthy Adults

% COHb	Symptoms
<10	No perceptible ill effects (Some studies have reported adverse health effects in some cardiac patients at 2% to 5% COHb)
10 to 20	Mild headache, labored breathing, decreased exercise tolerance
20 to 30	Throbbing headache, mild nausea
30 to 40	Severe headache, dizziness, nausea, vomiting, cognitive impairment
40 to 50	Confusion, unconsciousness, coma, possible death
50 to 70	Coma, brain damage, seizures, death
>70	Typically fatal

For some individuals who survive serious prolonged COHb elevations, the resulting brain hypoxia, and any consequent associated damage, may ultimately result in the phenomenon of delayed neurological sequelae (DNS). DNS is typically manifested within a few days or weeks after apparent recovery from the initial CO exposure. Symptoms can include emotional instability, memory loss, dementia, psychosis, Parkinsonism, incontinence, blindness, hearing loss, paralysis, and peripheral neuropathy. Some symptoms of DNS may respond to hyperbaric oxygen (HBO) therapy 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.[3]

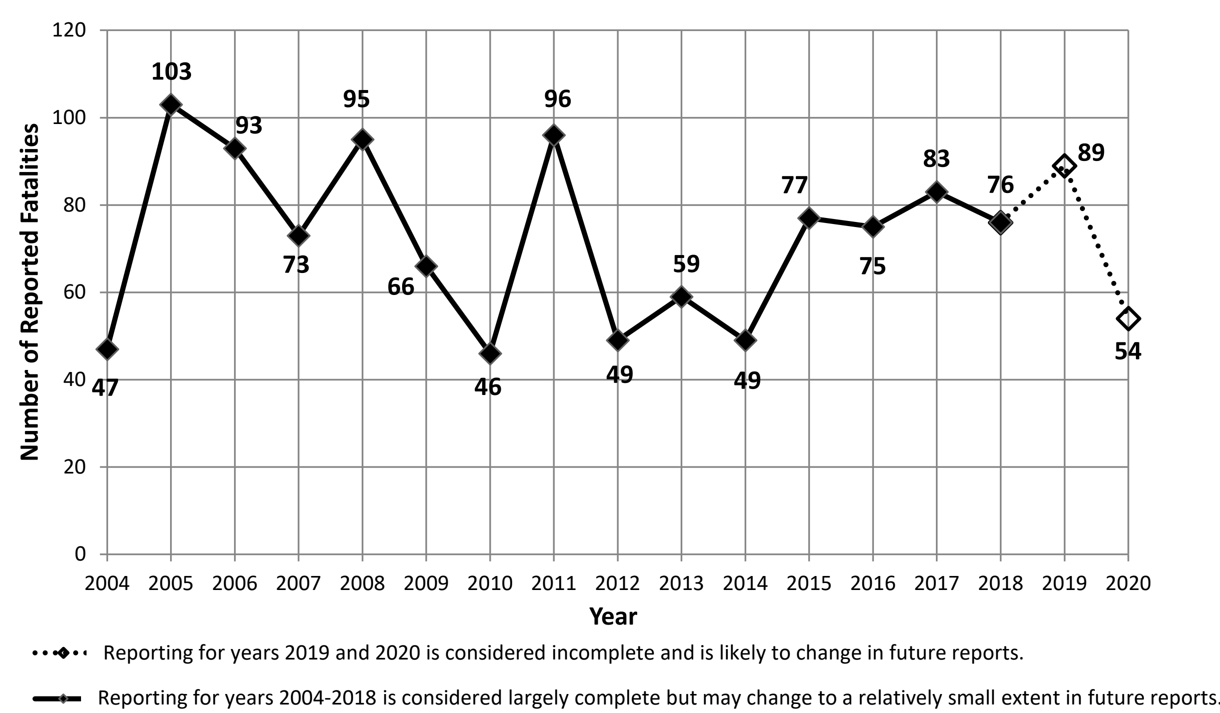
The high CO emission rates of current generators can cause the COHb levels of exposed individuals to rise suddenly and steeply, leading them to experience a rapid onset of confusion, loss of muscular coordination, and loss of consciousness. This can occur even if people do not experience the milder CO poisoning symptoms associated with a low, or slowly rising, CO level. The CO emission rates of the small engines that power portable generators, and other engine-driven tools, is higher than commonly understood; they are on the order of *hundreds* of times greater than the CO emission rates of cars.[8]

[c] COHb is measured with a blood sample from the exposed person. Measured COHb levels are influenced by the timing of the COHb measurement, relative to cessation of the CO exposure, and by provision of any oxygen therapy in the intervening period.

2.2.2 CO Fatalities from Portable Generators

CPSC staff publishes an annual report summarizing the in-scope[d] CO incidents captured in CPSC's databases that are associated with engine-driven generators and other engine-driven tools. Based on the data from those reports, Figure 2 shows the count of deaths involving a generator for each of the years 2004 through 2020.[4,5] Data for the two most recent years, 2019 and 2020, are incomplete, because data collection is ongoing, and the death count most likely will increase in future reports.

Figure 2. Number of Reported Non-Fire Carbon Monoxide Poisoning Deaths Involving Generators Entered in CPSC Databases by Year, 2004-2020



Sources: Hnatov, M. V., *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014.* U.S. Consumer Product Safety Commission, Bethesda, MD, June 2015.
Hnatov, M.V., *Fatal Incidents Associated with Non-Fire Carbon Monoxide Poisoning from Engine-Driven Generators and Other Engine-Driven Tools, 2010–2020*. U.S. Consumer Product Safety Commission, Bethesda, MD, June 2021.

Reducing CO deaths and injuries from generators is critical to making a significant reduction in consumer CO deaths caused by consumer products under CPSC's jurisdiction.

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[d] 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.

2.2.3 Hazard Patterns of Fatal Incidents

To gather more detailed information about the incidents and the products in use to characterize hazard patterns, CPSC Field Staff conducted in-depth investigations (IDI) on nearly all the deaths shown in Figure 2. A subset of the incidents from the years 2004 through 2012 were used for the effectiveness analysis that is discussed in this memorandum. However, the following general descriptions of that dataset hold true for the data for years 2004 through 2020, as presented in Figure 2:

- More than half of all deaths occurred in a fixed-structure home location, which includes houses, mobile homes, apartments, townhouses, and structures attached to the house, such as an attached garage.[e] Of these deaths:
  - More than one-third occurred when the generator was operated in the living space[f] of the home.
  - Approximately one-quarter occurred when the generator was in the attached garage or partially enclosed carport.
  - Approximately one-quarter occurred when the generator was in the basement or crawlspace.
  - A relatively small number occurred when the generator was operated outside at this home location.
- The remaining deaths occurred at a variety of locations, such as detached garages and sheds, travel trailers, RVs, boats, and vehicles, when the IDI identified a location.[g]
- In the incidents where generator size could be determined, almost all involved C1- and C2S size generators, with the former accounting for slightly more than one-third of the incidents, and the latter accounting for slightly less than two-thirds of the incidents.
- Approximately half of the incidents occurred among the coldest months of the year (November through February). Many of the fatalities can be directly related to the use of generators during power outages caused by winter weather conditions, such as ice or snow storms.
- Approximately one-third of the incidents occurred in the months of March, April, September, and October, which are typical months with transitional weather between summer and winter weather. These can be directly related to the use of generators during power outages caused by hurricanes and tropical storms, many occurring in September, and to a lesser extent, in October.
- Approximately one-quarter of the fatalities happened in multiple-fatality incidents, some involving entire families.

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[e] Travel trailers, campers, and recreational vehicles (RV) are not included in this classification; nor are external structures at the home, such as detached garages or sheds.

[f] Used here, living space includes all rooms, closets, doorways, and unidentified areas inside a home, except for basements, which are treated as a separate category.

[g] The incidents that occurred with travel trailers, RVs, boats, and vehicles involved portable generators that consumers placed in, on, or around them, not generators that were affixed by the manufacturer to them. Generators mounted in RVs and boats by the manufacturer are not in CPSC's jurisdiction (as noted in footnote d), and thus, they are out of scope for this effort.

- When the IDI identified the reason for using the generator, the three most common reasons were (1) there was a temporary power outage stemming from a weather problem or a problem with power distribution; (2) the power was shut off by the utility company for nonpayment of a bill, a bill dispute, or other reason; and (3) power was supplied to a temporary shelter or structure. The relative magnitude of these reasons varies from year to year.
- A number of IDIs reported that the consumer bought or rented the generator just before the incident. Most recently, between August 2020 and September 2021, at least four fatal incidents, resulting in seven consumer CO deaths, reportedly involved a newly purchased or rented generator, none of which were reported to have the CO hazard-mitigation features required in the voluntary standards that are the subject of this briefing package.

This information was used in the effectiveness analysis, which is discussed in general terms in section 3.1., and in greater detail in TAB A.

In the 9-year period from 2004 through 2012, staff estimates there were a minimum of about 25,400 medically attended CO poisoning injuries involving generators.[6] The hazard patterns associated with these injuries are unknown.

2.3 The Notice of Proposed Rulemaking

In October 2016, because there were no voluntary standards in place with effective requirements to address the CO poisoning hazard, staff delivered to the Commission a draft proposed rule. The proposed rule would limit the CO emission rates of the four different size categories of portable generators.[7] The proposed rates are CO emission rate reductions that range from 75 percent for HH generators to approximately 90 percent for C2S and C2T generators.[h] The Commission voted to approve publication of the draft proposed rule, and on November 21, 2016, the Commission issued an NPR that included a 75-day comment period.[8,9] Following a request for an extension, the Commission later approved to extend the comment period another 75 days.[10] The Commission also approved a notice of opportunity for oral presentation of comments, and this meeting for oral presentations was held on March 8, 2017. [11] The comments and other documents related to the rulemaking are available in docket CPSC-2006-0057 on www.regulations.gov.

The NPR remains in an open status. The Consumer Product Safety Act (CPSA) prohibits issuance of a final rule if a voluntary standard exists that is likely to eliminate or adequately reduce the risk of injury associated with portable generators, and if it is likely that there will be substantial compliance with the voluntary standard by products in the marketplace. After the NPR, by early 2018, two organizations that previously had been approved by the American National Standards Institute (ANSI) to be standards development organizations, Underwriters Laboratories (UL) and the Portable Generator Manufacturers Association (PGMA), had adopted CO hazard mitigation requirements into their voluntary standards for portable generators. This package provides staff's assessment of these two standards.

[h] TAB I in staff's briefing package for the NPR (reference 7) provides the technical rationale for the proposed rules' CO emission rate limits.

2.4 The Voluntary Standards' Adoption of CO Hazard Mitigation Requirements

On January 9, 2018, UL published the ANSI-approved *UL 2201, Standard for Safety for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition*.[12] UL 2201 includes a requirement for a maximum weighted CO emission rate of 150 grams per hour (g/h) and a requirement for the generator to shut off when the CO concentration, when measured 1 foot above the centerline of the top of the generator, registers either an average of 150 parts per million by volume (ppmv) of CO for a 10-minute period, or an instantaneous reading of 400 ppmv. The standard provides the option of using one of two test procedures for verifying the CO emission rate, either testing with the engine installed in the generator assembly in the configuration to be sold by the generator manufacturer, or by testing the standalone engine in accordance with the EPA's engine emission test procedure defined in the Code of Federal Regulations, 40 CFR part 1065. UL 2201 has no effective date, which means that any product certified to UL 2201 after publication of the 2nd Edition on January 9, 2018, must meet the requirements of the 2nd Edition.

On April 20, 2018, the Portable Generator Manufacturers Association (PGMA) published the ANSI-approved *ANSI/PGMA G300-2018 Safety and Performance of Portable Generators*.[i,13] PGMA G300 includes a requirement for generators to be equipped with an onboard CO sensor that is certified to requirements in UL 2034. Such a device, when tested to the requirements in the standard, must shut off the generator before the CO concentration, when measured at a location 1 to 2 inches above the approximate center of the portable generator's top surface, exceeds either a rolling 10-minute average of 400 ppmv of CO or an instantaneous reading of 800 ppmv. PGMA G300 requires notification after a shutoff event. This notification is required to be "a red indication," but the type of indicator is not specified (*e.g.*, the indication is not required to be a light). The standard allows, but does not require, the indication to be "blinking, with a maximum period of 2 seconds." The indication must remain for a minimum of 5 minutes after shutoff occurs unless the generator is restarted. The standard also includes requirements for: (1) a label about the automatic shutoff that must be located near the notification indicator, and that instructs the consumer to move the generator to an outdoor area and seek medical help if feeling sick; (2) an arrow on the generator to show the location of the exhaust; (3) a self-monitoring system; and (4) tamper resistance. PGMA G300 has an effective date of March 31, 2020, which means that if a manufacturer certifies to PGMA G300 after that date, it must be certified to the 2018 edition and not to the prior 2015 edition.

3. Discussion

This section provides staff's assessment of the effectiveness of the voluntary standards in addressing the hazard, staff's observations on the availability of compliant products in the marketplace, and the responses staff received from some manufacturers on their production of generators that comply with the standards.

[i] On May 1, 2020, PGMA issued an erratum update to PGMA G300-2018 that changed the requirement for packaging marking from a logo to the following text or equivalent wording: "This product complies with the ANSI/PGMA G300-2018 standard."

3.1 Assessment of Effectiveness of Voluntary Standards in Addressing CO Poisoning Hazard

In August 2018, staff held a meeting to brief stakeholders on the approach staff was considering to assess the effectiveness of the PGMA G300 and UL 2201 voluntary standards' requirements in addressing the risk of injury associated with portable generators. Staff of CPSC and NIST then collaborated to develop a detailed plan, which was published in NIST Technical Note (TN) 2048 in June 2019.[14] In July 2019, the Commission opened a 60-day comment period on the plan,[15] and in August 2019, staff held a public meeting with PGMA to answer clarifying questions on the plan, to assist in submission of comments. Following receipt of public comments, staff of CPSC and NIST then revised the plan and prepared responses to the comments, both of which were published in a CPSC staff memorandum in August 2020.[16] The Commission subsequently published a notice of its availability in the *Federal Register*.[17] In September 2021, staff held a public meeting with PGMA, at their request, to answer their questions regarding the plan.[18]

3.1.1 General Approach

Staff assessed the effectiveness of the standards by estimating the epidemiological benefits provided by each voluntary standard, based on simulations run by NIST using CONTAM, a multizone airflow and contaminant transport indoor air quality (IAQ) modeling program.[19] CONTAM has been used for several decades, and a range of validation studies have demonstrated its ability to predict reliably building air change rates and contaminant levels.[20,21,22] From the CO outputs of CONTAM, NIST staff calculated the health effects by using the nonlinear Coburn-Forster-Kane equation (CFK) to predict the COHb level of the occupants.[23,24] The nonlinear CFK differential equation is a physiologically based, mechanistic model for predicting CO uptake, and COHb formation and elimination in humans.[ref 1] 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.[25,26] Input values for these calculations include a respiratory minute volume (RMV) value of 10 L/min, representing a time-weighted average 24-hour value for males and females 16 to 80 years old, for expected residential indoor activity.[7] In addition to the simulated fatalities analysis, staff also assessed two levels of injury, each defined by a peak COHb value attained, from the COHb values. These two levels, described in TAB A, distinguish between a person who seeks medical attention, but is likely not hospitalized, and a person who is likely to be hospitalized or receive HBO or other specialized treatment.

NIST staff used CONTAM to simulate a 24-hour period during which a noncompliant generator (*i.e.*, a generator that does not comply with either voluntary standard, referred to as a baseline generator) emitted CO at a specified rate at a specified location inside a house for a specified number of hours, representing how long the generator could operate at the load that produced the specified CO rate until it expended a full tank of fuel. CONTAM simulated both the accumulation and transport of CO throughout the house while the generator was operating, and the continued transport of CO for the remainder of the 24-hour period after the generator stopped. CONTAM also simulated a 24-hour period for each of the voluntary standard-compliant generators, with the generator operating in the same location inside the house as the baseline generator. However, if the CO concentration in that location reached the voluntary standard's performance criteria for shutting off the generator, the CO emission stopped. The simulation then continued in one of a variety of ways for the remainder of the 24-hour period, with the generator either remaining off, or restarting 10 minutes later in the same location, in a new location that was also indoors, or outdoors. If restarted outdoors, the simulation continued with either a fraction of the generator's CO rate entering the house from outdoors or no CO entering from outdoors. If restarted in an indoor location, the CO would resume being emitted at the specified rate; but if the CO concentration in that location reached the voluntary standard's shut off criteria again, the specified CO emission stopped again. After a second shut off, the simulation continued with the generator restarting 10 minutes later outdoors, with either a fraction of the generator's CO rate entering the house from outdoors or no CO entering from outdoor. In all scenarios in which the generator was restarted in an indoor location and subsequently shut off a second time, the 24-hour simulation continued with the generator outdoors with CO being emitted until the fuel tank was empty, with the CO continuing to be transported throughout the house for the remainder of the period. Thus, in every simulation in which the generator was restarted, the voluntary standard-compliant generator operated until the full fuel tank was empty, just as the baseline generator operated.

Every simulation yielded CO concentrations in each room of the house as a function of time over the 24-hour analysis interval. These concentrations were then used to calculate COHb values for the house's theoretical occupants, which are identified as either an *operator*, who directly interacts with the generator, or a *collateral person*, who is another occupant in the house but does not directly interact with the generator.[j] These occupants' exposures differ when the generator is restarted because the operator is the one who restarts it, entering the room where the generator is located, and where the CO concentration is likely to be higher than in other areas of the house. Comparing the occupants' health effects from the simulation of a baseline generator to either of the voluntary standard-compliant generator provides staff's assessment of the benefits offered by the compliant generators.

Staff applied this general approach to simulating a subset of fatal incidents in CPSC's databases that occurred in the years 2004 through 2012. This subset consisted of 503 deaths that occurred when the generator was operated in an enclosed space of either a house or a detached garage, and 8 deaths when the generator was operated outside one of these spaces, but close enough that CO infiltrated indoors.[k]

The CO profiles attained throughout the houses and garages, which directly impact the health of the occupants, are affected by the following factors that are accounted for in the simulations: the characteristics of the houses and detached garages, the generator's location and orientation of its exhaust jet, the degree to which windows and doors (both interior and exterior) are open, the weather conditions, and the generator characteristics and shutoff criteria. These factors are

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[j] As described in section 2.2, CPSC's data show that approximately 25 percent of the fatalities occurred in incidents that involved multiple fatalities.

[k] These same 503 deaths were used in the benefits analysis for the NPR. Information on the incident data used as the basis of this analysis is provided in Appendix B of TAB K in staff's briefing package for the NPR (reference 7).

discussed in greater detail in NIST Technical Note (TN) 2202 *Simulation of Residential CO Exposures from Portable Generators with and without CO Hazard Mitigation Systems Meeting Requirements of Voluntary Standards* [27] and following the next section, which provides staff's rationale for including restart scenarios.

3.1.2 Rationale for Including Restart Scenarios

Restart scenarios are included for a variety of reasons. First, consumers who used their generators in indoor locations did so for one or more reasons, some of which are identified in the incident data (*i.e.*, ignorance of the hazard; fear of theft; concern about operating the generator in wet, icy, or snowy weather conditions; concern about noise to neighbors; not having a long enough extension cord). Often the reasons were not identified, however. The fact that a generator shuts off due to activation of the shutoff system may not cause the consumer to take it outdoors, at least not immediately, for those same reasons. Instead, the consumer may try to operate the generator elsewhere indoors, or they may try to keep it running at its original location.

Second, some currently marketed generators with shutoff systems are advertised that they will shut off the generator before or when hazardous levels of CO are detected. The CO that is emitted while the generator is running, however, can result in the consumer not recognizing that they have been exposed because no symptoms were evident at time of shutoff. The symptoms experienced by an exposed person may not be perceived immediately, but rather, may be delayed, depending on the CO level reached, how quickly the CO leaves the house, and what is the exposed person's general health and activity level during the exposure. For example, most of the tests documented in NIST TN 2049 in which the shutoff algorithm shut off the generator resulted in calculated COHb values for simulated occupants throughout the test house at the time the generator shut off that were well below the range associated with symptom onset. Thus, for these test, exposed persons likely would not experience any perceptible CO poisoning symptoms at the time of shutoff. Of the tests in which the COHb later rose to more than 15 percent, which is in the middle of the range commonly associated with onset of perceptible symptoms, such as mild headache and decreased exercise tolerance, the interval between when the generator shut off and when COHb values in the house reached 15 percent typically ranged from about 40 minutes to 2 or more hours, per NIST TN 2049. This imparts a reasonable expectation that consumers may try to restart the generator after shutoff, even if they are aware (perhaps due to notification by the generator) that shutoff may be due to the presence of CO. This expectation is also based in part on incident reports in which consumers had an activated CO alarm, but they removed the alarm batteries because they did not perceive any symptoms, and then a fatality occurred.

Third, another rationale for expecting some consumers to restart the generator is that UL 2201 does not have any notification requirement after a shutoff event, and PGMA G300 requires the notification to last for a minimum of 5 minutes. Regarding PGMA G300, if the consumer does not attend to the generator while a notification is present, they may not be aware that it shut off due to elevated levels of CO. This situation might occur if the consumer is not immediately aware that the generator shut off, or if the generator is in a more remote location, like the garage or basement.

3.1.3 Houses and Detached Garages

The house models used in the simulations for these incidents are based on a collection of just over 200 dwellings, previously defined by NIST, which together represented 80 percent of the U.S. housing stock.[28] NIST created a file containing multizone representations for each of the house models for use as an input to CONTAM. The tables in Appendix A of NIST TN 2202 describe, for all 200 house models, the key features that influence the house's air change rates and interzone airflow patterns.

Staff chose 37 house models from that collection for the simulations because their characteristics largely match those of the houses involved in the incidents.[1] These 37 models include 31 detached homes (25 chosen from the NIST collection and 6 that are modifications of 5 of those 25), 4 attached homes (4 chosen from the NIST collection, 3 of which are modified), and 2 manufactured home designs (1 chosen from the NIST collection and another that is a modification of that one). In addition to the 37 house models, NIST created models of 3 detached garages of various sizes, because many of the 511 fatalities involved detached garages. These same houses and garages were used in the benefits analysis for the NPR. Table B.1. in Appendix B of NIST TN 2202 lists all 40 models that were used in the simulations, and it also describes how NIST modified specific ones for this analysis.

3.1.4 Scenarios: Generator Locations, Exhaust Orientation, Window and Door Positions, and Weight Factors

As discussed in the description of the general approach, the simulations have different locations that the generator is started inside a house and have different ways the operator might respond after the generator shuts off when the shutoff criteria are met. Each constitutes what is referred to as a "scenario." The scenarios differ, depending on whether the house has a basement, garage, or crawlspace, because staff observed in the incident data that these spaces have some correlation to places where the consumer operated a baseline generator. Thus, the scenarios are grouped into tables, provided in Appendix A of TAB A, by five different house types: (1) houses with none of these spaces, (2) houses that have only one of these three spaces, and (3) houses that have both a basement and a garage but not a crawlspace. Table 3 below serves as an index for the scenario tables in Appendix A of TAB A. It lists the different locations that either the PGMA G300 or UL 2201 generator is initially started in each scenario for each house type, as well as the detached garages, and identifies which table in the appendix describes the restart scenarios for that initial start location. It also explains that these initial start locations for the compliant generators are the same locations where the baseline generator is operated.

[1] Information on how these buildings were selected from NIST's collection is provided in Appendix B of TAB K of staff's briefing package for the NPR (reference 7).

Table 3. Index of Scenario Tables in Appendix A of TAB A

Buildings	Scenario Tables G300 Generators	Scenario Tables UL 2201 Generators	*Initial* Start Location for G300 and UL 2201 Generators *The* Location for Baseline Generators
Houses with no basement, garage, or crawlspace	2.a.	9.a.	Kitchen
	2.b.i.	9.b.i.	First floor room with door with generator exhaust jet mixing In room
	2.b.ii.	9.b.ii.	First floor room with door with generator exhaust jet oriented out of door to house interior
	2.c.	9.c.	Outside
Houses with crawlspace only	3.a.	10.a.	Kitchen
	3.b.i.	10.b.i.	First floor room with door with generator exhaust jet mixing In room
	3.b.ii.	10.b.ii.	First floor room with door with generator exhaust jet oriented out of door to house interior
	3.c.	10.c.	Crawlspace
	3.d.	10.d.	Outside
Houses with basement only	4.a.	11.a.	Kitchen
	4.b.	11.b.	Basement
	4.c.	11.c.	Outside
Houses with garage only	5.a.	12.a.	Kitchen
	5.b.i.	12.b.i.	Garage with generator exhaust facing away from wall that has door to house interior. Exhaust mixes in garage.
	5.b.ii.	12.b.ii.	Garage with generator exhaust facing toward wall that has door to house interior. Exhaust jet pushes some of exhaust Into house.
	5.c.	12.c.	Outside
Houses with basment and garage (no crawlspace)	6.a.	13.a.	Kitchen
	6.b.	13.b.	Basement
	6.c.i.	13.c.i.	Garage with generator exhaust facing away from wall that has door to house interior. Exhaust mixes in garage.
	6.c.ii.	13.c.ii.	Garage with generator exhaust facing toward wall that has door to house interior. Exhaust jet pushes some of exhaust Into house.
	6.d.	13.d.	Outside
Detached 1-car and 2-car garages	7	14	Garage
Detached garage containing workshop or other room	8.a.	15.a.	Workshop
	8.b.i.	15.b.i.	Garage with exhaust oriented away from wall with door to workshop room. Exhaust mixes in garage.
	8.b.ii.	15.b.ii.	Garage with generator exhaust facing toward wall that has door to house interior. Exhaust jet pushes some of exhaust Into house.
Note: Tables 1.a. through 1.g. describe the timing of operator movements and window and door position changes.			

As seen in Table 3, some scenarios specify the direction of the generator's exhaust jet. These scenarios were included because the direction that a high-velocity exhaust jet is oriented, relative to the space in which a shutoff-equipped generator is operating, can affect how CO accumulates around a generator, and thus, how long the generator runs before it shuts off. This was demonstrated in tests documented in NIST TN 2049.[29] Scenarios with the generator in the doorway of a bedroom, with the exhaust pointed into the hallway, and with a generator in the garage, with the exhaust pointed towards the wall with a door leading into the house, were included because such scenarios were reported in incidents in CPSC's database. A description of how the simulations model exhaust, directed out of an interior door or towards a wall with a door to an adjacent space, is addressed in NIST TN 2202. In these scenarios, a portion of the generator's jet of high-velocity exhaust flows into the adjacent room. In scenarios where the generator is located within the space, and the exhaust orientation is not specified, the generator's jet remains within the room with the generator, and the exhaust transports out of the room through the normal interzonal airflows that CONTAM simulates.

The scenario tables in TAB A, Appendix A, also specify the degree to which the window and door (internal and external) are open (*i.e.*, their "positions"), because these openings affect airflows, and thus, also affect the transport of CO between the rooms and between the rooms and the outdoors.

Lastly, the tables contain weight factors: these are the probabilities that CPSC and NIST staff assigned to the likelihood to occur of each scenario listed in each table. PGMA G300 and UL 2201 have different tables, because although the scenarios are the same, some scenarios have different weight factors due to differences in the requirements of the two standards. The specific scenarios mentioned are when the generator is restarted outside the kitchen. The weight factors in the scenarios with exhaust entering the kitchen from outside, and not entering the kitchen from outside, are 0.10 and 0.90, respectively, for a PGMA G300 generator, and 0.25 and 0.75, respectively, for a UL 2201 generator. Staff assigned a lower probability for exhaust to enter the kitchen from outside for PGMA G300 generators, because the PGMA G300 voluntary standard has requirements for an information label on the generator near the required notification indicator to alert consumers to point exhaust away, and for an arrow on the generator to show the location of the exhaust.[m] The UL 2201 voluntary standard lacks these requirements. A description of how the simulations model exhaust coming inside when the generator is outside is addressed in NIST TN 2202.

3.1.5 Weather Conditions

As stated, ambient weather conditions can also significantly impact both air change rates and interzone airflow patterns in the buildings. Therefore, each house and generator combination was simulated in 28 individual days of weather that varied outdoor temperature, wind speed, and wind direction each day on an hourly basis. To approximate the distribution of incidents observed in the CPSC incident data at a generalized level, these 28 days of weather correspond to 2 weeks of cold weather, 1 week of warm weather, and 1 week of mild weather. The hourly weather data for these three conditions were a subset of typical weather files for the following three cities: Detroit in January (cold), Miami (FL) in July (warm), and Columbus (OH) in April (mild).[n]

3.1.6 Generator Characteristics

The four different sizes of generators described in section 2.1 were used in the simulations. Each is represented in CONTAM by a CO emission rate and a heat release rate. The latter was an input to CONTAM to account for thermal effects because the interaction of the generator heat source and the ambient weather conditions can significantly impact air change rates and interzone airflow patterns in the buildings. The generator run time, which is the number of hours that the generator can operate when starting with a full fuel tank when the engine is emitting the

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[m] There is more discussion on this topic in staff's memorandum cited in reference 16.

[n] The weather files were obtained from the EnergyPlus Energy Simulation Software website: https://energyplus.net/weather.

specified CO rate, is also associated with each of the generator sizes. These values are presented in Table 4.[o] The C1 and C2S generators were simulated in all 40 structures. The HH generators were simulated in only two detached houses, and the C2T generator was simulated in only one detached garage because these generator sizes were involved in only these structures in CPSC's incident data for the 511 deaths. The baseline generators' CO emission rates were increased by a factor of three after 2 hours of operation when the house or garage did not have any open exterior doors and the generators were in a space without an open window. This allowed the oxygen to get depleted and caused the CO emission rate to rise.[p,7] The CO emission rates for any size of the PGMA G300- or UL 2201-compliant generators were not increased because none of them ran for 2 hours in such conditions.

Table 4. Generator CO Emission Rates, Run Times and Heat-Release Rates

Generator Size Category	Average Weighted CO Rate for Baseline and PGMA G300 Generators (g/h)	Average Weighted CO Rate for UL 2201 Generators (g/h)	Average Run Time for 50% Load on Full Tank (h)	Average Heat Release Rate for 50% Load (kW)
Handheld (HH)	300	150	8	2
Class 1 (C1)	600	150	9	6
Class 2 single cylinder (C2S)	1570	150	10	13
Class 2 twin cylinder (C2T)	3030	150	9	25

Table 5 provides the shutoff criteria that were used in the simulations for the PGMA G300 and UL 2201 generators. These criteria are independent of the generator's size.

Table 5. Shutoff Criteria for Simulations

	PGMA G300 Criteria (ppmv)	UL 2201 Criteria (ppmv)
Instantaneous	>800	400
10-min rolling average	>400	150

[o] Information on how staff derived the CO emission and heat-release rates, as well as the full tank run times for each generator size is provided in Appendix A of TAB K in staff's briefing package for the NPR (reference 7).

[p] NIST staff conducted generator testing in a single-zone enclosed space, and the results showed that the engines depleted the oxygen in the space. As the oxygen dropped approximately from the normal oxygen level of 20.9 percent to approximately 17 percent oxygen, the CO emission rates for each load increased by an approximate 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. (See Appendix A of TAB K of staff's briefing package for the NPR (reference 7) for more details.) NIST accounted for the CO emission rate increase in scenarios where the zone's oxygen could not get replenished by outside air, by applying a factor of 3 to the emission rate after 2 hours of operation in such scenarios.

Given all the above, NIST ran approximately 140,000 simulations to support this effectiveness analysis. NIST TN 2202 describes the simulations in greater detail and provides samples of some of the results.

3.1.7 Results

As shown in TAB A and Table 6 below, staff's analysis of CONTAM's results and the COHb calculations found that the PGMA G300-compliant generators would avert 86.6 percent of the deaths, thereby, resulting in 69 deaths, but would cause 55 people to be hospitalized or transferred to a specialized treatment center, and 34 people to be treated and released after seeking medical treatment for their symptoms. Staff's analysis found the UL 2201-compliant generators would avert nearly[q] 100 percent of the deaths but cause three people to be hospitalized or transferred to a specialized treatment center, and 22 people to be treated and released after seeking medical treatment for their symptoms.

Table 6. Outcome of Effectiveness Analysis

Outcome for Operators and Collateral Occupants	Generators		
	Baseline (non-compliant)	G300	UL 2201
Fatality	511	69	0
Percentage of deaths averted versus baseline generators	--	86.6%	~100%
Survivors who are hospitalized or transferred to specialized treatment center	--	55	3
Survivors who seek medical treatment and are treated and released	--	34	22
Survivors who are likely not symptomatic and not seeking medical treatment	--	353	486

3.2 Information on Voluntary Standard-Compliant Product Availability

In September and October 2021, staff reviewed websites of generator manufacturers, brand names, and retailers to assess the availability of generators compliant with PGMA G300 or UL 2201. Staff's findings, for several brand names, are reported in the tables in Appendix A. The tables in Appendix A list the number of models of generators advertised online that have either a CO sensor or a shutoff system; generators with those features plus reduced CO emissions; and generators sold by the same manufacturers or with the same brand name without these advertised features. Some of staff's findings follow:

- Only four manufacturers or brand names reviewed by staff cited PGMA G300 or UL 2201 when referring to their generators' CO shutoff systems or CO sensors.
- Nineteen brands staff reviewed advertised at least one model that included CO-detection and shut-off features, and some models with these features also had reduced CO emissions. Three of these brands had a model with reduced CO emissions that staff

[q] Deaths were allocated across 40 house and garage structures and calculated as a probability spanning 28 weather days for various scenarios. Therefore, the percentage is not identically 100 percent, but is approximately so. See Tab A for more detail.

expects will meet the 150 g/hr requirement of UL 2201 but were not advertised as meeting that standard.
- Staff found two major retailers of generators in which a significant portion of their advertised models were described to have a CO sensor, a CO-shutoff system, or compliant with one of the voluntary standards.
- Some generator websites do not include models found on retailers' websites, and some models on the manufacturers' or brand names' websites did not appear to be available with any retailer. In some cases, the manufacturer listed a retailer from whom a model could be purchased, but the retailer's website did not list it as available for purchase.
- Many websites for brick-and-mortar retailers indicate that the generator model is either not in stock or not available in the store (or is available only in certain stores) but can be ready for pickup by a certain date. Other websites for both brick-and-mortar retailers and online-only retailers, and even manufacturer websites, indicate the generator model is not available at all.

In addition to the above online review, in September 2021, staff submitted questions to representatives of nine firms, eight that are members of PGMA, to gather current information on the extent to which manufacturers and private labelers of portable generators are conforming to either PGMA G300 or UL 2201. Staff sought information on the percentage of each company's conforming portable generator models marketed for the U.S. market since January 1, 2021, and the percentage of conforming portable generator units shipped or imported by each firm since January 1, 2021. Seven firms responded, six of them members of PGMA. Three manufacturers reported that all their models comply with either PGMA G300 or both PGMA G300 and UL 2201. The four other firms reported that compliance with PGMA G300 is expected to increase substantially in the next year. Firms cited sourcing of adequate supplies of CO sensor modules as contributing to delays in compliance. TAB B provides additional information supplied by the respondents.

4. Conclusions

CPSC and NIST staff conducted computer simulations of portable generators operating inside and outside of homes to determine the health effects of CO emitted from the generator engine's exhaust. Approximately 140,000 simulations were completed for 37 different house models and 3 detached garages, with various generator locations and generator sizes in 28 different weather conditions.

The simulations replicated 511 fatalities in CPSC's databases. Staff's analysis found that generators compliant with the PGMA G300 standard would avert nearly 87 percent of the deaths that occurred with baseline generators, with 55 survivors requiring hospitalization, and 34 survivors seeking medical treatment and then being released. Staff's analysis also found that generators compliant with the UL 2201 standard would avert nearly 100 percent of the deaths, with 3 survivors requiring hospitalization and 22 survivors seeking medical treatment and being released. Therefore, staff concludes that the CO hazard-mitigation requirements of UL 2201 are more effective than those of PGMA G300.

Based on staff's review, currently there does not appear to be wide compliance with either standard. Given the standards for CO hazard-mitigation were published nearly 4 years ago, staff is uncertain whether there is likely to be wide compliance with either voluntary standard in the future. Some manufacturers have informed CPSC staff that they intend to increase compliance substantially next year.

Staff intends to propose that the Fiscal Year 2023 Operating Plan include delivering a rulemaking briefing package on portable generators to the Commission.

5. References

[1] Inkster, Sandra, PhD, *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,* U.S. Consumer Product Safety Commission, Bethesda, MD, August 13, 2012. (TAB G in the staff report *Technology Demonstration of a Prototype Low Carbon Monoxide Emission Portable Generator* (available in www.regulations.gov in docket identification CPSC-2006-0057-0002.))

[2] Burton LE, (July 1, 1996) CPSC Health Sciences Memorandum, Toxicity from Low Level Human Exposure to Carbon Monoxide.

[3] U.S. EPA, (2000) Air Quality Criteria for Carbon Monoxide, EPA 600/P-99/001F. (weblink: http://www.epa.gov/NCEA/pdfs/coaqcd.pdf)

[4] Hnatov, M.V., *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2004-2014.* U.S. Consumer Product Safety Commission, Bethesda, MD, June 2015. (Docket Identification CPSC-2006-0057-0026, available online at www.regulations.gov)

[5] Hnatov, M.V., *Fatal Incidents Associated with Non-Fire Carbon Monoxide Poisoning from Engine-Driven Generators and Other Engine-Driven Tools, 2010–2020*. U.S. Consumer Product Safety Commission, Bethesda, MD, June 2021. https://www.cpsc.gov/content/Generators-and-OEDT-CO-Poisoning-Fatalities-Report-2021

[6] 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 L in reference 7, which is staff's briefing package for the NPR)

[7] *CPSC Staff Briefing Package for Notice of Proposed Rulemaking For Safety Standard For Carbon Monoxide Hazard For Portable Generators, October 5, 2016*. (available online at: https://www.cpsc.gov/s3fs-public/Proposed_Rule_Safety_Standard_for_Portable_Generators_October_5_2016.pdf)

[8] Commission Decisional Meeting Minutes, November 2, 2016. https://cpsc-d8-media-prod.s3.amazonaws.com/s3fs-public/Minutes%20of%20Commission%20Meeting%20-%20November%202%202016%20-%20Portable%20Generators%20Decisional.pdf

[9] 16 CFR part 1241, Proposed *Safety Standard for Portable Generators*, Federal Register, 81 FR 83556, November 21, 2016. https://www.federalregister.gov/documents/2016/11/21/2016-26962/safety-standard-for-portable-generators

[10] 16 CFR part 1241, Proposed *Safety Standard for Portable Generators*, Federal Register, 81 FR 89888, December 13, 2016. https://www.federalregister.gov/documents/2016/12/13/2016-29845/safety-standard-for-portable-generators-notice-of-extension-of-comment-period

[11] 16 CFR part 1240, *Portable Generators; Notice of Opportunity for Oral Presentation of Comments*, Federal Register, 81 FR 8907, February 1, 2017.

[12] *UL 2201, Standard for Safety for Carbon Monoxide (CO) Emission Rate of Portable Generators*, *Second Edition*, Dated January 9, 2018.

[13] *ANSI/PGMA G300-2018 (Errata Update), Safety and Performance of Portable Generators*, available online at https://www.pgmaonline.com/pdf/ANSI_PGMAG300-2018(ErrataUpdateApril2020).pdf

[14] Emmerich, S.J., et al., NIST Technical Note 2048: *Simulation and Analysis Plan to Evaluate the Impact of CO Mitigation Requirements for Portable Generators*, July 2019. (Available online at: http://dx.doi.org/10.6028/NIST.TN.2048).

[15] Federal Register, 84 FR 32729, July 9, 2019. *Notice of Availability: Plan to Evaluate CO Mitigation Requirements for Portable Generators*.

[16] Buyer, J.L, et al., Revisions to the Plan Documented in NIST Technical Note 2048: *Simulation and Analysis Plan to Evaluate the Impact of CO Mitigation Requirements for Portable Generators*, August 12, 2020. Available online at: www.regulations.gov under docket CPSC-2006-0057, document ID CPSC-2006-0057-0106.

[17] Federal Register, 85 FR 52096, August 24, 2020. *Notice of Availability: Revisions to the Plan Documented in NIST Technical Note 2048: Simulation and Analysis Plan to Evaluate the Impact of CO Mitigation Requirements for Portable Generators*.

[18] Log of Meeting with PGMA on 9/28/2021, available online at: https://www.cpsc.gov/s3fs-public/20210928MeetingwithPGMA.pdf?VersionId=5EAPs9D.YSeL4CzYJnp1z7l.ssbRXnW

[19] Dols, W.S. and B.J. Polidoro, NIST Technical Note 1887: CONTAM 3.2 User Guide and Program Documentation, National Institute of Standards and Technology, 2015.

[20] Emmerich, S.J., *Validation of Multi-zone IAQ Modeling of Residential-Scale Buildings: A Review*. ASHRAE Transactions. 107 (2): p.619-628, 2001.

[21] Emmerich, S.J., C. Howard-Reed, and S.J. Nabinger, *Validation of Multi-zone IAQ Model Predictions for Tracer Gas in a Townhouse*, Building Service Engineering Research Technology. 25(4): p. 305-316, 2004.

[22] Poppendieck, D.G., S.S. Khurshid, W.S. Dols, L.C. Ng, B.J. Polidoro, and S.J. Emmerich, *Formaldehyde Concentrations in a Net-Zero Energy House: Real-time Monitoring and Simulation*, Proceedings of Indoor Air 2016.

[23] Coburn RF, Forster RE, Kane PB, *Considerations of the Physiological Variables that Determine the Blood Carboxyhemoglobin Concentration in Man*, J. Clinical Investigation, 44:1899–1910, 1965.

[24] Peterson JE, Stewart RD, *Predicting the Carboxyhemoglobin Levels Resulting from Carbon Monoxide Exposures*, J. Applied Physiology, 39:633-638, 1975.

[25] U.S. Environmental Protection Agency EPA, (2010) Integrated Science Assessment for Carbon Monoxide (Final Report – January 2010) (EPA/600/R-09/019F). Ch. 4, Dosimetry and Pharmacokinetics of Carbon Monoxide and Ch. 5., Integrated Health Effects (weblink to full report and specific chapters located at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686)

[26] Agency for Toxic Substances and Disease Registry (ATSDR), (2012) Toxicological Profile for carbon monoxide, September, 2009 (weblink at: http://www.atsdr.cdc.gov/toxprofiles/tp201.pdf

[27] Emmerich, S.J., et al., NIST Technical Note 2202: *Simulation of Residential CO Exposures from Portable Generators with and without CO Hazard Mitigation Systems Meeting Requirements of Voluntary Standards*, February 2022. (https://doi.org/10.6028/NIST.TN.2202

[28] Persily, A.K., A. Musser, and D. Leber, *A Collection of Homes to Represent the U.S. Housing Stock. NISTIR 7330. National Institute of Standards and Technology*, 2006.

[29] Emmerich, S.J., et al., NIST Technical Note 2049: *Characterization of Carbon Monoxide Concentrations and Calculated Carboxyhemoglobin Profiles of Occupants in a Test House from Portable Generators with a Simulated CO Safety Shutoff Device*, June 2019. (Available online at: https://doi.org/10.6028/NIST.TN.2049).

Appendix A

The following tables list brand names of generators that do and/or do not have CO hazard-mitigation features, based on staff review of websites of generator manufacturers, brand names, and retailers, September 2021 to October 2021 (manufacture date unknown)**.**

* If rated wattage was not provided, but surge or peak wattage was, that is what is noted in the table. In a very limited number of cases, no wattage was provided, so the model number that staff assumes is a wattage is what is noted in the table. For dual-fuel generators, running wattage based on gasoline is what is noted in the table.

A number in parentheses following the wattage is the number of different models advertised with the same running wattage.

Advertised running wattage* (kW)	Generac		Firman		Honda		Champion		Briggs & Stratton		Predator		Yamaha		Duromax		GenConnex	
	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation
<1000				88 models of various sizes	0.9 kW			121 models of various sizes										
1000 or greater but less than 2000		1.7 kW			1.8 kW (4)				1.8 kW		1.1 kW, 1.4 kW	1.6 kW		1.6 kW, 1.8 kW		1.6 kW (2), 1.8 kW (3),		1.8 kW
2000 or greater but less than 3000		2.2 kW, 2.3 kW, 2.5 kW (2)			2.5 kW, 2.8 kW (2)	2.6 kW								2.8 kW				2.6 kW
3000 or greater but less than 4000		3.0 kW, 3.3 kW, 3.6 kW (2)			3.5 kW		3.5 kW, 3.65 kW (2)		3.5 kW (2)		3.5 kW	3.0 kW, 3.5 kW (2)			3.85 kW	3.3 kW, 3.5 kW (2), 3.65 kW		
4000 or greater but less than 5000					4.5 kW (2)									4.0 kW, 4.5 kW (2)	4.5 kW	4.0 kW, 4.5 kW (2),		
5000 or greater but less than 6000		5.0 kW (2)			5.5 kW (3)				5.5 kW, 5.0 kW (2), 5.75 kW			5.5 kW (2)		5.5 kW			5.5 kW (LP)	
6000 or greater but less than 7000	6.5 kW (2)	6.5 kW (6)					6.0 kW, 6.25 kW (2)		6.1 kW 6.25 kW					6.0 kW (2)				
7000 or greater but less than 8000			7.5 kW						7.0 kW		7.0 kW, 7.6 kW	7.25 kW (2)				7.0 kW, 7.6 kW,		
8000 or greater but less than 9000	8.0 kW (2), 8.5 kW	8.0 kW (5)					8.0 kW (2)		8.0 kW (2)						8.0 kW (2)	8.0 kW (2)		
9000 or greater but less than 10,000					9.0 kW		9.0 kW, 9.2 kW								9.5 kW (2)	9.5 kW (2)		
10,000 or greater but less than 12,000															10.5 kW	10.5 kW (2)		
12,000 or greater but less than 15,000							12.0 kW									12.5 kW (2)		
15,000 or greater		15.0 kW, 17.5 kW																

Advertised running wattage* (kW)	Ryobi		Echo		North Star		Lifan		Powermate		Craftsman		Mech Marvels		All Power		Green Power	
	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation
<1000		0.9 kW													0.8 kW			
1000 or greater but less than 2000	1.8 kW	1.7 kW	1.8 kW	1.0 kW				1.2 kW, 1.6 kW				1.7 kW	1.2 kW (2)	1.2 kW (2), 1.6 kW (2)	1.8 kW, 1.4 kW			1.2 kW (2), 1.6 kW, 1.8 kW
2000 or greater but less than 3000				2.8 kW								2.3 kW, 2.5 kW surge			2.5 kW			
3000 or greater but less than 4000	3.4 kW		3.4 kW	3.0 kW				3.2 kW (2), 3.8 kW, 3.9 surge, 3.5 kW (2)	3.6 kW (2)		3.5 kW (2); 3.3 kW surge on Craftsman.com	3.5 kW (4)	3.2 kW (2)	3.2 kW (2)	3.3 kW (2), 3.5 kW			3.0 kW (2), 3.3 kW (2), 3.6 kW, 3.85 kW (2)
4000 or greater but less than 5000						4.5 kW		4.0 kW surge, 4.1 kW surge									4.25 kW	4.25 kW
5000 or greater but less than 6000								5.7 kw surge, 6.0 kW (2)			5.0 kW, 5.75 kW on Craftsman website	5.0 kW (4)						5.3 kW, 5.5 kW
6000 or greater but less than 7000	6.5 kW					6.6 kW (2)		6.5 kW (2), 6.75 kW surge,	6.0 kW						6 kW			6.5 kW (2)
7000 or greater but less than 8000	7.0 kW			7.5 kW				7.0 kW			7.0 kW	7.0 kW (2)	7.5 kW (2)	7.5 kW (2)			7.5 kW	7.5 kW (3)
8000 or greater but less than 9000						8.5 kW		8.0 kW surge, 8.1 kW surge, 8.25kW surge, 8.0 kW			8.0 kW				8.0 kW (3)			8.0 kW
9000 or greater but less than 10,000															9.0 kW (3)		9.5 kW	9.5 kW (2)
10,000 or greater but less than 12,000						10.5 kW											10.5 kW	10.5 kW
12,000 or greater but less than 15,000						13.5 kW												
15,000 or greater																		

Advertised running wattage* (kW)	Gentron Power		Westinghouse		Black Max		Powerstroke		Dewalt		Wen		Pulsar		MI-T-M		Kipor	
	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation	CO mitigation	W/o CO mitigation
<1000												0.9 kW						0.7 kW, 0.9 kW
1000 or greater but less than 2000				1.0 kW, 1.8 kW	1.6 kW			1.1 kW, 1.7 kW (2), 1.8 kW	1.7 kW			1.0 kW, 1.35 kW, 1.6 kW, 1.7 kW, 1.8 kW, 1.9 kW		1.2 kW (surge), 1.6 kW, 1.8 kW (2),		1.6 kW		1.6 kW
2000 or greater but less than 3000				2.0 kW, 2.2 kW (3)				2.5 kW						2.5 kW		2.45 kW		2.3 kW, 2.8 kW
3000 or greater but less than 4000	3.3 kW (2)		3.6 kW (2)	3.5 kW (2), 3.6 kW (5), 3.7 kW (2)	3.6 kW			3.0 kW, 3.25 kW				3.2 kW, 3.4 kW, 3.5 kW, 3.6 kW, 3.75 kW, 3.8 kW,		3.0 kW, 3.7 kW		3.0 kW		
4000 or greater but less than 5000									4.0 kW	4.5 kW				4.25 kW (2)		4.4 kW		4.0 kW
5000 or greater but less than 6000			5.3 kW (6)	5.3 kW (4), 5.5 kW				5.0 kW (2), 5.7 kW		5.7 kW		5.0 kW (2)		5.0 kW, 5.5 kW (2)				5.5 kW
6000 or greater but less than 7000				6.0 kW				6.0 kW, 6.8 kW (2)	6.5 kW	6.0 kW				6.0 kW, 6.25 kW,		6.0 kW, 6.5 kW		
7000 or greater but less than 8000			7.5 kW (4)	7.5 kW (3)				7.0 kW (2), 7.5 kW		7.0 kW, 7.2 kW		7.5 kW				7.0 kW		
8000 or greater but less than 9000			8.5 kW	8.5 kW					8.0 kW			8.3 kW		8.0 kW (2)				
9000 or greater but less than 10,000	9.0 kW (4)		9.5 kW (3)	9.0 kW, 9.5 kW (2)										9.5 kW				
10,000 or greater but less than 12,000																		
12,000 or greater but less than 15,000			12.0 kW (2)	12.0 kW (2)						14.0 kW				12.0 kW		12.0 kW		
15,000 or greater				20.0 kW														

TAB A

United States
Consumer Product Safety Commission
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Memorandum

TO: Janet Buyer, Project Manager
Directorate for Engineering Sciences

DATE: February 16, 2022

THROUGH: Stephen Hanway, AED for Epidemiology
EPHA - Epidemiology

Risana Chowdhury, Director, Division of Hazard Analysis
EPHA - Epidemiology

FROM: Matthew V. Hnatov, Mathematical Statistician
Division of Hazard Analysis, EPHA - Epidemiology

SUBJECT: Assessment of Portable Generator Voluntary Standards Effectiveness in Addressing CO Hazard and Information on Availability of Compliant Portable Generators - Modelling Output and Analysis Methodology

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Introduction

This memo describes staff's methodology for assessing the adequacy of the carbon monoxide (CO) poisoning hazard-mitigation requirements in two voluntary standards for portable generators and it provides the results of these assessments.

1) **Effectiveness Analysis**

As described in the briefing memorandum (Buyer, 2022), CPSC staff's effectiveness analysis is based on the concept of estimating the number of deaths and injuries attributed to generators that comply with the two voluntary standards (VS) using NIST-performed simulation studies of incident scenarios like those reported in CPSC's incident data records. These estimates were compared to a generator of the same class not employing one of the CO mitigation strategies in either voluntary standard . In addition to estimating the number of deaths per VS, staff estimated the level of injury, if any, that survivors would endure, based on peak COHb levels. NIST modelling results were used to estimate CO levels and COHb levels resulting from baseline generators and those from generators employing one of the CO mitigation strategies as defined in the respective voluntary standards.

The CO mitigation strategies described in the two voluntary standards either do not require an indicator identifying the reason the generator shut off (UL 2201), or they require an indicator, but allow it to be visible for only a limited time (*i.e.*, as little as 5 minutes) (PGMA G300). Due in part to these limitations, CPSC staff assumes that some consumers may attempt to restart the generators because of a lack of understanding of why the generator shut off, or because of a continuing desire to provide power, despite possibly understanding that the generator shut off due to the presence of CO. CPSC's data show that fatal incidents are commonly associated with urgent circumstances; so providing power to heating devices, lighting, and/or refrigeration may overcome any concern about CO. The generator operation scenarios to be considered in the CPSC analysis (including no restart or up to two restarts) are provided in Appendix A of this memo, in Tables 2.a. to 8.b.ii. for PGMA G300-compliant generators, and Tables 9.a through 15.b.ii for UL 2201-compliant generators. These tables present the different options that CPSC staff believes are most likely for consumers to select. The scenario options are based on an assumed original generator location and reflect CPSC staff's best assessment of how the consumer would react to the generator shutting off. The options include:

i) No restart, or
ii) Restart in the same location, or
iii) Move to a more isolated area within the home and restart, or
iv) Move the generator outdoors and then restart, or
v) In the scenarios where a generator is restarted indoors, a second restart (third start) is also performed, but only after moving the generator outdoors.

In 48 percent of the fatal incidents, the size category of the generator involved was not obtainable. CPSC staff assumed that the same proportions in these unknown-size, generator category incidents would apply as those incidents in which the generator size category was known. Therefore, the unknown generator category incident fatalities were allocated proportionately to the known cases.

Table 1: Distribution of Known Fatalities and Allocated Fatalities by Generator Category

	Generator Located Indoors		Generator Located Outdoors		
Generator Category	**Known Fatalities – Generator Category Known**	**Allocated Fatalities for Unknown Generators**	**Known Fatalities – Generator Category Known**	**Allocated Fatalities for Unknown Generators**	**Total Allocated Fatalities**
Handheld	2.0	1.6	- -	- -	3.6
Class 1	90.0	86.4	1	1.2	178.6
Class 2 single cylinder	166.0	155.3	3	2.8	327.1
Class 2 twin cylinder	1.0	0.8	- -	- -	1.8
Total	259.0	244.0	4.0	4.0	511.0

2) Analytical Method

The analytical methodology used in CPSC staff's effectiveness analysis is like the analysis used in the NPR for the 503 deaths modeled by the simulations reported in NIST TN 1925. Changes to the simulation and analysis work performed in the NPR include the addition of:

i) restart scenarios, including a possible second restart outdoors;
ii) several outdoor scenarios associated with structures included in the simulation modelling (8 deaths);
iii) analyses of injuries from the lives saved; and
iv) normalizing the deaths to actual allocated deaths.

The effectiveness analysis involves estimating the differential between the actual generator-associated CO fatalities germane to this study and the number of predicted fatalities associated with a specific CO-mitigation strategy. Therefore, this analysis compares the 503 indoor-located, generator-related fatalities, plus the 8 outdoor-located, generator-related fatalities, to the estimated number of fatalities for each of the specific sets of shutoff criteria. In addition to the potential lives saved for a given set of shutoff criteria, estimates of CO injuries and their severity were determined.

The actual number of deaths (511 total) were assigned to each of the 40 NIST model houses/structures, proportionate to the incident data. The explanation of the specifics of the allocation methodology will follow.

Simulation of a baseline non-CO-mitigation generator (*i.e.*, a generator with no CO shut-off feature or CO emission-rate limitation) were run for each of the houses/structures. Due to all the assumptions used in simulations, there were several structure/generator-size simulations that yielded fewer fatalities than what appeared in the incident data. For these instances, the fatalities were scaled up to the actual known numbers. This same scaling factor was applied to each of the VS generators to equalize the results.

The specific CO-mitigation strategies that were analyzed and compared to the baseline generator results follow:

1. The PGMA G300 voluntary standard, which requires generators to shut off before the CO concentration exceeds 400 ppmv for a rolling 10-minute period, or before an instantaneous measurement of 800 ppmv measured at a specific location above the generator; and
2. The UL 2201 voluntary standard, which requires a maximum weighted CO emission rate of 150 g/h, and for generators to shut off when the CO concentration is either an average of 150 ppm of CO for a 10-minute period or an instantaneous reading of 400 ppm measured at a specific location above the generator during performance testing.

For CPSC staff to estimate the effectiveness of each of the above-mentioned CO-mitigation strategies, some or all the following factors were considered (depending on house/structure type and generator category):

1. Observed proportion of generator locations within house/structure model in the incident data;
2. Observed proportion of generator category involved by location within house/structure model in the incident data (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 in the incident data, including the allocation of unknown and non-exact match cases;
4. Proportion of fatalities associated with generator category in the incident data (Class 1 and Class 2 single cylinder generator categories only);
5. Simulated fatality rates by occupied zone;
6. On a per-house/structure basis, the actual fatalities (based on assumed CO rate for specific generator category) minus simulated fatalities from generators complying with specific CO mitigation strategies;
7. Restart scenarios based on CPSC staff's assessment of consumer actions taken after shutoff including no restart; and
8. On a per-house/structure basis, an assessment of simulated injuries from generators complying with specific CO mitigation strategies.

The methodological steps and the general equations used by CPSC staff to estimate deaths and injuries, as well as the percentage of deaths averted, are as follows (which are the same as those used in the NPR and use the same COHb criteria to determine fatality), starting with the following nomenclature and definitions:

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 ($A_j * B_k$)

$D_{i,j}$ = % Generator Used in i^{th} Zone (living space," "basement," "garage," or "crawlspace) in j^{th} Structure

$E_{i,j,k}$ = Weighting factor for the i^{th} Zone in j^{th} Structure and the k^{th} Restart Scenario

$F_{1,i,j}$ = Modeled Fatality Rate for Respective Current or Voluntary Standard Generator Placed in i^{th} Zone in j^{th} Structure = $\sum[D_{i,j} * E_{i,j,k} *$ Probability of Death$]$

where *Probability of Death* = ∑ of the binary variable for death for each 28 days/28

$F_{2,i,j}$ = Modeled *Hospitalization* Rate for Respective Current or Voluntary Standard Generator Placed in the i^{th} Zone in j^{th} Structure = ∑[$D_{i,j}$ * $E_{i,j,k}$ * *Probability of Hospitalization*]

where *Probability of Hospitalization* = ∑ of the binary variable for hospitalization for each 28 days/28

$F_{3,i,j}$ = Modeled *Treated & Released* Rate for Respective Current or Voluntary Standard Generator placed in the i^{th} Zone in jth Structure = ∑[$D_{i,j}$ * $E_{i,j,k}$ * *Probability of Treated & Released*]

where *Probability of Treated & Released* = ∑ of the binary variable for treated & released for each 28 days / 28

$F_{4,i,j}$ = Modeled *Unlikely to Seek Treatment* Rate for Respective Current or Voluntary Standard Generator Placed in i^{th} Zone in j^{th} Structure = ∑[$D_{i,j}$ * $E_{i,j,k}$ * *Probability of Unlikely to Seek Treatment*]

where *Probability of Unlikely to Seek Treatment* = ∑ of the binary variable for unlikely to seek treatment for each 28 days / 28

Details for each step in the process and the supporting rationale are given below.

2.1 ALLOTTED FATALITIES TO EACH STRUCTURE

A_j = Allotted Fatalities for j^{th} Structure (class 1 and class 2 single cylinder *Generators only)*

As was done in the analysis for the NPR, to account for all 503 generator-related fatalities in the simulations, all incidents had to be assigned or allocated to the different modeled structures. Incidents that occurred in structures that exactly match the parameters of one of the NIST models were assigned to that specific corresponding model only. Those incidents that occurred in structures that did not exactly match a modeled structure, or in situations where there was not sufficient information to characterize the structure, were allocated to one or more of the structures that were the closest match, based on available information. The methodology of allocation differed slightly by structure type, which is explained below.

In addition, there are eight fatalities that are new to this study that were associated with generators located outdoors of a modeled structure. Six of these were assigned to like structures. The other two did not match close enough to a modelled structure, and thus, they were apportioned to the other six matched structures.

2.2 ALLOCATION METHODOLOGY OF INCIDENT FATALITIES WITH UNMATCHED OR INCOMPLETE INFORMATION METHODOLOGY

Generally, for all incidents that occurred in structures that do not exactly match the characteristic parameters of a modeled structure (*i.e.*, structure type, size of structure, number of floors, foundation type, and presence of a garage), the deaths were allocated to 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 of category (*e.g.*, incidents in detached houses were only matched to other detached houses). If more than one structure for that type of category was identified as a closest match, then the deaths were allocated among the closest-match structures, proportional to the numbers of exact match cases for those modeled structures. For example, if two deaths needed to be allocated to two equally closest matched structures, where structure A had six exact match deaths in the incident data and structure B had two exact-match deaths, the allocation would be of the proportion 6:2 (A:B) or 3:1. Therefore, 75 percent of the two deaths (1.5 deaths) would be allocated to structure A and 25 percent of the two deaths (0.5) to structure B. This results 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 has been simplified and modified somewhat to account for the great variation that exists in real-world structures and the somewhat limited available selection of modeled structures.

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 do not have any exact match incidents. These were allocated across all like structures proportionally to the matched counts.

If the structures in non-exact match incidents are closest matched to structures with exact matches and structures with no exact matches, then all the incident deaths were allocated to the structures with exact matches only. If incidents are closest matched to only structures with no exact match fatalities, then all the deaths were allocated evenly amongst all the closest match structures.

2.3 STRUCTURE TYPE SPECIFIC CONSIDERATIONS FOR ALLOCATION OF INCIDENT DEATHS

Detached Houses – All Characteristic Parameters Known and Exact Match to Modeled Houses

For detached house incidents, an exact match is where the five incident structure characteristic parameters match exactly with one of the NIST modeled houses. Also, the garage type (“integral,” “attached,” or “none) must match. In these cases, all the incident fatalities were allotted to the exact match house.

Detached Houses – All Characteristic Parameters Known but No Direct Match

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 cannot be determined are 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 a match to both finished and unfinished basements, but not to concrete slab or crawlspace; allocation of the incident fatalities was performed as described. So, if there are both finished and unfinished basement closest match models, the deaths were allocated proportionately between the two. If there is only one closest matched model, then the allocation went to that model. If neither a matching finished nor unfinished basement model are in the exact match set, then this parameter was considered unmatched.

Table 2: Allocated CO Fatalities – Detached House (DH)

Matched Model	Exact Match Allocations	Partial Match Allocations from "No Basement" Subset*	Partial Match Allocations from "Basement" Subset*	Total Allocated Fatalities	Outdoor Fatalities
DH-1	3.0	6.7	0.0	9.7	0.0
DH-2	2.0	3.6	7.1	12.7	0.0
DH-2mod	0.0	1.0	1.5	2.5	0.0
DH-3	7.0	11.3	0.0	18.3	1.3
DH-5	3.0	6.7	0.0	9.7	0.0
DH-7	5.0	7.5	10.5	23.0	1.3
DH-8	6.0	9.5	0.0	15.5	1.3
DH-10	0.0	2.5	1.5	4.0	0.0
DH-12	1.0	2.4	2.3	5.6	0.0
DH-19mod	1.0	2.3	14.4	17.7	0.0
DH-21	17.0	14.4	0.0	31.4	0.0
DH-21mod	3.0	2.9	0.0	5.9	1.3
DH-24mod	4.0	1.2	0.0	5.2	0.0
DH-27	0.0	2.0	0.0	2.0	0.0
DH-32	0.0	6.0	0.0	6.0	1.3
DH-33mod	3.0	3.8	0.3	7.1	0.0
DH-34	9.0	10.8	1.8	21.6	0.0
DH-41	0.0	0.5	5.5	6.0	0.0
DH-44	0.0	0.0	1.0	1.0	0.0
DH-45	0.0	1.5	1.5	3.0	0.0
DH-45mod	1.0	13.8	18.6	33.4	0.0
DH-52mod	1.0	1.6	4.4	7.0	1.3
DH-56	0.0	0.5	7.0	7.5	0.0
DH-60	1.0	2.0	6.2	9.2	0.0
DH-60mod	0.0	2.0	1.5	3.5	0.0
DH-61	3.0	3.0	10.7	16.7	0.0
DH-61mod	8.0	6.6	13.4	28.0	0.0
DH-63mod1	2.0	5.6	16.7	24.3	0.0
DH-63mod2	0.0	0.0	7.0	7.0	0.0
DH-64	4.0	5.4	1.6	11.1	0.0
DH-81	0.0	0.0	5.5	5.5	0.0
Total	84.0	137.0	140.0	361.0	6.7

* 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.

Manufactured Houses

NIST used models of two manufactured houses in NIST TN 1925 that were also used in this study. One modified model (MH1mod) represents manufactured houses, sometimes called mobile homes, and a previously defined house model (MH1) represents other manufactured homes. When the type of manufactured house was known, mobile home incidents were allotted to the MH1mod model and all others to the existing 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 3: Allocated CO Fatalities – Manufactured House (MH)

Matched Model	Exact Match Allocations	Allocations for Partial Matches	Total Allocated Fatalities	Outdoor Fatalities
MH1	15.0	0.5	15.5	1.3
MH1mod	63.0	1.5	64.5	0.0
Total	78.0	2.0	80.0	1.3

Attached Houses – All Characteristic Parameters Known and Direct Match to Model

Attached house incidents were handled similarly to detached houses except that the "year-built" parameter was used given the small number of models.

Table 4: Allocated CO Fatalities – Attached House (AH)

Matched Model	Exact Match Allocations	Partial Match Allocations from "No Basement" Subset	Partial Match Allocations from "Basement" Subset	Total Allocated Fatalities	Outdoor Fatalities
AH3	3.0	4.0	0.5	7.5	0.0
AH10	3.0	1.0	0.5	4.5	0.0
AH21	1.0	0.0	0.0	1.0	0.0
AH34mod	2.0	0.0	1.0	3.0	0.0
Total	9.0	5.0	2.0	16.0	0.0

Detached Garages/External Structures

NIST developed three structures for NIST TN 1925 to represent various detached garages and other non-house external structures that were also used in this study. 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 5: Allocated CO Fatalities – Detached Structures

Matched Model	Exact Match Allocations	Allocations for Partial Matches	Total Allocated Fatalities	Outdoor Fatalities
GAR1	11.0	1.9	12.9	0.0
GAR2	12.0	1.7	13.7	0.0
GAR3	17.0	2.4	19.4	0.0
Total	40.0	6.0	46.0	0.0

Due to the relatively low number of indoor fatalities with a generator in use outdoors, only fatalities in houses that matched a specific house already being modeled were simulated.

2.4 PROPORTION OF GENERATORS INVOLVED IN FATAL CO-POISONING INCIDENTS AND ALLOTTED FATALITIES FOR STRUCTURE BY GENERATOR CLASS/TYPE

B_k = % by k^{th} Generator Category (structure specific considerations)
*C_j = Allotted Fatalities for j^{th} Structure by Generator class (A_j * B_k)*

There are many different types and sizes of generators that have reportedly been involved in fatal CO poisoning incidents, as recorded in the CPSC incident database. All generators involved in these incidents have been classified into one of four categories: Handheld, Class 1, Class 2 single cylinder, and Class 2 twin cylinder.[4] The majority of fatal incidents and deaths were associated 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 three structures were modeled separately. A Handheld generator incident occurred in a house matched to the DH8 detached house; DH8, was thus, handled independently of the other detached houses. A Handheld incident also occurred in a house matched to the MH1mod manufactured home. Therefore, MH1mod and MH1 were handled independently. One fatal incident related to a Class 2 twin-cylinder generator occurred in a detached structure matched to GAR3.

[4] When the information available about the incident did not report the generator's engine displacement, staff considered the reported wattage of the generator if that was available. 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 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 2 kW in 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 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 kW 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 kW or 13 kW typically have a rated power of 9 kW and higher. Rows and column counts may not add to totals due to rounding.

Given there were only three detached structure models, staff decided that each model (GAR1, GAR2, and GAR3) would be handled separately. Table 6 below summarizes fatalities and allocated fatalities associated with the different generator categories by structure type.

Table 6: Proportions of Generators Observed in Incident Data by Generator Category and Structure Type for Indoor Scenarios

	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	**3.6 (0.7 %)**	**176.4 (35.1 %)**	**321.3 (63.9 %)**	**1.8 (0.4 %)**	**503.0 (100.0 %)**

2.4.1 PROPORTION OF INCIDENTS BY LOCATION OF THE GENERATOR

$D_{i,j}$ *= % Generator 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 on the presence of a basement, crawlspace, and/or a garage, and the size of the generator. The incident data indicate that consumers who use generators indoors do so for several 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 was 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; not having a long enough extension cord; and attempts to comply with electrocution hazard warnings cautioning against use of the generator in wet weather.

The simulations that were run by NIST assume that the generator was operated in several modeled locations within the modeled structure, depending on structure type and configuration. These assumptions were based on an in-depth review of the CPSC incident data, which indicate 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 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 in where consumers tend to use a generator are apparent when the consumer has a choice of different locations, *e.g.*, basement and/or garage/crawlspace in addition to the living space. This choice may also depend on 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 percent of the fatalities occurred with a generator used in the living space, and 23.1 percent occurred when a generator was 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. Table 7 below shows the generator locations based on the structure configurations.

Table 7: Modeled Generator Indoor Locations Based on Structure Parameters

Detached houses, manufactured houses, attached houses			
Structure 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.)			
Structure 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)	

Table 8 presents the houses modeled, grouped by their similar structural features.

Table 8. Houses Grouped by Similar Structural Features

Basement	Crawlspace	Garage	House models
N	N	N	DH-21, DH-21(mod), DH-24(mod), DH-34, AH-3
N	Y	N	MH-1(mod), DH-3, MH-1
Y	N	N	DH-61, DH-63 (mod1), DH-61, DH-56, DH-63(mod2), DH-41, DH-81, DH-27, DH-44, AH-10
N	N	Y	DH-8, DH-64, DH-5, DH-1, DH-33(mod), DH-32
Y	N	Y	DH-45(mod), DH-7, DH-19(mod), DH-2, DH-60, DH-52(mod), DH-12, DH-10, DH-60(mod), DH-45, DH-2(mod), AH-34(mod), AH-21

Specific assumed probabilities of the restart scenarios are given in the appropriate tables in the Appendix of this report. Tables 1.a through 1.g outline some of the basic assumptions to all the scenarios; Tables 2.a. through 8.b.ii provide the scenarios for PGMA G300-compliant generators; Tables 9.a through 15.b.ii provide the scenarios for UL 2201-compliant generators. Baseline generators are assumed to run until the gas tank is empty, and the initial start locations are given in the Appendix of this report. For the VS-compliant generators, the optional restart scenarios are:

- No restart attempted;
- Restart in place;
- Generator moved to another, more isolated area and restarted; or
- Generator moved to an outdoors location and restarted.

In the cases where the generator is restarted indoors, a third restart is also attempted, but only after the generator is moved outdoors.

Within these scenarios, there may be one or more location-specific operational changes to the running environment, which include, but are not limited to, window position, interior door position, garage bay door position, and exhaust orientation.

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 (*i.e.,* not differentiated by generator size, as was the case for detached houses and manufactured houses). This was also done for the detached structures GAR1 and GAR2.

Table 9: Proportions of Fatalities Based on Indoor Generator Locations - Detached House – Class 1 Generators – By Structure Type (121.0 allocated fatalities)

House Characteristics		Generator Location			
Foundation	**Garage**	**Living space**	**Basement**	**Crawlspace**	**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 10: Proportions of Fatalities Based on Indoor Generator Locations - Detached House – Class 2 Single-Cylinder Generators – By Structure Type (238.1 allocated fatalities)

House Characteristics		Generator Location			
Foundation	**Garage**	**Living space**	**Basement**	**Crawlspace**	**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 11: Proportions of Fatalities Based on Indoor Generator Locations - Detached House (DH8 only) – Handheld Generators (1.9 allocated fatalities)

Foundation	Garage	living space	basement	crawlspace	garage
No basement	Garage	26.4 %	n/a	n/a	73.6 %

Table 12: Allocated Fatalities and Proportions of Fatalities Based on Indoor 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 13: Allocated Fatalities and Proportions of Fatalities Based on Indoor 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 14: Allocated Fatalities and Proportions of Fatalities Based on Indoor 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 15: Allocated Fatalities and Proportions of Fatalities Based on Indoor Generator Locations, Structure Model and Generator Category - Attached House – All Generator Categories

Structure Model	Allocated Fatalities	Living Space	Basement	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 16: Allocated Fatalities and Proportions of Fatalities Based on Indoor 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 17: Proportions of Fatalities Based on Indoor Generator Locations and Generator Category - Detached Structure – GAR3 (19.4 fatalities)

Generator Category	Garage/Larger Room	Workshop/Smaller Room
Class 1	12.5 %	87.5 %
Class 2 single cylinder	51.6 %	48.4 %
Class 2 twin cylinder	75.0 %	25.0 %

2.4.2 RESTART SCENARIOS

Tables 2.a. to 8.b.ii and Tables 9.a through 15.b.ii in the Appendix of this report summarize the restart scenarios and their associated probabilities. There are few generators that claim to comply with either of the voluntary standards on the market, and staff is not aware of any available incident data that may inform the actual probabilities. CPSC staff deliberated over setting the VS-specific probabilities to each initial start location and the specific restart scenarios and restart sub-scenarios within the observed probabilities of initial location of the generator within the structure. CPSC staff included participants from Mechanical and Combustion Engineering, Epidemiology, Human Factors, and Health Sciences in their deliberations. Restart scenarios included restarting the generator in-situ, moving the generator to a more isolating internal location, and restarting, or moving it outside of the residence and restarting.

All these scenario probabilities (weights) and sub-scenario probabilities (sub-weights) are combined such that the sum equals one, except for, in some cases, the exhaust orientation. In these cases, the orientation would be weighted 3/4 away from a wall with door and 1/4 towards the wall with a door.

2.4.3 OUTDOOR SCENARIOS

In addition to the 503 CO fatalities associated with generators located within structures included in this analysis, the incident data also included eight CO fatalities where an outdoor-located generator caused fatalities within fixed residential structures matching those included in this study. In these cases, fatal levels of CO entered and accumulated within the home. There were additional deaths from outdoor use of generators, but the structure where the victims were in do not match any of the structures in NIST’s inventory of building models. Six of the eight deaths could be associated with model-specific structures. For two of the deaths, staff knew only that the incident occurred in a house, but no specific structural information was available. Because only a few different types of homes were associated with the CO deaths, the two fatalities that occurred in homes whose types were unknown were allocated to the six home designs that were known to have outdoor-located generator fatalities that occurred inside the home. Table 17, below, lists the involved house designs and the allocated CO fatalities. Note that this table presents information also contained in Tables 2 and 3.

Table 17: Allocated Outdoor Generator CO Fatalities

Matched Model	Outdoor Fatalities
DH-3	1.3
DH-7	1.3
DH-8	1.3
DH-21mod	1.3
DH-32	1.3
DH-52mod	1.3
Total	8.0

2.4.4 CPSC STAFF-DERIVED ESTIMATES OF EFFECTIVENESS

NIST simulated the generator characteristics provided in Table 11 in this memo, based on several factors, including:

- Structure design;
- Location of the generator in the structure (structure design dependent);
- Generator runtime (generator type-specific);
  - Baseline generators: start with full tank, no refill; runs until gas tank is empty,
  - VS generators: start with full tank, no refill. Includes possible restart scenarios if the generator shut off due to a respective CO mitigation technology;
- Exposure duration of up to 24 hours, estimated using one-second simulation time steps with 1-minute output resolution, starting at 12:00 a.m.;
- 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. It should be noted that although the weather file data were 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 simulations is not affected by the previous day's results.)

The 1-minute interval CO concentrations generated by the NIST simulations were used to calculate COHb profiles for an occupant in each occupiable zone and to determine if, and when, a fatality is predicted, based on four criteria developed by CPSC Health Sciences (HS) staff for interpretation of modeled COHb values. The determination of fatalities was made on a zone-by-zone basis. As was done for the benefits analysis of the NPR, the four criteria used to interpret predicted fatal 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 with > 50 % COHb is less than 2 hours, and average duration between ≥40 % and <50 % COHb is less than 4 hours. In that case, assume survival.
3. If peak level is ≥40 % COHb, but <50 % COHb, assume death if duration of the average in

this range exceeds 6 hours. Otherwise, assume survival.
4. If peak level is ≤40 % COHb, assume survival.

The results of this COHb-level assessment for a given day yields a binary result, where 1 = death or 0 = survival.

In addition to the simulated fatalities analysis, CPSC HS staff developed criteria for estimating potential severity of injuries for the survivors of what formerly would have been fatal exposures. The injury level determinations also employ the calculated COHb levels, as in CPSC staff's fatality assessment, as follows:

1. <15 % COHb – assume minimal if any perceptible symptoms in healthy adults – unlikely to seek medical treatment
2. ≥15 % COHb but <25 % COHb – assume likely to perceive adverse symptoms and to seek medical evaluation in emergency room (ER) or other medical setting, but likely to be released without need for hospitalization or for a transfer to a hyperbaric oxygen (HBO)[5] treatment facility or other specialized treatment center
3. ≥25 % COHb but <40 % COHb for no more than 6 hours – assume likely to perceive adverse symptoms and to seek or be taken for medical evaluation in ER or other medical setting, and likely to be hospitalized or transferred to an HBO-treatment facility or other specialized treatment center

Like the fatality assessment above, levels of injuries also yield a binary variable for each given day. It should be noted that for any given day, there is only one outcome. The potential victim will be a fatality, be hospitalized, be treated, and released, or will not seek medical treatment.

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 were treated as a separate event with no carry-over effect from previous runs. The possible outcome at any given point in time for the potential victim would be a binary variable, either survival (0) or death (1). Therefore, the average of the outcomes over all 28 days would be the probability of death for the purposes of this analysis. Similar analyses were performed for potential injuries.

[5] An HBO chamber is a device 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, except for victims at risk of adverse outcomes (Clardy et al., 2010).

2) Generator locations within the house/structure are proportionately equal to the incident data.
3) The victim's location in the structure is assumed to have equal probability of occurring in any living-space room. This assumption was made for two reasons. In multi-fatality incidents, victims were often found in different locations within a structure. Frequently, it was unclear whether victims remained the entire time in the specific area in which they were found.

The following four tables summarize 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 configuration. 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 18: Class 1 Generator Placement Location Proportions

Class I Generators				Generator Location				
NIST Model	Allocated Deaths – All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawl-space	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 19: Class 2 Single-Cylinder Generator Placement Location Proportions

Class 2 Single-Cylinder Generators				Generator Location				
NIST Model	Allocated Deaths – All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawl-space	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 20: Handheld Generator Placement Location Proportions

Handheld Generators				Generator Location				
NIST Model	Allocated Deaths – All Gens	Proportion	Allocated Deaths	Living Space	Basement	Crawl-space	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 21: Class 2 Twin-Cylinder Generator Placement Location Proportions

Class 2 Twin-Cylinder Generators				Generator Location				
NIST Model	Allocated Deaths – All Gens	% TC	Allocated Deaths	Living Space	Basement	Crawl-space	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.

3) Epidemiological Benefits Analysis Results

As stated, the benefits assessment of each of the Voluntary Standards is the differential between the baseline generator fatalities and the respective VS-estimated fatalities. Also included are the estimates for each of the two different levels of injuries and the estimate of the number of individuals who sustained no significant injury. Note that for the baseline generators, staff did not attempt to model injuries. CPSC data do not contain complete CO injury data, especially from nonfatal incidents. The facts that are known to CPSC staff are the CO fatalities associated with portable generators, and this analysis attempts to model the outcomes. The estimates of the injuries associated with the VS generators are included because, although a life would have been saved, the societal costs of serious injuries can be significant.[r]

Injury Level	Baseline	G300	UL2201
Fatality	511.0	68.6	< 0.1
Percentage of Deaths averted versus Baseline generators	- -	86.6%	~100%
Injury Level 2 (hospitalized or transferred to specialized treatment center)	- -	55.0	3.4
Injury Level 1 (seeks medical treatment and is treated and released)	- -	34.1	21.7
Not likely symptomatic, not seeking medical treatment	- -	353.4	486.0

[r] For a discussion of societal costs associated with CO deaths and injuries from generators, see TAB L in staff's briefing package for the NPR (available online at: https://www.cpsc.gov/s3fs-public/Proposed_Rule_Safety_Standard_for_Portable_Generators_October_5_2016.pdf.)

Appendix A: Scenario Tables

The tables in this appendix detail the scenarios staff simulated. Table 1.a through 1.g provide assumptions about the generator operator and other building occupants. Tables 2.a through 15.b.ii describe the type of house, the location and exhaust direction of the generator upon initial startup, possible responses of the generator's operator to the first shutoff, and possible operator responses if the generator shut off a second time.

Table 1.a: Information for all tables

Occupants who are potential victims	Weight
Operator	75%
Collateral person	25%

Table 1.b: Common to All Scenarios – Occupant: Collateral person

	Action
1	Collateral person does not change zones, unless the operator moves the generator into the room the collateral person was occupying. In this situation, the collateral person moves to a bedroom.

Table 1.c: Operator – When restarting the generator in situ or moving it within the house

	Action
1	Operator restarts generator 10 min after shutoff. (The time represents an estimate of how long it takes to realize the generator has shut off, to move it to another zone [if called for in scenario], and to restart the generator.)
2	After restart, operator stays in the zone with the generator for 2 min, then returns to original location. The door between generator zone and the rest of the house is open 10 cm. If the generator is in a room in a finished basement, both the door to the basement and the door to the room with the generator are open 10 cm.
3	Generator shuts off, as dictated by the shutoff criteria in the voluntary standard.

Notes:

1. Door Positions: At 5 min after shutoff, door to generator zone is opened fully. At 12 min after shutoff, door is shut to 10 cm. to allow cords to pass through.
2. Window Positions: At 12 min after shutoff, changes to window positions will occur, as described in the tables. If the generator shuts off again in less than 2 min after restart, no changes are made to the window position.

Table 1.d: Operator – When moving and restarting the generator to outside the kitchen, where CO does not enter the home/does enter the home

	Action
1	Operator restarts generator 10 min after shutoff. (The time represents an estimate of how long it takes to realize the generator has shut off, to move it outside, and to restart the generator.)
2	After restart, operator stays outside for 2 min, then returns to original location. The door between kitchen and outside is open 10 cm.
3	Generator does not shut off until tank is empty.

Notes:

1. Door Positions: At 5 min after shutoff, door to outside kitchen is opened fully. At 12 min after shutoff, door is shut to 10 cm to allow cords to pass through.
2. Window Positions: At 12 min after shutoff, any open windows will be closed.

Table 1.e: Operator – When moving and restarting the generator to outside the garage, where CO does not enter the garage/does enter the garage

	Action
1	Operator restarts generator 10 min after shutoff. (The time represents an estimate of how long it takes to realize the generator has shut off, to move it outdoors, and to restart the generator.)
2	After restart, operator stays outside for 2 min, then returns to original location. Details on the bay door position are given in the tables.
3	Generator does not shut off until tank is empty.

Notes:

1. Door Positions: Door between garage and interior of the house is open 10 cm. At 5 min after shutoff, door from the house to the garage and garage bay door are opened fully. At 12 min after shutoff, door to interior of the house is shut to 10 cm., to allow cords to pass through and the garage bay door is shut, if the scenario calls for it (*i.e.*, "CO does not enter garage").
2. Window Positions: At 12 min after shutoff, any open windows will be closed.

Table 1.f: Operator – When moving and restarting the generator inside the garage

	Action
1	Operator restarts generator 10 min after shutoff. (The time represents an estimate of how long it takes to realize the generator has shut off, to move it, and to restart the generator.)
2	After restart, operator stays in the garage for 2 min, then returns to original location. For scenarios that have the operator open the bay door fully, it is opened 2 min after restart. If the generator shuts off in less than 2 min, the operator does not open the bay door.
3	Generator shuts off, as dictated by the shutoff criteria in the voluntary standard.

Notes:

1. Door Positions: Door between garage and interior of the house is open 10 cm. At 5 min after shutoff, door from the house to the garage is opened fully. At 12 min after shutoff, door to interior is shut to 10 cm, to allow cords to pass through.
2. Window Positions: At 12 min after shutoff, any open windows will be closed. If the generator shuts off again in less than 2 min after restart, no changes are made to the window position.

Table 1.g: Operator – When moving and restarting the generator in the crawlspace

	Action
1	Operator restarts generator 10 min after shutoff. (The time represents an estimate of how long it takes to realize the generator has shut off, to move it, and to restart the generator.)
2	After restart, operator stays in the crawlspace for 2 min, then returns to original location. The door between kitchen and outside is open 10 cm (there is no door on the crawlspace.)
3	Generator shuts off, as dictated by the shutoff criteria in the voluntary standard.

Notes:

1. Door Positions: At 5 min after shutoff, door to outside kitchen is opened fully. At 12 min after shutoff, door is shut to 10 cm to allow cords to pass through.
2. Window Positions: At 12 min after shutoff, any open windows will be closed. If the generator shuts off again in less than 2 min after restart, no changes are made to the window position.

Additional notes:

When the basement is unfinished, the interior door at top of stairs leading to the basement is closed when the source location is not on the basement level (*i.e.,* in the basement or in the garage that is on the basement level). When source location is on basement level, the interior door to basement is open 10 cm.
When basement is finished, the interior door at the top of the stairs leading down to the basement is open 10 cm, as is the door to the room with the generator, if the room has a door. There is no door at the bottom of the stairs entering in the basement.
When moving generator to or from basement level, the door is fully opened at 5 minutes, then changed to 10 cm.
Door from adjacent room to garage is normally closed, unless generator is in garage, then it is 10 cm open.

Table 2.a. [G300] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated In the Kitchen

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen			Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2025
B2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0225
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2025
B4					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0225
C1	Operator moves generator to other 1st floor room that has an isolating door.	0.2500	Window in room is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2250
C2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0250
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000		0.2250
D2			CO enters home.	0.1000	N/A	1.0000		0.0250

Table 2.b.i. [G300] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated In a First Floor Room that has a Door that Isolates It, with Generator Exhaust Jet Mixing In Room [Scenario weight total = 81.25%]

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:		Other 1st floor room with an isolating door			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:		Window in room is open 5 cm. Door to room is open 10 cm. Exhaust jet mixes inside room.						
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart		2nd Reaction Weight	
E	No restart	0.0500	N/A	1.0000	N/A		1.0000	0.0406
F1	Operator restarts in same room.	0.6167	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.2255
F2					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0251
F3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.2255
F4					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0251
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.9000	N/A		1.0000	0.2438
G2			CO enters home.	0.1000	N/A		1.0000	0.0271

Table 2.b.ii. [G300] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated in a First Floor Room that has an Isolating Door with Generator Exhaust Jet Oriented Out of Door to House Interior [Scenario weights = 18.75%]

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room that has an isolating door			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Window in room is open 5 cm. Door to room is fully open. Exhaust jet oriented out door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0094
I1	Operator restarts in same room.	0.6167	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.0520
I2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0058
I3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.0520
I4					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0058
J1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.9000	N/A	1.0000	0.0563
J2			CO enters home.	0.1000	N/A	1.0000	0.0063

Table 2.c. [G300] Scenario for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated Outside

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
K	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A	Actual Deaths for specific house model

Table 3.a. [G300] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In the Kitchen

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart		2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A		1.0000	0.0500
B1	Operator restarts in kitchen.	0.3500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.1575
B2					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0175
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.1575
B4					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0175
C1	Operator moves generator to other 1st floor room that has an isolating door.	0.2000	Window in room is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.1800
C2					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0200
D1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2000	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.		0.9	0.1800
D2					Operator moves generator to outside of kitchen where CO enters home.		0.1	0.0200
E1	Operator moves generator to outside of kitchen.	0.2000	CO does not enter home.	0.9000	N/A		1.0000	0.1800
E2			CO enters home.	0.1000	N/A		1.0000	0.0200

Table 3.b.i. [G300] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In a First Floor Room with an Isolating Door with Generator Exhaust Jet Mixing In Room [Scenario weight total = 81.25%]

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room with isolating door			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Window in room is open 5 cm. Door to room is open 10 cm. Exhaust jet mixes inside room.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
F	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0406
G1	Operator restarts in same room.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.1645
G2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0183
G3			Window in room is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.1645
G4					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0183
H1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2500	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.1828
H2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0203
I1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000	0.1828
I2			CO enters home.	0.1000	N/A	1.0000	0.0203

Table 3.b.ii. [G300] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In a First Floor Room with an Isolating Door with Generator Exhaust Jet Oriented Out of Door to House Interior [Scenario weight total = 18.75%]

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:		Other 1st floor room with isolating door			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:		Window in room is open 5 cm. Door to room is fully open. Exhaust jet oriented out door to house interior.						
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
J	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0094
K1	Operator restarts in same room.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.0380
K2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0042
K3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.0380
K4					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0042
L1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2500	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.0422
L2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0047
M1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000		0.0422
M2			CO enters home.	0.1000	N/A	1.0000		0.0047

Table 3.c. [G300] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated in the Crawlspace

Structure Type: HOUSE		Scenario Weight	Garage: No	Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Crawlspace		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Generator is in crawlspace. Exhaust jet mixes in crawlspace.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	FINAL SCENARIO WEIGHTS
N	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
O1	Operator restarts in crawlspace. The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.6167	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.5550
O2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0617
P1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.9000	N/A	1.0000	0.3000
P2			CO enters home.	0.1000	N/A	1.0000	0.0333

Table 3.d. [G300] Scenario for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated Outside

Structure Type: HOUSE			Garage: No	Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	FINAL SCENARIO WEIGHTS
Q	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	N/A	N/A	N/A	Actual Deaths for specific house model

Table 4.a. [G300] Scenarios for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated in Kitchen

Structure Type: HOUSE			Garage: No		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2025
B2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0225
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2025
B4					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0225
C1	Operator moves and restarts the generator in basement. Exhaust jet mixes in basement.	0.2500	Window in basement is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2250
C2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0250
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000		0.2250
D2			CO enters home.	0.1000	N/A	1.0000		0.0250

Table 4.b. [G300] Scenarios for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated in Basement

Structure Type: HOUSE		Garage: No	Basement: Yes		Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Basement		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Basement stairway door is open 10 cm. Window in basement is closed. Exhaust jet mixes in basement.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
E	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
F1	Operator restarts generator in basement.	0.6167	No change.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2775
F2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0308
F3			Window in basement open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2775
F4					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0308
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.9000	N/A	1.0000	0.3000
G2			CO enters home.	0.1000	N/A	1.0000	0.0333

Table 4.c. [G300] Scenario for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated Outside

Structure Type: HOUSE		Garage: No	Basement: Yes		Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	N/A	N/A	N/A	Actual Deaths for specific house model

Table 5.a. [G300] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in the Kitchen

Structure Type: HOUSE		Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2025
B2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0225
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2025
B4					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0225
C1	Operator moves and restarts generator in garage. Bay door closed.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C3			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
C5	Operator moves and restarts in garage. Bay door is open fully.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C7			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000	0.2250
D2			CO enters home.	0.1000	N/A	1.0000	0.0250

Table 5.b.i. [G300] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in Garage with Generator Exhaust Facing Away from Wall that has Door to House Interior. Exhaust Mixes in Garage. [Scenario weight total = 75%]

Structure Type: HOUSE		Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
E	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0375
F1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
F2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
F3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
F4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
G1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.1250
G2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.1250

Table 5.b.ii. [G300] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in Garage with Generator Exhaust Facing Toward Wall that has Door to House Interior. Exhaust Jet Pushes Some of Exhaust Into House. [Scenario weight total = 25%]

Structure Type: HOUSE			Garage: Yes	Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust facing toward wall with door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
J1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
J2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.0417

Table 5.c. [G300] Scenario for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated Outside

Structure Type: HOUSE			Garage: Yes	Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
K	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A	Actual Deaths for specific house model

Table 6.a. [G300] Scenario for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Kitchen

Structure Type: HOUSE		Garage: Yes	Basement: Yes	Crawlspace: No			FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2025
B2					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0225
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9	0.2025
B4					Operator moves generator to outside of kitchen where CO enters home.	0.1	0.0225
C1	Operator moves and restarts generator in garage. Bay door closed.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C3			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
C5	Operator moves and restarts in garage. Bay door is open fully.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C7			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.9000	N/A	1.0000	0.2250
D2			CO enters home.	0.1000	N/A	1.0000	0.0250

Table 6.b. [G300] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Basement

Structure Type: HOUSE			Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Basement				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Basement stairway door is open 10 cm. Window in basement is closed. Exhaust jet mixes in basement							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
E	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
F1	Operator restarts generator in basement.	0.6167	No change.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2775
F2					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0308
F3			Window in basement open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.9		0.2775
F4					Operator moves generator to outside of kitchen where CO enters home.	0.1		0.0308
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.9000	N/A	1.0000		0.3000
G2			CO enters home.	0.1000	N/A	1.0000		0.0333

Table 6.c.i. [G300] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Garage, with Generator Exhaust Facing Away from Wall that has Door to House Interior. Exhaust Mixes In Garage. [Scenario weight total to 75%]

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0375
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
J1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.1250
J2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.1250

Table 6.c.ii. [G300] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Garage, with Generator Exhaust Facing Toward Wall that has Door to House Interior. Exhaust Jet Pushes Some of Exhaust Into House. [Scenario weight total to 25%]

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet is facing towards wall that has door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
K	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
L1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
L2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
L3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
L4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
M1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
M2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.0417

Table 6.d. [G300] Scenario for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated Outside

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Generator located outside kitchen. Door to kitchen is open 10 cm.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
N	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A	Actual Deaths for specific house model

Table 7. [G300] Scenarios for Detached 1-Car and 2-Car Garages (GAR1 and GAR2) with Generator Operated In Garage

Structure Type: DETACHED GARAGE			GAR1 & GAR2					FINAL SCENARIO WEIGHTS
Initial Location:	Garage		Weight for Home Type: (# deaths allocated to this home * % this location)					
Initial Conditions:	Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1542
B2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1542
B3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1542
B4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1542
C1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to garage.	0.3333	None. CO does not enter garage.	0.5000	NA	1.0000		0.1667
C2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000		0.1667

Table 8.a. [G300] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated in Workshop Room

Structure Type: DETACHED GARAGE			GAR3				FINAL SCENARIO WEIGHTS
Initial Location:	Workshop in Garage		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Bay door is closed. Generator is in center of workshop room. Workshop door is closed. Exhaust jet mixes in workshop room.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Restart in same room with generator exhaust jet staying in room.	0.4500	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1125
B2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1125
B3			Window in workshop room is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1125
B4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1125
C1	Move and restart in garage. Bay door closed.	0.1250	Door to workshop room is open 10 cm. Exhaust facing away from wall with door to workshop room. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C3			Door to workshop room is open 10 cm. Exhaust facing toward the wall with door to shop. Exhaust jet pushes some of exhaust into workshop room.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
C5	Move and restart in garage. Bay door is open fully.	0.1250	Door to workshop room is open 10 cm. Exhaust facing away from wall with door to workshop room. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C7			Door to workshop room is open 10 cm. Exhaust facing toward the wall with door to shop. Exhaust jet pushes some of exhaust into workshop room.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
D1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.2500	None. CO does not enter garage.	0.5000	NA	1.0000	0.1250
D2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000	0.1250

Table 8.b.i. [G300] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated In Garage, with Exhaust Oriented Away from Wall with Door to Workshop Room [Scenario weight total to 75%]

Structure Type: DETACHED GARAGE			GAR3				FINAL SCENARIO WEIGHTS
Initial Location:	Garage		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Door to workshop is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust is facing away from wall with door to workshop. Exhaust mixes in garage.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
E	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0375
F1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1156
F2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
F3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1156
F4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
G1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.3333	None. CO does not enter garage.	0.5000	NA	1.0000	0.1250
G2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000	0.1250

Table 8.b.ii. [G300] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated in Garage, with Exhaust Oriented Toward Wall with Door to Workshop Room. Exhaust Jet Pushes Some of Exhaust Into Workshop. [Scenario weight total to 25%]

Structure Type: DETACHED GARAGE		GAR3					FINAL SCENARIO WEIGHTS
Initial Location:	Garage	Weight for Home Type: (# deaths allocated to this home * % this location)					
Initial Conditions:	Door to workshop is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust is facing toward wall with door to workshop. Exhaust jet pushes some of exhaust into workshop room.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0385
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0385
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
J1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.3333	None. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
J2			Bay door is open fully. CO enters the garage.	0.5000	N/A	1.0000	0.0417

Table 9.a. [UL2201] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated In the Kitchen

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1688
B2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0563
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1688
B4					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0563
C1	Operator moves generator to other 1st floor room that has an isolating door.	0.2500	Window in room is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1875
C2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0625
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000		0.1875
D2			CO enters home.	0.2500	N/A	1.0000		0.0625

Table 9.b.i. [UL2201] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated In a First Floor Room that has a Door that Isolates It, with Generator Exhaust Jet Mixing In Room [Scenario weight total = 81.25%]

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room with an isolating door				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Window in room is open 5 cm. Door to room is open 10 cm. Exhaust jet mixes inside room.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
E	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0406
F1	Operator restarts in same room.	0.6167	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1879
F2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0626
F3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1879
F4					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0626
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.7500	N/A	1.0000		0.2031
G2			CO enters home.	0.2500	N/A	1.0000		0.0677

Table 9.b.ii. [UL2201] Scenarios for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated in a First Floor Room that has an Isolating Door with Generator Exhaust jet Oriented Out of Door to House Interior [Scenario weights = 18.75%]

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room that has an isolating door		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Window in room is open 5 cm. Door to room is fully open. Exhaust jet oriented out door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0094
I1	Operator restarts in same room.	0.6167	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.0434
I2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0145
I3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.0434
I4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0145
J1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.7500	N/A	1.0000	0.0469
J2			CO enters home.	0.2500	N/A	1.0000	0.0156

Table 9.c. [UL2201] Scenario for Houses with No Basement, Garage, or Crawlspace with Generator Initially Operated Outside

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
K	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A	Actual Deaths for specific house model

Table 10.a. [UL2201] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In the Kitchen

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Operator restarts in kitchen.	0.3500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1313
B2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0438
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1313
B4					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0438
C1	Operator moves generator to other 1st floor room that has an isolating door.	0.2000	Window in room is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1500
C2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0500
D1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2000	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1500
D2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0500
E1	Operator moves generator to outside of kitchen.	0.2000	CO does not enter home.	0.7500	N/A	1.0000		0.1500
E2			CO enters home.	0.2500	N/A	1.0000		0.0500

Table 10.b.i. [UL2201] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In a First Floor Room with an Isolating Door with Generator Exhaust Jet Mixing In Room [Scenario weight total = 81.25%]

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room with isolating door				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Window in room is open 5 cm. Door to room is open 10 cm. Exhaust jet mixes inside room.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
F	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0406
G1	Operator restarts in same room.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1371
G2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0457
G3			Window in room is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1371
G4					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0457
H1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2500	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.1523
H2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0508
I1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000		0.1523
I2			CO enters home.	0.2500	N/A	1.0000		0.0508

Table 10.b.ii. [UL2201] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated In a First Floor Room with an Isolating Door with Generator Exhaust Jet Oriented Out of Door to House Interior [Scenario weight total = 18.75%]

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Other 1st floor room with isolating door			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Window in room is open 5 cm. Door to room is fully open. Exhaust jet oriented out door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
J	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0094
K1	Operator restarts in same room.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.0316
K2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0105
K3			Window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.0316
K4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0105
L1	Operator moves generator to crawlspace. Exhaust jet mixes inside crawlspace The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.2500	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.0352
L2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0117
M1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000	0.0352
M2			CO enters home.	0.2500	N/A	1.0000	0.0117

Table 10.c. [UL2201] Scenarios for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated in the Crawlspace

Structure Type: HOUSE		Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Crawlspace			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Generator is in crawlspace. Exhaust jet mixes in crawlspace.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
N	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
O1	Operator restarts in crawlspace. The only exposure in the crawlspace is of operator entering the crawlspace to move the generator and/or restart the generator.	0.6167	None.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.4625
O2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.1542
P1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.7500	N/A	1.0000	0.2500
P2			CO enters home.	0.2500	N/A	1.0000	0.0833

Table 10.d. [UL2201] Scenario for Houses with Crawlspace But No Basement or Garage, with Generator Initially Operated Outside

Structure Type: HOUSE			Garage: No		Basement: No	Crawlspace: Yes		FINAL SCENARIO WEIGHTS
Initial Location:	Outside							
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
Q	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	N/A	N/A	N/A		Actual Deaths for specific house model

Table 11.a. [UL2201] Scenarios for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated in Kitchen

Structure Type: HOUSE			Garage: No		Basement: Yes	Crawlspace: No	FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
C1	Operator moves and restarts the generator in basement. Exhaust jet mixes in basement.	0.2500	Window in basement is open fully.	1.0000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1875
C2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0625
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000	0.1875
D2			CO enters home.	0.2500	N/A	1.0000	0.0625

Table 11.b. [UL2201] Scenarios for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated in Basement

Structure Type: HOUSE			Garage: No	Basement: Yes		Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Basement			Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Basement stairway door is open 10 cm. Window in basement is closed. Exhaust jet mixes in basement.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
E	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
F1	Operator restarts generator in basement.	0.6167	No change.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.2313
F2					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0771
F3			Window in basement open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75		0.2313
F4					Operator moves generator to outside of kitchen where CO enters home.	0.25		0.0771
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.7500	N/A	1.0000		0.2500
G2			CO enters home.	0.2500	N/A	1.0000		0.0833

Table 11.c. [UL2201] Scenario for Houses with Basement, But No Crawlspace or Garage, with Generator Initially Operated Outside

Structure Type: HOUSE			Garage: No	Basement: Yes		Crawlspace: No	FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	N/A	N/A	N/A	Actual Deaths for specific house model

Table 12.a. [UL2201] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in the Kitchen

Structure Type: HOUSE		Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
C1	Operator moves and restarts generator in garage. Bay door closed.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C3			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
C5	Operator moves and restarts in garage. Bay door is open fully.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C7			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000	0.1875
D2			CO enters home.	0.2500	N/A	1.0000	0.0625

Table 12.b.i. [UL2201] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in Garage with Generator Exhaust Facing Away from Wall that has Door to House Interior. Exhaust Mixes in Garage. [Scenario weight total = 75%]

Structure Type: HOUSE			Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:		Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:		Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage.						
Restart Scenarios								
Scenario	Response to Shutoff		Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
E	No restart		0.0500	N/A	1.0000	N/A	1.0000	0.0375
F1	Restart in garage.		0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
F2						Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
F3				Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.1156
F4						Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1156
G1	Operator opens bay door, moves and restarts generator outside garage.		0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.1250
G2				Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.1250

Table 12.b.ii. [UL2201] Scenarios for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated in Garage with Generator Exhaust Facing Toward Wall that has Door to House Interior. Exhaust Jet Pushes Some of Exhaust Into House. [Scenario weight total = 25%]

Structure Type: HOUSE		Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust facing toward wall with door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
J1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
J2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.0417

Table 12.c. [UL2201] Scenario for Houses with Garage But No Basement or Crawlspace, with Generator Initially Operated Outside

Structure Type: HOUSE			Garage: Yes		Basement: No	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside							
Initial Conditions:	Exterior door to kitchen is open 10 cm. Start generator in a location outside of kitchen where CO enters home.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
K	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A		Actual Deaths for specific house model

Table 13.a. [UL2201] Scenario for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Kitchen

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Kitchen		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Kitchen window is closed. Exhaust jet mixes in kitchen.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Operator restarts in kitchen.	0.4500	None.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
B3			Kitchen window is open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.1688
B4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0563
C1	Operator moves and restarts generator in garage. Bay door closed.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C3			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
C5	Operator moves and restarts in garage. Bay door is open fully.	0.1250	Exhaust facing away from wall that has door to house interior. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0469
C7			Exhaust facing toward the wall that has door to house interior. Exhaust jet pushes some of exhaust into house.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0156
D1	Operator moves generator to outside of kitchen.	0.2500	CO does not enter home.	0.7500	N/A	1.0000	0.1875
D2			CO enters home.	0.2500	N/A	1.0000	0.0625

Table 13.b. [UL2201] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Basement

Structure Type: HOUSE			Garage: Yes		Basement: Yes		Crawlspace: No	FINAL SCENARIO WEIGHTS
Initial Location:	Basement			Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Basement stairway door is open 10 cm. Window in basement is closed. Exhaust jet mixes in basement							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
E	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500	
F1	Operator restarts generator in basement.	0.6167	No change.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.2313	
F2					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0771	
F3			Window in basement open fully.	0.5000	Operator moves generator to outside of kitchen where CO does not enter home.	0.75	0.2313	
F4					Operator moves generator to outside of kitchen where CO enters home.	0.25	0.0771	
G1	Operator moves generator to outside of kitchen.	0.3333	CO does not enter home.	0.7500	N/A	1.0000	0.2500	
G2			CO enters home.	0.2500	N/A	1.0000	0.0833	

Table 13.c.i. [UL2201] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Garage, with Generator Exhaust Facing Away from Wall that has Door to House Interior. Exhaust Mixes In Garage. [Scenario weight total to 75%]

Structure Type: HOUSE			Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage				Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart		2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A		1.0000	0.0375
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.		0.5	0.1156
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.		0.5	0.1156
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.		0.5	0.1156
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.		0.5	0.1156
J1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A		1.0000	0.1250
J2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A		1.0000	0.1250

Table 13.c.ii. [UL2201] Scenarios for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated In Garage, with Generator Exhaust Facing Toward Wall that has Door to House Interior. Exhaust Jet Pushes Some of Exhaust Into House. [Scenario weight total to 25%]

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Garage			Weight for Home Type: (# deaths allocated to this home * % this location)			
Initial Conditions:	Door to house interior is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust jet is facing towards wall that has door to house interior.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
K	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
L1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
L2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
L3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to house.	0.5	0.0385
L4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
M1	Operator opens bay door, moves and restarts generator outside garage.	0.3333	Bay door is closed after operator returns to house. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
M2			Operator leaves bay door open after returning to house. CO enters the garage.	0.5000	N/A	1.0000	0.0417

Table 13.d. [UL2201] Scenario for Houses with Garage and Basement But No Crawlspace, with Generator Initially Operated Outside

Structure Type: HOUSE		Garage: Yes		Basement: Yes	Crawlspace: No		FINAL SCENARIO WEIGHTS
Initial Location:	Outside						
Initial Conditions:	Generator located outside kitchen. Door to kitchen is open 10 cm.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
N	Generator does not shutoff until the tank is empty; therefore, there are no restart scenarios.	Actual Deaths for specific house model	N/A	N/A	N/A	N/A	Actual Deaths for specific house model

Table 14. [UL2201] Scenarios for Detached 1-Car and 2-Car Garages (GAR1 and GAR2) with Generator Operated In Garage

Structure Type: DETACHED GARAGE			GAR1 & GAR2				FINAL SCENARIO WEIGHTS
Initial Location:	Garage		Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Bay door is closed. Generator is in center of garage. Exhaust jet mixes in garage						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
A	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0500
B1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1542
B2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1542
B3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.1542
B4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.1542
C1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to garage.	0.3333	None. CO does not enter garage.	0.5000	NA	1.0000	0.1667
C2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000	0.1667

Table 15.a. [UL2201] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated in Workshop Room

Structure Type: DETACHED GARAGE			GAR3					FINAL SCENARIO WEIGHTS
Initial Location:	Workshop in Garage			Weight for Home Type: (# deaths allocated to this home * % this location)				
Initial Conditions:	Bay door is closed. Generator is in center of workshop room. Workshop door is closed. Exhaust jet mixes in workshop room.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
A	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0500
B1	Restart in same room with generator exhaust jet staying in room.	0.4500	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1125
B2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1125
B3			Window in workshop room is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1125
B4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1125
C1	Move and restart in garage. Bay door closed.	0.1250	Door to workshop room is open 10 cm. Exhaust facing away from wall with door to workshop room. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.0469
C2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.0469
C3			Door to workshop room is open 10 cm. Exhaust facing toward the wall with door to shop. Exhaust jet pushes some of exhaust into workshop room.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.0156
C4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.0156
C5	Move and restart in garage. Bay door is open fully.	0.1250	Door to workshop room is open 10 cm. Exhaust facing away from wall with door to workshop room. Exhaust jet mixes inside garage.	0.7500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.0469
C6					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.0469
C7			Door to workshop room is open 10 cm. Exhaust facing toward the wall with door to shop. Exhaust jet pushes some of exhaust into workshop room.	0.2500	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.0156
C8					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.0156
D1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.2500	None. CO does not enter garage.	0.5000	NA	1.0000		0.1250
D2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000		0.1250

Table 15.b.i. [UL2201] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated In Garage, with Exhaust Oriented Away from Wall with Door to Workshop Room [Scenario weight total to 75%]

Structure Type: DETACHED GARAGE			GAR3					FINAL SCENARIO WEIGHTS
Initial Location:	Garage		Weight for Home Type: (# deaths allocated to this home * % this location)					
Initial Conditions:	Door to workshop is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust is facing away from wall with door to workshop. Exhaust mixes in garage.							
Restart Scenarios								
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight		
E	No restart	0.0500	N/A	1.0000	N/A	1.0000		0.0375
F1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1156
F2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1156
F3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5		0.1156
F4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5		0.1156
G1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.3333	None. CO does not enter garage.	0.5000	NA	1.0000		0.1250
G2			Bay door is open fully. CO enters the garage.	0.5000	NA	1.0000		0.1250

Table 15.b.ii. [UL2201] Scenarios for Detached Garage Containing a Workshop or Other Room (GAR3) with Generator Initially Operated in Garage, with Exhaust Oriented Toward Wall with Door to Workshop Room. Exhaust Jet Pushes Some of Exhaust Into Workshop. [Scenario weight total to 25%]

Structure Type: DETACHED GARAGE		GAR3					FINAL SCENARIO WEIGHTS
Initial Location:	Garage	Weight for Home Type: (# deaths allocated to this home * % this location)					
Initial Conditions:	Door to workshop is open 10 cm. Bay door is closed. Generator is in center of garage. Exhaust is facing toward wall with door to workshop. Exhaust jet pushes some of exhaust into workshop room.						
Restart Scenarios							
Scenario	Response to Shutoff	Scenario Weight	Changes from Initial Conditions	Sub-Scenario Weight	2nd restart	2nd Reaction Weight	
H	No restart	0.0500	N/A	1.0000	N/A	1.0000	0.0125
I1	Restart in garage.	0.6167	None.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0385
I2					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
I3			Bay door is open fully.	0.5000	Restart after moving generator to outside of garage where CO does not enter garage. Garage bay door is open until operator returns to inside garage.	0.5	0.0385
I4					Restart after moving generator to outside of garage where CO enters garage. Garage bay door is open by operator and remains open.	0.5	0.0385
J1	Operator opens bay door, moves and restarts generator outside garage. Operator returns to original location.	0.3333	None. CO does not enter garage.	0.5000	N/A	1.0000	0.0417
J2			Bay door is open fully. CO enters the garage.	0.5000	N/A	1.0000	0.0417

TAB B

United States
Consumer Product Safety Commission
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Memorandum

DATE: February 16, 2022

TO: Janet Buyer, Portable Generators Project Manager,
Division of Mechanical and Combustion Engineering
Directorate for Engineering Sciences

THROUGH: Alexander P. Moscoso, Associate Executive Director
Directorate for Economic Analysis

FROM: Charles L. Smith, Economist, Directorate for Economic Analysis

SUBJECT: Portable Generator Voluntary Standards Addressing CO Hazard:
Information on Voluntary Standard-Compliant Product Availability

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1. Background

In October 2016, staff of the Consumer Product Safety Commission (CPSC) delivered a notice of proposed rulemaking (NPR) briefing package to the Commission recommending that the Commission address the carbon monoxide (CO) poisoning hazard from portable generators, by issuing a proposed rule that would limit the CO emission rates of four different-size categories of portable generators. On November 21, 2016, the Commission issued an NPR based on the standard drafted by staff. This rulemaking remains in an open status. Following that action, Underwriters Laboratories (UL) and the Portable Generator Manufacturers Association (PGMA) adopted into their respective voluntary standards for portable generators (UL2201 and PGMA G300) requirements intended to address the CO poisoning hazard. In response, CPSC staff worked with the National Institutes of Science and Technology (NIST) to model simulations to assess the effectiveness of PGMA G300 and UL 2201 at reducing CO poisoning deaths and injuries. The briefing memorandum (Buyer, 2022) and the effectiveness analysis memorandum (Hnatov, 2022, Tab A), in the current briefing package, detail the results of this work.

The market availability of generators conforming to the voluntary standards is an important aspect of the voluntary standards being able to reduce CO poisoning effectively. Staff presents this market information is presented in the section below.

2. Market Information on Availability of Generators Conforming with CO Hazard Provisions

In 2021, staff of the Directorate for Engineering Sciences (ES) and the Directorate for Economic Analysis (EC) conducted an Internet review of portable generator product descriptions and a survey of nine manufacturers. The information garnered from this research provided CPSC

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staff with information on the availability of portable generators with features that address CO poisoning in the U.S. consumer market.

2.1. **Survey of Manufacturers**

EC staff submitted questions to representatives of nine firms in September 2021, to gather current information on the extent to which manufacturers and private labelers of portable generators are conforming to either ANSI/PGMA G300-2018 or ANSI/UL 2201.[19] EC staff sought information on the percentage of each company's conforming portable generator models marketed for the U.S. market since January 1, 2021, and the percentage of conforming portable generator units shipped or imported by each firm since January 1, 2021. EC staff advised survey respondents that responses provided for each firm's production would not be reported separately. Representatives of seven firms submitted at least partial information in response to EC staff's questions; six of these firms are members of PGMA.

Although most of the firms responding are PGMA members, reported conformance varied considerably. Two of the firms providing conformance estimates reported that 100 percent of their models and units that shipped since January 1, 2021, conformed with one (or both) of the voluntary standards. A third firm reported that all its generator production from June 2021 are G300-2018-compliant, and all future shipments to dealers will be compliant. EC staff reviewed the firm's website and confirmed that all models are advertised as having CO protection, although conformance with G300-2018 is not clearly stated. Four other firms that provided some information reported that models conforming to G300-2018 ranged from 11 percent to 50 percent of all models they offer. EC staff also reviewed current portable generators presented on the websites of the two firms that did not respond to our information request. Seventy percent of the models listed on one firm's website (7 of 10 models) are listed as having CO detection and shutoff features in compliance with PGMA G300-2018, and the other firm had such features on about 17 percent of listed models (7 of 42) (although compliance with one of the voluntary standards was not clearly stated). EC staff does not have data on percentages of portable generator *units* manufactured or imported by these firms for this year.[20]

One manufacturer noted that, although nearly all their portable generator models will be compliant with G300-2018 by mid-2022, their progress towards full product compliance has been slowed by several factors, including supply chain constraints that have limited the number of CO sensor modules available for generator production. Problems with obtaining adequate supplies of CO sensors reportedly required the firm to switch suppliers, necessitating a redesign of their CO shutoff system. Redesign and performance validation reportedly delayed deployment of complying generators several months. More recently, according to the manufacturer, the firm has been faced with managing new supply chain constraints, resulting from the current COVID-19 pandemic and the consequent resulting global chip shortage. CO sensor modules from all manufacturers have been in short supply and have extended lead times to many months, according to the respondent. This issue was also cited by a representative of another firm that has

[19] The Paperwork Reduction Act (PRA) specifies that requesting the same information from 10 or more people or entities requires PRA clearance.

[20] However, for the firm that offers 17 percent of models with CO shutoff features, those models are more prominently advertised on its website and in online product listings of some major retailers. This indicates that a higher percentage of units currently manufactured or imported by the firm have the CO hazard mitigation feature.

not achieved substantial conformance to G300-2018, commenting that "one of the biggest challenges faced is technology (sensor and other hardware) shortages to implement. This will continue to be a struggle in the coming future as headwinds to implementation. We continue to work with our suppliers to mitigate this." Another respondent (an importer) commented that it began introducing compliant generators earlier this year but is in the process of transitioning their entire portable generator product line to comply with PGMA G300-2018. The importer conveyed that, barring unanticipated additional shipping delays or manufacturing delays due to COVID-19 restrictions or component shortages, 100 percent of their imports of portable generators going forward are expected to be compliant with the CO shutoff requirements of PGMA G300-2018 by the end of 2021.

The Executive Director of the PGMA also pointed out supply chain issues that have hampered full implementation of ANSI/PGMA G300-2018.[21] Susan Orenga noted that "because each member's production line and supply chain are unique, some members have needed to do more back-end work than others in transitioning their product lines towards conformance . . .. With continuing supply chain challenges, it has been difficult to obtain parts, including CO sensors, to move forward any quicker." Ms. Orenga stated that "nonetheless, as of the end of Q2 2021 (a little more than one year since G300 was adopted[22]) members were at [about] 28 percent compliance to the standard and nearly 40 percent to the CO shut off portion. Even more encouragingly, by end of 2022 they will be at significant compliance."

Obtaining necessary CO sensing modules and other components, and incorporating them into the product designs, has been a factor in delaying compliance for some manufacturers, but apparently not for others. Respondents representing firms that do not have all their models compliant with G300-2018 expressed an intent to increase compliance substantially within the next year.

2.2. Online Review of Portable Generators with CO Shutoff Features

As noted, most of the nine firms surveyed in September 2021, are members of PGMA. These firms would be more likely to produce and import portable generators that incorporate CO shutoff features than firms that are not members of the association. CPSC staff obtained information on the general extent to which generator manufacturers offer models with CO shutoff features from Internet reviews of models. In September and October 2021, CPSC staff reviewed websites of generator manufacturers and retailers looking for availability of generators that comply with either PGMA G300-2018 or UL 2201. Staff's findings are reported in tables in Appendix A to the briefing memorandum, which includes models of generators that are advertised online as having either a CO sensor or a shut-off system with or without reduced CO emissions, as well as generators advertised by the same manufacturers, or with the same brand name, without these features. Overall, 19 of 27 brands listed in the tables in Appendix A included these features among at least one of their advertised models. However, only four manufacturers or brand names cited PGMA G300-2018 or UL 2201 in reference to their

[21] Email from Susan Orenga, Executive Director, PGMA, to Charles Smith, EC, CPSC, September 23, 2021.
[22] Staff clarifies that PGMA G300 adopted the CO hazard mitigation requirements in April 2018. Ms. Orenga is referring to PGMA G300's effective date of March 31, 2020, which means that if a manufacturer certifies to PGMA G300 after that date, it must be certified to the 2018 edition, not the prior 2015 edition.

generators' CO shutoff systems or CO sensors. Additional discussion of information provided by the online review is provided in the briefing memorandum (Buyer, 2022).

3. Summary of Market Information on Voluntary Standard Conformance

Information gained from a limited survey of manufacturers, statements by the executive director of PGMA, and a staff review of portable generators advertised on websites of manufacturers and retailers indicate that models with CO detection and shutoff features are available for consumers to purchase. Three manufacturers report that all their models are compliant with PGMA G300-2018 or both PGMA G300-2018 and UL 2201. Four other firms reported that compliance with PGMA G300-2018 is expected to increase substantially in the next year. Firms cited sourcing of adequate supplies of CO sensor modules as contributing to delays in compliance. Staff's review of generators advertised on websites of manufacturers and retailers found 19 brands that offer one or more models with CO protection. However, statements of compliance with a voluntary standard were noted for just four brands.

Based on the current review, conformance with UL 2201 appears to be minimal; conformance with PGMA G300-2018, although greater, is still lacking for most models or units currently sold for consumer use.

References

Buyer, J. (February 2022). Briefing Memorandum: CPSC staff assessments of portable generator voluntary standards' effectiveness in addressing CO hazard and information on compliant product availability. Office of Hazard Identification and Reduction, Consumer Product Safety Commission, Bethesda. MD.

Hnatov, M.V. (February 2022). Memorandum: Assessment of portable generator voluntary standards effectiveness in addressing CO hazard and information on availability of compliant portable generators - modeling output and analysis methodology. Division of Hazard Analysis, Directorate for Epidemiology, Consumer Product Safety Commission, Bethesda. MD. (TAB A of Briefing Package on Assessment of Portable Generator Voluntary Standards' Effectiveness in Addressing CO Hazard, and Information on Availability of Compliant Portable Generators.)