NIST Technical Note
NIST TN 2202r1

Simulation of Residential CO Exposures from Portable Generators with and without CO Hazard Mitigation Systems Meeting Requirements of Voluntary Standards

Revision 1

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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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Abstract

This report documents work performed by the U.S. National Institute of Standards and Technology (NIST) and the U.S. Consumer Product Safety Commission (CPSC or Commission) under an interagency agreement[1] in support of the Commission's effort to address the carbon monoxide (CO) poisoning hazard associated with consumer use of portable generators. This report documents the plan, developed by NIST and CPSC staff, for a computer simulation study performed by NIST and provides examples of the study results. CPSC staff will use the study's results to evaluate the effectiveness of CO hazard mitigation requirements that were adopted in two voluntary standards in 2018. These two ANSI-approved standards are *ANSI/PGMA G300-2018, Safety and Performance of Portable Generators* (referred to as PGMA G300) and *UL 2201, Standard for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition* (referred to as UL 2201). Both voluntary standards have requirements for a system that will shut the generator off when specific CO concentrations are present near the generator. PGMA G300 also has other requirements, including a notification to the user after the generator has shut off, while UL 2201 has a reduced CO emission rate requirement.

The methodology of the simulation study was largely similar to that used by CPSC staff to evaluate the benefits of the proposed rule issued by the Commission in 2016 to address the hazard of CO poisoning from portable generators.[2] This simulation study used the same forty buildings, weather conditions, and generator characteristics to study the rate at which the CO emitted from the generator accumulates in, transports within, and leaves the homes and detached garages for generators with and without the CO mitigation requirements prescribed in the voluntary standards. The plan involved performing approximately 140,000 simulations using NIST's indoor air quality modeling program CONTAM. This report presents the simulation plan and detailed CO and COHb simulation results for sample scenarios from two of the houses and one of the detached garages.

Note: At the request of CPSC staff, NIST staff performed additional simulations using a 15 % longer run time for UL 2201 generators in a subset of the house models. These simulations are documented with sample results in new Appendix D of this report.

Keywords

Generator; carbon monoxide; carboxyhemoglobin; CONTAM; exposure; indoor air quality; measurements; multizone airflow model; safety; simulation

[1] CPSC-I-17-0023.
[2] Proposed *Safety Standard for Portable Generators*, Federal Register, 81 FR 83556, November 21, 2016.

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Acknowledgements

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1. Introduction

The U.S. Consumer Product Safety Commission (CPSC) is focused on addressing the hazard of acute carbon monoxide (CO) poisonings of consumers from portable generators that can result in serious, long-term health effects or death. CPSC produces two annual reports which contain information on CO poisoning related to generator usage, a CO poisoning from Engine-Driven Tools (EDT) report (Hnatov 2021a) and a report that contains annual estimates of CO poisoning from consumer products (Hnatov 2021b). The first report contains only the actual data as reported to CPSC through 2020 and are not annual estimates. It should also be noted that data for the latter years of the report should be considered incomplete as new data often becomes available to CPSC staff a few years after an incident occurs due to reporting delays. Hnatov 2021a contains more detailed information on the specific incidents and the victims involved that are not in the estimates report. As of May 17, 2021, CPSC databases contain records of at least 753 consumer deaths (711 from generator use alone, 42 from generator use in conjunction with another CO-producing consumer product) from CO poisoning associated with non-work-related use of generators between 2010 and 2020. Typically, these deaths occur when consumers use a generator in an enclosed or partially enclosed space or outdoors near an open door, window or vent. They often occur after severe weather events such as hurricanes and ice or snowstorms.

The second CPSC report contains the annual estimates of generator CO fatalities and indicates the magnitude of generator-related CO poisoning deaths in relation to all consumer product-related CO poisoning deaths. The estimated percentage of CO poisoning deaths specifically associated with generators, excluding the estimates that involved a generator and another CO-producing consumer product, for the five most recent years of data are 33 % (2014), 49 % (2015), 38 % (2016), 51 % (2017) and 42% (2018). Per the Hnatov 2021b report, the estimated CO fatalities from all consumer products under CPSC's jurisdiction have risen for six straight years. Part of this increase in the estimated CO fatalities is due to an increase in the number of CO fatalities associated with EDTs. In the eleven years covered by this report, portable generators are responsible for over 81 % of all EDT-related CO deaths, and approximately 87% when another CO producing product may have also contributed.

The initial health impact of CO is caused by anoxia: deprivation of oxygen supply. When inhaled, CO preferentially binds with the oxygen carrier in the red blood cells, hemoglobin (Hb), to form carboxyhemoglobin (COHb), which causes anoxia (Stewart 1975). The COHb level reflects the percentage share of the body's total hemoglobin pool occupied by CO. In modeling acute exposure scenarios, it serves as a useful measure of expected poisoning severity in a reference individual.

The work performed previously under CPSC-I-15-0024, documented in National Institute of Standards and Technology (NIST) Technical Note (TN) 1925 (Emmerich et al. 2016), involved a computer simulation study conducted to provide CPSC staff with information to support estimations of modeled residential CO exposures reflecting operation of current designs of portable engine-driven electric generators, inside homes or in attached and detached garages. These results were compared to the simulated operation of generators with reduced CO emission rates so that CPSC staff could estimate the effectiveness of the reduced CO generators in preventing deaths that occurred with current generators. CPSC staff then recommended specific reduced CO emission rates as performance requirements to the Commission in a briefing package for a notice of proposed rulemaking (NPR) as the means to address the CO hazard associated with portable generators. The Commission subsequently voted to approve the NPR (Proposed *Safety Standard for Portable Generators*, Federal Register, 81 FR 83556, November 21, 2016.). These previous NIST simulations employed the multizone airflow and contaminant transport model CONTAM, which was applied to 40 buildings (37 houses and 3 detached garages, considered representative of many of the fatal CO poisoning incidents reported in CPSC databases) that are based on a collection of building models representative of the U.S. housing stock (Persily et al. 2006).

After CPSC issued the NPR, two different industry voluntary standards adopted CO hazard mitigation requirements and were ANSI approved in 2018: *ANSI/PGMA G300-2018, Safety and Performance of Portable Generators* (referred to as PGMA G300) and *UL 2201, Standard for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition* (referred to as UL 2201).

PGMA G300 includes a requirement for generators to be equipped with an onboard CO sensor. Such a device, when tested to the requirements in the standard, must shut the generator off before the CO concentration measured at a location one inch to two 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 also 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 active for a minimum of 5 minutes after shutoff occurs unless the generator is restarted. PGMA G300 also includes requirements for (1) a label about the automatic shutoff that must be in close proximity to 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.

UL 2201 includes a requirement of 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 one foot above the centerline of the top of the generator registers either an average of 150 ppmv of CO for a 10-minute period or an instantaneous reading of 400 ppmv.

Following publication of the PGMA G300 and UL 2201 standards, NIST and CPSC conducted an experimental study on generators with prototype shutoff mechanisms based on the requirements in these standards to provide information to support model-based estimates of residential CO exposures reflecting the operation of current portable engine-driven electric generators, inside and outside homes and in attached garages. The experimental study was reported in NIST Technical Note 2049 (Emmerich et al. 2019). A follow-on study built on the work reported in NIST TN 2049 by testing generators in the marketplace that come equipped to meet either PGMA G300 or UL 2201 shutoff and other requirements. That study was reported in NIST Technical Note 2200 (Zimmerman et al. 2022).

To estimate the expected impact of these requirements on CO exposure, this report documents NIST's and CPSC's plan for a computer simulation study using CONTAM, from which CPSC staff will use the results to arrive at estimates of effectiveness for the voluntary standards. The basic methodology developed for NIST TN 1925 was used as the basis for these simulations. This study included the same forty buildings and weather conditions to study CO levels within the buildings for generators with and without CO mitigation systems. Simulations also considered different behaviors of the generator's operator after a shutoff system turns the generator off.

The plan described in this report was developed by staff of both NIST and CPSC working closely together and evolved from an original plan published in NIST TN 2048 in July 2019 (Emmerich et al. 2019). Following publication of NIST TN 2048, CPSC solicited public comments for a 60-day period (Federal Register, July 9, 2019) and received four sets of comments in response.[3] NIST and CPSC staff then reviewed the comments, and CPSC staff subsequently published a memorandum to document how NIST and CPSC staff intended to revise the original plan and provided responses to all the comments (Buyer et al., 2020).

This report describes the approach used to perform the simulations, including descriptions of CONTAM; the building models; the scenarios for each group of building models, including the generator location and ventilation conditions; the weather conditions; the CO concentration criteria for shutting off the generator; and the characteristics of the different generator sizes that were simulated in the building models, including CO emission rates, run times on a full tank, and heat release rates. These factors affect the rate at which the CO emitted from the generator accumulates in, transports within, and leaves a building, and thus affect the simulated occupants' COHb profiles. In a separate CPSC report, CPSC staff will use the predicted COHb profiles to evaluate the effectiveness of the voluntary standards in preventing CO deaths and injuries in the scenarios that were simulated in this plan. This report presents detailed CO and COHb simulation results for sample scenarios for two of the houses and one of the detached garages.

This simulation plan does not replicate every home, condition, and generator operation. Rather, the plan is intended to provide a reasonable test of how generators that comply with each standard operate in a wide range of conditions, drawing upon scenarios identified by CPSC staff in their review of the incident data in CPSC's databases.

[3] The comments are available online at www.regulations.gov, under docket CPSC-2006-0057, document identification numbers 0101 through 0104.

2. Simulation Plan

2.1. Description of CONTAM

Indoor CO concentrations were calculated in the study using the multizone airflow and contaminant transport model CONTAM (Dols and Polidoro 2015). CONTAM is a simulation tool for predicting airflows and contaminant concentrations in multizone building airflow systems. When using CONTAM, a building is represented as a series of interconnected zones (*e.g*., rooms), with the airflow paths (e.g., leakage sites, open doors) between the zones and the outdoors defined as mathematical relationships between the airflow through the path and the pressure difference across it. Outdoor weather conditions are also input into CONTAM, as they are key determinants of pressure differences across airflow paths in exterior walls. System airflow rates must also be defined to capture their effects on building and inter-zone pressure differences. These inputs are used to define mass balances of air into and out of each zone, which are solved simultaneously to determine the inter-zone pressure relationships and resulting airflow rates between each zone, including the outdoors. These airflow rates can be calculated over time as weather conditions and system airflow rates change. Once the airflows are established, CONTAM can then calculate contaminant concentrations over time in each building zone based on contaminant source characteristics and contaminant removal information, such as that associated with filtration. CONTAM has been used for several decades, and a range of validation studies have demonstrated its ability to reliably predict building air change rates and contaminant levels (Emmerich 2001, Emmerich et al. 2004, Poppendieck et al. 2016). Emmerich and Dols (2016) reported on a validation study that specifically evaluated the model's capability to predict CO concentrations in a test house from portable generator operation in an attached garage.

CONTAM assumes that the concentration of a contaminant (CO in this study) is uniform within each zone. This was a reasonable assumption for the simulations performed in NIST TN 1925, given that the generator run time was dependent on the fuel consumption and capacity rather than being linked to a single-point value of CO. For the analysis of CO safety shutoff requirements, however, the assumption of uniform concentration may not be valid for the prediction of the run time before shutoff because the CO concentration may vary within the space while the generator is operating. A non-uniform concentration of CO in the space around the generator can affect the time to shutoff since the shutoff sensor is at a single location. The distribution of CO in a space is dependent on multiple factors such as where the generator is located within the space, how the exhaust is oriented relative to surfaces that the exhaust jet comes into contact with, how close those surfaces are to the generator, and the velocity and temperature at which the exhaust jet exits the tailpipe. For example, in many cases, a generator operating in a room creates higher CO concentrations downstream of the exhaust jet during operation. This non-uniformity of CO in the space where a generator with a CO safety shutoff system is operating may result in longer run times when compared to the same scenario where the CO is assumed to be uniformly distributed. Increased runtime results in increased mass of CO emitted and, for a given set of ventilation and leakage conditions in a building where the generator is operating, creates higher COHb profiles compared to when the generator shuts off more quickly. Therefore, the simulations in this study accounted for non-uniformity of CO so that more accurate CO levels and runtimes before shutoff were predicted by CONTAM and then used to estimate COHb profiles. The manner in which non-uniform CO concentrations were accounted for is discussed in section 2.7.

2.2. Building Models

The house models used in the simulations are from a collection of dwellings that were previously defined by Persily et al. (2006), which includes just over 200 dwellings that together represented 80 % of the U.S. housing stock. Those dwellings are grouped into four categories: detached (83 homes), attached (53 homes), manufactured (4 homes), and apartments (69). The definition of that set of dwellings was based on the following variables using the US Census Bureau's American Housing Survey (AHS) (HUD 1999) and the US Department of Energy's (DOE) Residential Energy Consumption Survey (RECS) (DOE 2005): housing type, number of stories, heated floor area, year built, foundation type, presence of a garage, type of heating equipment, number of bedrooms, number of bathrooms, and number of other rooms. The tables in Appendix A of this report summarize the characteristics of these dwellings and identify the corresponding CONTAM project file name and associated floor plan. In addition to defining the dwellings, multizone representations were created in CONTAM to support their use in analyzing a range of ventilation and indoor air quality issues. The project files and floor plans can be downloaded at the CONTAM website https://www.nist.gov/el/energy-and-environment-division-73200/nist-multizone-modeling/ under Case Studies.

Based on the CPSC analysis of CO poisoning death incidents from 2004 through 2012 (Hnatov 2015), a subset of the NIST suite of homes collection described above (in some cases with modifications), which CPSC staff assessed were representative of homes in which the incidents occurred, was used in the analysis presented in NIST TN 1925. These houses were used again in this study (with some additional modifications that are described in Table B1 of Appendix B of this report). The subset of homes includes 31 detached house (DH) models (25 chosen from the original NIST collection and 6 that are modifications of 5 of those 25), 4 attached house (AH) models (4 chosen from the original NIST collection, 3 of which are modified), and 2 manufactured house (MH) models (1 chosen from the original NIST collection plus a modification of that one). Additionally, 3 new detached garage (GAR) buildings were defined in NIST TN 1925 and included 2 single-zone garage/sheds (single-car size and two-car size) and 1 larger garage/shed with a separate workspace inside. These detached garages were also used in this study. More information on how these particular buildings were selected from the associated incident data is provided in "TAB K" of the briefing package of the NPR (CPSC Staff Briefing Package 2016).

2.2.1. Air Handling System Operation

While the homes in the NIST suite of homes collection include air handling systems for heating and cooling, this analysis assumed that the forced-air distribution systems were not operating. This is consistent with the CPSC analysis of the CO incident reports, which typically do not include incidents where the generator was used to operate the central HVAC system when there was a power outage associated with the use of the generator. Similarly, all local exhaust fans (kitchen and bath) were also assumed to be off.

2.2.2. Door and Window Positions and Sizes and Changes made to the models

Interior doors were modeled as open 10 cm during the simulations and all exterior doors and windows were fully closed, with exceptions as noted in the specifics of the scenarios, which are provided in the tables in Appendix C. Fully open interior and exterior doors and doorways without doors were modeled with openings of 2.0 m high by 0.8 m wide (or a smaller opening width as specified in the scenario descriptions). Fully open windows on the main floor were modeled with openings of 0.5 m high by 0.8 m wide. Basement windows and a window in the larger detached garage/shed with a separate workshop (GAR-3) were modeled with openings of 0.3 m high by 0.8 m wide. All other windows were modeled as closed. Table B1 in Appendix B includes descriptions of where open windows and exterior doors were added to the models.

All open garage bay doors, whether attached to a house or on a detached garage, were modeled with openings of 2.0 m high by 2.4 m wide. The bay door was always closed unless the scenario table stated otherwise (scenario tables are discussed in section 2.6). The door between the garage and an adjacent space into the house was normally closed unless the generator was in the garage, in which case the door was opened 10 cm. This door was not considered an interior door.

2.2.3. Indoor Air Temperatures

As in the NIST TN 1925 study, temperature distributions within the simulated buildings were calculated using a version of the CONTAM model with the ability to also model heat transfer (Emmerich 2006, Wang et al. 2012). This model accounts for heat transfer through the building envelope and for the heat produced by the generator, resulting in more realistic spatial and temporal temperature variations. The generator heat source varied depending on the generator size, as described in section 2.5.

2.3. Weather Conditions

As mentioned previously, weather affects how quickly the CO accumulates in, transports through, and leaves a house. Therefore, each scenario was simulated with the building model being subjected to 28 different days of weather conditions that varied on an hourly basis by outdoor temperature, wind speed, and wind direction. These 28 days of weather correspond to two weeks of cold weather (due to the observed frequency of events in CPSC's incident data during the winter season), one week of warm weather and one 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, MI in January (cold); Miami, FL in July (warm); and Columbus, OH in April (mild). The files were obtained from the EnergyPlus Energy Simulation Software website: https://energyplus.net/weather. Table 1 presents a summary of the weather conditions for the 28 days in the form of daily average, minimum and maximum outdoor temperatures and wind speeds.

A CONTAM model of a building is associated with a terrain shielding coefficient to account for the impacts of surrounding terrain, buildings, and vegetation on surface-averaged, wind-induced pressures on the exterior façade of the building. CONTAM specifies three categories of terrain for flat exposed areas (e.g., airport), suburban, and dense urban centers, and a user can input coefficients to capture a range of terrain options between the flat and urban extremes. As was done in NIST TN 1925, the simulations employed the suburban category of terrain shielding, which corresponds to areas with obstructions of the size and spacing of single-family homes. All 37 houses and 3 garages were oriented in the same direction such that the left side, as viewed when outside the house and facing the front door or the garage bay door for the three garages, was facing 10 degrees North, which was the predominant wind direction among all the hourly wind data in the 28 days of weather used in the simulations.

Table 1 Summary of Hourly Weather Data Used in Simulations

Day	Outdoor temperature, °C			Wind speed, m/s		
	Average	Minimum	Maximum	Average	Minimum	Maximum
1-Jan	0.7	-1.7	5.6	3.2	0.0	5.7
2-Jan	6.1	0.0	12.2	3.9	2.1	5.7
3-Jan	2.5	1.1	4.4	3.1	2.1	4.1
4-Jan	0.9	0.0	1.7	2.9	0.0	4.6
5-Jan	-2.9	-5.0	0.0	5.8	4.1	8.2
6-Jan	-3.3	-5.0	-1.7	5.2	1.5	8.2
7-Jan	-3.8	-6.1	-2.2	3.2	0.0	5.2
8-Jan	-1.7	-3.3	0.0	2.4	0.0	5.2
9-Jan	-0.1	-1.7	1.1	3.5	1.5	6.2
10-Jan	1.8	1.0	2.8	3.5	0.0	6.7
11-Jan	0.6	-0.6	1.1	4.3	0.0	5.7
12-Jan	4.9	0.6	13.3	3.9	0.0	8.8
13-Jan	9.2	0.6	14.4	6.4	2.6	10.3
14-Jan	-5.5	-9.4	1.1	5.3	2.6	7.2
3-Apr	6.0	2.8	8.3	6.9	0.0	9.8
4-Apr	6.3	-0.6	13.3	2.1	0.0	5.7
5-Apr	9.0	1.1	15.6	1.8	0.0	3.6
6-Apr	11.9	5.0	18.9	3.7	2.1	6.2
7-Apr	16.2	11.1	22.8	5.4	0.0	12.4
8-Apr	11.0	7.0	13.9	6.0	0.0	9.8
9-Apr	8.5	3.9	13.3	5.5	0.0	8.2
25-Jul	28.5	25.6	33.3	2.5	1.0	5.2
26-Jul	29.3	25.0	35.0	3.4	1.5	7.2
27-Jul	29.5	25.0	35.0	2.5	1.5	6.2
28-Jul	30.0	25.6	35.6	3.0	1.0	5.2
29-Jul	28.5	25.6	33.9	3.3	1.0	11.3
30-Jul	29.2	26.1	33.3	3.0	1.0	6.2
31-Jul	29.0	27.8	31.7	4.3	0.0	8.2

2.4. CO Concentration Criteria for Shutoff

Both PGMA G300 and UL 2201 specify two CO concentration limits when shutoff must occur: an instantaneous value and a time-averaged value. The simulations used the shutoff criteria contained in each standard. In addition, current generators with no shutoff systems, hereafter referred to as baseline generators, were also simulated.

PGMA G300 requires a generator to shut off before the concentration of the measured CO exceeds an instantaneous value of 800 ppmv or a 10 minute rolling average of 400 ppmv. The rolling average is calculated in accordance with Section 3.9.1 of PGMA G300 as shown below:

$$M_t = \frac{x_t + x_{t-1} + \cdots + x_{t-N+1}}{N}$$

where,

M_t= Rolling average @ time *t* (ppmv)
x= Measured values taken by the onboard sensor (ppmv)
N= Number of meaurements

Using the equation above, the simulations were conducted such that the generator can run less than 10 minutes and still be shut off due to reaching the 10-min rolling average shutoff criteria.

UL 2201 requires a generator to shut off when the measured CO reaches an instantaneous value of 400 ppmv or a rolling 600 second average measured at a frequency of 1 Hz reaches 150 ppmv.

Table 2 provides the shutoff criteria that were used in the simulations.

Table 2 Shutoff Criteria for Simulations

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

2.5. Generator Characteristics

The simulation inputs associated with the generator include CO emission rate, heat release rate, and run time, which is the number of hours that the generator can operate when starting on a full tank of gas when the engine is emitting the specified CO rate. As done in NIST TN 1925, generators were divided into four size ranges, distinguished by the engine powering the generator using the U.S. Environmental Protection Agency (EPA) definitions for classification of engines in portable generators typically used by consumers: Handheld (HH) generators (powered by spark-ignited (SI) Handheld engines), Class 1 (C1) generators (powered by SI Class I non-handheld engines), Class 2 generators distinguished by either single cylinder or twin cylinder (powered by SI Class II non-handheld engines, referred to as Class 2 single cylinder (C2S) or twin cylinder generators (C2T)).[4]

Table 3 contains the CO emission rates at normal ambient oxygen levels (nominally 21 %), heat release rates, and run times that were used in the simulations. Detailed descriptions of how these values were derived are provided in Appendix A of TAB K in CPSC Staff Briefing Package for the NPR, 2016.

Table 3 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

2.6. Scenarios

Descriptions of the scenarios used in the simulations are contained in the tables in Appendix C. The houses were divided into 5 groups, with each group defined by whether the house has a basement, crawlspace, and/or garage, as shown in Table 4.

[4] Per 40 C.F.R. § 1054.801, the EPA broadly categorizes small SI engines as either Non-handheld or Handheld and within each of those categories further distinguishes them into different classes, which are based upon engine displacement. Non-handheld engines are divided into Class I and Class II, with Class I engines having displacement above 80 cubic centimeters (cc) up to 225 cc and Class II having displacement at or above 225 cc but maximum power of 19 kilowatts (kW). Handheld engines, which are divided into Classes III, IV, and V, are all at or below 80 cc. Some Handheld engines are used to power very small portable generators, but the vast majority are powered by Class I and Class II engines. Class II single cylinder engines typically power generators with 3.5kW up to and including 9 kW rated power output. These are referred to as Class 2 single cylinder generators in this report. Class II twin cylinder engines typically power generators over 9 kW rated power, potentially up to approximately 18 kW. These are referred to as Class 2 twin cylinder generators in this report. Class I engines typically power generators with rated power of 2 kW to just under 3.5 kW rated power and are referred to as Class 1 generators in this report. Handheld engines typically power generators with rated power below 2 kW and are referred to as Handheld generators in this report (CPSC Staff Briefing Package 2016).

Table 4 Houses by Group

House Group	Basement	Crawlspace	Garage	Tables of Scenarios for G300 generators	Tables of Scenarios for UL 2201 generators
1	No	No	No	2.a. through 2.c.	9.a. through 9.c.
2	No	Yes	No	3.a. through 3.d.	10.a. through 10.d.
3	Yes	No	No	4.a. through 4.c.	11.a. through 11.c.
4	No	No	Yes	5.a. through 5.d.	12.a. through 12.d.
5	Yes	No	Yes	6.a. through 6.d.	13.a. through 13.d.

Each scenario table describes 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 it shuts off a second time.[5] In all cases, except when the generator was not restarted, the the operator responds to the second shutoff by moving the generator outside and restarting it there. Once running outside, the generator would run until the full fuel tank was emptied, as in the baseline scenario regardless of whether it was inside or outside. There are separate scenario tables for PGMA G300 and UL2201 generators to allow for different scenario weighting factors given the different requirements in the two standards. The weighting factors contained in each table are probabilities that NIST and CPSC staff assigned to the likelihood for each scenario to occur. They will be used by CPSC staff in their effectiveness analysis, not by NIST in performing the simulations, and are not discussed further in this report.

2.7. Simulation Methodology

All the scenarios defined in Appendix C were simulated for a 24-hr period over each of the 28 different days of weather conditions, the shutoff criteria associated with the 2 voluntary standards, and the CO emission rates/run times/heat release rates for the C1 and C2S generators and with no shutoff criteria for baseline generators. Simulations involving the HH and C2T generator categories were run only for the scenarios involving the building models that represent those houses and garages involved in fatal incidents with those size generators in the CPSC databases, which were house models MH-1(mod) and DH-8 for HH generators and garage model GAR-3 for C2T generators. The simulations used the CO emission rates in Table 3, with the baseline generators' CO rates increased by a factor of 3 times the CO emission rate at normal oxygen after 2 hours of operation to reflect reduced O_2 levels associated with operation in rooms without open windows or any open exterior doors (as described in NIST TN 1925). Neither PGMA G300 nor UL 2201 generators, of any size, ran for two hours in such conditions, so their CO rates were not increased.

The following emission rates apply to scenarios 1) where the generator is outside and the exhaust is coming in from outside, and 2) where the generator's exhaust is described as having a particular orientation:

- For scenarios with the generator started or restarted outside the kitchen, 22 % of the generator's CO emission rate in Table 3 was simulated as being emitted in the kitchen.

[5] The simulated occupants of the house include an *operator*, who directly interacts with the generator and a *collateral person*, who is another occupant in the house who does not directly interact with the generator.

- For scenarios when the generator was started or restarted outside of the garage with the bay door open, 100 % of the generator's CO emission rate was simulated as being emitted in the garage.
- For scenarios where the generator was near the doorway of a first-floor room with the exhaust pointed out of the room, 100 % of the generator's CO emission rate was simulated as being emitted in the adjacent space.
- For scenarios where the generator was in the garage with the exhaust facing the wall with the door into the house but not in alignment with that door, either 5 % or 15 % of the generator's CO emission rate, depending on the generator size, was simulated as being emitted in the adjacent space and the remainder was simulated as being emitted in the garage.

Table 5 summarizes these rates. Test data and analyses supporting these percentages are provided in NIST Technical Notes 2049 and 2200.

Table 5 Source Location CO Emission Rates For Specified Scenarios

Generator Type	Generator Size Category	100% CO emission rate (g/h)	CO rate after 2 h if gen is indoor & no open windows/doors in the source location (g/h)	CO rate in kitchen when generator is outside kitchen door and exhaust is flowing in (g/h)	CO rate in garage when generator is outside garage with open bay door	CO rate in the garage and in the adjacent space when generator is in garage with bay door closed and exhaust facing wall, but not in alignment, with door to adjacent space			
						Garage (95% for C2S and C2T)	Adjacent Space (5% for C2S and C2T)	Garage (85% for C1)	Adjacent Space (15% for C1)
PGMA G300	HH	300	NA	66	300	NA	NA	NA	NA
	C1	600	NA	132	600	NA	NA	510	90
	C2S	1570	NA	345	1570	1492	79	NA	NA
	C2T	3030	NA	667	3030	2879	152	NA	NA
UL 2201	HH	150	NA	33	150	NA	NA	NA	NA
	C1	150	NA	33	150	NA	NA	128	23
	C2S	150	NA	33	150	143	8	NA	NA
	C2T	150	NA	33	150	143	8	NA	NA
Baseline	HH	300	900	66	300	NA	NA	NA	NA
	C1	600	1800	132	600	NA	NA	510	90
	C2S	1570	4710	345	1570	1492	79	NA	NA
	C2T	3030	9090	667	3030	2879	152	NA	NA

As discussed in section 2.1, non-uniform CO concentrations in a zone are created by the velocity and direction of the generator's exhaust, as well as its release of heat. An experimental effort conducted by NIST and CPSC staff at NIST, reported in NIST TN 2049, showed that generator operation in NIST's test house consistently resulted in non-uniform CO concentrations near the generator due in large part to the generator heat release and exhaust velocity. Tables 2 through 7 in that report show the ratio of the zone average CO concentration to the shutoff sensor concentration at the time of shutoff. NIST and CPSC staff performed additional testing, reported in Tables 1 and 2 of NIST TN 2200 to further explore this non-uniformity. Because the non-uniformity can affect how quickly the generator shuts off if the CO concentration at the location of the generator's CO sensing system is different from elsewhere in the zone, NIST analyzed the test results to calculate ratios of the measured zone average concentration to the concentration measured near the position of the shutoff sensor located on the generator. These ratios were calculated using the 10-minute average concentration if the shutoff was based on the average concentration (a total of 68 shutoffs in TN 2049 and TN 2200) and the instantaneous concentration if the shutoff was based on the instantaneous value (a total of 41 shutoffs in TN 2049 and TN 2200). The averages of these ratios from all the tests, which are provided in Table 6, were used in the CONTAM simulations to account for non-uniformity. Specifically, in the simulations, the CO concentration in the CONTAM zone with the generator was divided by a shutoff ratio, and that CO value was used to determine when the generator would shut off.

Table 6 Shutoff Ratios Used in the Simulations

Average Shutoff Ratio for 68 Shutoffs due to 10-min Average Shutoff	Average Shutoff Ratio for 41 Shutoffs due to Instantaneous Criteria
1.3	1.1

In scenarios where the exhaust was oriented out the doorway of a first-floor room toward the house interior, the adjacent zone to this room was the zone in CONTAM where the CO source was located (source zone) and the zone where the generator was located was the zone containing the shutoff sensor (shutoff measurement zone). For these scenarios, the shutoff ratio was applied to the CO concentrations in the shutoff measurement zone because the shutoff ratios reported in Table 5 in TN 2049 indicate that use of the shutoff ratio in this zone is warranted.

In all simulations, the generator was started at the beginning of the simulation period and it ran until one tank of gas was used if the shutoff criteria did not turn off the generator either initially or after any prescribed restart. For a restart scenario, the generator was restarted after a 10-minute delay to simulate the time it may take an occupant to notice, investigate, and restart the generator. All simulations used a five-second time step and reported CO concentrations in each room of the house for each minute during the 24-hour analysis interval. These one-minute concentrations were then used to calculate COHb values for a collateral occupant as well as an operator of the generator in each occupiable zone (i.e., all rooms except bathrooms, stairs, hallways, attic, and similar type locations). The exposure of the operator, who is the person that restarts the generator, was specifically considered because the operator restarting the generator in its initial start location may be exposed to the highest CO concentrations anywhere in the house or garage. The series of tables (1.a through 1.g) in Appendix C describe the assumptions on how each operator’s and collateral occupant’s exposures were determined in the simulations depending on where the generator was located. COHb levels were calculated and reported in the same manner as in NIST TN 1925 using the Coburn-Forster-Kane (CFK) non-linear differential equation (Peterson and Stewart 1975, Coburn et al. 1965), which is provided in Appendix 2 of NIST TN 2049. Input values for these calculations, determined by CPSC staff, include an RMV (respiratory minute volume) 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) (CPSC 2016). CPSC staff will use the COHb levels for their effectiveness analyses for the two voluntary standards, which will be reported in a separate CPSC report.

According to Inkster 2012, “The % COHb can serve as a useful approximation of expected CO poisoning severity in healthy adults during acute uptake of CO, although it is recognized that the relationship is not absolute, and there is variation among individuals due to different physiological characteristics and/or health status. It should also be noted that 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. Notwithstanding these caveats, increasing % COHb levels are generally related to progressively worsening symptoms." See Table 7.

Table 7 Symptoms Associated with % COHb Levels (Burton 1996)

% 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

As described in Appendix A of NIST TN 2048, the one-minute CO concentrations generated by the CONTAM simulations were used to calculate COHb profiles for operators and collateral occupants of the houses in each occupiable zone to determine if, and when, a fatal scenario is predicted based on four criteria developed by CPSC Health Sciences (HS) staff for interpretation of modeled COHb values. 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 the average duration of elevation > 50 % COHb is less than 2 hours and average duration of elevation between ≥40 % and <50 % COHb is less than 4 hours.
3. If peak level is ≥40 % COHb, but <50 % COHb, assume death if the duration of the average in this range exceeds 6 hours.
4. If peak level is ≤40 % COHb, assume survival.

In addition to the simulated fatalities analysis, CPSC HS staff developed criteria for estimating the potential severity of injuries for the survivors of formerly fatal exposures. The injury level determination also employed 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 and < 25 % COHb = assume likely to perceive adverse symptoms and to seek medical evaluation (in emergency room (ER) or other medical settings), but likely to

be released without need for hospitalization or transfer to a hyperbaric oxygen (HBO)[6] treatment facility or other specialized treatment center

3. ≥25 % COHb but <40 % COHb for 6 h = assume likely to perceive adverse symptoms and to seek or be taken for medical evaluation (in ER or other medical settings) and likely to be hospitalized or transferred to an HBO-treatment facility or other specialized treatment center

3. Sample Results

This section presents sample results from among the simulations discussed in the previous section for three of the modeled buildings.

3.1. Sample results for a mid-sized detached house with basement and integral garage DH45mod

This section presents sample simulation results for a C2S generator (see Table 3) operating in mid-sized detached house DH45(mod) on January 1. Results are presented for all three generator types: PGMA G300, UL 2201, and baseline. Figure 1 shows the floor plan of DH-45mod as represented in the CONTAM Sketchpad for this study. As noted in Table B1, this house was modified from that used in NIST TN 1925 by switching the position of the kitchen and the dining room so that an exterior door could be added to the kitchen. DH-45mod has a floor area of 180 m^2 with a kitchen, dining room, living room, two bathrooms, and one bedroom on the first floor and three bedrooms, a bathroom and a den on the second floor. DH-45mod was modeled for three initial generator locations, the kitchen, the unfinished basement and the garage. The graphs included here present data in which the generator is initially operated in the kitchen with the kitchen window closed.

[6] An HBO chamber is a facility used for exposing patients to 100 percent oxygen under supra-atmospheric conditions to shorten the time it otherwise normally takes for the CO to leave the bloodstream and to increase the amount of oxygen dissolved in the blood. A broad set of recommendations has been established for HBO treatment for CO poisoning, which includes a COHb level above 25 percent, loss of consciousness, severe metabolic acidosis, victims with symptoms such as persistent chest pain or altered mental status, and pregnant women. Treatment is not recommended for mild-to-moderate CO poisoning victims, other than for those at risk of adverse outcomes (Inkster 2012).

Figure 1 Floor plan of house DH-45mod as represented in CONTAM. Symbol ⊡ indicates a source location.

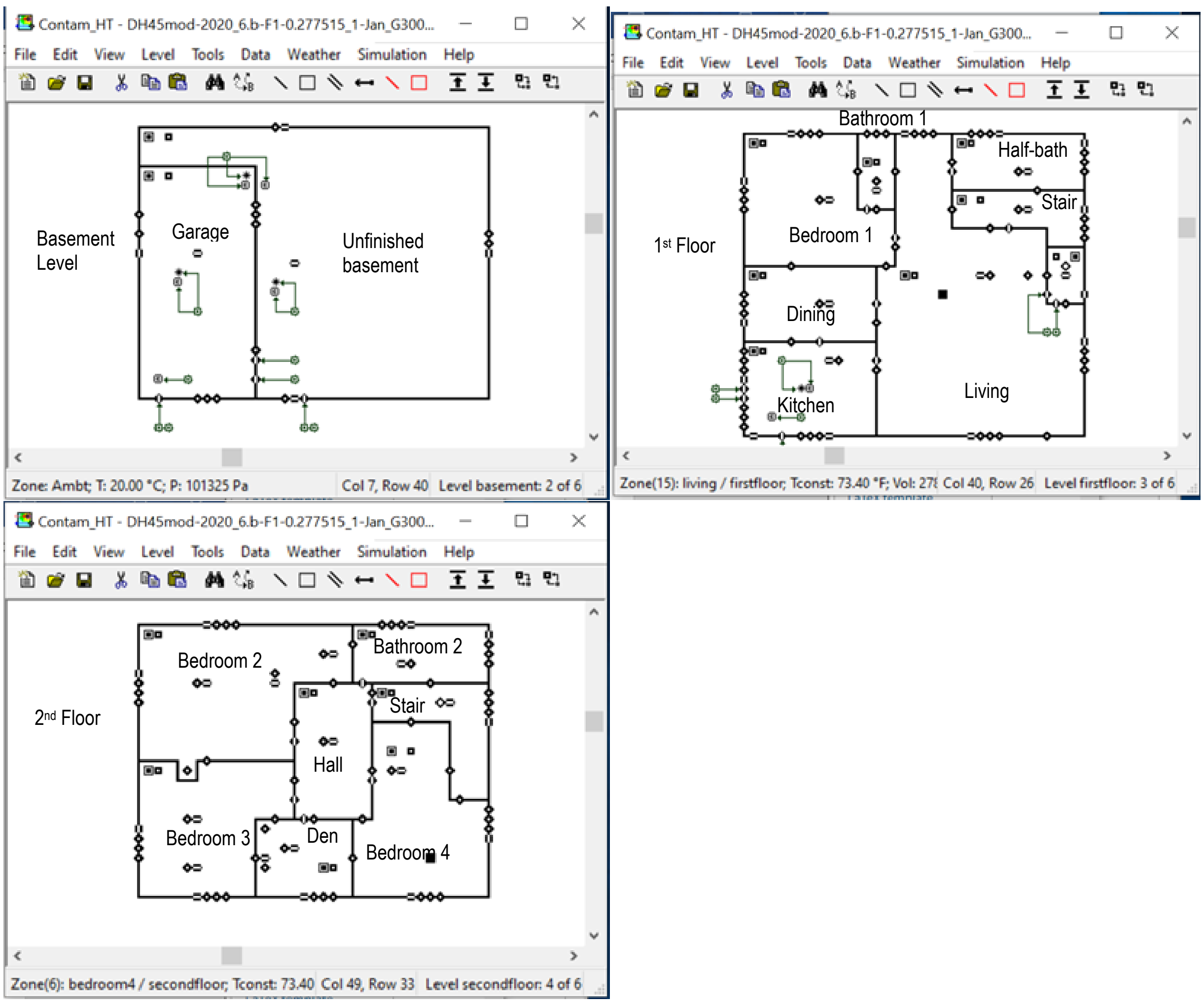


Figure 2 shows the simulated 24-hour CO profiles in four first-floor rooms in the house that resulted from operating the baseline C2S generator in the kitchen until it ran out of fuel. Note that in all results figures, CO concentration is presented in the SI unit uL/L which is equivalent to the commonly used ppmv. Figure 3 shows the predicted COHb profiles for occupants who stay in each of those rooms for all 24 hours. Note that the calculation of COHb was cut off at 95 % for all cases because the calculated COHb levels are not meaningful at these high levels. Based on the levels of COHb and the criteria in Section 2.7 that are assumed to cause a fatality, occupants in those rooms are predicted to die in 45 minutes (kitchen) to 1 hour 13 minutes (bedroom 1).

Figure 2. CO profiles in 4 Rooms in DH45(mod) with Baseline C2S Generator Operating in Kitchen on January 1.

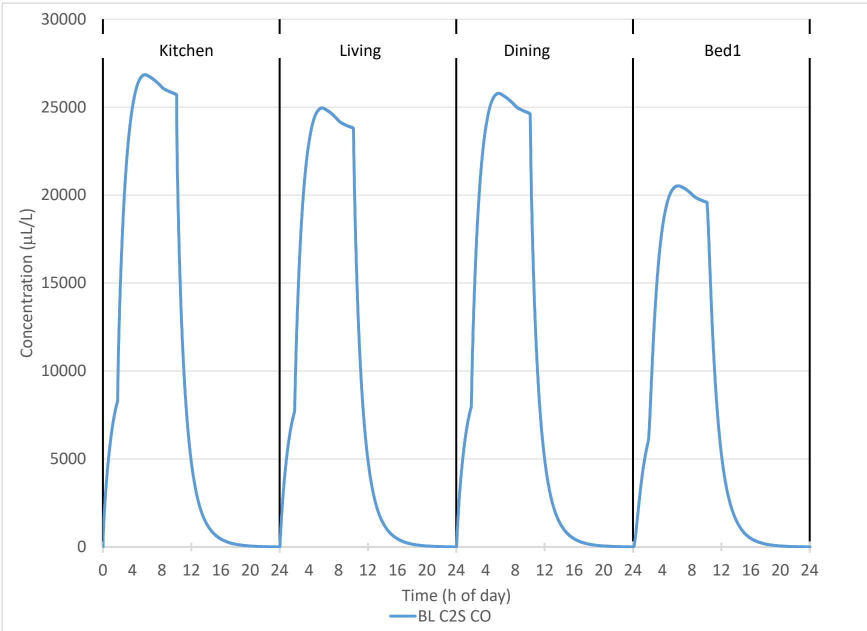
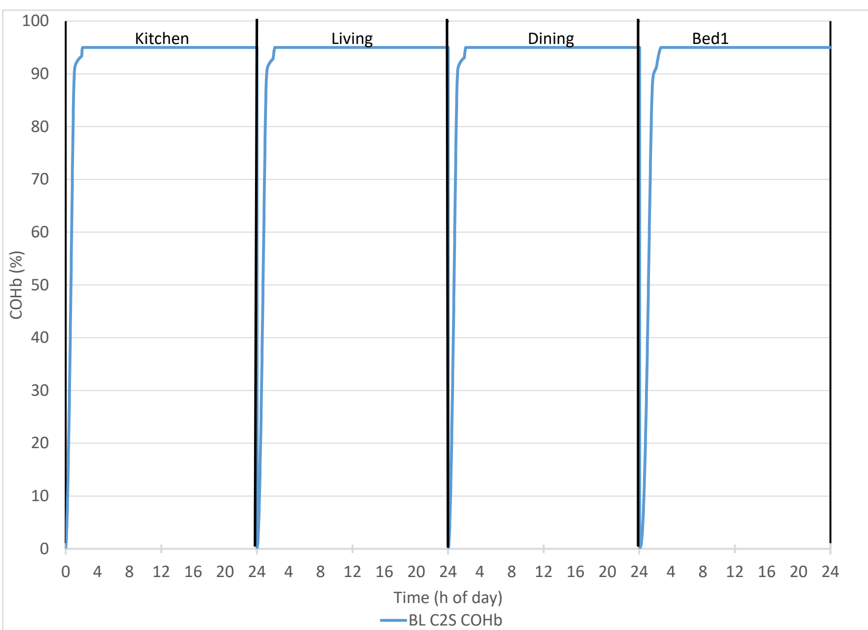


Figure 3. COHb profiles for Occupants in 4 Rooms in DH45(mod) with Baseline C2S Generator Operating in Kitchen on January 1.



Figures 4 through 7 show results for the PGMA G300 and the UL 2201 C2S generators in the B1 restart scenario of Tables 6a and 13a in Appendix C, respectively. After the initial start in the kitchen, both generators shut off (PGMA G300 in 3 minutes, UL 2201 in 16 minutes). The highest

COHb among the operators in each of the four rooms at the time of the first shutoff is 1 %. Then, without changing the kitchen window position or moving the generator out of the kitchen, the PGMA G300 and UL 2201 generators are restarted 10 minutes after shutting off. Both generators shut off a second time (PGMA G300 within 1 minute, UL 2201 within 7 minutes). After the second shutoff, both generators are then moved outside of the kitchen through an exterior kitchen door, which is opened fully 5 minutes after shutoff, and restarted 10 minutes after it shut off. Two minutes after the generator has been restarted, the kitchen door is changed to a 10 cm opening. No generator exhaust from outside enters the house in this scenario.

Figure 4 shows the simulation results for the 24-hour CO exposure profile of the operator in each of four first floor rooms who is restarting the generator in the kitchen after the first shutoff, moving the generator from the kitchen to outside and restarting it a second time, and then returning to the room they originally occupied. As explained in Table 1c of Appendix C, each operator's exposure profile during the 10 minutes after the generator's first shutoff is an average of the CO profile of the room they were in while the generator was operating and that of the room where the generator is, in this case, the kitchen. For the 2-minute period after the generator is restarted the first time, the operator's exposure profile is that of the kitchen. After that, the operator returns to the room they originally occupied so their exposure profile is that of that room. After the generator's second shutoff, the operator's exposure profile during the next 10 minutes is a time-weighted average of the CO profile of the room they returned to, the kitchen, and outside (which is assumed to be zero). Figure 5 shows the simulation results for just the operator in the kitchen. Figure 6 and 7 show the predicted COHb profiles for each operator based on the CO exposure profile shown in Figures 4 and 5. Based on these COHb profiles and the criteria in Section 2.7, these operators would not be expected to perceive adverse symptoms or to seek or be taken for medical evaluation.

Figure 4 CO Exposure Profiles of Operators in 4 Rooms in DH45(mod) with PGMA G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B1 Scenario on January 1.

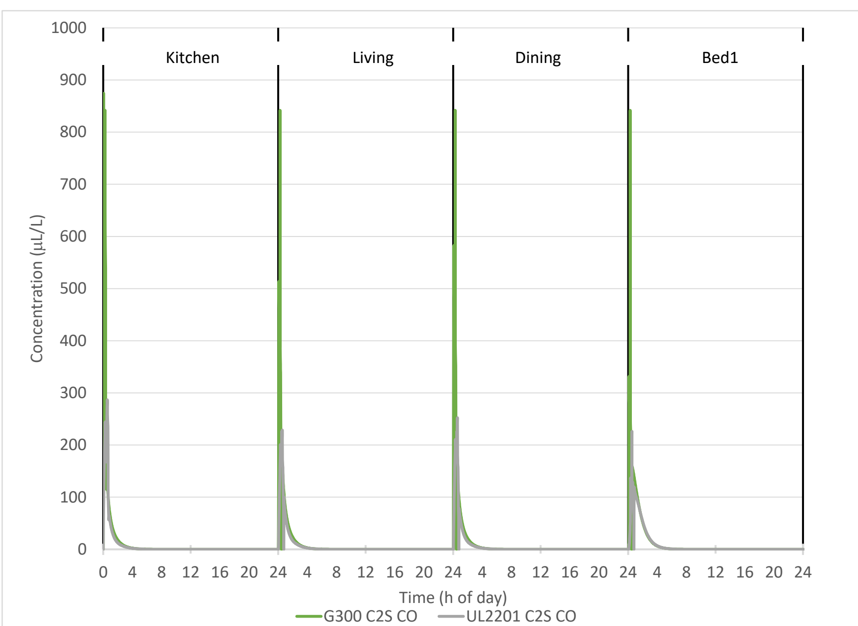


Figure 5. CO Exposure Profile of Operator in Kitchen in DH45(mod) with PGMA G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B1 Scenario on January 1.

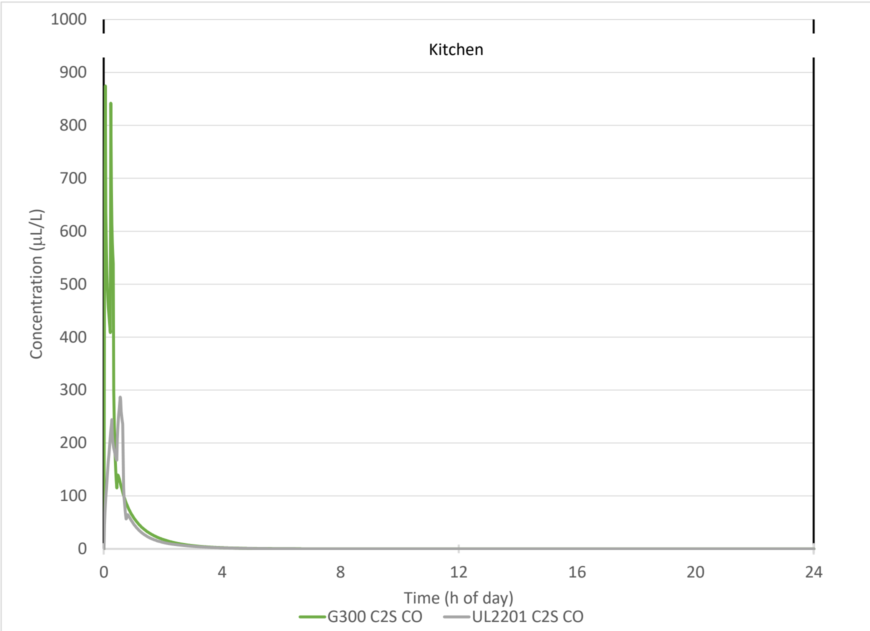


Figure 6 COHb Profiles of Operaturs in 4 rooms in DH45(mod) with PGMA G300 and UL 2201 C2S generator Initially Started in Kitchen and Restarted in Kitchen Per B1 Scenario on January 1.

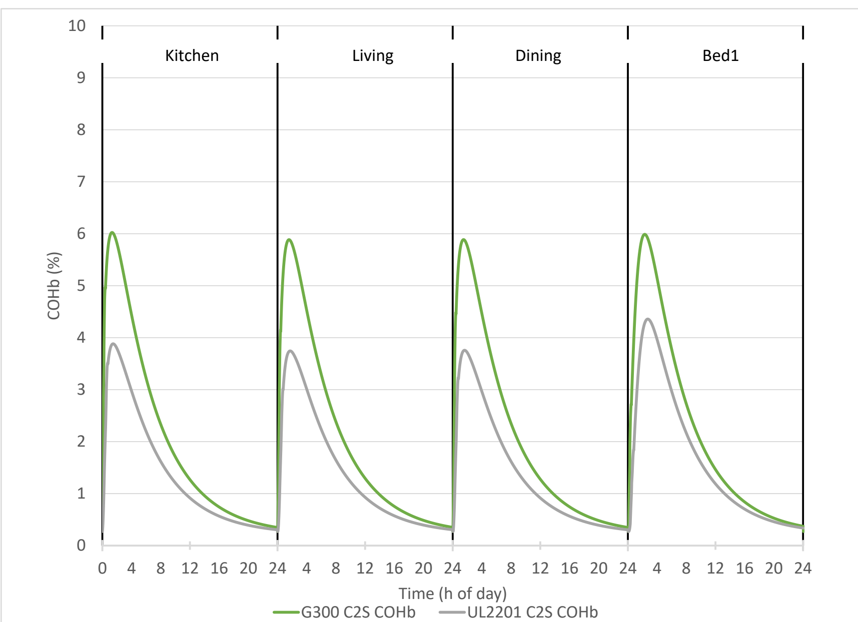
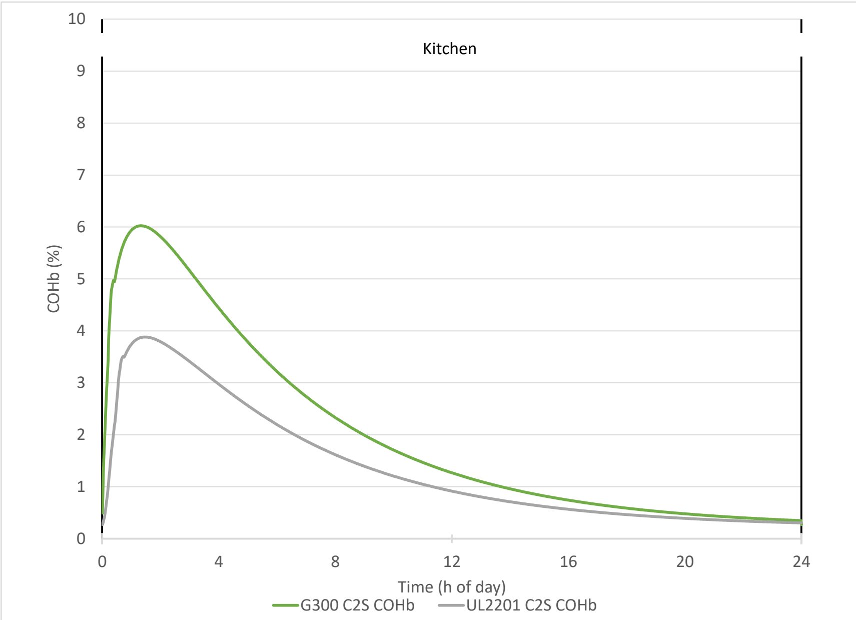


Figure 7 COHb Profile of Operator in Kitchen in DH45(mod) with PGMA G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B1 Scenario on January 1.



Figures 8 through 11 show CO exposure and COHb profiles for the PGMA G300 and the UL 2201 C2S generators in the B2 restart scenario of Tables 6a and 13a in Appendix C, respectively for DH45mod. Scenario B2 has the same sequence of events described above for the B1 restart scenario, except CO enters the kitchen from outside after the second restart. Based on the levels of COHb and the criteria in Section 2.7 that are assumed to cause a fatality, with a PGMA G300 C2S generator in the scenario, occupants in those rooms are predicted to die in 4 hours 2 minutes (kitchen) to 5 hours 13 minutes (bedroom 1). With a UL 2201 C2S generator in this scenario, none of these occupants would be expected to perceive adverse symptoms or to seek or be taken for medical evaluation.

Figure 8 CO Exposure Profiles of Operators in 4 Rooms in DH45(mod) with PGMA G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B2 Scenario on January 1

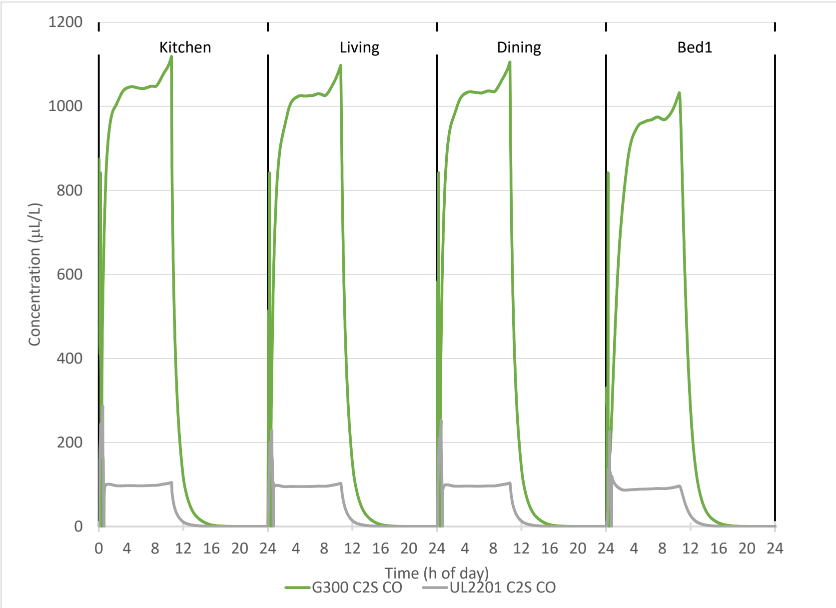


Figure 9 CO Exposure Profile of Operator in Kitchen in in DH45(mod) with PGMA G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B2 Scenario on January 1.

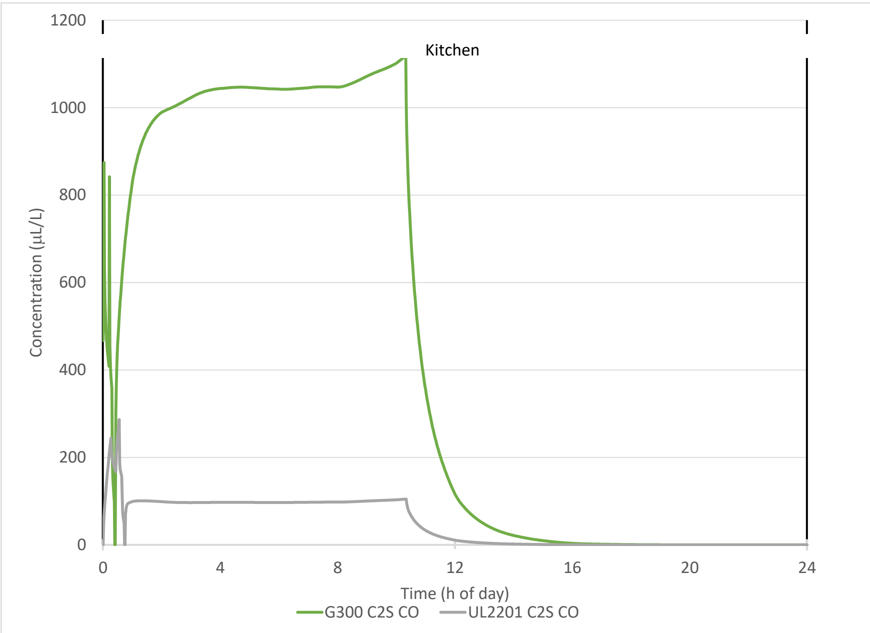


Figure 10 COHb Profiles of Operators in 4 rooms in DH45(mod) with PGMA G300and UL 2201 C2S generator Initially Started in Kitchen and Restarted in Kitchen Per B2 Scenario on January 1.

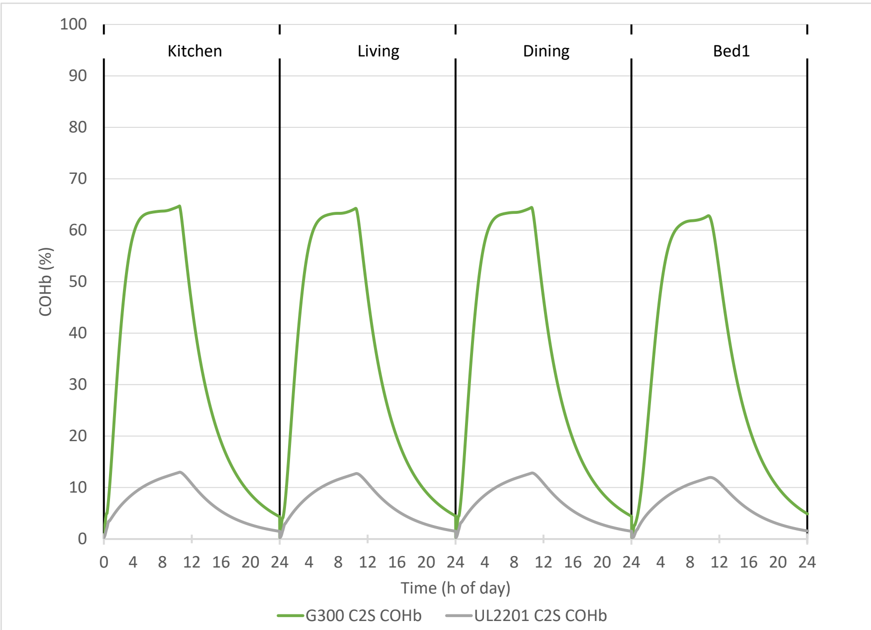
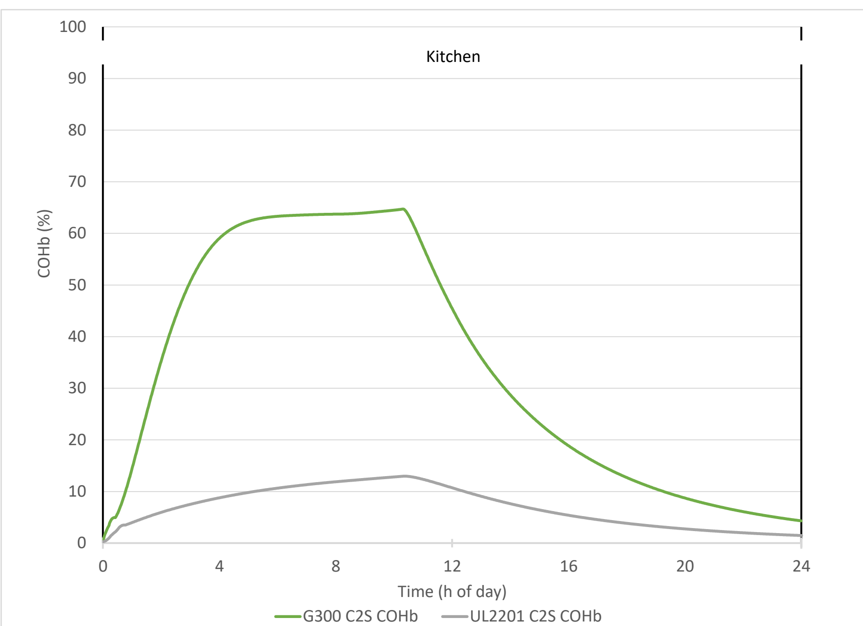


Figure 11 COHb Profile of Operator in Kitchen in DH45(mod) with G300 and UL 2201 C2S Generator Initially Started in Kitchen and Restarted in Kitchen Per B2 Scenario on January 1.



3.2. Sample results for a small, manufactured house MH1mod

This section presents sample results for the building MH1mod, which was created for this project as a smaller version of the manufactured house MH-1 (also included in this study) from the NIST suite of homes discussed earlier. Figure 12 shows the floorplan of MH1mod as represented in the CONTAM Sketchpad. MH1mod has 82.5 m^2 of floor area with 2 bedrooms, 1 bathroom and a kitchen. MH1mod was modeled with generators located in the kitchen, bedroom 2 and the crawlspace. The graphs included here present data in which the generator is initially operated in bedroom 2 with a window open with the generator exhaust jet oriented out of the door to the house interior.

Figure 12 Floor plan of house MH1mod as represented in CONTAM. Symbol ⊡ indicates a source location.

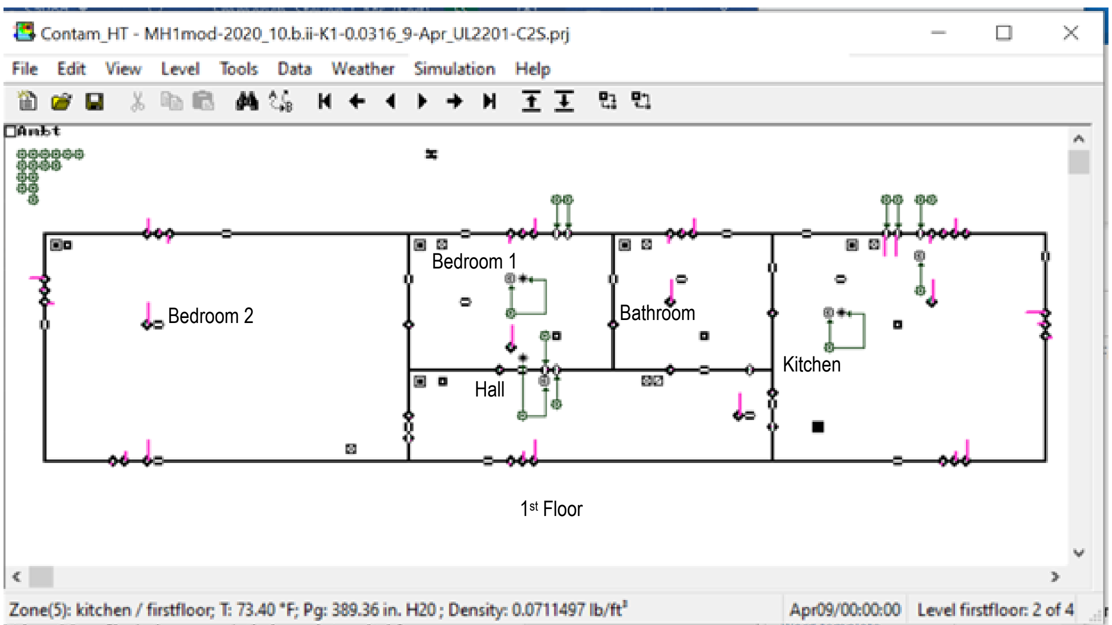


Figure 13 shows the simulated 24-hour CO profiles in three rooms in the house that resulted from operating the baseline C2S generator in bedroom 1 with a window open with the generator exhaust jet oriented out of the door towards the house interior until it ran out of fuel. Figure 14 shows the predicted COHb profiles for occupants who stay in each of those rooms for all 24 hours. Based on the levels of COHb that are assumed to cause a fatality, occupants in those rooms are predicted to die in 1 hour 27 minutes (kitchen) to 2 hours 28 minutes (bedroom 1).

Figure 13 CO profiles in 3 Rooms in MH1(mod) with Baseline C1 Generator Operating in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior on July 25

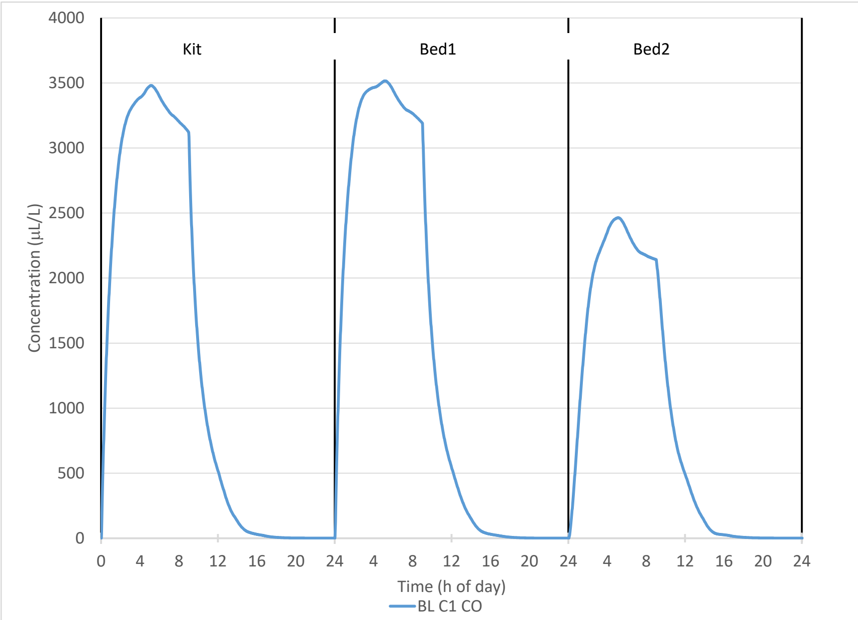
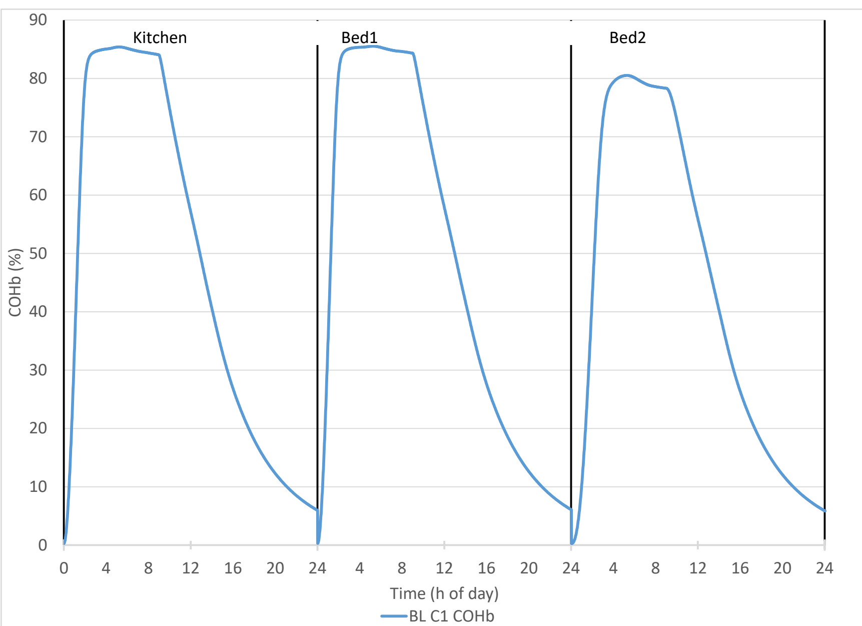


Figure 14 COHb profiles for Occupants in 3 Rooms in MH1(mod) with Baseline C1 Generator Operating in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior on July 25



Figures 15 through 18 show results for the PGMA G300 and the UL 2201 C1 generators in the K1 restart scenario of Tables 3.b.ii and 10.b.ii in Appendix C, respectively. After the initial start in the bedroom 1, both generators shut off (PGMA G300 in 12 minutes, UL2201 in 17 minutes). The highest COHb among the operators in each of the three rooms at the time of the first shutoff is 3 %. Then, without changing the bedroom 2 window position or moving the generator out of the bedroom 1, the PGMA G300 and UL 2201 generators are restarted 10 minutes after shutting off.

Both generators shut off a second time (PGMA G300 within 4 minutes, UL 2201 within 7 minutes). After the second shutoff, both generators are then moved outside of the kitchen through an exterior kitchen door, which is opened fully 5 minutes after shutoff, and restarted 10 minutes after it shut off. Two minutes after the generator has been restarted, the kitchen door is changed to a 10 cm opening. No generator exhaust from outside enters the house in this scenario.

Figure 15 shows the simulation results for the 24-hour CO exposure profile of a person in each of the three rooms who is restarting the generator in bedroom 2 after the first shutoff, moving the generator from bedroom 1 to outside and restarting it a second time, and then returning to the room they originally occupied. As explained in Table 1c of Appendix C, each operator's exposure profile during the 10 minutes after the generator's first shutoff is an average of the CO profile for the room they were in while the generator was operating and that of the room where the generator is, in this case, bedroom 1. For the 2-minute period after the generator is restarted the first time, the operator's exposure profile is that of the bedroom 1. After that, the operator returns to the room they originally occupied, so their exposure profile is that of that room. After the generator's second shutoff, the operator's exposure profile during the next 10 minutes is a time-weighted average of the CO profile of the room they returned to, bedroom 1, and outside (which is assumed to be zero). Figure 16 shows the simulation results for just the operator in bedroom 2. Figures 17 and 18 show the predicted COHb profiles for each operator based on the CO exposure profile shown in Figures 15 and 16. Based on these COHb profiles and the criteria in Section 2.7, the PGMA G300 generator operators are predicted to reach levels such that they would be expected to perceive adverse symptoms and to seek or be taken for medical evaluation and, for one operator, likely to be hospitalized or transferred to an HBO-treatment facility or other specialized treatment center. The UL 2201 generator operator would not be expected to reach levels to perceive adverse symptoms or to seek or be taken for medical evaluation.

Figure 15 CO Exposure Profiles of Operators in 3 Rooms in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K1 Scenario on July 25

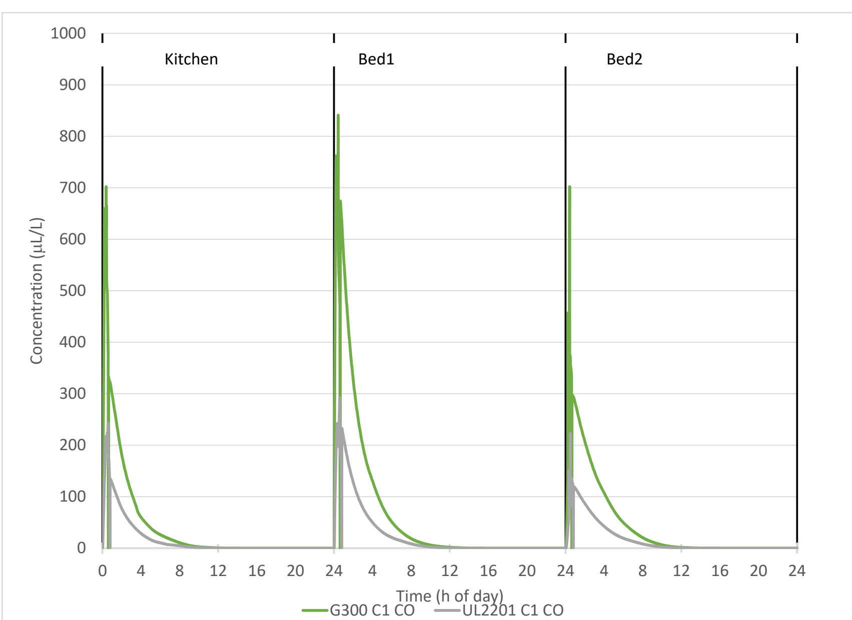


Figure 16 CO Exposure of Operator in Bedroom 1 in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 2 with the generator exhaust jet oriented out of the door to the house interior Per K1 Scenario on July 25

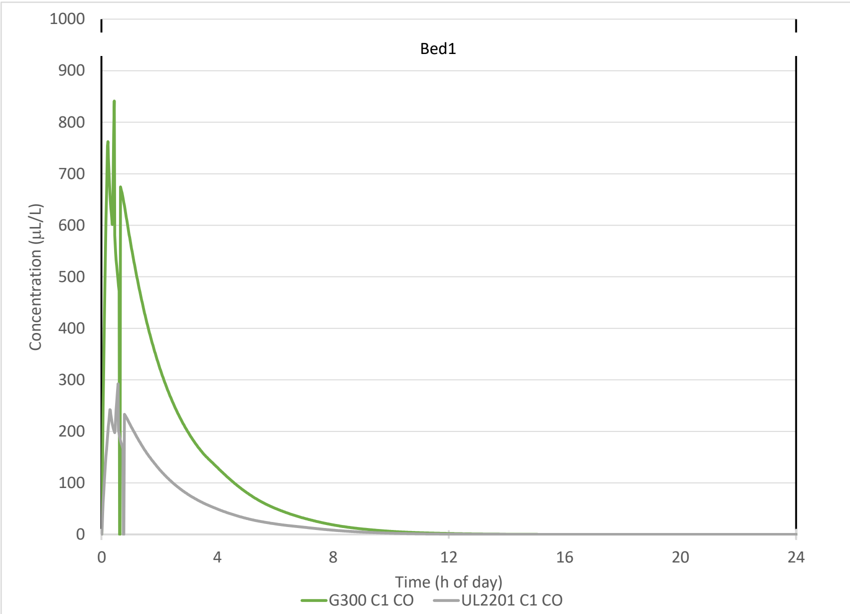


Figure 17 COHb Profiles of Operators in 3 Rooms in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K1 Scenario on July 25

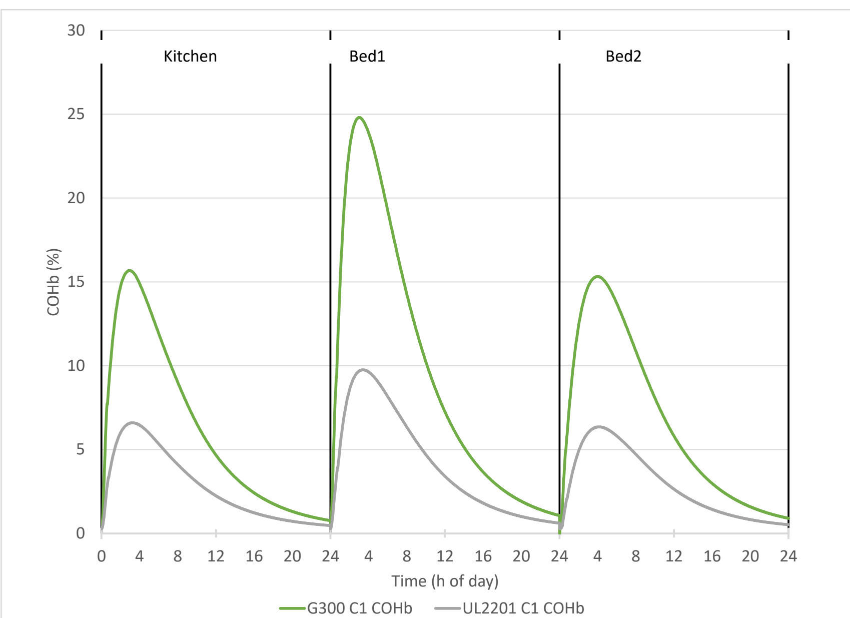
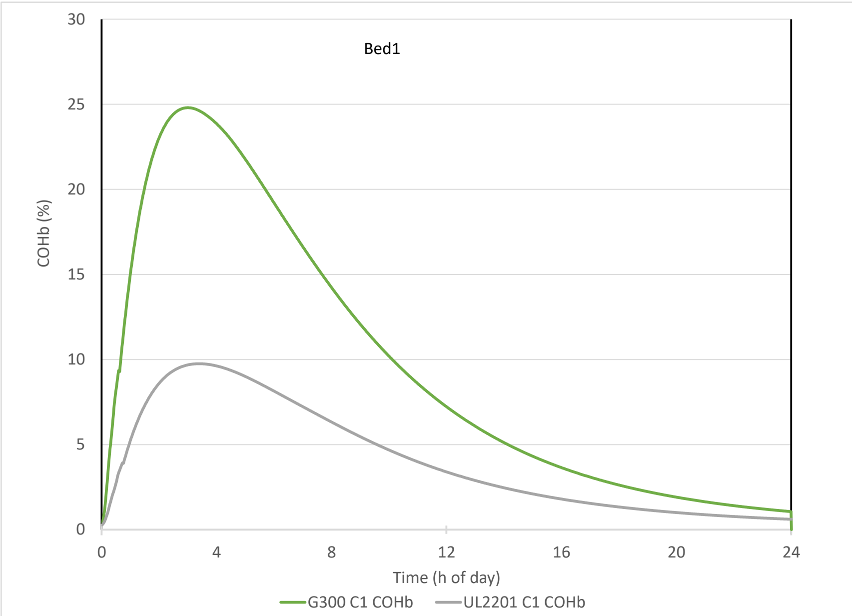


Figure 18 COHb Profile of Operator in Bedroom 1 in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K1 Scenario on July 25



Figures 19 through 22 show CO exposure and COHb profiles for the PGMA G300 and the UL 2201 C2S generators in the K2 restart scenario for MH1mod. Scenario K2 has the exact same sequence of events described above for the K1 restart scenario except CO enters the kitchen from outside during the second restart. Based on these COHb profiles and the criteria in Section 2.7, with a G300 C1 generator in the scenario, occupants in two of those rooms are predicted to die in 4 hours 9 minutes (kitchen) to 7 hours 11 minutes (bedroom 1). With a UL 2201 C1 generator in the scenario, one of the UL 2201 generator operators is predicted to reach levels such that they would be expected to perceive adverse symptoms and to seek or be taken for medical evaluation and a second operator is predicted to be likely to be hospitalized or transferred to an HBO-treatment facility or other specialized treatment center.

Figure 19 CO Exposure Profiles of Operators in 3 Rooms in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K2 Scenario on July 25

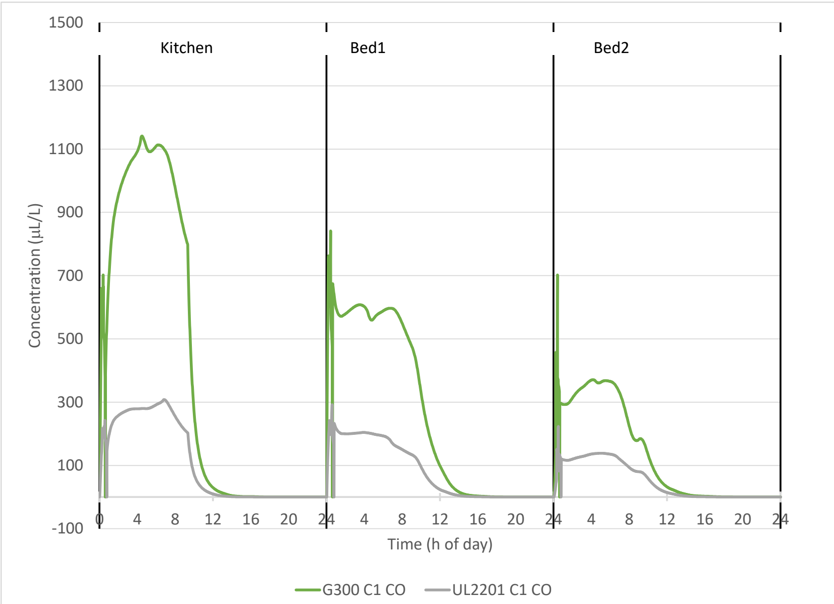


Figure 20 CO Exposure Profile of Operator in Bedroom 1 in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom1 with the generator exhaust jet oriented out of the door to the house interior Per K2 Scenario on July 25

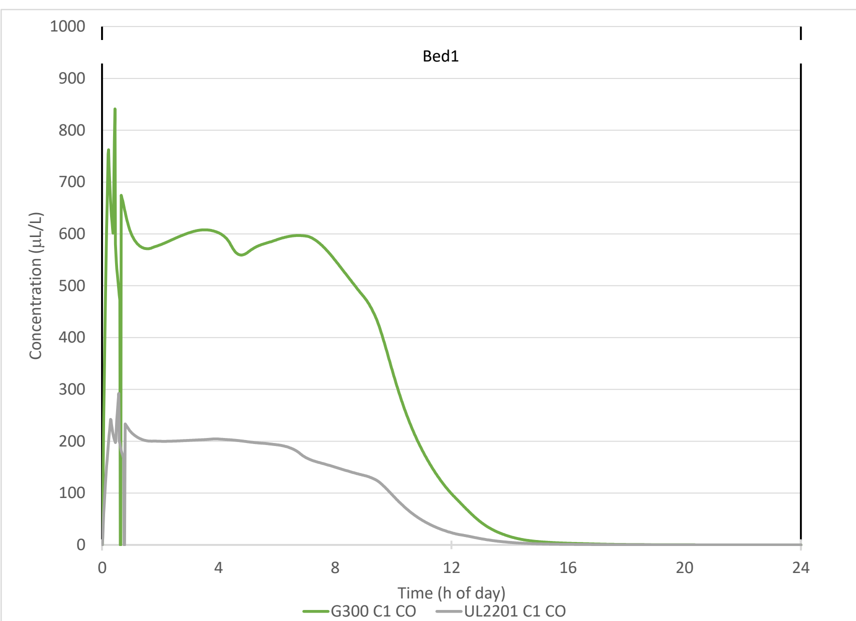


Figure 21 COHb Profiles of Operators in 3 Rooms in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K2 Scenario on July 25

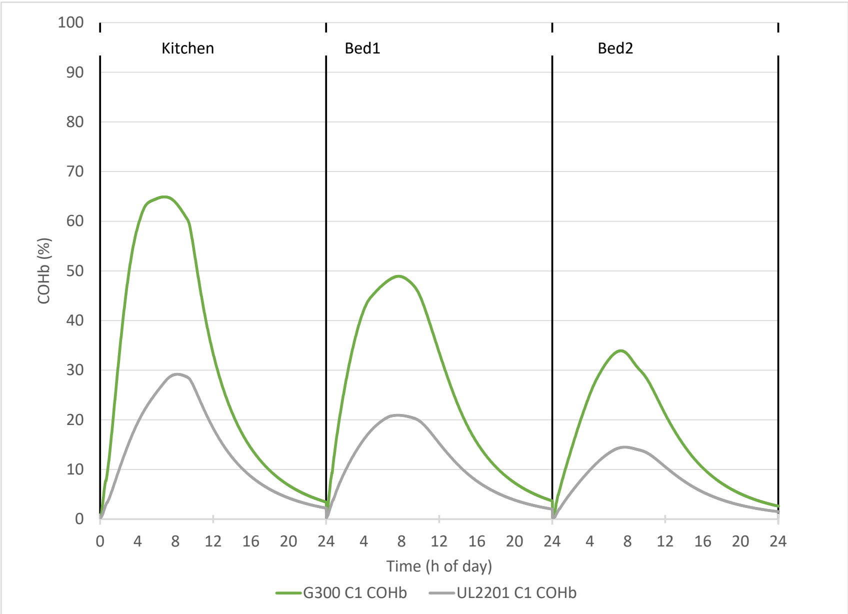
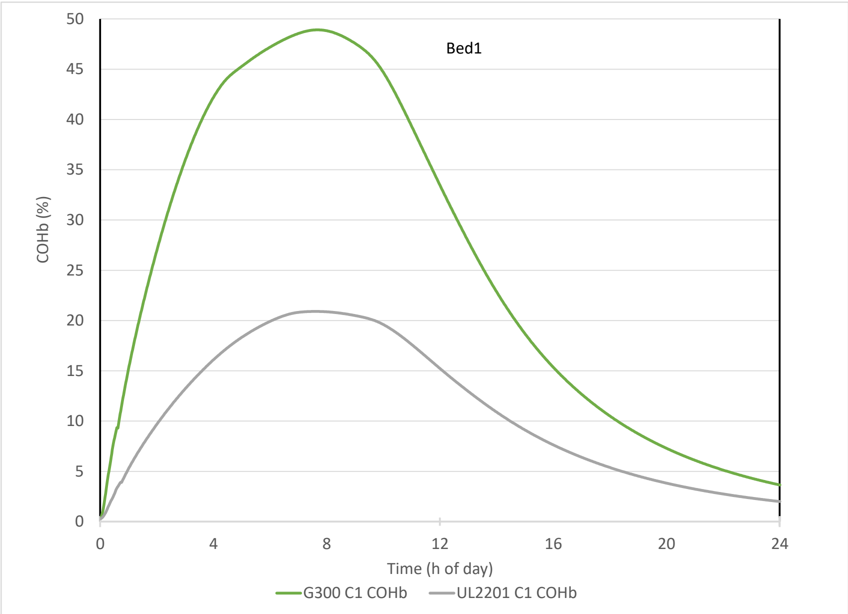


Figure 21 COHb Profile of Operator in Bedroom 1 in MH1(mod) with PGMA G300 and UL 2201 C1 Generator Initially Started in Bedroom 1 with the generator exhaust jet oriented out of the door to the house interior Per K2 Scenario on July 25



3.3. Sample results for a garage with workshop GAR3

This section presents sample results for the building GAR3, which was created for this project as a large two zone garage with 60.4 m^2 of floor area including a separate workshop zone. Figure 23 shows the floorplan of GAR3 as represented in the CONTAM Sketchpad. GAR3 was modeled with generators located in the workshop and garage. The graphs included here present data in which the generator is initially operated in the workshop.

Figure 24 shows the simulated 24-hour CO profiles in the workshop and the garage that resulted from operating the baseline C2S generator in the workshop until it ran out of fuel. Figure 25 shows the predicted COHb profiles for occupants who stay in each of those rooms for all 24 hours. Based on the levels of COHb that are assumed to cause a fatality, occupants in those rooms are predicted to die in 33 minutes (workshop) to 3 hours 49 minutes (garage).

Figure 23 Floor plan of house GAR3 as represented in CONTAM. Symbol ⊡ indicates a source location.

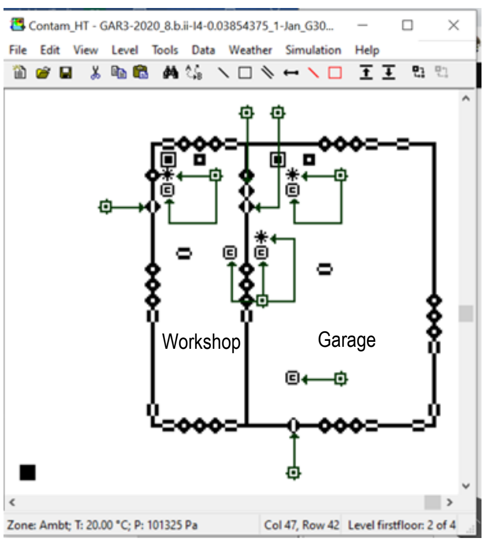


Figure 24 CO profiles in 2 Rooms in GAR3 with Baseline C2S Generator Operating in Workshop on April 4

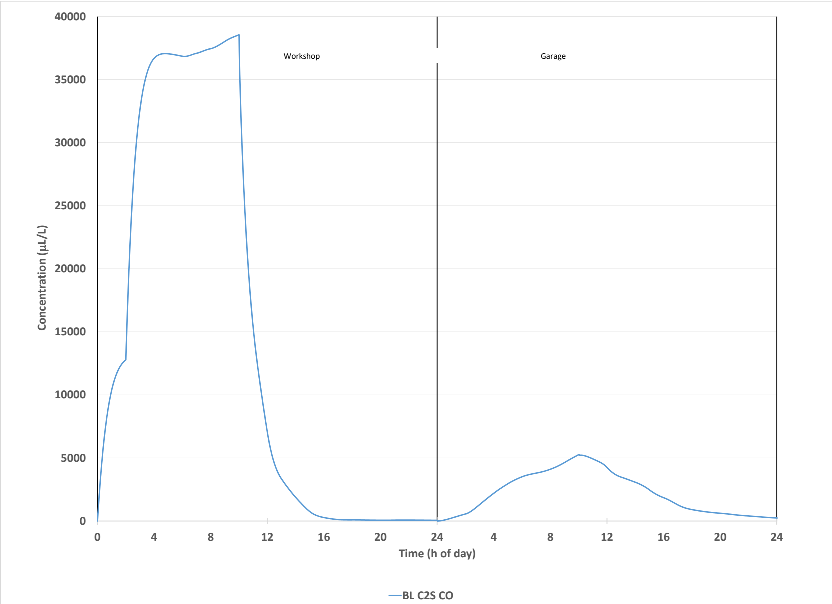
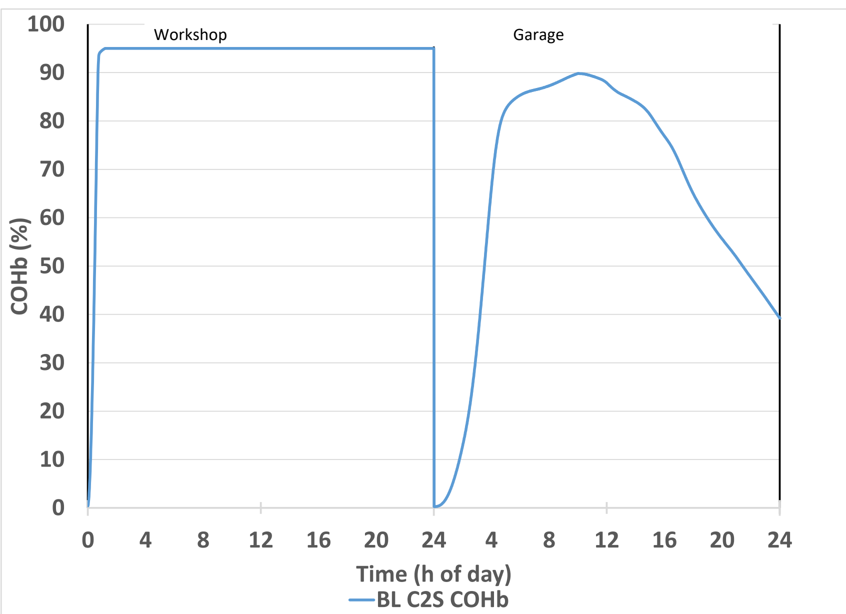


Figure 25 COHb profiles for Occupants in 2 Rooms in GAR3 with Baseline C2s Generator Operating in Workshop on April 4



Figures 26 through 27 show results for the PGMA G300 and the UL 2201 C2S generators in the C7 restart scenario of Tables 8.a and 15.a in Appendix C, respectively. After the initial start in the workshop, both generators shut off (PGMA G300 in 3 minutes, UL2201 in 12 minutes). Then, the PGMA G300 and UL 2201 generators are moved to the garage with the bay door fully open and the door from the garage to the workshop open 10 cm, positioned such that the exhaust is facing toward the wall with door to the workshop, and restarted 10 minutes after shutting off. Both generators shut off a second time (PGMA G300 within 5 minutes, UL 2201 within 14 minutes). After the second shutoff, both generators are then moved outside of the garage through the bay door and restarted 10 minutes after it shut off. Two minutes after the generator has been restarted, the bay door is closed. No exhaust from outside enters the garage in this scenario.

Figure 26 shows the simulation results for the 24-hour CO exposure profile of the operator in each of the two rooms who is restarting the generator in the garage after the first shutoff, moving the generator from the garage to outside and restarting it a second time, and then returning to the room they originally occupied. As explained in Table 1c of Appendix C, each operator's exposure profile during the 10 minutes after the generator's first shutoff is an average of the CO profile of the room they were in while the generator was operating and that of the room where the generator is, in this case, the workshop for the first shutoff and the garage for the second shutoff. For the 2-minute period after the generator is restarted the first time, the operator's exposure profile is that of the workshop. After that, the operator returns to the room they originally occupied so their exposure profile is that of that room. After the generator's second shutoff, the operator's exposure profile during the next 10 minutes is an average of the CO profile of the room they returned to, the garage, and outside (which is assumed to be zero). Figure 27 shows the predicted COHb profiles for each operator based on the CO exposure profile shown in Figure 26. Based on these COHb profiles and the criteria in Section 2.7, these operators would not be expected to perceive adverse symptoms or to seek or be taken for medical evaluation.

Figure 26 CO Exposure Profiles of Operators in 2 Rooms in GAR3 with PGMA G300 and UL 2201 C2S Generator Initially Started in Workshop per C7 Scenario on April 4

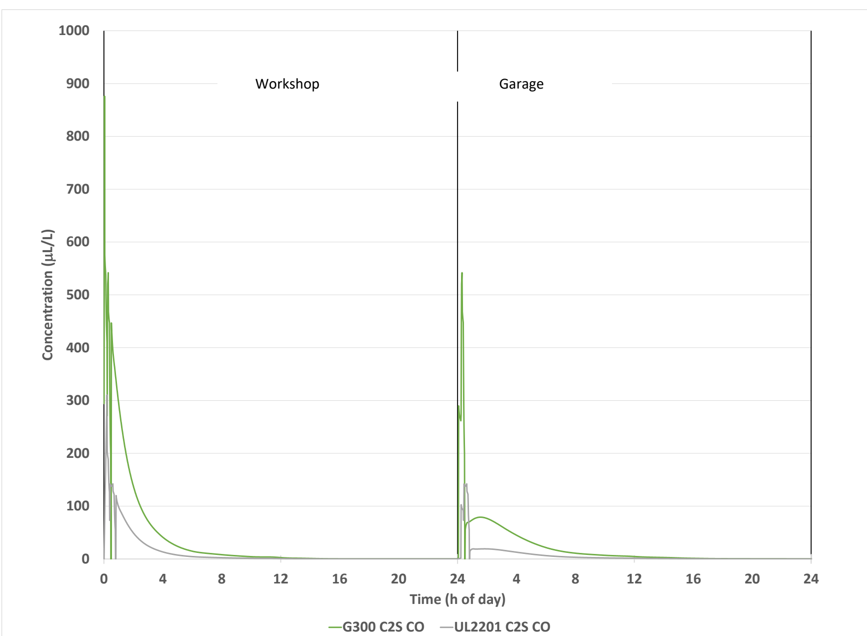
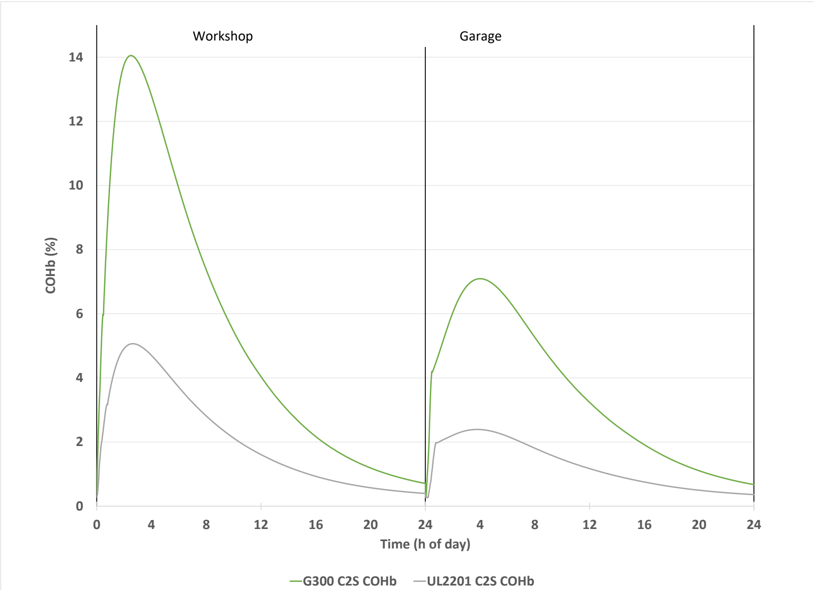


Figure 27 COHb Profiles of Operators in 2 Rooms in GAR3 with PGMA G300 and UL 2201 C2S Generator Initially Started in Workshop per C7 Scenario on April 4



Figures 28 through 29 show CO exposure and COHb profiles for the PGMA G300 and the UL 2201 C2S generators in the C8 restart scenario for GAR3. Scenario C8 has the exact same sequence of events described above for the C7 restart scenario except the garage bay door is left fully open and CO enters the garage from outside during the second restart. Based on these COHb profiles and the criteria in Section 2.7, with a PGMA G300 C2S generator in the scenario, occupants in those rooms are predicted to die in 7 hours 9 minutes (garage) to 7 hours 40 minutes (workshop). With a UL 2201 C2S generator in the scenario, the garage generator operator would be expected to perceive adverse symptoms and to seek or be taken for medical evaluation.

Figure 28 CO Exposure Profiles of Operators in 2 Rooms in GAR3 with PGMA G300 and UL 2201 C2S Generator Initially Started in Workshop per C8 Scenario on April 4

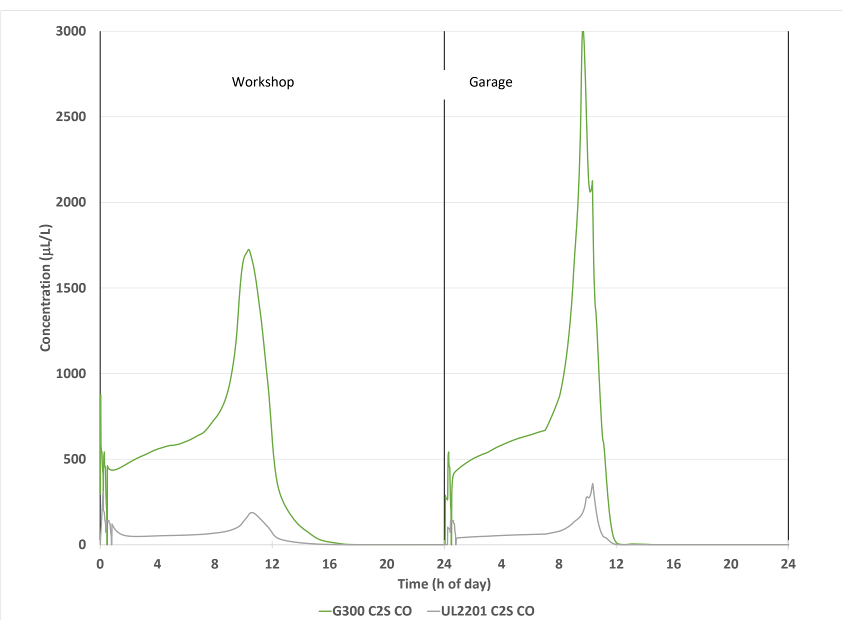
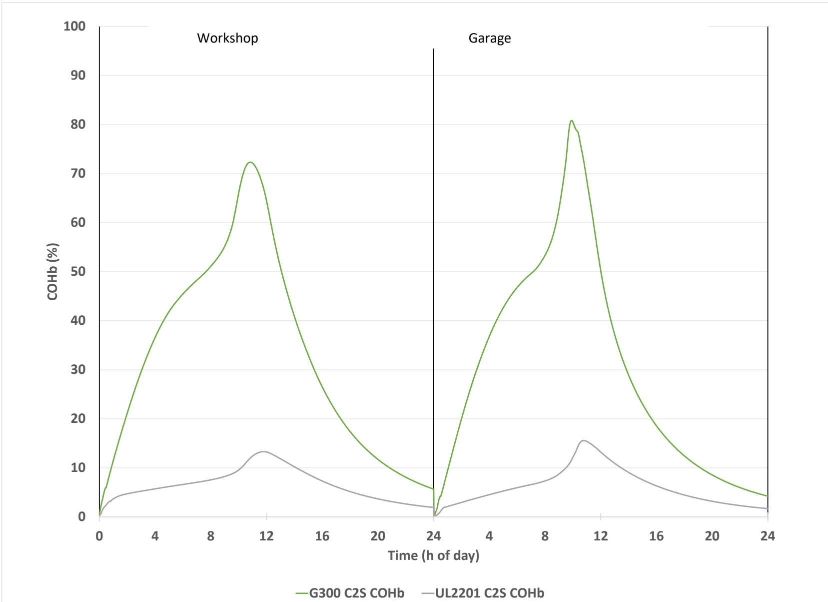


Figure 29 COHb Profiles of Operators in 2 Rooms in GAR3 with PGMA G300 and UL 2201 C2S Generator Initially Started in Workshop per C8 Scenario on April 4



Tables 8.a and 8.b summarize the sample results presented in Figures 1 through 29 for DH45mod, MH1mod and GAR 3 including the time until the first shutoff, the time between the first restart and the second shutoff, the highest operator COHb at the times of those shutoffs, the time until the first occupant reaches 15 % COHb, and the range of peak COHb levels during the 24 hour simulations. In all these sample cases, the predicted operator COHb is well below symptomatic levels at the time of both first and second shutoff and, thus, they are expected to be capable of performing the scenario actions (e.g., restarting a generator, moving a generator, opening or closing a door or window). These results are consistent with the test results reported in NIST TN 2049 and TN 2200. For example, a vast majority of the tests documented in NIST TN 2049 in which the shutoff algorithm shut the generator off resulted in calculated COHb values for simulated occupants throughout the test house at the time the generator shut off that were well below 10 %, which is the lower end of the range where symptom onset is expected. Thus, exposed persons likely would not experience perceptible CO poisoning symptoms (Burton, 1996) at the time of shutoff for these tests. Of those tests in which the calculated occupant COHb later rose to above 15 %, which is in the middle of the range commonly associated with onset of perceptible symptoms such as mild headache and decreased exercise tolerance, the time interval between when the generator shut off and when calculated occupant COHb values reached 15 % typically ranged from about 40 minutes to two or more hours.

Table 8.a Summary of Sample Results for PGMA G300

House	Date	Gen Size	Scenario	PGMA G300					
				Minutes to 1st shutoff	Minutes between 1st restart and 2nd shutoff	Highest COHb among all operators at time of 1st shutoff (%)	Highest COHb among all operators at time of 2nd shutoff (%)	Time until first occupant reaches 15 % COHb (min)	Range of peak COHb levels among all occupants (%)
DH45mod	1-Jan	C2S	B1	3	1	1	4	NA	5 to 7
			B2					60	63 to 65
MH1mod	25-Jul	C1	K1	12	4	3	7	53	15 to 26
			K2					53	34 to 65
GAR 3	4-Apr	C2S	C7	3	5	1	4	101	7 to 16
			C8					69	72 to 81

Table 8.b Summary of Sample Results for UL 2201

House	Date	Gen Size	Scenario	UL 2201					
				Minutes to 1st shutoff	Minutes between 1st restart and 2nd shutoff	Highest COHb among all operators at time of 1st shutoff (%)	Highest COHb among all operators at time of 2nd shutoff (%)	Time until first occupant reaches 15 % COHb (min)	Range of peak COHb levels among all occupants (%)
DH45mod	1-Jan	C2S	B1	16	7	1	3	NA	3 to 4
			B2					NA	12 to 13
MH1mod	25-Jul	C1	K1	17	7	1	3	NA	6 to 10
			K2					177	14 to 29
GAR 3	4-Apr	C2S	C7	12	14	1	3	NA	2 to 6
			C8					629	13 to 16

4. Summary

This simulation study was conducted to evaluate indoor CO exposure to support CPSC staff evaluation of portable generator CO hazard mitigation requirements in two voluntary industry standards. These two ANSI-approved standards are *ANSI/PGMA G300-2018, Safety and Performance of Portable Generators* and *UL 2201, Standard for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition*. Both voluntary standards have requirements for a system that will shut the generator off when specific CO concentrations are present near the generator in addition to other requirements.

These simulations employed the multizone airflow and contaminant transport model CONTAM, which was applied to 40 residential buildings including 37 versions of dwellings drawn from an existing collection that are representative of the U.S. housing stock plus 3 detached garage buildings. Approximately 140,000 individual 24-hour simulations were conducted that covered a range of house layouts and sizes, airtightness levels, weather conditions, generator locations, generator sizes and generator operation scenarios. The simulated generator locations include interior rooms, attached garages, crawlspaces and basements, in the houses that have such spaces. These concentrations were then used to calculate COHb levels for the house's simulated 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 who does not directly interact with the generator.

This report presents sample simulation results of predicted CO concentrations and calculated occupant and operator COHb levels in individual zones for selected scenarios in two of the modeled houses and one of the garages. The sample results presented predict that the requirements in both voluntary standards have the potential to reduce CO exposure and possible health impacts from generator use in many of these scenarios compared to baseline generators without CO hazard mitigation features. For these sample scenarios, the simulations predicted occupant deaths could still occur for the PGMA G300 generators when they are restarted outdoors in a location such that a substantial fraction of the emitted CO still enters the buildings. These limited sample cases should not be interpreted as representing the overall results of this simulation effort nor as predicting the outcome of any specific real-world incident. These simulation results will be used by CPSC staff along with the weighting factors and other information to evaluate the effectiveness of the requirements contained in each voluntary standard.

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Appendix A. House Characteristics

This appendix contains three tables that define the dwellings in the NIST Suite of Homes, with one table for each housing type: detached (A1), attached (A2) and manufactured home (A3). The dwelling definitions in the table are in terms of the variables discussed in detail in the report that defines these homes (Persily et al. 2006). Note that not all of these models were used in this simulation study and that some of the models were modified to better fit the houses in the CPSC CO incident database. See Appendix B for the details of which houses were used and what modifications were made to the models.

Table A1. Detached Homes (83 total)

Key for Table A1:

# of floors: 1 = one story; 2 = two story
Floor area: 1 = less than 148.5 m^2 (1,599 ft^2); 2 = 148.6 m^2 to 222.9 m^2 (1,600 ft^2 to 2,399 ft^2); 3 = 223.0 m^2 (2,400 ft^2) or more
Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer
Foundation: 1 = concrete slab; 2 = crawl space; 3 = finished basement, 4 = unfinished basement
Garage: 1 = none; 2 = attached garage
Forced Air: 1 = other; 2 = central system present

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Foundation	Garage	Forced -air	Bedrooms	Full baths	Half baths	Other	
DH-1	1	2	3	1	2	2	3	2	0	3	DH-B(1)
DH-2	1	1	2	3	2	2	3	1	0	3	DH-A(8)
DH-3	1	1	2	2	1	1	2	1	0	2	DH-A(1)
DH-4	1	1	2	2	2	2	3	1	0	3	DH-A(7)
DH-5	1	1	3	1	2	2	3	2	0	3	DH-A(2)
DH-6	2	1	1	3	2	2	3	1	0	3	DH-D(3)
DH-7	1	2	2	3	2	2	3	2	0	4	DH-B(5)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Foundation	Garage	Forced -air	Bedrooms	Full baths	Half baths	Other	
DH-8	1	1	2	1	2	2	3	2	0	3	DH-A(2)
DH-9	2	1	2	3	2	2	3	1	0	3	DH-D(3)
DH-10	2	2	3	3	2	2	4	2	1	4	DH-E(8)
DH-11	1	1	2	2	2	1	3	1	0	3	DH-A(7)
DH-12	2	3	3	3	2	2	4	2	1	5	DH-F(4)
DH-13	1	2	2	2	2	2	3	2	0	3	DH-B(1)
DH-14	2	2	1	3	2	2	3	1	1	4	DH-E(5)
DH-15	2	3	4	3	2	2	4	3	1	5	DH-F(5)
DH-16	1	1	2	2	1	2	3	1	0	3	DH-A(7)
DH-17	2	2	2	3	2	2	3	2	1	4	DH-E(6)
DH-18	2	1	1	3	1	2	3	1	0	3	DH-D(3)
DH-19	1	1	3	3	2	2	3	1	0	3	DH-A(8)
DH-20	2	2	1	3	2	1	4	1	0	4	DH-E(7)
DH-21	1	1	2	1	1	2	3	1	0	3	DH-A(7)
DH-22	2	3	3	1	2	2	4	3	1	5	DH-F(1)
DH-23	2	1	1	3	2	1	3	1	0	3	DH-D(3)
DH-24	2	2	3	1	2	2	4	2	1	4	DH-E(3)
DH-25	1	1	2	3	2	1	3	1	0	3	DH-A(8)
DH-26	1	1	2	1	1	1	2	1	0	2	DH-A(1)
DH-27	1	1	2	3	1	2	3	1	0	3	DH-A(8)
DH-28	2	3	4	1	2	2	4	3	1	4	DH-F(2)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Foundation	Garage	Forced -air	Bedrooms	Full baths	Half baths	Other	
DH-29	1	1	1	2	1	1	2	1	0	3	DH-A(3)
DH-30	1	2	3	2	2	2	3	2	0	3	DH-B(1)
DH-31	1	1	3	2	2	2	3	2	0	3	DH-A(2)
DH-32	1	1	4	1	2	2	3	2	0	2	DH-A(6)
DH-33	1	3	3	1	2	2	4	2	0	4	DH-C(1)
DH-34	1	1	3	1	1	2	3	1	0	3	DH-A(7)
DH-35	1	2	2	1	2	2	3	2	0	3	DH-B(1)
DH-36	2	2	4	1	2	2	4	2	1	4	DH-E(3)
DH-37	1	2	3	3	2	2	3	2	1	3	DH-B(4)
DH-38	1	1	3	2	1	2	3	1	0	3	DH-A(7)
DH-39	1	2	2	2	1	2	3	2	0	3	DH-B(1)
DH-40	2	2	3	2	2	2	4	2	1	4	DH-E(3)
DH-41	2	2	1	3	1	2	3	1	0	4	DH-E(1)
DH-42	1	1	3	2	1	1	3	1	0	2	DH-A(4)
DH-43	2	2	2	3	2	1	4	2	0	4	DH-E(2)
DH-44	1	1	1	3	2	2	2	1	0	3	DH-A(9)
DH-45	2	2	3	4	2	1	4	2	1	4	DH-E(3)
DH-46	1	1	2	1	2	1	2	1	0	2	DH-A(1)
DH-47	1	1	3	2	2	1	3	1	0	3	DH-A(7)
DH-48	1	1	4	2	1	2	3	2	0	3	DH-A(2)
DH-49	1	1	2	3	1	1	3	1	0	3	DH-A(8)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Foundation	Garage	Forced -air	Bedrooms	Full baths	Half baths	Other	
DH-50	2	1	1	3	1	1	3	1	0	3	DH-D(3)
DH-51	2	3	3	2	2	2	4	2	1	4	DH-F(3)
DH-52	2	3	1	4	2	2	4	2	1	4	DH-F(3)
DH-53	1	2	3	1	1	2	3	2	0	3	DH-B(1)
DH-54	1	1	1	2	1	2	2	1	0	3	DH-A(3)
DH-55	1	1	4	2	2	2	3	2	0	2	DH-A(6)
DH-56	2	1	2	3	1	2	3	1	0	3	DH-D(3)
DH-57	1	2	2	2	2	1	3	2	0	4	DH-B(3)
DH-58	2	2	4	3	2	2	3	2	1	4	DH-E(6)
DH-59	2	3	2	3	2	1	4	2	1	5	DH-F(4)
DH-60	1	1	3	4	2	1	3	1	0	3	DH-A(7)
DH-61	1	1	1	4	1	2	2	1	0	2	DH-A(1)
DH-62	2	3	1	3	2	1	4	2	1	5	DH-F(4)
DH-63	2	1	2	4	2	1	3	1	1	3	DH-D(4)
DH-64	1	2	4	1	2	2	3	2	0	3	DH-B(1)
DH-65	1	1	1	4	1	1	2	1	0	3	DH-A(3)
DH-66	1	2	2	1	2	1	3	1	0	3	DH-B(2)
DH-67	1	1	1	2	2	2	3	1	0	3	DH-A(7)
DH-68	2	1	2	3	1	1	3	1	0	3	DH-D(3)
DH-69	2	3	3	4	2	1	4	2	1	4	DH-F(3)
DH-70	1	1	3	1	1	1	2	1	0	2	DH-A(1)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Foundation	Garage	Forced -air	Bedrooms	Full baths	Half baths	Other	
DH-71	2	1	3	1	2	2	3	2	1	3	DH-D(1)
DH-72	1	2	1	4	2	2	3	2	0	4	DH-B(3)
DH-73	2	1	3	4	2	2	3	2	0	4	DH-D(2)
DH-74	1	3	3	4	2	2	3	2	1	5	DH-C(2)
DH-75	3	2	3	1	2	2	4	2	1	3	DH-G(1)
DH-76	1	1	4	4	2	2	3	2	1	3	DH-A(5)
DH-77	3	2	3	4	2	2	3	2	1	4	DH-G(2)
DH-78	1	1	3	1	2	1	3	1	0	3	DH-A(7)
DH-79	1	2	3	2	1	2	3	2	0	3	DH-B(1)
DH-80	1	2	2	4	1	2	3	2	0	4	DH-B(3)
DH-81	2	2	1	4	1	1	3	2	0	4	DH-E(4)
DH-82	1	2	2	4	2	1	3	2	0	3	DH-B(1)
DH-83	1	1	3	3	1	2	3	1	0	3	DH-A(8)

Table A2. Attached Homes (53 total)

Key for Table A2:

# of floors: 1 = one story; 2 = two story

Floor area: 1 = fewer than 148.5 m^2 (1,599 ft^2); 2 = 148.6 m^2 to 222.9 m^2 (1,600 ft^2 to 2,399 ft^2); 3 = 223.0 m^2 (2,400 ft^2) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Foundation: 1 = concrete slab; 2 = crawl space; 3 = finished basement, 4 = unfinished basement

Garage: 1 = none; 2 = attached garage

Forced Air: 1 = other; 2 = central system present

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Found -ation	Garage	Forced -air	Bed-rooms	Full baths	Half baths	Other	
AH-1	2	1	1	3	1	2	2	1	0	3	AH-C(11)
AH-2	2	1	3	1	1	2	2	2	1	3	AH-C(7)
AH-3	1	1	3	1	1	2	2	1	0	2	AH-A(2)
AH-4	1	1	3	1	2	2	2	1	0	3	AH-A(3)
AH-5	2	1	2	3	1	1	3	1	0	3	AH-C(15)
AH-6	2	1	3	1	2	2	2	2	1	3	AH-C(4)
AH-7	2	1	3	3	1	2	3	2	1	3	AH-C(16)
AH-8	1	1	2	1	1	1	2	1	0	2	AH-A(2)
AH-9	2	1	1	3	2	1	3	2	1	4	AH-C(17)
AH-10	2	1	1	3	1	1	2	1	0	3	AH-C(11)
AH-11	2	1	2	3	1	2	3	1	0	3	AH-C(15)
AH-12	1	1	4	1	2	2	2	1	0	2	AH-A(1)
AH-13	2	1	2	1	1	2	2	2	1	2	AH-C(6)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Found -ation	Garage	Forced -air	Bed-rooms	Full baths	Half baths	Other	
AH-14	1	1	2	1	1	2	2	1	0	2	AH-A(2)
AH-15	2	2	3	1	2	2	3	1	0	3	AH-D(1)
AH-16	2	1	1	2	1	1	2	1	0	2	AH-C(2)
AH-17	1	1	2	2	1	1	1	1	0	2	AH-A(5)
AH-18	2	1	3	1	1	1	2	1	0	2	AH-C(2)
AH-19	2	1	2	1	2	2	2	1	0	3	AH-C(3)
AH-20	2	1	1	4	2	2	3	1	0	3	AH-C(12)
AH-21	2	2	1	4	2	2	3	1	0	3	AH-D(4)
AH-22	2	1	3	1	2	1	2	2	1	2	AH-C(1)
AH-23	2	1	3	4	2	2	3	2	1	3	AH-C(13)
AH-24	2	2	1	3	1	1	3	1	0	3	AH-D(5)
AH-25	1	1	2	1	2	1	2	1	0	2	AH-A(1)
AH-26	2	1	4	1	1	2	3	2	1	2	AH-C(5)
AH-27	2	2	1	4	2	1	3	1	0	5	AH-D(6)
AH-28	2	2	3	3	1	2	3	2	1	3	AH-D(7)
AH-29	2	2	4	1	2	2	2	1	0	3	AH-D(2)
AH-30	1	1	3	2	2	1	2	1	0	2	AH-A(1)
AH-31	1	1	2	3	1	2	1	1	0	3	AH-A(7)
AH-32	1	1	2	4	2	2	2	1	0	3	AH-A(4)
AH-33	1	1	1	3	1	2	1	1	0	2	AH-A(6)
AH-34	2	3	3	3	1	2	4	3	2	4	AH-E(1)

House Number	# of Floors	House Variable					# of Rooms				Floor plan
		Floor area	Year Built	Found -ation	Garage	Forced -air	Bed-rooms	Full baths	Half baths	Other	
AH-35	2	1	2	1	1	1	2	1	0	2	AH-C(2)
AH-36	1	1	2	1	2	2	2	1	0	2	AH-A(1)
AH-37	1	1	2	2	2	1	2	1	0	2	AH-A(1)
AH-38	1	1	1	4	2	1	2	1	0	3	AH-A(4)
AH-39	1	1	4	1	1	2	2	1	0	2	AH-A(2)
AH-40	2	1	1	1	1	1	1	1	0	1	AH-C(8)
AH-41	2	2	2	3	1	2	3	2	1	4	AH-D(8)
AH-42	2	1	2	4	2	2	2	1	0	3	AH-C(10)
AH-43	1	2	3	1	2	2	3	1	0	3	AH-B(1)
AH-44	1	1	3	2	1	1	1	1	0	2	AH-A(5)
AH-45	1	1	2	2	1	2	2	1	0	2	AH-A(2)
AH-46	2	1	2	2	1	2	3	1	0	3	AH-C(9)
AH-47	1	1	3	4	2	2	3	2	1	3	AH-A(8)
AH-48	2	1	3	2	1	2	2	2	1	2	AH-C(6)
AH-49	1	1	1	2	2	1	2	1	0	2	AH-A(1)
AH-50	2	1	3	2	2	2	2	2	1	3	AH-C(4)
AH-51	2	1	3	3	1	1	2	1	0	3	AH-C(11)
AH-52	2	2	3	1	1	2	3	2	1	4	AH-D(3)
AH-53	1	1	4	2	1	2	2	1	0	2	AH-A(2)

TABLE A3. Manufactured Homes

Key for Table A3:

Floor area: 1 = less than 148.5 m^2 (1,599 ft^2); 2 = 148.6 m^2 (1,600 ft^2) or more

Year Built: 1 = before 1940; 2 = 1940-69; 3 = 1970-89; 4 = 1990 and newer

Forced Air: 1 = other; 2 = central system present

House Number	Floor area	Year Built	Forced-air	# of Bedrooms	# of Baths	# of Half baths	# of Other rooms	Floor plan
MH-1	1	3	2	2	1	0	2	MH-B(1)
MH-2	1	4	2	3	2	0	2	MH-A(1)
MH-3	1	3	1	2	1	0	2	MH-B(1)
MH-4	1	2	2	2	1	0	2	MH-B(1)

Appendix B. Model Modifications and Source Locations for Each Building

Table B1 describes, for the 40 buildings modeled in this simulation study, the modifications made to each and shows the locations of the generator simulated for each building.

House number	Description of any changes to original project file (prior to simulations for NIST TN 1925), excluding windows and door added per columns to the right.	Wall(s) with kitchen door (open 10 cm and fully) and kitchen window (open fully) added	Wall with bedroom, basement or workshop window (open fully or 5 cm) added	Wall with garage bay door added	Floor plan	Source locations		
						Garage	Basement/ crawlspace	Interior room(s)
DH-1	n.a.	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-B(1)	GAR	n.a.	Kit
DH-2	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-A(8)	GAR	Bed1	Kit
DH-2mod	Bedroom 1 was converted to an integral garage.	back (top of sketchpad)	back (top of sketchpad)	front (bottom of sketchpad)	DH-A(8)	GAR	Bed2	Kit
DH-3	n.a.	back (top of sketchpad)	back (top of sketchpad)	n.a.	DH-A(1)	n.a.	Crawl	Kit, Bed1
DH-5	n.a.	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-A(2)	GAR	n.a.	Kit
DH-7	n.a.	back (top of sketchpad)	back (top of sketchpad)	front (bottom of sketchpad)	DH-B(5)	GAR	Bed3	Kit
DH-8	n.a.	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-A(2)	GAR	n.a.	Kit
DH-10	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-E(8)	GAR	Den	Kit
DH-12	n.a.	back (top of sketchpad)	back (top of sketchpad)	front (bottom of sketchpad)	DH-F(4)	GAR	Bed4	Kit
DH-19mod	Bedroom 1 was converted to an integral garage.	back (top of sketchpad)	back (top of sketchpad)	front (bottom of sketchpad)	DH-A(8)	GAR	Bed2	Kit
DH-21	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(7)	n.a.	n.a.	Kit, Bed3

DH-21mod	Air leakage was modified based on year built and floor area per Table 1 and Equation 1 of Persily et.al (2013) to represent the oldest category of construction (before 1940).	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(7)	n.a.	n.a.	Kit, Bed3
DH-24mod	The side attached garage was deleted and air leakage was modified based on year built and floor area to represent the oldest category of construction (before 1940).	left (left side of sketchpad)	back (top of sketchpad)	n.a.	DH-E(3)	n.a.	n.a.	Kit, Bed1
DH-27	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(8)	n.a.	Bed1	Kit
DH-32	n.a.	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-A(6)	GAR	n.a.	Kit
DH-33mod	Air leakage was modified based on year built and floor area to represent the oldest category of construction (1990 and newer).	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-C(1)	GAR	n.a.	Kit
DH-34	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(7)	n.a.	n.a.	Kit, Bed3
DH-41	n.a.	Kitchen door is on left (left side of sketchpad). Kitchen window is on back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-E(1)	n.a.	Den	Kit
DH-44	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-A(9)	GAR	Bed1	Kit
DH-45	The dining room and kitchen were switched.	front (bottom of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-E(3)	GAR	Unfinished basement	Kit

DH-45mod	Three modifications were made to the original DH-45. Part of the unfinished basement was converted to an integral garage and air leakage was modified based on year built and floor area to represent the newest category of construction (1990 and newer); these 2 modifications were made for NIST TN 1925. The dining room and kitchen were switched for this study.	Kitchen door is on left (left side of sketchpad). Kitchen window is on front (bottom of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-E(3)	GAR	Unfinished basement	Kit
DH-52mod	Air leakage was modified based on year built and floor area to represent the oldest category of construction (1990 and newer).	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-F(3)	GAR	Unfinished basement	Kit
DH-56	n.a.	Kitchen door is on left (left side of sketchpad). Kitchen window is on back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-D(3)	n.a.	Bed2	Kit
DH-60	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-A(7)	GAR	Unfinished basement	Kit
DH-60mod	Integral garage was added and air leakage was modified based on year built and floor area to represent the second oldest category of construction (1940 to 1969).	back (top of sketchpad)	front (bottom of sketchpad)	front (bottom of sketchpad)	DH-A(7)	GAR	Unfinished basement	Kit
DH-61mod	Air leakage was modified based on year built and floor area to represent the second	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(1)	n.a.	Unfinished basement	Kit

	oldest category of construction (1940 to 1969).							
DH-61	n.a.	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-A(1)	n.a.	Unfinished basement	Kit
DH-63mod1	The side attached garage was deleted and air leakage was modified based on year built and floor area to represent the oldest category of construction (before 1940).	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-D(4)	n.a.	Unfinished basement	Kit
DH-63mod2	The side attached garage was deleted.	back (top of sketchpad)	front (bottom of sketchpad)	n.a.	DH-D(4)	n.a.	Unfinished basement	Kit
DH-64	n.a.	back (top of sketchpad)	n.a.	front (bottom of sketchpad)	DH-B(1)	GAR	n.a.	Kit
DH-81	n.a.	left (left side of sketchpad)	front (bottom of sketchpad)	n.a.	DH-E(4)	n.a.	Unfinished basement	Kit
MH-1	n.a.	back (top of sketchpad)	Back (top of sketchpad)	n.a.	MH-B(1)	n.a.	Crawl	Kit, Bed1
MH-1mod	MH1 was modified to be smaller with 78 m^2 (840 ft^2) of floor area. The air leakage was modified based on year built and floor area to represent the oldest category of construction (before 1940).	back (top of sketchpad)	back (top of sketchpad)	n.a.	n.a.	n.a.	Crawl	Kit, Bed1
AH-3mod	The kitchen was moved to the front, upper right corner as viewed in both the floorplan and sketchpad views so that the front door will be the exterior door into the kitchen.	front (right side of sketchpad)	back (left side of sketchpad)	n.a.	AH-A(2)	n.a.	n.a.	Kit, Bed1

AH-10	n.a.	back (left side of sketchpad)	front (right side of sketchpad)	n.a.	AH-C(11)	n.a.	Den	Kit
AH-34mod	First floor living room was converted to an integral garage.	back (left side of sketchpad)	back (left side of sketchpad)	front (right side of sketchpad)	AH-E(1)	GAR	Bed3	Kit
AH-21mod	n.a.	back (left side of sketchpad)	back (left side of sketchpad)	front (right side of sketchpad)	AH-D(4)	GAR	Unfinished basement	Kit
GAR-1	n.a.	n.a.	n.a.	front (bottom of sketchpad)	n.a.	GAR	n.a.	n.a.
GAR-2	n.a.	n.a.	n.a.	front (bottom of sketchpad)	n.a.	GAR	n.a.	n.a.
GAR-3	n.a.	n.a.	left (left side of sketchpad)	front (bottom of sketchpad)	n.a.	GAR	n.a.	Shop

Appendix C. Scenario Tables

The tables in Appendix C detail scenarios that were 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 shuts off a second time.

Table 1.a: Information for all tables

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

Notes:

1. These weights, which CPSC staff will use in their effectiveness analysis, relates to CPSC's incident data in which staff found that approximately one-quarter of the fatalities happened in multiple-fatality incidents.

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

	Action
1	Collateral person does not change zones, unless the generator is moved by the operator into the room they were 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 positions.

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 bay door is not opened.
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 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 positions.

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 outside, 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 positions.

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 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		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.	0.9	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	
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.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

Appendix D. CONTAM Simulations of Extended Generator Run Time Supplementing NIST Technical Note 2202

The purpose of this Appendix is to document additional simulations that staff of the U.S. National Institute of Standards and Technology (NIST) performed, at the request of staff of the U.S. Consumer Product Safety Commission (CPSC), to supplement the simulations that NIST performed and reported 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*. These additional simulations used a 15 % longer run time (referred to as "extended run time") for UL 2201 generators than the run times provided in Table 3 of TN 2202 in twelve of the structures documented in TN 2202.

Background

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* (Emmerich et al. 2022) describes a simulation study conducted to evaluate indoor CO exposure to support CPSC staff evaluation of portable generator CO hazard mitigation requirements in two voluntary industry standards. These two ANSI-approved standards are *ANSI/PGMA G300-2018, Safety and Performance of Portable Generators* and *UL 2201, Standard for Carbon Monoxide (CO) Emission Rate of Portable Generators, Second Edition*. Both voluntary standards have requirements for a system that will shut the generator off when specific CO concentrations are present near the generator in addition to other requirements.

These simulations employed the multizone airflow and contaminant transport model CONTAM (Dols and Polidoro 2015), which was applied to 40 residential buildings including 37 versions of dwellings drawn from an existing collection (Persily et al. 2006) that are representative of the U.S. housing stock plus 3 detached garage buildings. Approximately 140,000 individual 24-hour simulations were conducted that covered a range of house layouts and sizes, airtightness levels, weather conditions, generator locations, generator sizes and generator operation scenarios. The simulated generator locations include interior rooms, attached garages, crawlspaces and basements, in the houses that have such spaces. These concentrations were then used to calculate carboxyhemoglobin (COHb) levels for the house's simulated 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 who does not directly interact with the generator.

Simulation Method

Apart from generator run times, these additional simulations used the same simulation method along with all of the same building models, generator characteristics, weather conditions, and operation scenarios as described in TN 2202. Table 1 provides the extended run times for each generator size used in these additional simulations.

Table 1. Generator Run times Used in Simulations

Generator Size Category	Extended Run Time for UL2201 generators (h)
Handheld (HH)	9.2
Class 1 (C1)	10.35
Class 2 single cylinder (C2S)	11.5
Class 2 twin cylinder (C2T)	10.35

The UL 2201 generators with extended run times were simulated operating in and outside of 12 of the structures listed in TN2202 including: MH1mod, DH45mod, DH21, DH61mod, DH8, DH3, DH34, DH64, DH7, DH63mod1, and garages GAR2 and GAR3.

Sample Results

Sample results of three of the structures with the generator running the extended run time are presented in the following figures. The graphs in the figures also include the results from the same scenario where the generator ran the number of hours under the simulations in TN 2202.

DH45mod (mid-sized detached house with basement and integral garage)

Figure 1: CO exposure profiles of operators in 4 rooms in DH45(mod) with UL 2201 C2S generator and same generator with 15 % longer run time, initially started in kitchen and restarted in kitchen, then restarted a second time outside the kitchen, per B2 scenario on January 1. Note that all of the scenarios are described in detail in TN 2202.

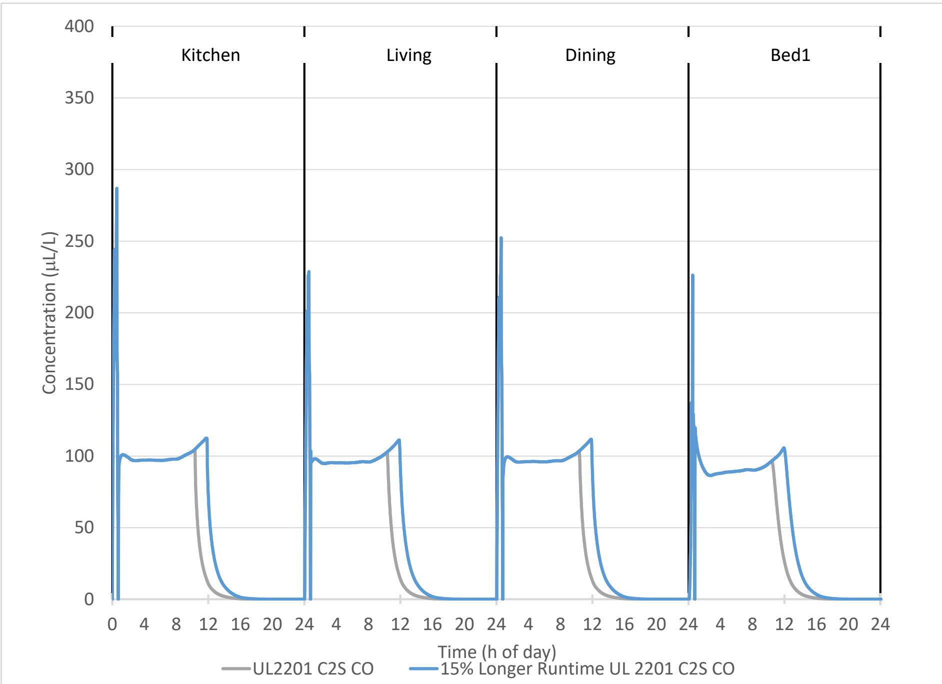
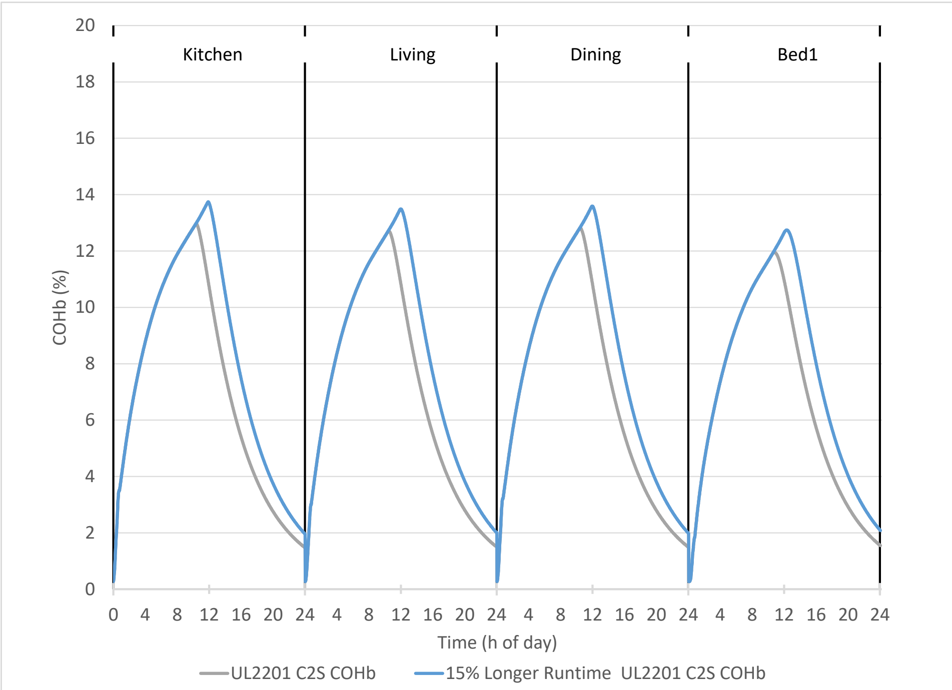


Figure 2: COHb profiles of Operators in 4 rooms in DH45(mod) with UL 2201 C2S generator and same generator with 15 % longer run time, initially started in kitchen and restarted in kitchen, then restarted a second time outside the kitchen, per B2 scenario on January 1.



MH1mod (small manufactured house with crawlspace)

Figure 3: CO exposure profiles of operators in 3 Rooms in MH1(mod) with UL 2201 C1 generator and same generator with 15 % longer run time, initially started and restarted in bedroom 1 with the generator exhaust jet oriented out of the door to the house interior, then restarted a second time outside with CO entering the kitchen, per scenario K2, on July 25.

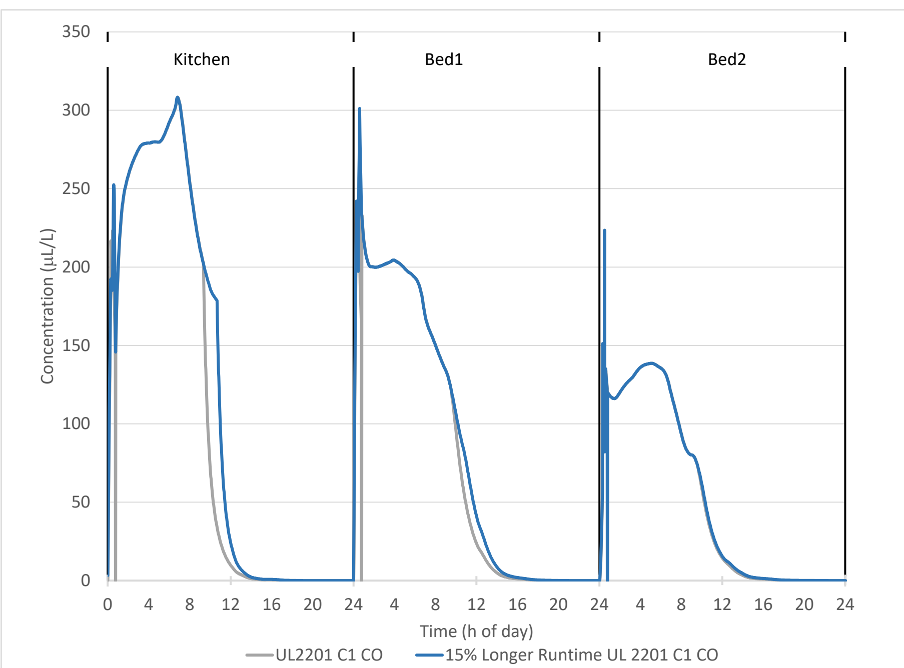
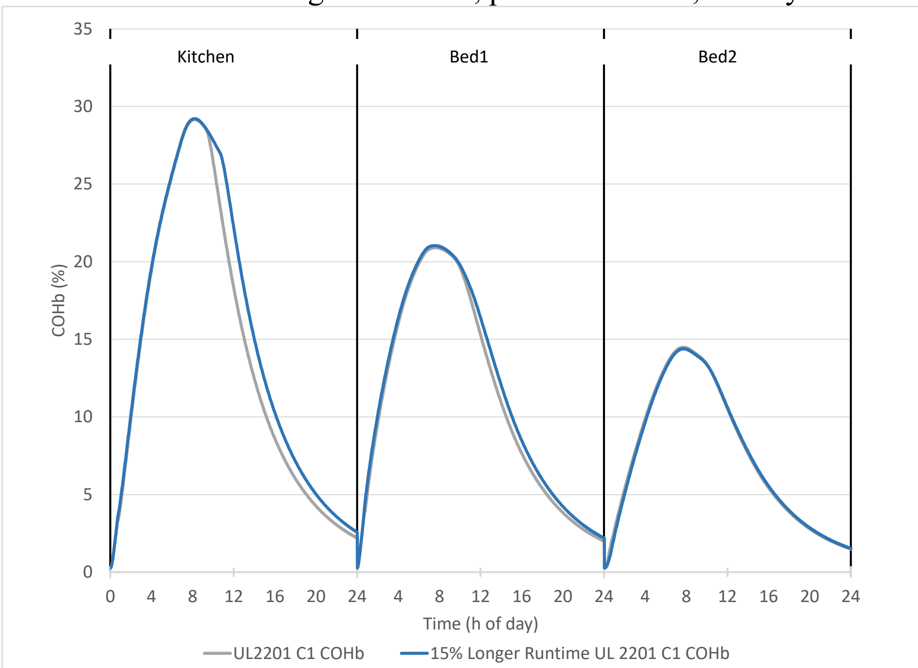


Figure 4: COHb profiles of operators in 3 Rooms in MH1(mod) with UL 2201 C1 generator and same generator with 15 % longer run time, initially started and restarted in bedroom 1 with the generator exhaust jet oriented out of the door to the house interior, then restarted a second time outside with CO entering the kitchen, per scenario K*2*, on July 25.



GAR3 (large garage with workshop)

Figure 5: CO exposure profiles of operators in GAR3 with UL 2201 C2S generator and same generator with 15 % longer run time, initially started in workshop room then restarted in open garage, per scenario C8, on April 4.

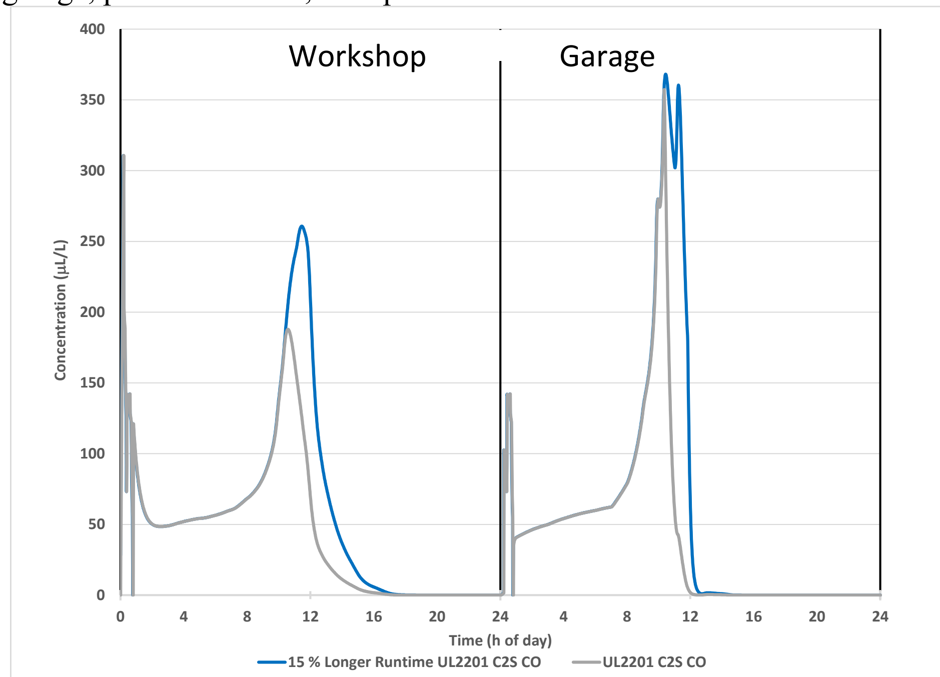
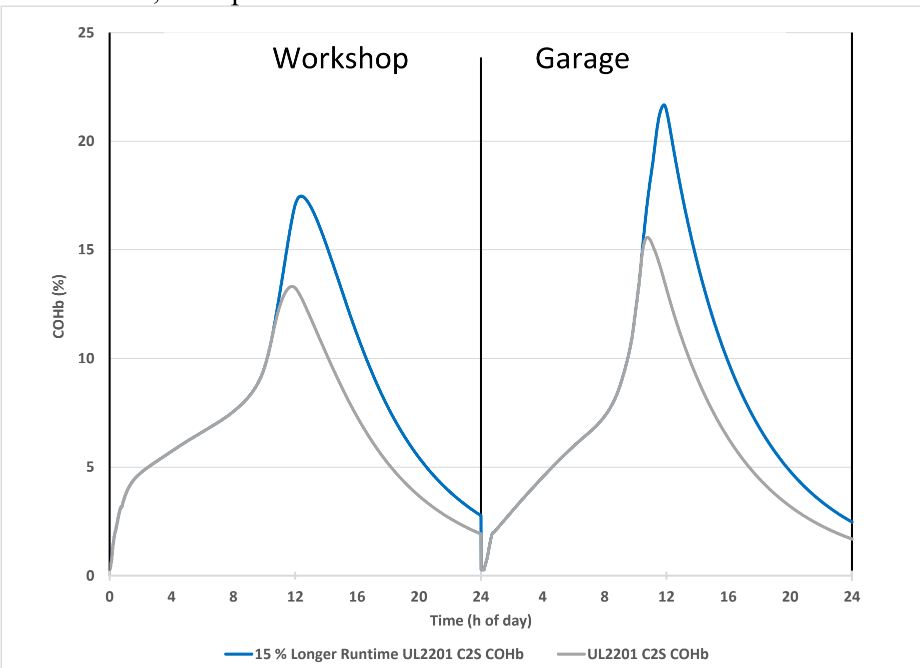


Figure 6: COHb profiles of operators in GAR3 with UL 2201 C2S generator and same generator with 15 % longer run time, initially started in workshop room then restarted in open garage, per scenario C8, on April 4.



Summary

In these sample scenarios, and referring to the criteria that CPSC staff provided in NIST TN 2202 as to what COHb level aligns with different levels of injuries, no one who was hospitalized from the original run time became a fatality with the extended run time. Furthermore, no one who had a CO exposure from the original run time that prompted them to seek medical evaluation but was not hospitalized progressed into an injury requiring hospitalization with the extended run time. Only the operator in the workshop of GAR3 would likely seek medical evaluation but would not be hospitalized with the extended run time compared to not being symptomatic with the original run time. These limited sample cases should not be interpreted as representing the overall results of this additional simulation effort nor as predicting the outcome of any specific real-world incident. These simulation results will be used by CPSC staff to estimate the impact of an additional 15 % run time on all UL 2201 generators in all 40 structures that were modeled in NIST TN 2202.

Acknowledgements

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