

Developing New Strategies for Portable Generator Safety
May 20, 2004

- 9:30 AM Welcome: CPSC Chairman Hal Stratton and Commissioners
- 9:45 AM Introductions and Overview: Hugh M. McLaurin, CPSC Associate Executive Director,
Directorate for Engineering Sciences
- 10:00 AM Defining the Hazard: CPSC Staff Presentations
Incident data, market information, portable generator testing: Janet Buyer, CPSC engineer
Modeling and CO poisoning hazard: Sandra Inkster, CPSC physiologist
Staff warning and labeling activities: Timothy Smith, CPSC engineering psychologist
Questions and Answers
- 11:15 AM Break
- 11:30 AM Potential Product Solutions to Reduce CO Emissions: Jim Carroll, Southwest Research Institute
Questions and Answers
- Noon Lunch (on your own)
- 1:15 PM Open Discussion: Potential Product Solutions to Shield Consumers from Potential Hazards
Weatherization (for operation in cold temps and wet conditions)
Anti-theft measures
Extension cords and CO alarms sold with generators or co-located on store shelves
Gas-sensing engine interlock
Other product solutions
Discussion of Voluntary Standards Requirements
- 2:30 PM Break
- 2:45 PM Open Discussion: Other Methods to Warn and Educate the Public about the CO Hazard
Information campaigns by retailers; manufacturers; utility companies; federal, state, and local
health and safety officials
Literature available at point-of-sale
Other methods
- 3:45 PM Summary of New Strategies to Improve Portable Generator Safety Next Steps
- 4:00 PM Close

Portable Generators



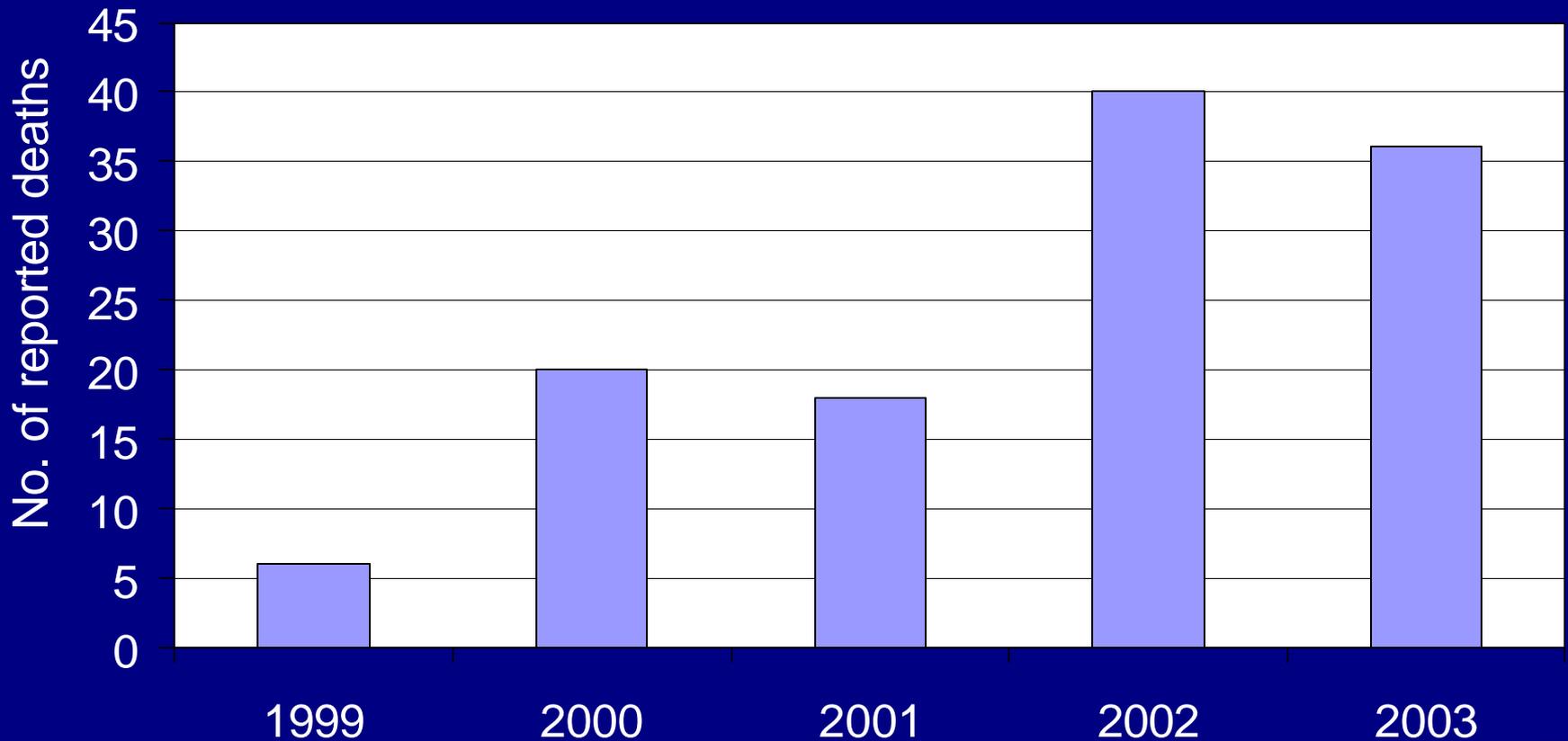
May 20, 2004

Presented by Janet Buyer, Project Manager
Analyses prepared by
Susan Vagts Carlson, Mathematical Statistician
Mary Donaldson, Economist
Christopher Brown, Mechanical Engineer

These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.



Number of CO Deaths* Associated with Generators Reported to CPSC 1999-2003 (120 total)



* - These are the number of CO deaths reported to the CPSC as of 3/1/04.



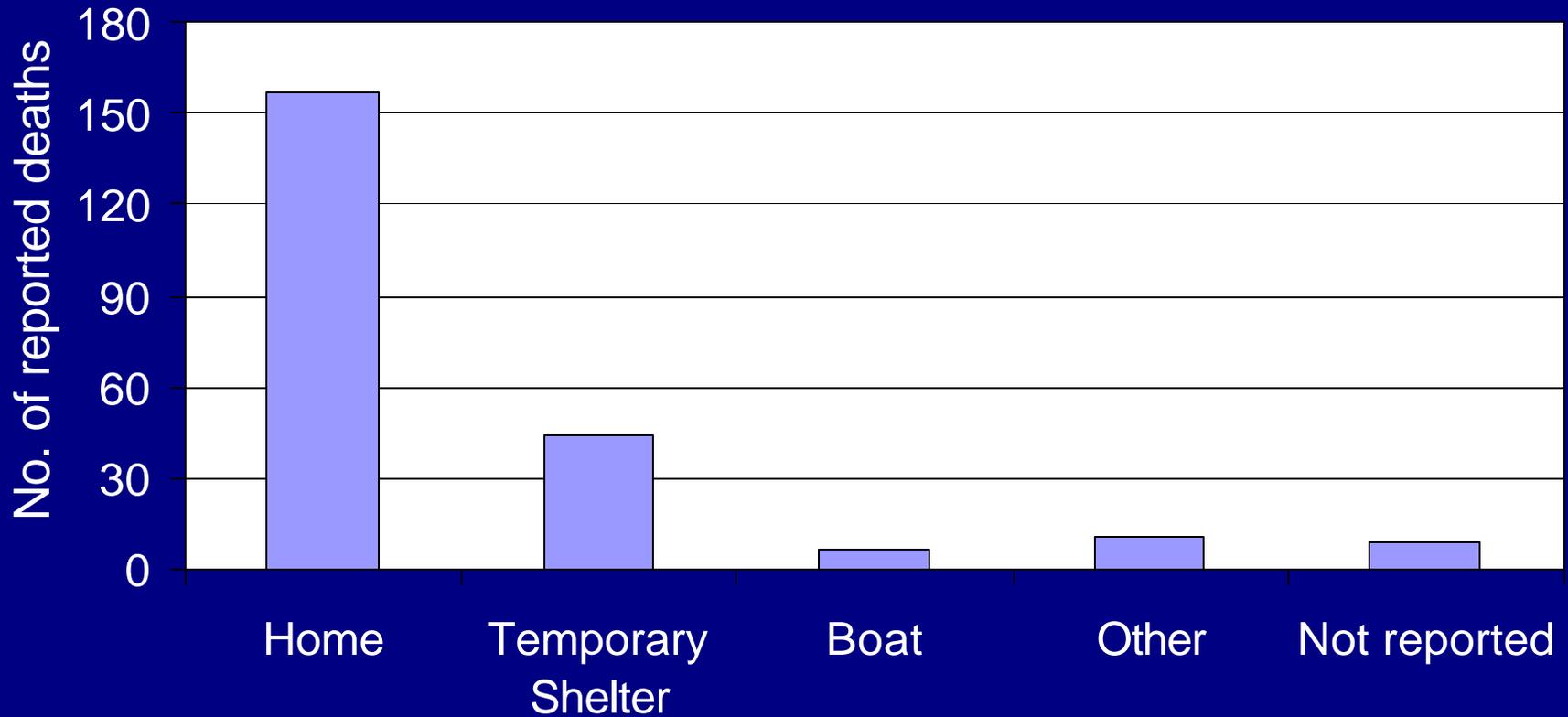
CO Incidents, Deaths, and In-Depth Investigations Associated With Generators - 1990-2003

- **212 incidents total**
 - 43 incidents were nonfatal, but treatment sought
 - 169 incidents had at least one fatality
 - 228 deaths

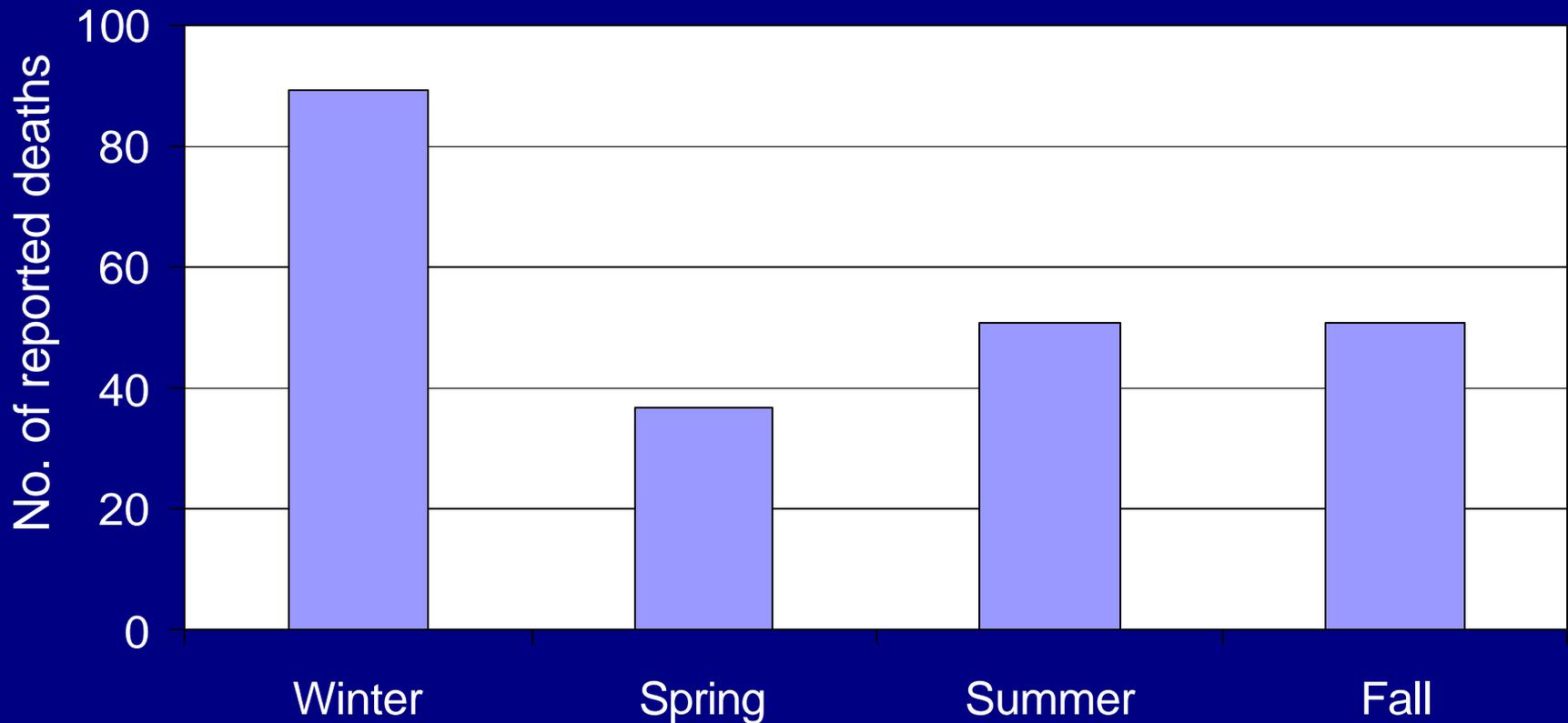
- **26% of fatal generator incidents involved more than one fatality.**



Number of CO Deaths Associated with a Generator Reported to CPSC by Location, 1990-2003



Number of CO Deaths Associated with a Generator Reported to CPSC by Season, 1990-2003



In-Depth Investigations of Fatal CO Poisonings Involving Generators

- In-depth investigations conducted for 102 fatal generator incidents, involving 138 deaths.
- Data not a statistical sample; national totals may not be derived from these 102 incidents.

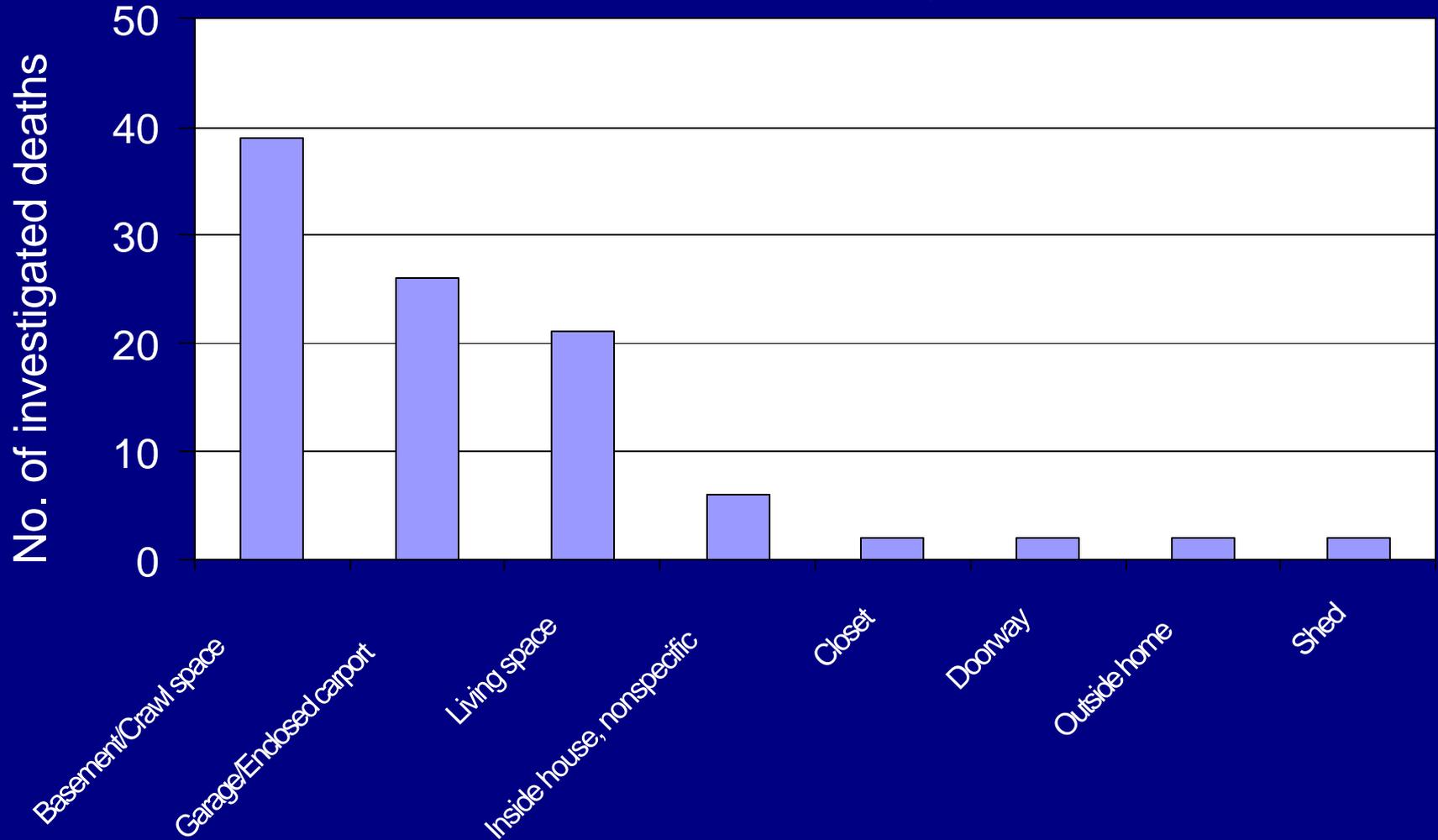


In-Depth Investigations, cont'd

- Generator commonly used to provide electricity temporarily or power to “remote” location.
- COHb levels determined for 86 of the 138 fatalities. 82 victims had COHb level \geq 40%.



Investigated Deaths Associated with a Generator and a CO Fatality in the Home by Location of Generator, 1990-2003



Note: 100 of the 138 investigated deaths occurred at the home.



Why was generator used in an enclosed space?

- **20 investigated deaths stated reason**
 - 10 deaths: user feared theft of generator
 - 2 deaths: extension cord prevented access door from closing
 - 2 deaths: muffle engine noise
 - 2 deaths: hide fact that electricity turned off
 - 1 death: complaint from property owner
 - 1 death: to fix generator
 - 1 death: did not think about operating it outside
 - 1 death: when generator ran outside it would stall so user operated it inside doorway for some time, then put it outside until it stalled again; this was done repeatedly

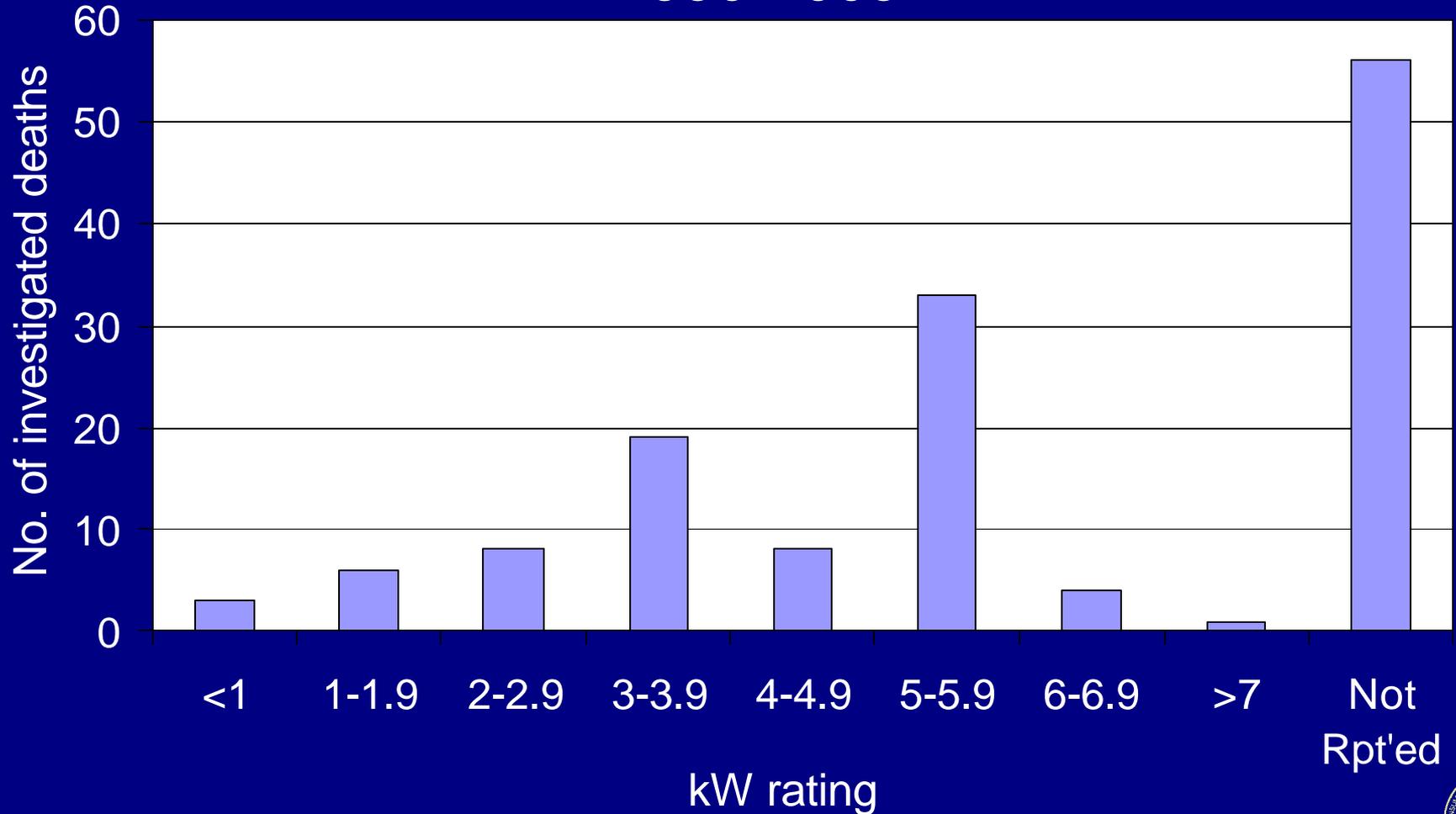


25 Investigated Deaths Reported Attempt to Vent the Generator or Ventilate the Space Where it was Operating

- 19 deaths reported an open window, door, garage door, or combination of these.
- 2 deaths associated with generator placed outside home near open window.
- 2 deaths associated with generator used on boat with modified exhaust system intended for boat generator.
- 1 death associated with generator used in garage with door open while generator running. Incident occurred after generator was turned off and garage door closed.
- 1 death associated with generator used outdoors until it would stall and then operated inside doorway for short time; did this repeatedly.



kW Rating of Generator Associated with an Investigated CO Death 1990-2003



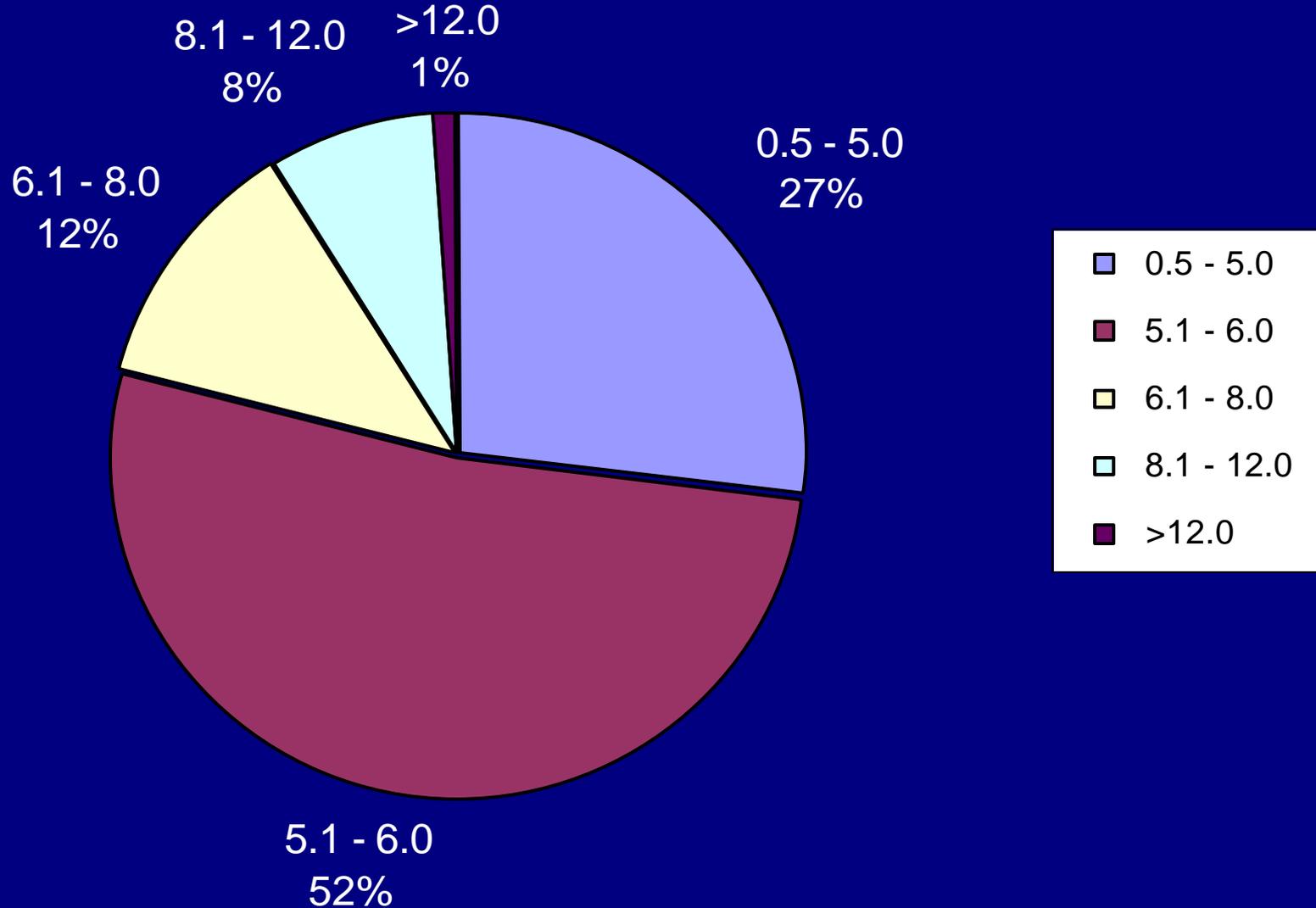
Market Information

- Homeowners are largest end users of light duty (<15 kW) portable generators.
- CPSC staff estimates about 1 million portable generators in US households.
- More than half of light duty portable generators are sold through standard mass market channels (hardware stores, discount retailers, home centers).
- Most popular generators cost \$500-\$800.

Sources: Frost & Sullivan, *North American Portable Power Markets*
CPSC Product Population Model
The Columbus Dispatch, 4/5/99



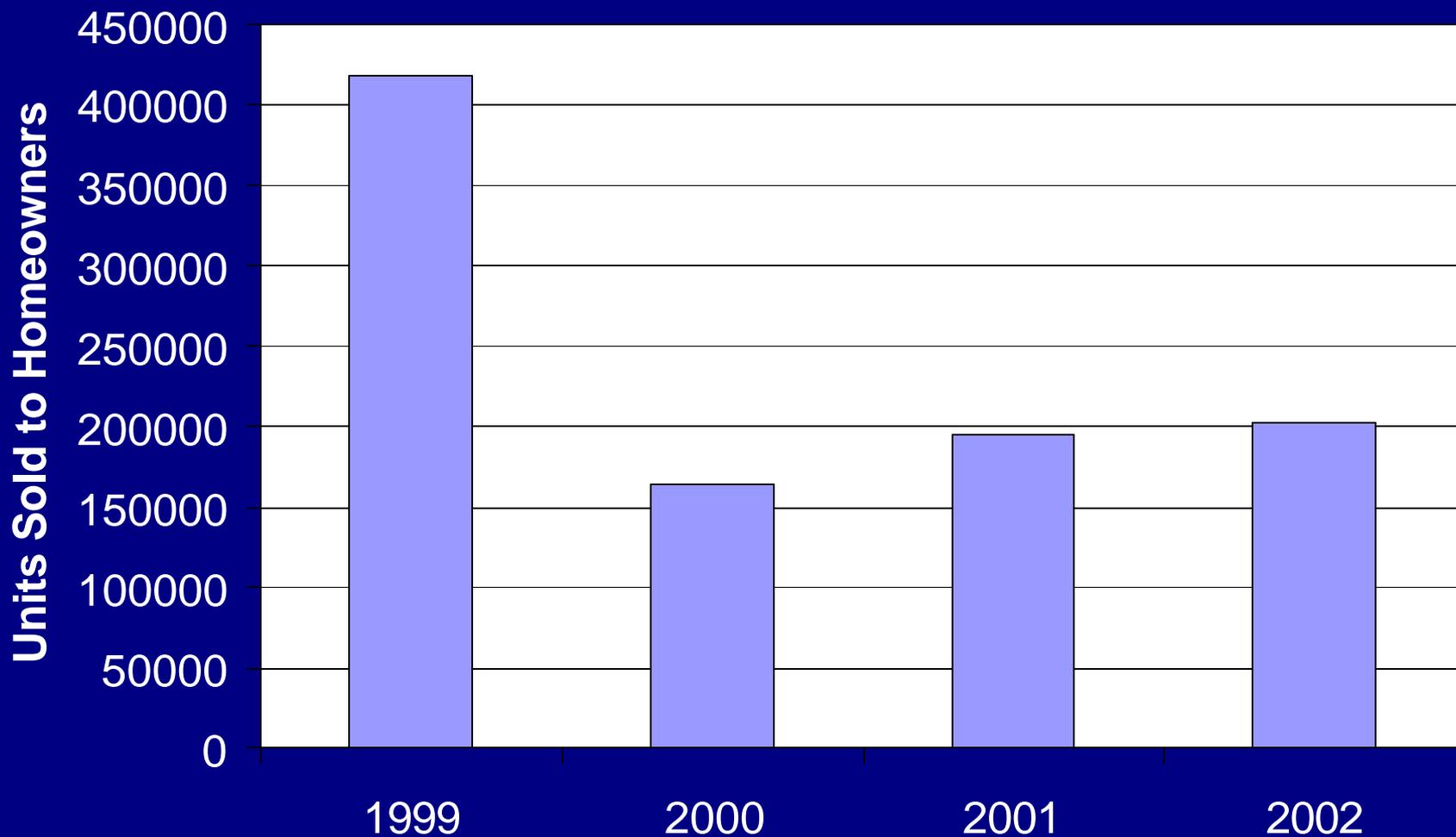
Light Duty Generator Sales by kW Output, 2002



Source: Frost & Sullivan, *North American Portable Power Markets*



Estimated Homeowner Purchases of Light Duty Portable Generators, 1999-2002



Source: Frost & Sullivan, *North American Portable Power Markets*



For more information...

- Carlson, S.; “*Incidents, Deaths, and In-Depth Investigations Associated with Carbon Monoxide and Engine-Driven Tools, 1990-2003;*” Washington, D.C.; U.S. Consumer Product Safety Commission; March 8, 2004.
- Donaldson, M.; “*Portable Generators;*” Washington, D.C.; U.S. Consumer Product Safety Commission; April 12, 2004.
- Both available on-line at www.cpsc.gov/library/foia/foia04/os/os.html



Generator Testing and Modeling

Purpose: Characterize health hazard posed by consumer use of portable generators by estimating how quickly people would be incapacitated and possibly die if exposed to exhaust.

1. Testing: Experimentally-determined CO generation rates of representative generators.
2. Modeling: Using experimental data and EPA model of two-story house, estimated CO infiltration throughout house with generator running in the basement.
3. Modeling: Used modeled CO concentrations in house in conjunction with COHb models to estimate how quickly occupants would be incapacitated and possibly die.



Specifications of Generators Tested

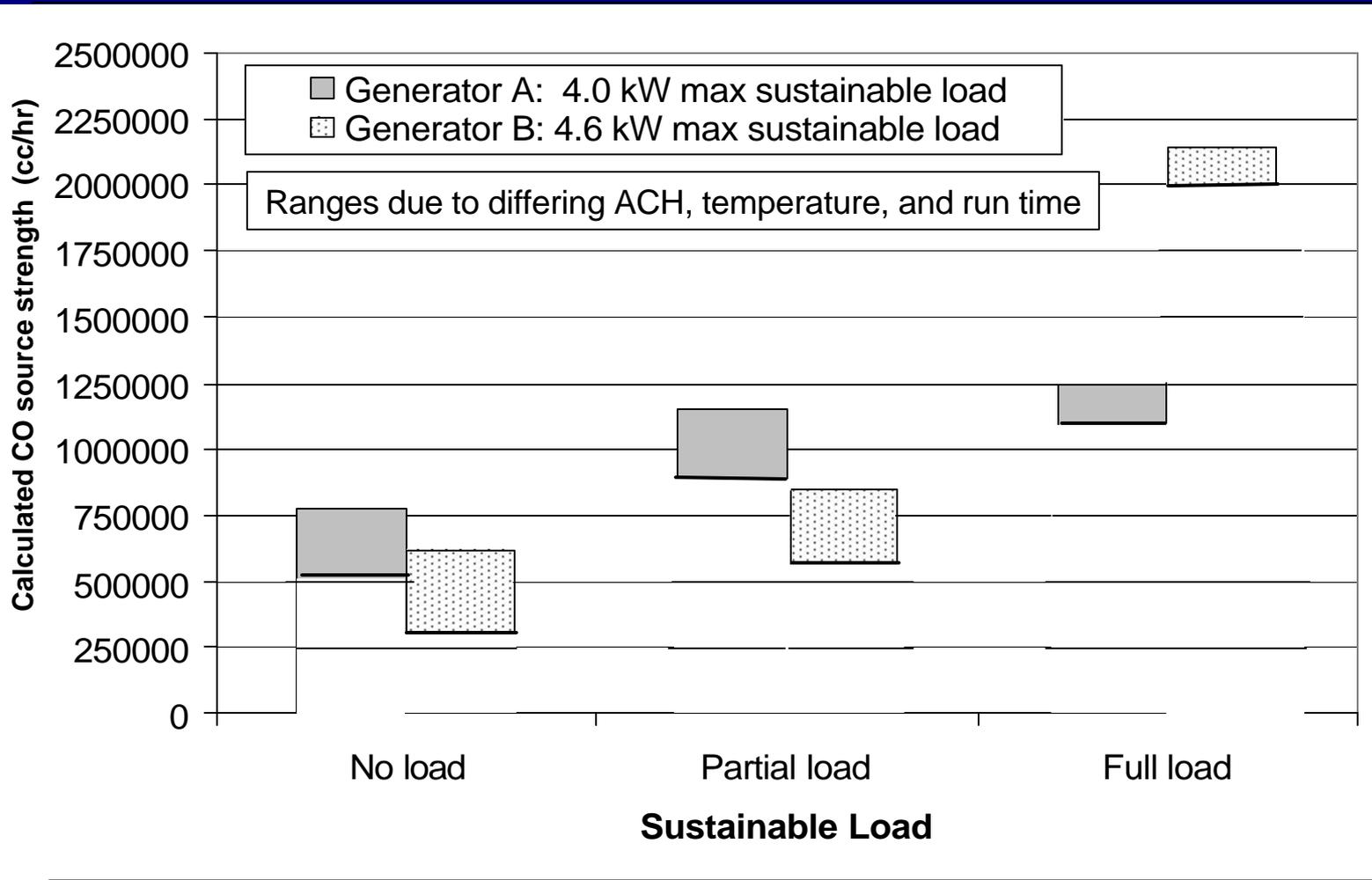
- **Two similar units tested**
 - AC Output: 8.5 kW surge, 5.5 kW continuous, 120/240V
 - Engine: 10 HP, gasoline, single-cylinder, overhead valve, air-cooled, 4-stroke
 - 5 gallon fuel tank (advertised 10 hours run time at 50% load)

Major Test Variables

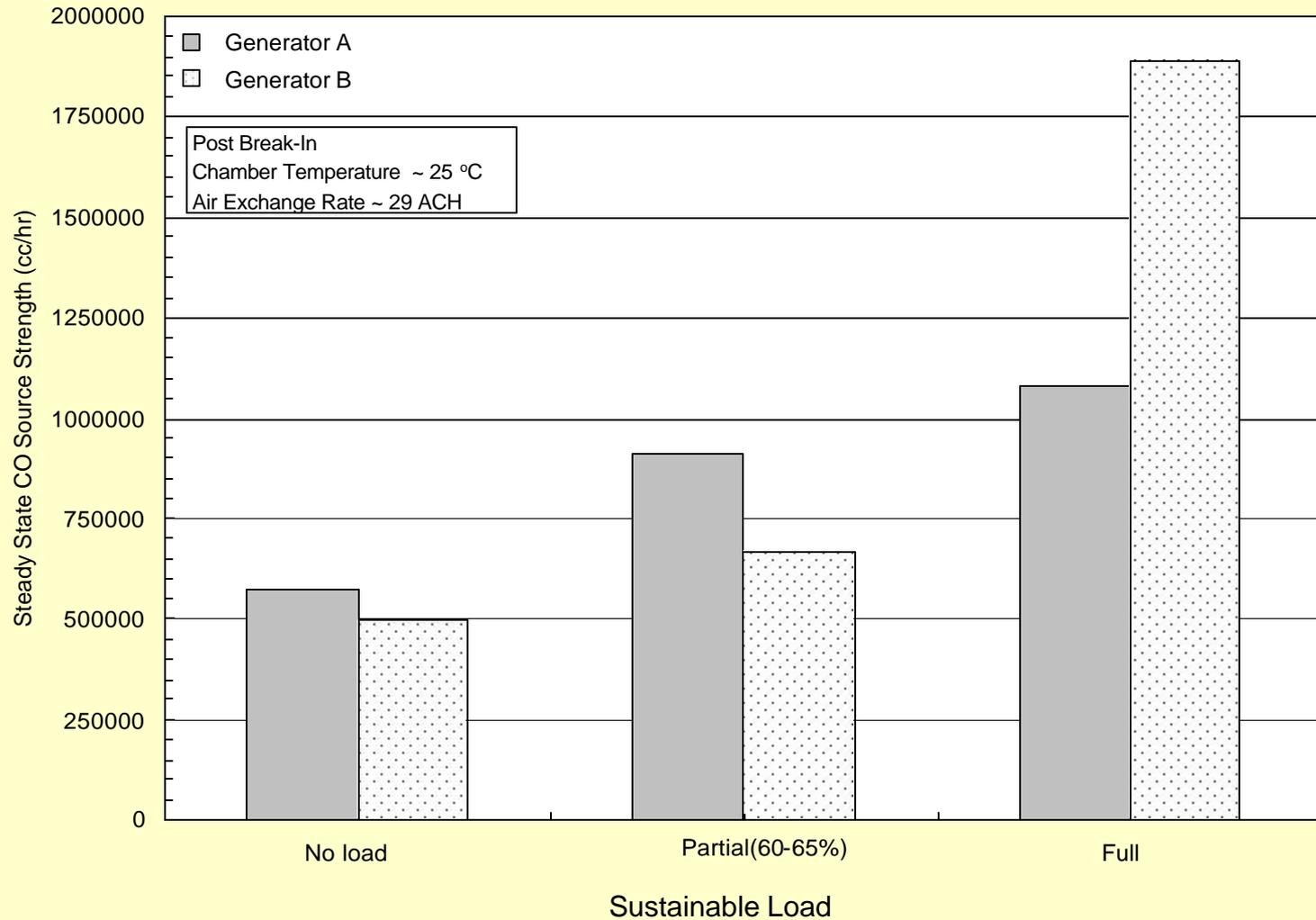
- Air changes per hour (ACH)
- Temperature
- Load
- Accumulated engine run time



Generator CO Generation Rates



Steady State CO Generation Rate Vs. Load



Test Program Observations

- Generators capable of high CO generation rates under normal operating conditions.
- Increased load = increased CO generation rate.
- Wide range of CO generation rates under different operating conditions. 7-fold increase from no load to full load for one generator.
- Increase in CO generation rate was not consistent between two generator models which had identical power output specifications.



Test Program References

- Brown, Christopher; DRAFT “*Medium-Sized Combustion Chamber - System Characterization Tests;*” Washington, D.C.; U.S. Consumer Product Safety Commission.
- Buyer, Janet; DRAFT “*Test Program for the Engine-Driven Tools Project, Phase 1 Test Plan;*” Washington, D.C.; U.S. Consumer Product Safety Commission.
- Brown, Christopher; DRAFT “*Engine-Driven Tools Project: Preliminary Generator Results;*” Washington, D.C.; U.S. Consumer Product Safety Commission.
- Brown, Christopher; “*Engine-Driven Tools Project: Test Results for Two Generators Tested in the M-Chamber;*” Washington, D.C.; U.S. Consumer Product Safety Commission.



Published reports of storm-related CO poisonings associated with generators (partial list)

January 1993, Washington state ice storm

- P. Houck, et.al., "Epidemic Carbon Monoxide Poisoning Following a Winter Storm," *Journal of Emergency Medicine*, Vol. 15, No.4., 1997.
- N. Hampson, et.al., "Unintentional Carbon Monoxide Poisoning Following a Winter Storm," *MMWR*, Vol.42, No.6, February 19, 1993.

February 1994, Tennessee ice storm and March 1991, New York ice storm

- K.Wrenn, et.al., "Carbon Monoxide Poisoning During Ice Storms: A Tale of Two Cities," *Journal of Emergency Medicine*, Vol. 15, No.4., 1997.

September 1996, Hurricane Fran in North Carolina

- B. Cohen, et.al., "Carbon Monoxide Poisoning in the Aftermath of Hurricane Fran," *American Journal of Public Health*, Vol.89, No.1, January 1999.

January 1998, Maine ice storm

- W. Daley, et.al., "An Outbreak of Carbon Monoxide Poisoning After a Major Ice Storm in Maine," *Journal of Emergency Medicine*, Vol. 18, No.1., 2000.
- Maine Department of Human Services, "Press Release: Study on January 1998 Ice Storm Shows Improper Placement of Gasoline-Powered Generators and Kerosene Heaters Major Cause of Carbon Monoxide Poisoning Outbreak," January 12, 2000



Published reports of storm-related CO poisonings associated with generators (partial list), cont'd.

January 1998, Maine ice storm, continued

- D. Holt, et.al., "Community Needs Assessment and Morbidity Surveillance Following an Ice Storm - Maine, January 1998," MMWR, Vol. 47, No.17, May 8, 1998.
- Colorado Department of Public Health and Environment, "News Release: Generators Can Be Deadly If Not Vented Properly," December 17, 1999.

December 2002, North Carolina ice storm

- E. Lavonas, et.al., "Use of Carbon Monoxide Alarms to Prevent Poisonings During a Power Outage - North Carolina, December 2002," MMWR, Vol. 53, No.9, March 12, 2004

Public Health Ordinance requiring CO alarms in all residences , Mecklenburg County, NC

- initially adopted Sept 2000, exemptions made for all-electric homes w/o attached garages, hardwired CO alarms w/o battery back up okay.
- revised Oct 2003, removed exemptions, requires battery-operated CO alarms or hardwired with battery backup.



Other published work (partial list)

- **G. Earnest, et.al., "Carbon Monoxide Poisonings from Small Gasoline-Powered, Internal Combustion Engines: Just What Is a "Well-Ventilated Area"?", American Industrial Hygiene Association Journal, November 1997.**
- **Safety Alert "Preventing Carbon Monoxide Poisonings from Small Gasoline Powered Engines and Tools," issued by NIOSH, CDPHE, CPSC, OSHA, EPA, 1996.**
- **A. Greife, et.al., "Carbon Monoxide Poisoning from Gasoline-Powered Engines: Risk Perception among Midwest Flood Victims," American Journal of Public Health, Vol. 87, No.3, March 1997.**

Numerous other published and unpublished reports.



Health Hazard Assessment of Carbon Monoxide Poisoning Associated with Portable Gasoline-Powered Generator Emissions



May 20, 2004

Presented by Sandra Inkster, Ph.D., Physiologist/Pharmacologist,
CPSC Directorate for Health Sciences

Modeling of Indoor Air CO Levels in Different Locations of a Home
analysis prepared by Warren Porter, CPSC Laboratory Sciences
Modeling of Corresponding % COHb Time Course Profiles
analysis prepared by Sandra Inkster, CPSC Health Sciences

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Properties of Carbon Monoxide (CO)

- Chemical asphyxiant: interferes with the body's oxygen (O_2) supply
- CO binds to hemoglobin (oxygen carrying protein in blood) $>200-250x$ more readily than O_2 : forms carboxyhemoglobin (COHb)
- Level of O_2 deprivation increases as COHb levels increase
- Brain, heart, and exercising muscle have highest O_2 demands so are most sensitive to CO poisoning effects.



Approximate Correlation Between % COHb Levels and Symptoms In Healthy Adults

| % COHb | Expected Symptoms |
|--------|--|
| <10 | No perceptible effects* |
| 10-20 | Mild headache, labored breathing, decreased exercise tolerance |
| 20-30 | Throbbing headache, mild nausea |
| 30-40 | Severe headache, dizziness, vomiting, cognitive impairment |
| 40-50 | Confusion, unconsciousness, coma, possible death |
| 50-70 | Coma, brain damage, seizures, death |
| >70 | Typically fatal |

***some studies report adverse effects in cardiac patients at 2-5% COHb (source: Burton, 1996)**



Key Factors Affecting COHb Levels

- Maximum level of CO attained; parts per million (ppm)
- Rate of increase in CO levels
- Duration of CO elevation/CO exposure
- Breathing rate of exposed individual; influenced by activity level (RMV = air intake in liters/minute)
- General health status of exposed individual.



Relationship Between CO ppm and Equilibrium % COHb Levels

| Ambient CO (ppm) | ~ % COHb at Equilibrium | % COHb Thresholds |
|------------------|-------------------------|----------------------------------|
| 100 | 14.3 | |
| 200 | 25.2 | >20% concern of DNS in survivors |
| 400 | 40.2 | >40% Incapacitation |
| 600 | 50.2 | |
| 800 | 57.3 | |
| 1000 | 62.7 | >60% likely fatal |
| 1200 | 66.8 | NIOSH "IDLH" level |
| 1400 | 70.2 | >70% Typically fatal |



Assumptions Used to Model CO Time Course Profiles Within a Home

- 4 bedroom, 3 level, single family home
- 2,250 ft² (18,000 ft³) home, 750 ft² (6,000 ft³) each level
- 5.5 kilowatt gasoline-powered generator operating in basement for 6 hours under 3 different load conditions (no load, partial load, and full load), followed by 12 hour decay period.



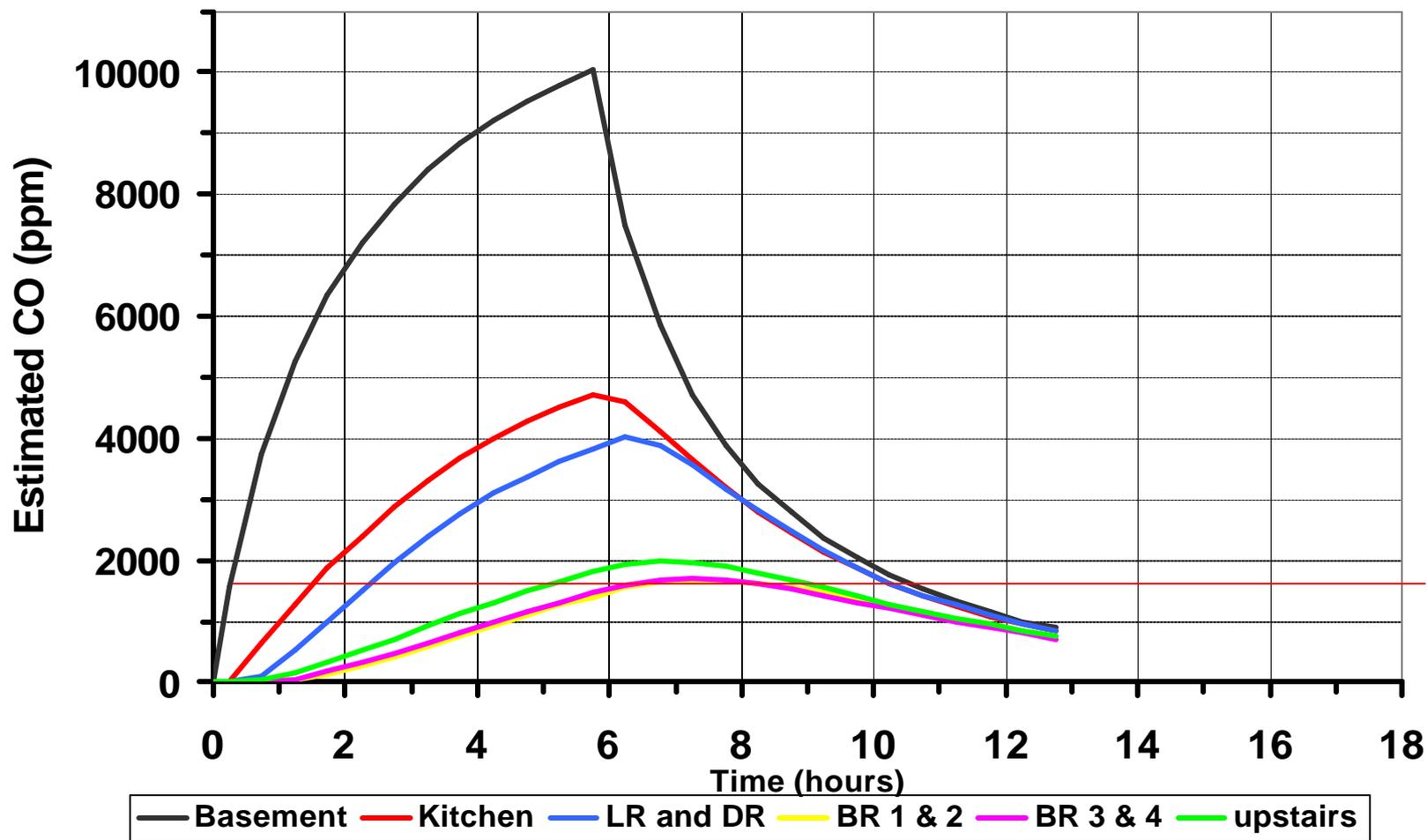
Modeling Parameters for CO Time Course Profiles Within a Home

- Ambient air exchange rates
- Inside home air exchange rates
- HVAC fan status
- US EPA's RISK 1.9.22 Indoor Air Modeling Program



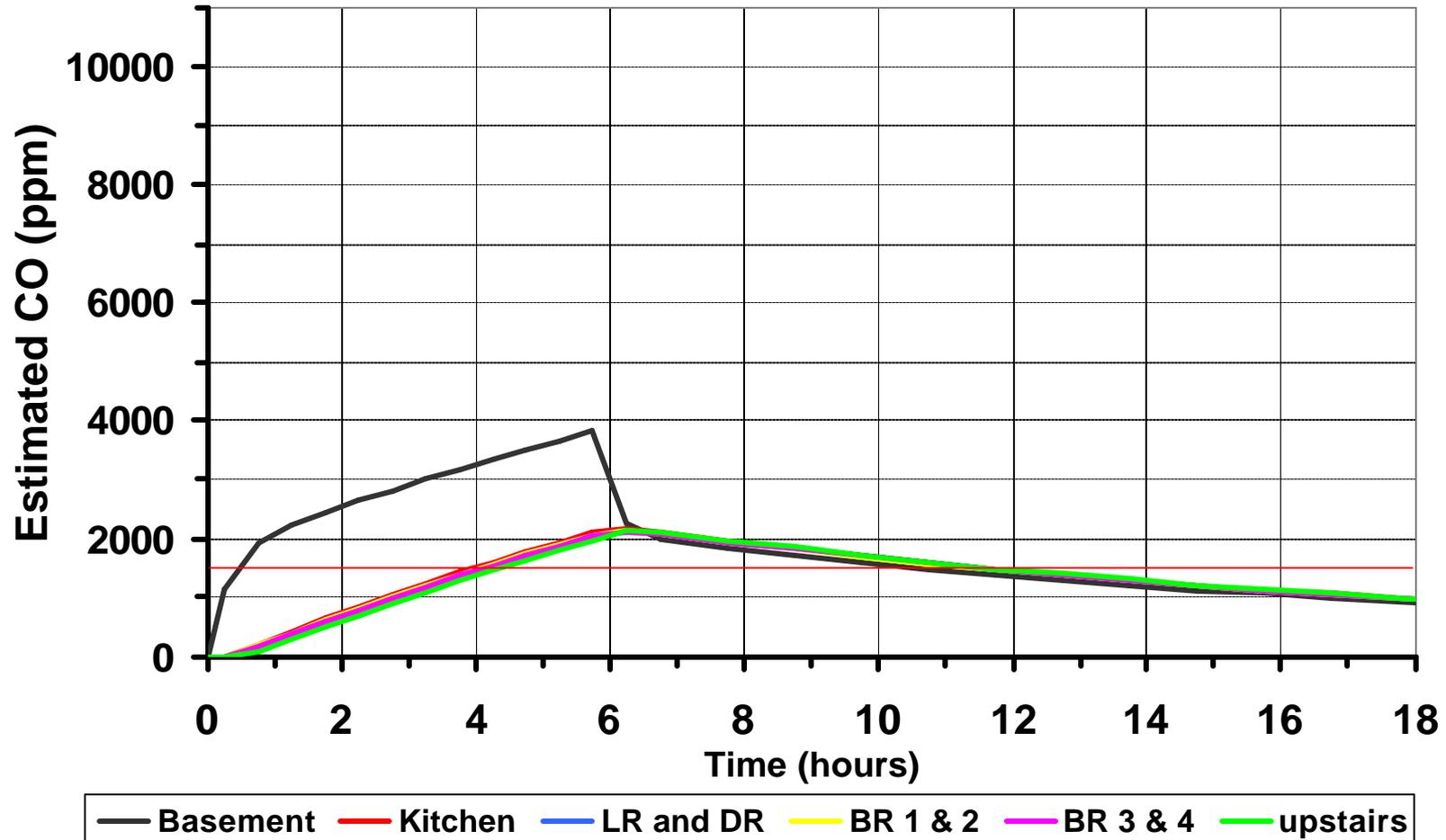
CO Time Course Profiles In Home Model HVAC Fan Off

(5.5 kW generator running in basement for 6h with full load)



CO Time Course Profiles In Home Model HVAC Fan On

(5.5 kW generator running in basement for 6h with full load)

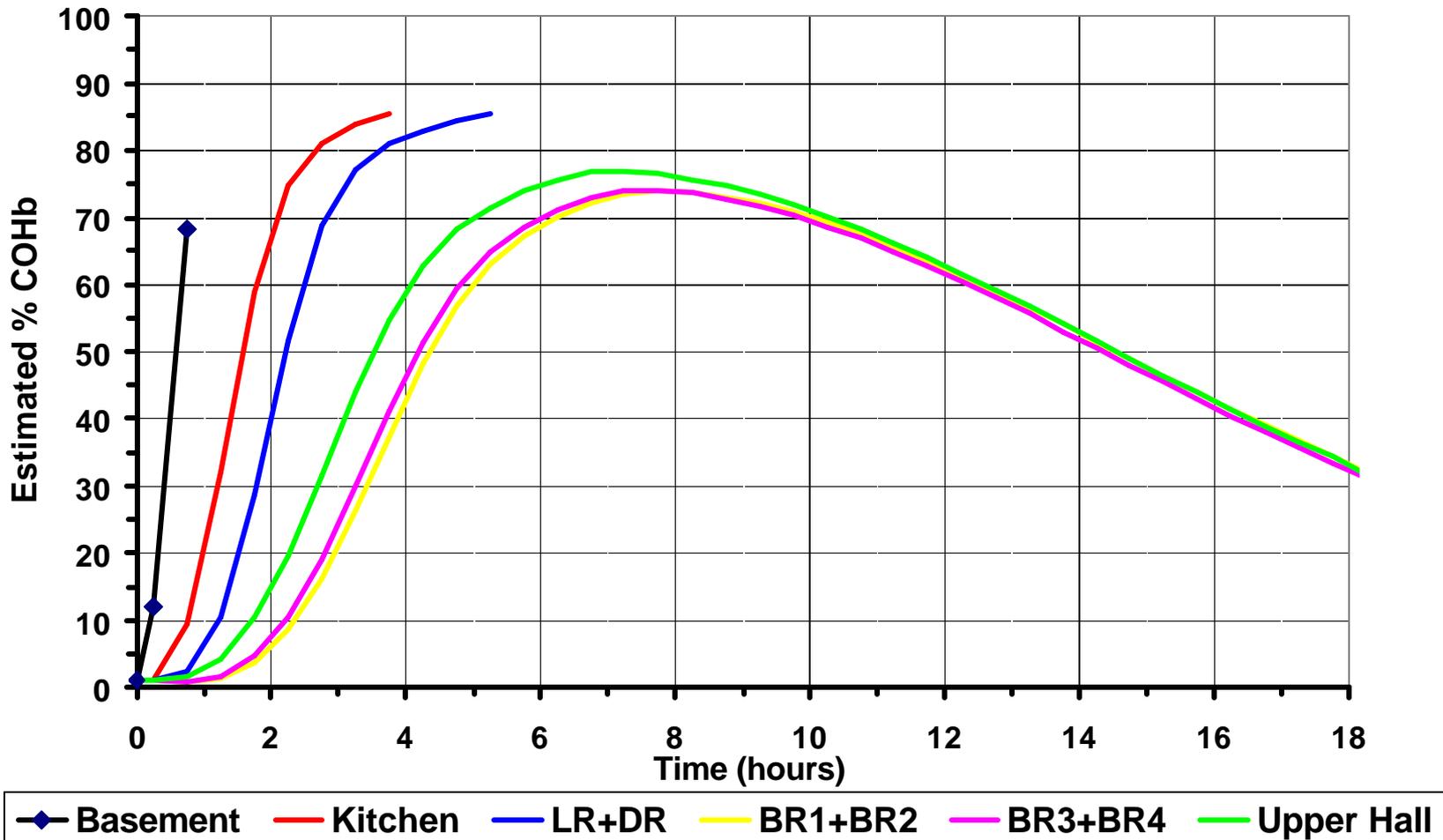


Approach Used to Model % COHb Profiles from CO Time Course Profiles

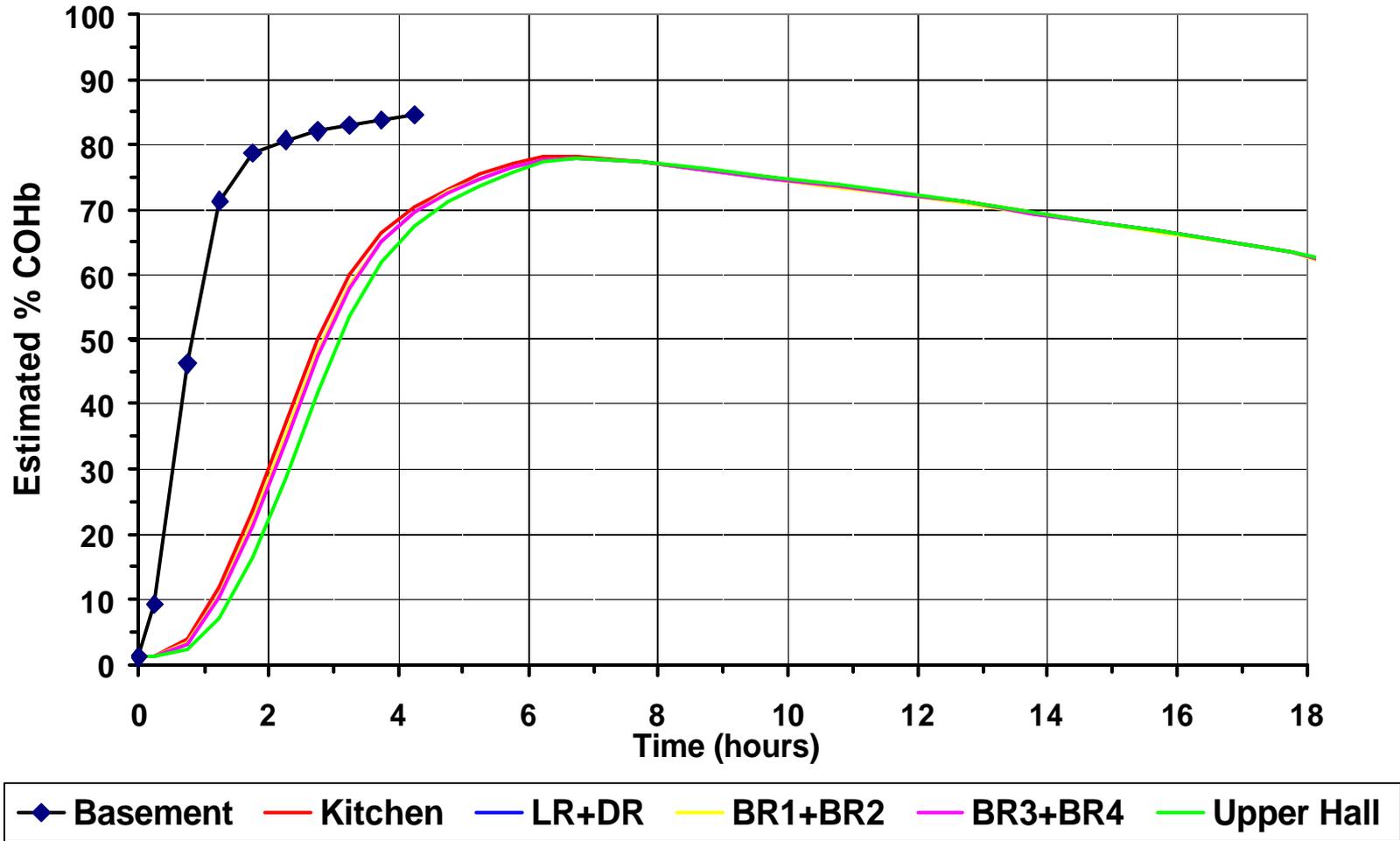
- Customized computer based model of the Coburn-Forster Kane (CFK) differential equation (Coburn, Forster, Kane, 1965).
- CFK equation considers multiple physical and physiological parameters that affect COHb levels
- Applied 2 activity levels for home occupants: Resting and Moderate



Predicted % COHb Profiles for Moderately Active Individuals In Different Areas of Model Home: HVAC Fan Off (5.5 kW generator running in basement for 6h with full load)



Predicted % COHb Profiles for Moderately Active Individuals In Different Areas of Model Home: HVAC Fan On (5.5 kW generator running in basement for 6h with full load)



Results of Modeling Studies

- CO exceeded 1200 ppm in 33/36 modeled profiles for different home locations
- % COHb exceeded 20% and 40% for all scenarios modeled (72/72)
- % COHb exceeded 60% in 69/72 scenarios modeled
- % CO exceeded 70% for 54/72 scenarios modeled



Results of Modeling Studies, cont'd.

Worst Case Scenario : Full Load, Moderately Active Person

Basement : HVAC fan off (HVAC fan on)

- incapacitation at ~ 29 minutes (~ 40 minutes)
- death at ~ 40 minutes (~ 60 minutes)

Upper Bedrooms: HVAC fan off (HVAC fan on)

- incapacitation at ~ 232 minutes (~ 146 minutes)
- death at ~ 300 minutes (~ 201 minutes)



Results of Modeling Studies, cont'd.

Scenario : Partial Load, Moderately Active Person

Basement : HVAC fan off (HVAC fan on)

- incapacitation at ~ 37 minutes (~ 45 minutes)
- death at ~ 45 minutes (~ 68 minutes)

Upper Bedrooms: HVAC fan off (HVAC fan on)

- incapacitation at ~ 246 minutes (~ 157 minutes)
- death at ~ 326 minutes (~ 222 minutes)



Conclusions

- Operation of 5.5 kilowatt gasoline-powered generator within basement can RAPIDLY create potentially lethal CO environment throughout home
- Explains why victims typically found dead or severely poisoned within a few hours of being missed by family, friends, or coworkers.
- NOTE: Factors affecting severity/outcome of CO poisoning include : generator size and load, home size and design, AERs with the outdoor environment and within home; operational status of HVAC fan; victim location; victim activity level and general health.



Generator Warnings



Tim Smith
Engineering Psychologist
Division of Human Factors, CPSC

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Recent Warning Activities

- Currently no U.S. standard for portable generators
- CPSC staff participating in UL standards technical panel (STP) to develop UL 2201, *Portable Engine-Generator Assemblies*
- Staff participating on STP working group to develop CO hazard warnings for
 - on-product labels
 - instruction/owner's manuals



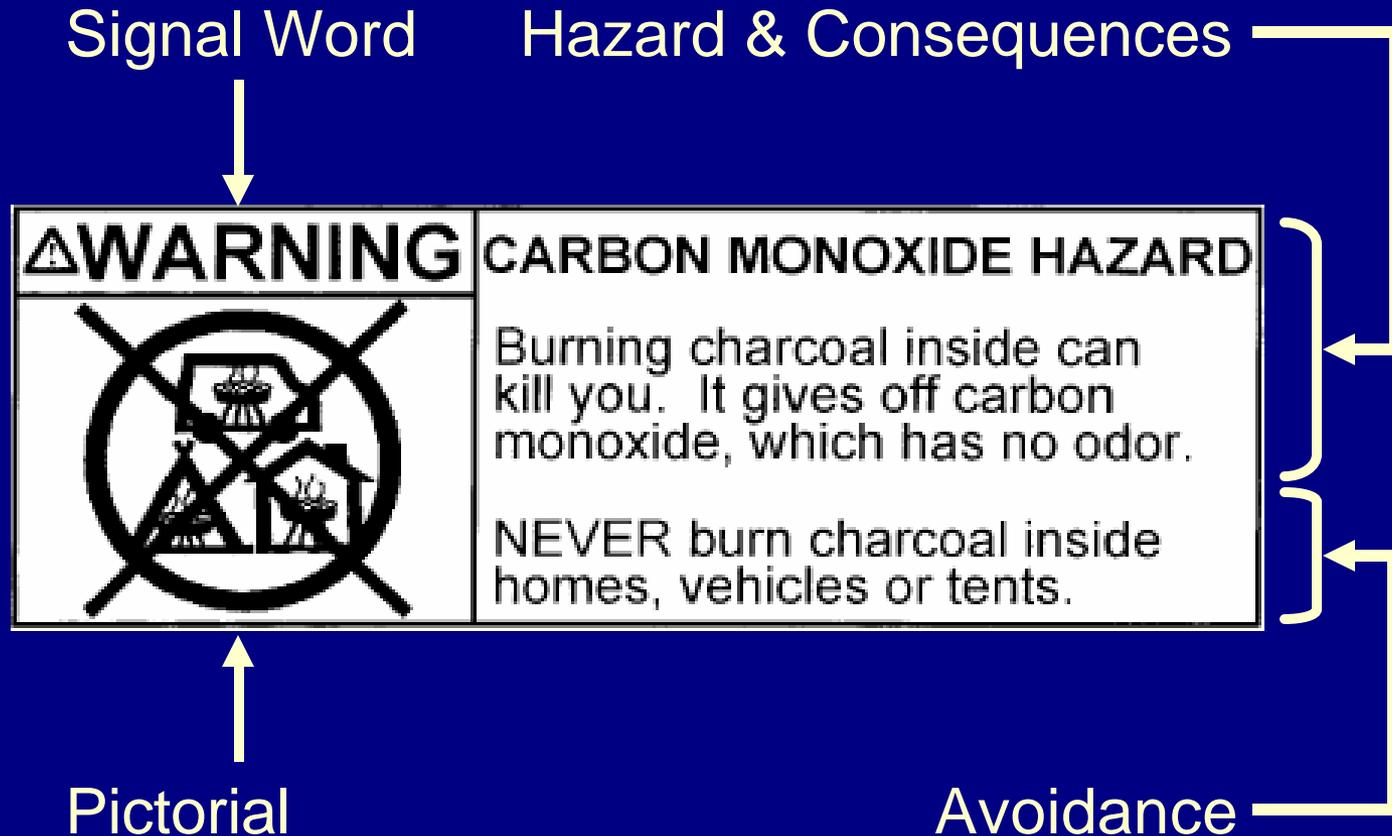
Necessary Warning Information

- Description of hazard
- Consequences of exposure to hazard
- How to avoid hazard

- Signal word (severity/seriousness)
 - CAUTION: Possible minor to moderate injury
 - WARNING: Possible serious injury or death
 - DANGER: Certain serious injury or death



Example: Charcoal Labeling



Hazard & Consequences

- Current label language
 - “Breathing hazard”
 - Is “breathing” really the hazard?
 - Potential for “carbon monoxide poisoning”
 - What is the source?
 - Engine exhaust could “cause injury or death”
 - Why?
 - What about the exhaust is hazardous?



Hazard & Consequences (cont.)

- Staff's proposals
 - Identify “carbon monoxide”
 - Describe characteristics of CO
 - Identify source of CO
 - Explicitly state that CO “can kill you”
- For example, “Generator exhaust contains carbon monoxide, a poisonous gas that can kill you. You cannot see or smell it.”



Hazard Avoidance

- Current label language
 - Provide proper ventilation
 - Do not operate in confined or enclosed area
- Both open to interpretation by reader
 - What is proper ventilation?
 - Opening windows/doors?
 - Operating fans?
 - What is a confined or enclosed area?



Hazard Avoidance (cont.)

- Staff's proposals
 - Describe where, precisely, generator should be placed during use
 - Describe where NOT to place generator during use, and identify specific locations
 - Warn reader that opening windows/doors or running fans may not avoid hazard
- For example, “Only use generator outside and away from open doors, windows, and vents. Never use inside homes, garages, or crawl spaces. Fans or open doors and windows do not provide enough fresh air.”



Warning Compliance Problems

- Weatherization issues
 - Stalling in cold or inclement weather
 - Conflicting electrocution hazard warning
 - Do not “let generator get wet,” “keep generator dry,” etc.
 - However, inclement weather conditions likely to precipitate generator use
- Fear of theft



Other Considerations

- Addition of pictorial?



- Warnings in instruction/owner's manuals
 - Place at beginning (current practice)
 - Embed in operating instructions
 - Include more detail, such as symptoms of CO overexposure
- Warning on packaging?

Conclusions

- Consumers currently presented with inconsistent, vague, and incomplete information about generator CO hazard
- Warnings must be more explicit about the hazard, consequences, and how to avoid
- Warnings unlikely to be effective until compliance problems, particularly weatherization issues, are resolved

