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

This document has been electronically approved and signed.

**DATE:** July 31, 2019

**BALLOT VOTE SHEET**

**TO:** The Commission
Alberta E. Mills, Secretary

**THROUGH:** Mary T. Boyle, Executive Director
Patricia M. Hanz, General Counsel

**FROM:** Patricia M. Pollitzer, Assistant General Counsel
David M. DiMatteo, Attorney, OGC

**SUBJECT:** Draft Federal Register Notice: Draft Advance Notice of Proposed Rulemaking: "Performance Requirements for Residential Gas Furnaces and Boilers"

BALLOT VOTE DUE: Wednesday, August 7, 2019

Staff is forwarding to the Commission a briefing package recommending that the agency publish an advance notice of proposed rulemaking (ANPR) concerning the risk of injuries and death associated with residential gas furnaces and boilers. The Office of the General Counsel is providing for the Commission's consideration the attached draft ANPR, which seeks comments and commences rulemaking under the Consumer Product Safety Act (15 U.S.C. §§ 2051-2089).

Please indicate your vote on the following options:

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

________________________________ ______________________
(Signature) (Date)

II. Approve publication of the attached notice in the *Federal Register*, with the specified changes.

______________________________ (Signature)  ________________ (Date)

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

______________________________ (Signature)  ________________ (Date)

IV. Take other action specified below.

______________________________ (Signature)  ________________ (Date)

Attachment: Draft *Federal Register* Notice Advance Notice of Proposed Rulemaking: "Performance Requirements for Residential Gas Furnaces and Boilers"

[BILLING CODE 6355-01-P]

**CONSUMER PRODUCT SAFETY COMMISSION**

**16 CFR Chapter II**

**[Docket No. CPSC-2019-XXXX]**

**Performance Requirements for Residential Gas Furnaces and Boilers; Advance Notice of Proposed Rulemaking**

**AGENCY:** Consumer Product Safety Commission.

**ACTION:** Advance notice of proposed rulemaking.

**SUMMARY:** The Consumer Product Safety Commission (Commission or CPSC) is considering developing a rule to address the risk of injury and death associated with carbon monoxide (CO) production and leakage from residential gas furnaces and boilers. This advance notice of proposed rulemaking (ANPR) initiates a rulemaking proceeding under the Consumer Product Safety Act (CPSA). We invite comments concerning the risk of injury associated with CO production and leakage from residential gas furnaces and boilers, the alternatives discussed in this notice, and other possible alternatives for addressing the risk. We also invite interested parties to submit existing voluntary standards or a statement of intent to modify or develop a voluntary standard that addresses the risk of injury described in this notice.

**DATES:** Submit comments by [**insert 60 days from date of publication in the FEDERAL REGISTER**].

**ADDRESSES:** You may submit comments, identified by Docket No. CPSC-2019-XXXX, by any of the following methods:

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

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

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

*Docket*: For access to the docket to read background documents or comments received, go to: www.regulations.gov, and insert the docket number CPSC-2019-XXXX, into the "Search" box, and follow the prompts.

**FOR FURTHER INFORMATION CONTACT:** Ronald A. Jordan, Project Manager, Directorate for Engineering Sciences, U.S. Consumer Product Safety Commission, 5 Research Place, Rockville, MD 20850; telephone: (301) 987-2219; e-mail: rjordan@cpsc.gov.

**SUPPLEMENTARY INFORMATION:**

## I. Background

The Commission is aware of numerous injuries and deaths resulting from CO poisoning caused by residential gas furnaces and boilers. Gas-fired central furnaces and boilers historically have been among the leading causes of non-fire CO poisoning deaths associated with consumer products. To address this risk, CPSC staff reviewed incident data for residential gas furnaces and boilers and determined that residential gas furnaces and boilers were involved in a significant number of fatalities and injuries from CO poisoning. From 2013 to 2015, there were 57 deaths (average 19 deaths per year) related to residential gas furnaces and boilers reported to CPSC. In addition, an estimated 7,590 injuries related to CO poisoning associated with residential gas furnaces and boilers were reported to CPSC from 2013 to 2015.

In the late 1980s, the voluntary standards for a variety of gas appliances, including gas furnaces and boilers, were revised to address some of the operating, installation, or usage conditions of the products that could result in hazards, such as fire, explosion, and leakage of CO into the living space. Despite revisions to the voluntary standards that addressed some CO hazards, gas furnaces and boilers continue to be the second leading cause of CO deaths (portable generators are the leading cause of CO deaths[1] among all consumer products) and the leading cause among all heating systems. CPSC staff has advocated for more effective performance requirements for gas furnaces and boilers since 1993 to protect consumers from CO hazards that were not addressed by the voluntary standards for these products.

Starting in 2000, CPSC staff sought to address CO hazards at the source of production (*i.e.*, in the heat exchanger and flue passageways) in these appliances by working with voluntary standards organizations proposing[2] that that they add "CO shutoff/response" provisions to the voluntary standards. Despite repeated requests from CPSC staff for the U.S. standards development organizations (SDO) to address the CO risk at the source of production in gas

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[1] *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products. 2015 Annual Estimates,* Hnatov, M. December 2018.

[2] Jordan, R., CO shutoff/response proposal letter Canadian Standards Association International, CPSC. November 2000.

appliances, and the existence of the Japanese and European performance requirements for CO and combustion product sensors, voluntary standards in the United States have not adopted similar requirements to address the CO hazard. The rationale U.S. SDOs cited for not adopting similar requirements is that the CO and combustion product-sensing devices needed to implement the requirements must have a 20-year lifespan and that no such devices are currently available.

The Commission is considering developing a mandatory standard to reduce the risk of death and injury associated with CO production and leakage from residential gas furnaces and boilers. CPSC staff prepared a briefing package to describe the products at issue, further assess the relevant incident data, examine relevant voluntary standards, and discuss options for addressing the risk associated with residential gas furnaces and boilers. That briefing package is available at: [**Insert link**].

## II. Relevant Statutory Provisions

To address the risk of injury associated with CO production and leakage from residential gas furnaces and boilers, the Commission is considering developing a mandatory safety standard. The rulemaking falls under the CPSA. 15 U.S.C. 2051-2089. Under section 7 of the CPSA, the Commission may issue a consumer product safety standard if the requirements of the standard are "reasonably necessary to prevent or reduce an unreasonable risk of injury associated with [a] product." *Id.* 2056(a). The safety standard may consist of performance requirements or requirements for warnings and instructions. *Id*. However, if there is a voluntary standard that would adequately reduce the risk of injury the Commission seeks to address, and there is likely to be substantial compliance with that standard, then the Commission must rely on the voluntary standard, instead of issuing a mandatory standard. *Id*. 2056(b)(1). To issue a mandatory standard under section 7, the Commission must follow the procedural and substantive requirements in section 9 of the CPSA. *Id*. 2056(a).

Under section 9 of the CPSA, the Commission may begin rulemaking by issuing an ANPR. *Id*. 2058(a). The ANPR must identify the product and the nature of the risk of injury associated with it; summarize the regulatory alternatives the Commission is considering; and include information about any relevant existing standards, and why the Commission preliminarily believes those standards would not adequately reduce the risk of injury associated with the product. The ANPR also must invite comments concerning the risk of injury and regulatory alternatives and invite the public to submit existing standards or a statement of intent to modify or develop a voluntary standard to address the risk of injury. *Id.* 2058(a).

After publishing an ANPR, the Commission may proceed with rulemaking by reviewing the comments received in response to the ANPR and publishing a notice of proposed rulemaking (NPR). An NPR must include the text of the proposed rule, alternatives the Commission is considering, a preliminary regulatory analysis describing the costs and benefits of the proposed rule and the alternatives, and an assessment of any submitted standards. *Id*. 2058(c). The Commission would then review comments on the NPR and decide whether to issue a final rule, along with a final regulatory analysis.

## III. The Product

The ANPR covers residential, gas-fired central furnaces, boilers, wall furnaces, and floor furnaces (gas furnaces and boilers). These appliances are fueled by natural gas or propane (gas). Residential gas furnaces and boilers are vented gas heating appliances that are used to heat all categories of consumer dwellings, including single family homes, townhomes, condominiums, and multifamily dwellings, as well as small-to medium-sized commercial dwellings. These products provide heat to a dwelling by burning a mixture of fuel (either natural gas or propane) and air within the combustion chamber of a heat exchanger. As the mixture of fuel and air is burned, heat is released and transferred through the wall of the heat exchanger to the medium surrounding the heat exchanger and circulated through air ducts or water pipes throughout the dwelling, or into the ambient air to provide heat. Burning the mixture of fuel and air results in the formation of combustion products that are typically composed of oxygen, carbon dioxide, water vapor, and CO. When the mixture of fuel and air is burned completely, the concentration of CO produced should remain relatively low, typically below 50 parts per million (ppm), depending on the design of the gas appliance. The combustion products are exhausted to the outdoors through a vent system.

In a gas-fired central furnace, air is the medium that surrounds and is heated by the heat exchanger. A large fan is used to force the heated air across the exterior surfaces of the heat exchanger, through a duct system, and then the heated air exits the duct system through warm air registers in each room within the dwelling. In a gas boiler, water in the liquid phase or vapor phase (*i.e.*, steam) is the medium that surrounds and is heated by the heat exchanger. The heated water or steam is circulated, using a pump to force the fluid through a piping system to radiators in each room of the dwelling. Heat is transferred from the heated water or steam supplied to the radiators to the room through radiative and conductive heat transfer. Gas-fired central furnaces and boilers are considered central heating appliances, because they provide heat to each room of a dwelling. The combustion products of gas-fired central furnaces and boilers are vented to the outdoors, either vertically through the roof, or horizontally through a side wall through the vent pipe.

In addition to central gas-fired furnaces and boilers, the ANPR also covers gas wall furnaces and gas floor furnaces. As their names indicate, gas wall furnaces are installed in wall spaces, typically between the wall stud framing members; and floor furnaces are installed in the floor, typically between the floor joist framing members. Wall furnaces and floor furnaces both provide localized heating directly to the room in which they are located, and indirectly to adjoining rooms within the dwelling. The combustion products of wall furnaces are vented to the outdoors, either vertically through the roof, or horizontally through a side wall with the vent pipe running along the length of the wall studs between which the unit is installed. The combustion products of a floor furnace are typically vented horizontally through a side wall, with the vent pipe normally running along the length of the floor joists between which the unit is installed and through an exterior wall.

## IV. Market Information

Of the gas appliances covered by this ANPR, central gas-fired furnaces are the type most commonly used in U.S. households. Natural gas and propane central furnaces are the primary heating equipment in 50.3 million homes; from 2.6 to 3.1 million units were shipped annually between 2013 and 2017. Gas boilers are the next most commonly used heating appliances in U.S. homes, accounting for the main heating source in 6.8 million U.S. homes and about 390,000 annual shipments. The average product life of gas furnaces (including boilers) ranges from 15 to 20 years. Floor and wall furnaces are less common than central furnaces and boilers, but they still accounted for heating in 800,000 U.S. homes. No annual shipment data were available for floor or wall furnaces.

## V. Risk of Injury

### *A. Incident Data*

1. Fatalities

In 2015, (the latest time period for which data are available) there were an estimated 175 unintentional, non-fire CO poisoning deaths associated with consumer products under the CPSC's jurisdiction.[3] Of that number, heating systems were associated with an estimated 37 (21 percent) of the deaths. Gas furnaces and boilers (liquefied petroleum, natural gas, and unspecified gas) were associated with the largest share of CO deaths (19 deaths or 51 percent) among heating systems and the second largest share (11 percent) among all consumer products. For the 11-year period, 2005 through 2015, gas furnaces accounted for 248 CO deaths (44 percent) among heating appliances, and 14 percent among all consumer products.

2. Injury estimates

Staff estimates that annually there were about 1,850 gas furnace or boiler non-fire, CO-related injuries treated between 2013 and 2015 at U.S. hospital emergency departments (EDs).[4] Combined with estimates of medically attended injuries that were treated outside of hospital EDs, and using estimates from the CPSC's Injury Cost Model (ICM),[5] staff estimates an average of 7,590 non-fire, CO-related injuries annually between 2013 and 2015, which were associated

[3] *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products 2015 Annual Estimates*. M. Hnatov. CPSC Directorate for Epidemiology. December 2018.

[4] Physicians have noted difficulty in correctly diagnosing these injuries (*e.g.,* Aniol, 1992). Carbon monoxide poisoning may mimic many conditions, including alcohol or drug intoxication, psychiatric disorders, flulike illnesses, and others conditions that can lead to misdiagnoses (ibid). Measurement of HbCO levels in the blood can also be confounded, based on the time elapsed and any breathing treatment administered that can lower counts before measurement. Absent an attempt to provide NEISS cases where carbon monoxide was diagnosed, however, it would not be possible to compute nonfatal injuries. Thus, a potential underestimate was deemed more practical than assuming the injury costs would be zero. Aniol, M. J. *Carbon Monoxide Toxicity: The Difficulty in Diagnosing This Leading Cause of Poisoning.* Can Fam Physician. 1992 2123-2134, 2174.

[5] The ICM is fully integrated with NEISS and uses empirical relationships between the characteristics of injuries and victims initially treated in hospital EDs and those treated elsewhere, to estimate the number of medically attended injuries treated outside of hospital EDs.

with gas furnaces and boilers. This includes the estimate from NEISS of 1,850 ED-treated injuries and an additional 5,750 medically attended cases not treated in EDs.

*B. Hazard Patterns*

CPSC staff routinely relies on in-depth investigations (IDIs) to understand failure modes and conditions that reportedly caused or contributed to incidents involving the production and leakage of dangerous levels of CO into the living space. For CO exposure to occur from a vented gas appliance, two conditions typically must exist. First, a condition must exist that prevents complete combustion of the fuel. Second, there must be a path or mechanism that allows or causes combustion products, including CO, to leak from the flue passageways or vent system of the gas appliance into the living space. In 2012, CPSC staff conducted reviews of CO-related IDIs that involved "modern" (*i.e.*, manufactured after 1989) gas furnace or boiler.[6] Of these incidents involving "modern" gas appliances, staff identified two primary concurrent hazard patterns for CO exposure:

- a condition that resulted in production of a hazardous level of CO by the appliance; and
- a condition that allowed hazardous CO to leak into a living space.

Staff confirmed that the failure modes that led to production of dangerous levels of CO included too much fuel (*i.e.,* "overfiring") to the appliance or inadequate air for combustion. The failure modes that led to leakage of CO into the living space included: disconnected or breached vents; blocked vents, heat exchangers, or chimneys; depressurization of the space or back drafting of exhaust products; and improper venting. Staff also determined that the majority of the CO incidents occurred from appliances that were reported to be 15 years old or less at the

[6] Jordan, R., Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and "Modern" Gas Furnaces and Boilers. CPSC. September 2012.

time of the incident, and the average age of appliances involved in CO incidents was 9.6 years. The average age of the appliances indicates that these products were “modern” appliances equipped with the latest safety devices, and that these safety devices were not capable of protecting against CO exposure.

From review of CO-related IDIs, staff has been able to establish the following hazard patterns for gas appliances:

**Incomplete combustion**: Complete combustion of hydrocarbon fuels, such as natural gas or liquefied petroleum gas (LP-gas or propane), requires a proper mixture of air (*i.e.*, combustion air) and fuel, as well as an adequate amount of heat to ignite the combustion air-fuel mixture. Incomplete combustion of the fuel supplied to gas appliances can lead to production of hazardous levels of CO and can occur when the following conditions exist:

- *Inadequate combustion air*: Inadequate air for combustion supplied to an appliance occurs when: (1) air openings to the appliance combustion chamber or burner assembly are blocked; (2) combustion air inlet piping (in the case of direct vent appliances) to the appliance is blocked; (3) the exhaust outlet from the appliance is blocked; (4) the appliance is installed in a room that does not have a large enough volume to provide the proper amount of air for combustion; or (5) the appliance is installed in a smaller room or closet that does not have adequately sized combustion and ventilation air openings to support proper combustion.

- *Too much fuel (i.e., over-firing)*: Causes of over-firing can occur when the appliance gas manifold pressure is too high, causing the quantity of fuel delivered to the burner to be too high for complete combustion of the fuel/air mixture. This causes incomplete combustion of the fuel/air mixture and production of CO. This scenario can occur as a result of improper adjustment by a service technician or a product defect or component failure/malfunction associated with the gas valve or the burner orifice.

- *Reduced flame temperature*: Inadequate or reduced flame temperature can occur when the appliance burner is misaligned, causing the burner flame to come into contact with a metal surface within the combustion chamber. Because the metal surface is much cooler than the burner flame, direct contact will cause a greater rate of heat transfer from the flame to the metal, resulting in a reduction in the flame temperature (*i.e.*, flame quenching). Depending on the severity and duration, all of these conditions can result in incomplete combustion of the fuel.

**Exhaust leakage**: Combustion products from a gas furnace or boiler are normally vented to remove them from the home. However, a potential CO hazard in a home can arise when a path or mechanism exists that allows or causes CO to leak from the flue passageways or vent system of the gas appliance into the living space. Typical leakage paths include: (1) a totally or partially blocked vent, chimney, or heat exchanger; or (2) a disconnected vent pipe, or a hole in the vent pipe. Sometimes leakage can occur when an exhaust fan or fireplace is installed in the same room, or in a room adjacent to a gas appliance. The actions of the exhaust fan or a warm chimney created by the fireplace can have the effect of pulling air out of the room in which the gas appliance is installed. This action can depressurize the room, resulting in reverse flow of the combustion products through the appliance vent system or flue passageways. Instead of being vented safely to the outdoors, depressurization can cause combustion products, including CO, to spill into the living space. Other mechanisms that can lead to spilling include a vent with lower capacity than the gas appliance(s) connected to it. This can be caused by total or partial vent blockage, installation of a vent pipe that is too small, or the connection of so many appliances to the vent that the vent is rendered too small.

## VI. Existing Voluntary and International Standards

### *A. U.S. Voluntary Standards*

#### 1. Description of Existing U.S. Voluntary Standards

The four gas appliance types within the scope of the ANPR are covered by the following domestic ANSI Z21 voluntary standards:

- ANSI Z21.13, *Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers*

This standard specifies the construction and performance requirements for gas-fired, low-pressure steam and hot water boilers with input ratings of less than 12,500,000 Btu/hr (3,663 kW). The first edition of the standard was published in 1934 and has been revised several times, with the latest edition published in 2017.

- ANSI Z21.47, *Standard for Gas-fired central furnaces*

This standard specifies the construction and performance requirements for gas-fired central furnaces with input ratings up to and including 400,000 Btu/hr (117 kW). The requirements for gas-fired central furnaces were initially included in ANSI Z21.13, before becoming a separate standard in 1964. From 1978 through 1993, a separate standard for direct vent central furnaces (ANSI Z21.64) was in place before being consolidated into a single standard and harmonized with Canadian standard requirements in 1993, with the latest edition published in 2016.

- ANSI Z21.86, *Standard for Vented Gas-Fired Space Heating Appliances*

This standard specifies the construction and performance requirements for vented gas-fired space-heating appliances with input ratings up to and including 400,000 Btu/hr (117 kW), including vented room heaters (Parts III and IV), gravity and fan-type direct-vent wall furnaces (Parts V and VI), gravity and fan-type wall furnaces (Part VII), gravity and fan-type vented wall furnaces (VIII), and gravity and fan-type floor furnaces for the United States only (Parts IX and X). The scope of this ANPR only includes gravity and fan-type direct-vent wall furnaces (Parts V and VI), and gravity and fan-type floor furnaces (IX and X). The ANSI Z21.86 standard was first published in 1998, with the latest edition published in 2016; however, individual standards for gravity and fan-type direct-vent wall furnaces and gravity and fan-type floor furnaces predate this standard and were likely covered in the first edition of ANSI Z21.13.

The voluntary standards listed above all require the appliances to:

- not produce CO in excess of 400 ppm;
- shut off when vent or flue is fully blocked;
- shut off when blower door is not sealed properly (gas-fired central furnaces only);
- shut off if flames issue outside of the burner inlet openings.

2. Assessment of Existing U.S. Voluntary Standards

Despite the requirements of the ANSI Z21 voluntary standards, as well as a number of improvements to these standards that have been made over the years, these standards do not include requirements to protect against many of the failure modes or conditions that have been associated with production and leakage of CO into living spaces of U.S. households. Furthermore, the voluntary standards requirements do not address the long-term use of the products once installed in a dwelling or the various conditions that can cause or contribute to CO production and leakage. There are a number of leakage paths or mechanisms by which CO can leak into a living space; however, the ANSI Z21 standards for gas furnaces, boilers, wall furnaces, and floor furnaces only address leakage caused by a totally blocked vent. Staff has identified a variety of conditions that are not addressed by the ANSI requirements. Those conditions include, but are not limited to:

- disconnected or breached flues, vents, and chimneys;
- partially blocked heat exchangers, flues, vents, and chimneys;
- over-fired appliances; and
- inadequate combustion air to appliances.

Based on the hazard patterns identified in the staff's review of fatal CO poisoning incidents involving gas appliances, requirements to address CO risk at the source of production, before potentially deadly levels of CO can enter the living space, would reduce the occurrence of CO-related deaths, injuries, and exposures associated with gas furnaces, boilers, wall and floor furnaces.

In 2015, CPSC staff proposed requirements for CO shutoff/response to the respective voluntary standards development organizations for gas-fired central furnaces, boilers, wall furnaces, and floor furnaces. Staff's proposal would have required the appliance to limit the production of CO below a threshold level, or for the appliance to shut off when CO emissions in the combustion chamber, flue passageways, or vent pipe exceed a hazardous level. The 2015 staff proposal was supported by the proof-of-concept testing[7] previously conducted by CPSC staff in 2001, 2004, and 2007, and by current standards for gas appliances in Europe and Japan, which include similar requirements to use combustion sensors to regulate CO production and

[7] This testing was initially used to support a CO shutoff/response requirements proposed by CPSC staff to the same voluntary standards organizations in 2001.

shut down the appliance or modulate its performance if CO production exceeds a specified safe level. To date, no revisions to the ANSI Z21 voluntary standards have been made that incorporate staff's proposed performance requirements to address the hazard patterns discussed above. Therefore, the existing ANSI Z21 voluntary standards currently do not adequately address the risk of injury and death associated with CO production and leakage from residential gas furnaces and boilers for the reasons discussed above.

*B. International Standards*

1. Japanese Gas Appliance Standards

The primary gas heating appliances used in Japan appear to be gas water heaters, gas boilers, and gas space heaters. Based on our limited review of the Japanese gas appliance market, instantaneous, tankless gas water heaters appear to be more common than traditional gas water heaters with storage tanks. The governing voluntary performance and safety standards for these appliances in Japan are:

- JIS-S-2109 - *Gas burning water heaters for domestic use*
- JIS S 2112 - *Gas hydronic heating appliances for domestic use*[8]
- JIS S 2122 - *Gas burning space heaters for domestic use.*

These Japanese Industrial Standards (JIS) have explicit performance requirements for vented gas water heaters, gas boilers, and gas space heaters that require shutoff of the appliance in response to CO levels above a certain threshold (*i.e.*, 300 ppm CO). The CO-detection

[8] JIS-S-2112 and JIS-S-2122 were not available in English. To confirm the existence of incomplete combustion preventive device requirements with these standards, the table of contents and sections of the standards pertaining to incomplete combustion, carbon monoxide, and CO were translated from Japanese to English using: https://www.bing.com/search?q=translate+from+japanese+to+english&form=IENTHT&mkt=en-us&httpsmsn=1&refig=ffc0d5a3070d45d3c5187baeb690b6dd&sp=1&ghc=1&qs=AS&pq=translate+from+japanese+to+english&sc=8-34&cvid=ffc0d5a3070d45d3c5187baeb690b6dd. Staff's partial translation and review of these standards confirmed that they both included requirements for devices to prevent incomplete combustion to protect against CO poisoning and that were consistent with the requirements in JIS-S-2109.

strategies used by Japanese manufacturers include detection of CO within the combustion chamber of the appliance and shutoff or combustion control in response to detection of hazardous levels of CO.

Although gas water heaters are not within the scope of the ANPR, the Japanese standard, JIS-S-2109, is relevant because the combustion process and technology involved in heating water is similar to the combustion process and technology used for gas furnaces and boilers sold in the United States. In addition, the Japanese standard's CO shutoff requirements are similar to CPSC staff's 2000 and 2015 CO shutoff/response proposals, and the CO detection and combustion components are applicable to gas furnaces and boilers sold in the United States.

To protect against CO exposure, JIS-S-2109 includes requirements that vented gas water heaters be equipped with what they call an "Incomplete Combustion Prevention Device" (ICPD). A gas appliance experiencing incomplete combustion means that the fuel is not being burned or combusted completely, and as a result, can produce elevated concentrations of CO. Section 7.7.6 of JIS-S-2109, Incomplete Combustion Preventive Device of FE includes requirements that the water heater shut off when CO concentrations reach 0.03 percent (300 ppm)[9] in:

- the room in which the water heater is installed; and
- the adjacent room.

According to the Japanese Standards Association (JSA), the Incomplete Combustion Preventative Device provisions in JIS-S-2109 have been required since 2001. JSA also indicated that JIS-S-2109 does not have separate performance standards for ICPDs, requirements for a minimum life span for the device, and that these devices are replaced, if necessary, based on use and functionality. All of the performance requirements for ICPDs are specified in JIS-S-2109.

[9] 0.03 percent converts to 300 ppm CO by multiplying 0.03 percent by 10,000.

In addition, JIS-S-2109 includes flame roll-out and blocked vent requirements (respectively, similar to the Flame Roll-Out and Blocked Vent Safety requirements in ANSI Z21.13 and ANSI Z21.47).

Another similarity between the ICPD requirements of JIS-S-2109 and CPSC staff's 2000 and 20015 CO shutoff/response proposals is that they both necessitate that the device be within the harsh environment of appliance combustion chamber, flue passageways, or vent system.

2. European Gas Appliance and Combustion Sensor Standards

Gas boilers are a common space-heating appliance used throughout Europe in residential settings, and they are similar in design and function to residential gas boilers certified to ANSI Z21.13 and sold in the United States. The relevant European Committee for Standardization (CEN) domestic gas boiler standards are:

- EN 15502 -1, *Gas-fired heating boilers, Part 1: General requirements and tests*;
- EN 15502-2-1, *Gas-fired central heating boilers, Part 2-1: Specific standard for type C appliances and type B2, B3 and B5 appliances of a nominal heat input not exceeding 1000 kW*; and
- EN 15502-2-2, *Gas-fired central heating boilers, Part 2-2: Specific standard for type B1 appliances*.

These standards (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2) include requirements to ensure the proper supply of combustion air and gas to the combustion process (*i.e.*, air proving) through the use of one of the following mechanisms:

- Carbon Monoxide (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2);
- Supervision of the combustion air pressure or the combustion products pressure (EN 15502 -1);

- Supervision of the combustion air rate or the combustion products rate (EN 15502-2-1 and EN 15502-2-2);
- Gas/air ratio control (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2); or
- Indirect supervision (*e.g.*, fan speed supervision) (EN 15502 -1).

The second and third bullets listed above, Supervision of the combustion air rate or the combustion products rate, and Gas/air ratio control, are the most similar to CPSC staff's 2000 and 2015 CO Shutoff proposals to the ANSI Z21/83 Technical committee and furnace and boiler subcommittees. Additionally, these standards include performance requirements for blocked vents.

These standards also have combustion product discharge provisions, which are similar to the Flame Roll-Out provisions of the ANSI standards (*i.e.*, ANSI Z21.13 and ANSI Z21.47). In addition to the common requirements for all three of the standards, EN 15502-2-1 also includes test conditions and CO emission limits for: Boilers without gas/air ratio controls (Section 8.12.2.101) and Boilers using gas/air ratio controls (Section 8.12.2.102). Both requirements specify that the maximum permissible CO concentration not exceed 0.10 percent (1,000 ppm). EN 15502-2-2 includes a provision, Section 8.12.101, Supplementary test for natural draught boilers, which specifies that the maximum permissible CO concentration not exceed 0.10 percent (1,000 ppm).

Unlike the JIS standards, the CEN includes separate standards for combustion monitoring devices and controls that are used in domestic gas boilers. The relevant CEN standards are:

- EN 13611, *Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements.*

This standard specifies the general safety, design, construction, and performance requirements and testing for safety, control, or regulating devices use for burners or appliances burning gaseous or liquid fuels. The standard is designed to be used in conjunction with the various CEN standards that govern the above types of control devices. Because they address combustion process monitoring and modulation, EN 12067-2 and EN 16340 are of particular relevance to this ANPR.

- EN 12067-2, *Gas/air ratio controls for gas burners and gas burning appliances-Part 2: Electronic types*

This standard specifies the safety, construction, and performance requirements for closed-loop electronic gas/air ratio control systems (GARCs) for use with gas burners and gas-burning appliances. A GARC provides the electromechanical interface to the burner or the gas valve and the combustion air supply that allows these devices to be modulated or controlled to increase or decrease gas flow or combustion air flow. This allows the GARC to maintain the combustion efficiency of the appliance by monitoring and maintaining an optimal gas/air ratio. An optimal gas/air ratio ensures that the gas/air mixture supplied to the appliance burner is burned completely, thereby maintaining combustion efficiency.

- EN 16340, *Safety and control devices for burners and appliances burning gaseous or liquid fuels— Combustion product sensing devices*

This standard specifies the safety, construction, and performance requirements for combustion product-sensing devices (CPSD) designed to measure combustion products, as part of combustion control systems for burners and appliances that operate by burning gaseous or liquid fuels. This standard covers sensing devices that measures CO, as well as other flue gases. This standard is designed to be used in conjunction with EN 13611, Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements.

We note the similarities to CPSC staff's voluntary standards CO Shutoff/Response proposals. EN 16340 is compatible with CPSC staff's CO shutoff/response proposals because it establishes performance requirements for a device that monitors: (1) within the same parameters (*i.e.*, combustion gases, including CO); and (2) within the same harsh environment (*i.e.*, the combustion chamber). Consequently, these devices are subject to the same harsh operating conditions (*i.e.*, high operating temperature, relative humidity, combustion gases, thermal cycling) that the Z21/83 Technical Committee and its subordinate technical subcommittees (for gas furnaces and boilers) and CO/combustion sensor working groups raised questions about in response to CPSC staff's 2000 and 2015 CO shutoff/response proposals.

3. International Standards as Examples of Technological Feasibility

A lack of technological feasibility can be a barrier to implementing a new or proposed standard. Therefore, CPSC staff has sought to identify technologies that might be capable of implementing the staff-recommended CO shutoff/response proposals made to voluntary standards groups in 2000 and 2015. In addition, staff has also assessed international standards that required the same or similar performance requirements as staff's 2000 and 2015 CO shutoff/response proposals. The Japanese and European standards discussed above identify several gas-sensing technologies that are being used for CO shutoff or combustion control of residential gas appliances in Japan and Europe. As discussed, the CO-detection strategies used by Japanese manufacturers include detection of CO within the combustion chamber of the appliance and shutoff or combustion control in response. In Europe, residential gas boilers are required to meet certain combustion-efficiency requirements, as well as CO safety requirements.

The combustion-control strategies used by European gas boiler manufacturers are often accomplished by monitoring the gas/air mixture, the combustion flame, or the concentration of CO, oxygen, or carbon dioxide within the combustion products. The combustion-control strategies are also used to detect CO, but rather than shutting down the appliance, CO production is either prevented or limited by modulating the appliance's operation. The Japanese and European standards do not specify a minimum lifespan for sensing devices used to implement their respective CO safety and combustion efficiency requirements.

The Japanese and European standards demonstrate that it is technologically feasible, using current technology, to address the hazard patterns identified by staff regarding CO poisoning in a safety standard. The Japanese and European standards discussed above are examples of existing international standards that address the risk of injury and death associated with CO production and leakage from residential gas furnaces and boilers that are the subject of this ANPR.

## VII. Regulatory Alternatives the Commission Is Considering

The Commission is considering several alternatives to address the risk of death and injury associated with CO poisoning from residential gas furnaces and boilers.

### *A. Mandatory Standard*

The Commission could develop a rule under the CPSA establishing performance requirements and/or warnings and instructions for residential gas furnaces and boilers to prevent or reduce an unreasonable risk of death or injury associated with the production and leakage of CO from these products.

*B. Rely on Voluntary Standards*

The Commission could continue to address the hazard through voluntary standards, ANSI Z21.13, ANSI Z21.47, and ANSI Z21.86, and continue to work to develop more effective voluntary standard requirements to address the identified hazards, instead of issuing a mandatory rule. However, as previously discussed, the Commission preliminarily believes that the existing ANSI standards do not adequately reduce the risk of injury associated with residential gas furnaces and boilers. The Commission is assessing the level of compliance with the voluntary standards.

*C. Reliance on Recalls*

The Commission has recalled residential gas furnaces and boilers related to CO leakage hazards. The Commission could continue to conduct recalls, both voluntary and mandatory, instead of promulgating a mandatory rule. However, recalls may not be as effective at reducing the risk of injury as a mandatory standard. Recalls only apply to an individual manufacturer and product and do not extend to similar products. Additionally, recalls can only address products that are already on the market, and cannot prevent unsafe products from entering the market.

*D. Information and Education Campaign*

The Commission could continue to issue annual and semi-annual news releases warning consumers about the dangers of CO poisoning and promoting the importance of consumers getting annual safety inspections of their residential fuel burning heating systems.

## VIII. Request for Comments and Information

The Commission requests comments on all aspects of this ANPR, but specifically requests comments regarding:

- Information or analysis regarding mechanisms or performance requirements to mitigate more effectively the following hazard patterns that lead to CO production and leakage:
  - Inadequate air for combustion supplied to the appliance;
  - Too much fuel supplied to the appliance burner (*i.e.*, over-firing);
  - Reduction of burner flame temperature below the ignition temperature of the combustion air-fuel mixture (*i.e.*, flame quenching);
  - Disconnected or breached vent pipe, chimney, heat exchanger, or flue passageway;
  - Partially blocked vent pipe, chimney, heat exchanger, or flue passageways;
  - Snow blockage of side-wall vented gas appliances;
  - Improperly sized vent pipes; and
  - Depressurization of the room in which the gas appliance is installed.
- Studies, tests, analysis, or surveys performed to evaluate the effectiveness of gas-sensing and shut-off devices and performance standards, laws, or codes in reducing carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters and other gas heating appliances in Europe and Japan;

- Studies or analysis of the costs of incorporating carbon monoxide sensors or combustion controls systems into residential gas furnaces, boilers, or water heaters in Japan, Europe, or the United States;
- Studies or analyses that evaluate secondary cost impacts of using gas-sensing and shut-off devices in reducing carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters, and other gas heating appliances in Europe and Japan;
- Studies or analyses that evaluate the impact of carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters and other gas heating appliances in Europe and Japan;
- Data or analyses on the alternatives the Commission is considering, including the cost and effectiveness of the CO shutoff/response requirements under consideration;
- Studies, test, or analyses that correlate the effects of incomplete combustion to carbon monoxide production and changes in the combustion efficiency of natural gas and propane appliances.
- Information on any factors or trends that, independent of any CPSC rulemaking, could act to reduce (or increase) CO poisoning associated with gas furnaces, boilers, wall furnaces, and floor furnaces described in the ANPR;
- Information on any feasible means of addressing this hazard, along with the specific costs that might be involved, including information on the costs associated with the maintenance over the service life of the equipment that would likely result from potential remedies. We also request information on how effective the different remedies would be in reducing the hazard;

- Standards in Japan and some European Union countries require some gas appliances to have a means by which CO production or perhaps fuel consumption is measured. We request information on those standards, the means by which compliance with the standards is achieved, the impact of the standards on the cost of equipment, including the maintenance costs, and the effectiveness of the standards at achieving their intended purpose;
- Any available information on the distribution of CO emissions of natural or LP gas furnaces in use, or in other words, the number of gas furnaces that are not in compliance with the 400 ppm air-free standard at any given time and the degree to which they might be producing CO in excess of that standard. We also request information on the causes of equipment producing excessive CO and their frequency of occurrence, such as improper installation, changes in installation, poor maintenance of the equipment, and so forth; and
- Any available information on the relationship between excessive CO production and fuel consumption and complete/incomplete combustion in residential furnaces and boilers that are producing excessive CO emissions may also be consuming excessive fuel or not burning fuel completely.

In addition, the Commission invites interested parties to submit any existing standards, or portions of them, for consideration as a consumer product safety standard. The Commission also invites interested persons to submit a statement of intention to modify or develop a voluntary consumer product safety standard addressing the risk of injury associated with CO poisoning from residential gas furnaces and boilers, including a description of the plan to develop or modify such a standard.

Please submit comments in accordance with the instructions in the **ADDRESSES** section at the beginning of this ANPR.

Dated: _______________________

_____________________________________
Alberta E. Mills, Secretary
U.S. Consumer Product Safety Commission

BRIEFING PACKAGE

ADVANCE NOTICE OF PROPOSED RULEMAKING:
PERFORMANCE REQUIREMENTS TO ADDRESS CARBON MONOXIDE DEATHS AND INJURIES CAUSED BY RESIDENTIAL GAS FURNACES AND BOILERS

July 31, 2019

For Further Information Contact:

Ronald Jordan
Project Manager
Directorate for Engineering Sciences
301-987-2219

# Table of Contents

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

Date:

**TO :** The Commission
Alberta Mills, Secretary

**THROUGH:** Patricia M. Hanz, General Counsel
Mary T. Boyle, Executive Director
DeWane Ray, Deputy Executive Director for Safety Operations

**FROM :** Duane Boniface, Acting Assistant Executive Director
Office of Hazard Identification and Reduction
Ronald Jordan, Project Manager
Directorate for Engineering Sciences

**SUBJECT :** Advance Notice of Proposed Rulemaking: Performance Requirements to Address Carbon Monoxide Deaths and Injuries Caused by Residential Gas Furnaces and Boilers

## I. INTRODUCTION

This briefing package includes a draft advance notice of proposed rulemaking (ANPR) to initiate rulemaking proceedings that could result in establishing mandatory performance requirements, labeling requirements, or both, to reduce the risk of serious injury or death caused by carbon monoxide (CO) production and leakage from gas central furnaces, boilers, wall furnaces, and floor furnaces.

## II. BACKGROUND

Gas-fired central furnaces and boilers historically have been among the leading causes of non-fire CO poisoning deaths associated with consumer products. In the late 1980s, the voluntary standards for a variety of gas appliances, including gas furnaces and boilers, were revised to address some of the operating, installation, or usage conditions of the products that could result in hazards, such as fire, explosion, and leakage of CO into the living space. Despite revisions to the voluntary standards that addressed some CO hazards, gas furnaces and boilers continue to be the second leading cause of CO deaths (portable generators are the leading cause of CO deaths[1] among all consumer products) and the leading cause among heating systems. Based on our review of incident reports and assessment of the standards, staff believes that these incidents continue to occur because the voluntary standards do not include more stringent performance requirements, which would address most of the known failure modes and conditions that cause or contribute to CO poisoning incidents.

[1] *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products. 2015 Annual Estimates*, Hnatov, M. December 2018

CPSC staff has advocated for more effective voluntary standard performance requirements for gas furnaces and boilers since 1993 to protect consumers from CO hazards that were not addressed in the voluntary standards for these products. In 2000, CPSC staff sought to address CO hazards at the source of production (*i.e.*, in the heat exchanger and flue passageways) in these appliances by proposing [2] that "CO shutoff/response" provisions be added to the voluntary standards. More specifically, CPSC staff proposed voluntary standard provisions that would require a furnace:

(1) to shut down if the vent pipe became disconnected; and
(2) to shut down if the vent pipe became totally or partially blocked; or
(3) to have a means to prevent CO emissions from exceeding the standard limits once installed in the field; or
(4) to have a means, once installed in the field, to shut down if CO emissions exceeded the standard limits.

To support this proposal, CPSC staff provided the following test and analysis to the voluntary standards groups:

- Emissions testing of gas furnaces,[3] analysis of the results,[4] and assessment of health concerns related to the emissions[5] from 1999 through 2000;
- CO-related incident data involving gas furnaces and boilers in 2002[6, 7]; and
- Proof-of-concept testing of technologies that could be used to implement the proposed voluntary standards requirements in 2001[8] and 2004.[9]

In 2002, the ANSI Z21/83 Technical Committee (TC) established a working group (WG) to evaluate the feasibility of using CO and combustion sensor technology to implement CPSC staff's CO shutoff/response proposal. CPSC staff participated in that WG from 2002 through 2005. This WG was disbanded in 2005, before the feasibility of using sensor technology could be evaluated, out of a concern that there were no sensors commercially available that had the durability or longevity to operate within a gas furnace for the expected 20-year lifespan of a typical gas furnace. CPSC staff conducted additional sensor testing from 2007 to 2008[10] to evaluate the ANSI ZS21/83 TC's and address WG's concerns. Staff found that the sensors under test were durable enough to survive within a gas furnace throughout its lifespan. In 2012, staff provided the ANSI Z21/83 TC an updated review of

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[2] Jordan, R., CO shutoff/response proposal letter Canadian Standards Association International, CPSC. November 2000.
[3] Brown, C., Jordan, R., and Tucholski, D., Furnace CO Emissions Under Normal and Compromised Vent Conditions, emissions reports for furnace numbers. 1–5, CPSC. 2000.
[4]Porter, W. Indoor Air Modeling for Furnaces with Blocked or Disconnected Vents IAQ modeling reports for furnace numbers 1–5, CPSC. 2000.
[5] Inkster, S., Carbon Monoxide (CO) emissions from Furnaces: Health concerns related to projected consumer exposure, health assessment reports for furnace numbers 1–5, CPSC. 2000.
[6] Jordan, R. and Vagts, S., In-Depth Investigations Associated with Certain Vented Gas Appliances. CPSC. April 2002.
[7] Jordan, R. and Vagts, S., In-Depth Investigations of Carbon Monoxide (CO) Incidents Associated with "Modern" Gas Fired Furnaces", CPSC. September 2002.
[8] Furnace Combustion Sensor Test Results, R.A. Jordan, Directorate for Engineering Sciences, CPSC, September 2001.
[9] Combustion Sensor Test Results, R.A. Jordan, Directorate for Engineering Sciences, CPSC, December 2004.
[10] Evaluation of the Durability and Longevity of Chemical Sensors Used In-Situ For Carbon Monoxide Safety Shutdown of Gas Furnaces, R.A. Jordan. R. Butturini, Directorate for Engineering Sciences, CPSC, September 2012.

CO-related IDIs involving gas furnaces and boilers.[11] In 2014, CPSC issued a request for information, and staff hosted a forum to gather more information on the availability and feasibility of CO and combustion sensors for use in gas furnaces and boilers. In 2015, CPSC staff proposed that updated CO shutoff/response[12] provisions be added to the voluntary standards for gas furnaces, boilers, wall furnaces, and floor furnaces that would:

1. Require a means to limit:
   a. CO emissions to below 0.04 percent; or
   b. combustion conditions that result in CO emissions at or in excess of 0.04 percent; or
2. Require a means to shut-off in response to:
   a. CO emissions at or in excess of 0.04 percent; or
   b. combustion conditions that result in CO emissions at or in excess of 0.04 percent; or
3. Require a means to modulate operation to reduce CO emissions in response to:
   a. CO emissions at or in excess of 0.04 percent; or
   b. combustion conditions that result in CO emissions at or in excess of 0.04 percent.

In 2015, the Z21/83 TC established another WG to evaluate CPSC staff's new proposal. CPSC staff participated in that WG (2016 through 2019) by identifying Japanese and European standards and related technologies that could be used as benchmarks to implement the CPSC staff's proposals and providing redacted CO-related incident reports involving gas furnaces and boilers.[13] However, the WG disbanded in 2019 despite not accomplishing all of its objectives.

Despite CPSC staff's efforts, as well as developments in voluntary standards for Japan and Europe that address the CO risk and combustion efficiency at the source of production in gas appliances, the voluntary standards community in the United States has not adopted any new performance requirements that address the CO hazard. In contrast, voluntary standards for gas appliances in Japan and Europe include performance requirements for CO and combustion product sensors to achieve safety and combustion efficiency goals. However, despite requests from CPSC staff for the U.S. standards development organizations (SDO) to address the CO risk at the source of production in gas appliances, voluntary standards in the United States have not adopted similar requirements to address the CO hazard. The rationale cited by U.S. SDOs for not adopting similar requirements continues to be claims that CO and combustion product-sensing devices needed to implement the requirements must have a 20-year lifespan and that no such devices are currently available.

## III. DISCUSSION

### A. The Products

The draft ANPR covers residential, gas-fired central furnaces, boilers, wall furnaces, and floor furnaces (gas furnaces and boilers). These appliances are fueled by natural gas or propane (gas).

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[11] Jordan, R., Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and "Modern" Gas Furnaces and Boilers. CPSC. September 2012.
[12] Jordan, R. Updated CO shutoff proposal letters (3 total) to the ANSI/CSA Technical Subcommittees for gas-fired central furnaces, boilers, and wall/floor furnaces. CPSC. September 2015.
[13] Redacted CO IDIs (79 IDIs) involving gas furnaces and boilers emailed to the Z21/83 Cross Functional Working Group for Carbon Monoxide Detector Sensors for Gas Appliances. CPSC. Emailed to Working Group between October 2016 and January 2017.

Residential gas furnaces and boilers are vented gas heating appliances that are used to heat all categories of consumer dwellings, including single family homes, townhomes, condominiums, and multifamily dwellings, as well as small-to medium-sized commercial dwellings. These products provide heat to a dwelling by burning a mixture of fuel (either natural gas or propane gas) and air within the combustion chamber of a heat exchanger. As the mixture of fuel and air is burned, heat is released and transferred through the wall of the heat exchanger to the medium surrounding the heat exchanger and circulated through air ducts, water pipes throughout the dwelling, or into the ambient air to provide heat. Burning the mixture of fuel and air results in the formation of combustion products that are typically composed of oxygen, carbon dioxide, water vapor, and carbon monoxide (CO). When the mixture of fuel and air is burned completely, the concentration of CO produced should remain relatively low, typically below 50 parts per million (ppm), depending on the design of the gas appliance. The combustion products are exhausted to the outdoors through a vent system.

In a gas-fired central furnace (Figure 1), air is the medium that surrounds and is heated by the heat exchanger. A large fan is used to force-circulate the heated air across the exterior surfaces of the heat exchanger, through a duct system, and then the heated air exits the duct system through warm air registers in each room within the dwelling.

In a gas boiler (Figure 2), water in the liquid phase or vapor phase (*i.e.*, steam) is the medium that surrounds and is heated by the heat exchanger. The heated water or steam is circulated, using a pump to force the fluid through a piping system to radiators in each room of the dwelling. Heat is transferred from the heated water or steam supplied to the radiators to the room through radiative and conductive heat transfer. Gas-fired central furnaces and boilers are considered central heating appliances, because they provide heat to each room of a dwelling. The combustion products of gas-fired central furnaces and boilers are vented to the outdoors, either vertically through the roof, or horizontally through a side wall through the vent pipe.

Figure 1. Gas-fired central furnace

Figure 2. Gas boiler

In addition to central gas-fired furnaces and boilers, the scope of the draft ANPR also includes gas wall furnaces (Figure 3) and gas floor furnaces (Figure 4). As their names indicate, gas wall furnaces are installed in wall spaces, typically between the wall stud framing members; and floor furnaces are installed in the floor, typically between the floor joist framing members. Wall furnaces and floor furnaces both provide localized heating directly to the room in which they are located, and indirectly to adjoining rooms within the dwelling. The combustion products of wall furnaces are vented to the outdoors, either vertically through the roof, or horizontally through a side wall with the vent pipe running along the length of the wall studs between which the unit is installed. The combustion products of a floor furnace are typically vented horizontally through a side wall, with the vent pipe normally running along the length of the floor joists between which the unit is installed and through an exterior wall.

Figure 3. Gas wall furnace

Figure 4. Gas floor furnace

In the late 1980s, the voluntary standards for furnaces and boilers were revised to address some of the conditions of the products that could result in CO leakage into the living space. "Modern" furnaces are furnaces that were manufactured after 1987, and equipped with additional safety components (*i.e.*, blocked-vent shutoff switches, flame-rollout switches, and blower-door interlock switches for central furnaces only) that meet the applicable updated voluntary standard. "Modern" boilers are boilers that were manufactured after 1989, and equipped with additional safety components (*i.e.*, blocked-vent shutoff switches and flame-rollout switches) that meet the applicable updated voluntary standard.

## B. Incident Data

### 1. *Fatalities (Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products 2015 Annual Estimates, TAB A)*

In 2015 (the latest time period for which data are available), there were an estimated 175 unintentional, non-fire CO poisoning deaths associated with consumer products under the CPSC's jurisdiction.[14] Of that number, heating systems were associated with an estimated 37 (21 percent) of the deaths. Gas furnaces and boilers (liquefied petroleum, natural gas, and unspecified gas) were associated with the largest share of CO deaths (19 deaths or 51 percent) among heating systems and the second largest share (11 percent) among all consumer products. For the 11-year period, 2005 through 2015, gas furnaces accounted for 248 CO deaths (44 percent) among heating appliances and 14 percent among all consumer products.

### 2. *Injury estimates (TAB B)*

To estimate the annual number of injuries associated with CO exposure from natural gas and propane furnaces and boilers, an interdisciplinary team of CPSC staff evaluated injuries reported though the National Electronic Injury Surveillance System (NEISS) (TAB B). Staff queried NEISS for data between the years 2013 and 2015, product codes for gas furnaces and boilers (*i.e.*, codes 308, 310, 322, 392, and 393), and for carbon monoxide poisoning-related diagnosis codes (*i.e.*, codes 65 and 68). After eliminating out-of-scope cases, staff estimates that annually there were about 1,850 gas furnace or boiler non-fire, CO-related injuries treated between 2013 and 2015, at U.S. hospital emergency departments (EDs).[15] When combined with estimates of medically attended injuries that were treated outside of hospital EDs, based on estimates from the CPSC's Injury Cost Model (ICM), staff estimates an average of 7,590 non-fire, CO-related medically attended injuries annually between 2013 and 2015 that were associated with gas furnaces and boilers. This includes the estimate of 1,850 ED-treated injuries from NEISS and an additional 5,750 medically attended cases not treated in EDs.

### 3. *Hazard Patterns (TAB C)*

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[14] *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products 2015 Annual Estimates*. M. Hnatov. CPSC Directorate for Epidemiology. December 2018.

[15] Physicians have noted difficulty in correctly diagnosing these injuries (*e.g.*, Aniol, 1992). Carbon monoxide poisoning may mimic many conditions, including alcohol or drug intoxication, psychiatric disorders, flulike illnesses, and others conditions that can lead to misdiagnoses (ibid). Measurement of HbCO levels in the blood can also be confounded, based on the time elapsed and any breathing treatment administered that can lower counts before measurement. Absent an attempt to provide NEISS cases where carbon monoxide was diagnosed, however, it would not be possible to estimate nonfatal injuries. M.J. Aniol, Carbon Monoxide Toxicity: The Difficulty in Diagnosing This Leading Cause of Poisoning. *Can Fam Physician*. 1992 2123-2134, 2174.

The reports on “Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products” (TAB A) are the primary means CPSC staff uses to measure annual trends in CO poisonings. However, these reports do not provide detailed information about the failure mode that led to, or contributed to, the CO leakage and subsequent CO poisoning, nor do the reports identify the age or year of manufacture of the products involved. This type of information is important in developing performance and safety standards because it provides real-world conditions to inform the design of new standards and can be used to evaluate the effectiveness of existing standards in addressing real-world conditions that increase the risk of CO poisoning. CPSC staff routinely relies on IDIs to understand failure modes and conditions that reportedly caused or contributed to incidents involving the production and leakage of dangerous levels of CO into the living space.

For CO exposure to occur from a vented gas appliance, two conditions typically must exist. First, a condition must exist that prevents complete combustion of the fuel. Second, there must be a path or mechanism that allows or causes combustion products, including CO, to leak from the flue passageways or vent system of the gas appliance into the living space. CPSC staff conducted the following reviews of CO-related IDIs, and provided them to the voluntary standards Technical Committee (TC), Technical Subcommittees (TSCs), or WGs to support CPSC Staff’s 2000 and 2015 CO shutoff/response proposals to the voluntary standards groups:

- In-Depth Investigations Associated with Certain Vented Gas Appliances. April 2002.
- In-Depth Investigations of Carbon Monoxide (CO) Incidents Associated with “Modern” Gas Fired Furnaces. September 2002.
- Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and “Modern” Gas Furnaces and Boilers. September 2012.

In the most recent of these reports (September 2012), CPSC staff conducted an extensive review of IDIs associated with non-fire-related carbon monoxide incidents and gas furnaces/boilers that were reported from January 2002 to December 2009 (TAB C). The incidents included were from the CPSC’s In-Depth Investigation (INDP) File. Data from the CPSC INDP files are not a statistical sample, and national totals cannot be derived from the number of incidents investigated. The data do provide minimum case count examples of actual incidents and anecdotal information. The initial database search identified 435 IDIs from January 2002 through December 2009, involving carbon monoxide poisonings or exposures associated with gas furnaces and boilers. After the initial database search, staff screened the incidents to determine if they were within scope. Incidents were considered out of scope or indeterminate for the reasons below:

- Furnace or boiler was converted to or from solid fuel or oil to natural or liquefied petroleum (LP) gas;
- Furnace was not a gas-fired central furnace;
- Furnace or boiler was manufactured prior to 1987;
- The furnace’s age or vintage could not be determined or estimated from available information;
- The incident was associated with a fire or a gas leak; or
- No evidence was provided within the investigation that CO leakage or exposure was related to furnace or boiler malfunction or failure.

The review identified 83 incidents that conclusively involved either a "modern" (*i.e*., manufactured after 1989) gas furnace or boiler. Of these incidents involving "modern" gas appliances, staff identified the two primary concurrent hazard patterns needed for CO exposure: (1) a condition that resulted in production of hazardous level of CO by the appliance, and (2) a condition that allowed hazardous CO to leak into a living space. Staff determined that the failure modes that led to production of dangerous levels of CO included: too much fuel (*i.e.,* "overfiring") to the appliance or inadequate air for combustion. The failure modes that led to leakage of CO into the living space included: disconnected or breached vents; blocked vents, heat exchangers, or chimneys; depressurization of the space or back drafting of exhaust products; and improper venting. These hazard patterns were consistent with findings in earlier IDI reviews and the general understanding within the gas appliance industry. Staff also determined that the majority of the CO incidents occurred in appliances that were reported to be 15 years old or less at the time of the incident, and the average age of appliances involved in CO incidents was 9.6 years.

From review of CO-related IDIs, staff has been able to establish the following hazard patterns for gas appliances:

<u>Incomplete combustion</u>: Complete combustion of hydrocarbon fuels, such as natural gas or liquefied petroleum gas (LP-gas or propane), requires a proper mixture of air (*i.e.*, combustion air) and fuel, as well as an adequate amount of heat to ignite the combustion air-fuel mixture. Incomplete combustion of the fuel supplied to gas appliances can lead to production of hazardous levels of CO and can occur when the following conditions exist: (1) there is inadequate air for combustion supplied to the appliance; (2) too much fuel is supplied to the appliance burner (*i.e*., over-firing); or (3) the burner flame temperature falls below the ignition temperature of the combustion air-fuel mixture (*i.e*., flame quenching).

- *Inadequate combustion air*: Inadequate air for combustion supplied to an appliance occurs when: (1) air openings to the appliance combustion chamber or burner assembly are blocked; (2) combustion air inlet piping (in the case of direct vent appliances) to the appliance is blocked; (3) the exhaust outlet from the appliance is blocked; (4) the appliance is installed in a room that does not have a large enough volume to provide the proper amount of air for combustion; or (5) the appliance is installed in a smaller room or closet that does not have adequately sized combustion and ventilation air openings to support proper combustion.

- *Too much fuel*: Causes of over-firing can occur when the appliance gas manifold pressure is too high, causing the quantity of fuel delivered to the burner to be too high for complete combustion of the fuel/air mixture. This causes incomplete combustion of the fuel/air mixture and production of CO. This scenario can occur as a result of improper adjustment by a service technician or a product defect or component failure/malfunction associated with the gas valve or the burner orifice.

- *Reduced flame temperature*: Inadequate or reduced flame temperature can occur when the appliance burner is misaligned, causing the burner flame to come into contact with a metal surface within the combustion chamber. Because the metal surface is much cooler than the burner flame, direct contact will cause a greater rate of heat transfer from the flame to the metal, resulting in a reduction in the flame temperature (*i.e*., flame quenching). Depending on the severity and duration, all of these conditions can result in incomplete combustion of the fuel, which, in turn, can result in the gas appliance producing dangerous levels of CO.

Exhaust leakage: Combustion products from a gas furnace or boiler are normally vented to remove them from the home; however, a potential CO hazard in a home can arise when a path or mechanism exists that allows or causes CO to leak from the flue passageways or vent system of the gas appliance into the living space. Typical leakage paths include: (1) a totally or partially blocked vent, chimney, or heat exchanger; or (2) a disconnected vent pipe, or a hole in the vent pipe. A leakage mechanism that is sometimes encountered occurs when an exhaust fan or fireplace is installed in the same room, or in a room adjacent to a gas appliance. The actions of the exhaust fan or a warm chimney created by the fireplace can have the effect of pulling air out of the room in which the gas appliance is installed. This action can depressurize the room, resulting in reverse flow of the combustion products through the appliance vent system or flue passageways. Instead of being vented safely to the outdoors, depressurization can cause combustion products, including CO, to spill into the living space. Other mechanisms that can lead to spillage include a vent that is undersized for the gas appliance(s) connected to it. This can be caused by total or partial vent blockage, installation of a vent pipe that is too small, or the connection of so many appliances to the vent that the vent is rendered too small.

**C.** Market information (TAB B*)*

Of the four gas appliance types within the scope of the draft ANPR, gas central furnaces are the most commonly used in U.S. households. Natural gas and propane central furnaces are the primary heating equipment in 50.3 million homes; between 2.6 and 3.1 million units were shipped annually between 2013 and 2017 (TAB B). Gas boilers were the next most commonly used heating appliances in U.S. homes, accounting for the main heating source in 6.8 million U.S. homes and about 390,000 annual shipments. The average product life of gas furnaces (including boilers) ranges from 15 to 20 years (Appliance, 2009). Floor and wall furnaces are less common than central furnaces and boilers, but still accounted for heating in 800,000 U.S. homes. No annual shipment data were available for floor or wall furnaces.

## D. Existing Voluntary Standards (TAB D)

### *1. U.S. Voluntary Standards*

The four gas appliance types within the scope of the draft ANPR are governed by the following U.S. voluntary standards:

- ANSI Z21.13, Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers
- ANSI Z21.47, Standard for Gas-fired central furnaces
- ANSI Z21.86, Standard for Vented Gas-Fired Space Heating Appliances

These standards all require the appliances to do the following:

- not produce CO in excess of 400 ppm
- shut off when vent or flue is fully blocked
- shut off when blower door is not sealed properly (gas-fired central furnaces only)
- shut off if flames issue outside of jacket.

Despite these requirements, and a number of improvements made over the years, these standards do not include requirements that protect against many of the failure modes or conditions that have been associated with production and leakage of CO into living spaces of U.S. households. Furthermore, the voluntary standard requirements do not address the long-term use of the products once installed in a dwelling and the various conditions that can cause or contribute to CO production and leakage. There are a number of leakage paths or mechanisms by which CO can leak into a living space, but the Z21 standards for gas furnaces, boilers, wall furnaces, and floor furnaces only address leakage caused by a totally blocked vent. Staff's review of IDIs (TAB C) identified a variety of conditions that the ANSI requirements do not address. Those conditions include, but are not limited to:

- disconnected or breached flues, vents, and chimneys
- partially blocked heat exchangers, flues, vents, and chimneys
- over-fired appliances, and
- inadequate combustion air to appliances.

Based on the hazard patterns identified in the review of fatal CO poisoning incidents involving gas appliances, CPSC staff believes requirements to address CO risk at the source of production, before potentially deadly levels of CO can enter the living space, will reduce the occurrence of CO-related deaths, injuries, and exposures associated with gas furnaces, boilers, wall and floor furnaces.

In 2015, CPSC staff proposed requirements for CO Shutoff/Reponses to the respective voluntary standards development organizations for gas-fired central furnaces, boilers, wall furnaces, and floor furnaces. The proposed voluntary standard performance requirements would have required the appliance to limit the production of CO below a threshold level, or for the appliance to shut off when CO emissions in the combustion chamber, flue passageways, or vent pipe exceed a hazardous level. This proposal was supported by proof-of-concept testing conducted by CPSC staff and by current standards for gas appliances in Europe and Japan that include similar requirements to use combustion sensors to regulate CO production and shut down the appliance or modulate its performance if CO production exceeds a specified safe level.

*2. International Standards*

Staff is aware of Japanese and European gas appliance voluntary standards that include CO shutoff or combustion control requirements, as well as several gas sensing technologies that are being used to implement those standards' requirements.

The primary gas heating appliances used in Japan appear to be gas water heaters, gas boilers, and gas space heaters. Based on our limited review of the Japanese gas appliance market, instantaneous tankless gas water heaters (Figure 5) appear to be more common than traditional gas water heaters with storage tanks.

Figure 5. Japanese tankless gas water heater

Figure 6. European gas boiler

The governing voluntary performance and safety standards for these appliances in Japan are:[16]

- JIS-S-2109 - Gas burning water heaters for domestic use
- JIS S 2112 - Gas hydronic heating appliances for domestic use
- JIS S 2122 - Gas burning space heaters for domestic use.

These Japanese Industrial Standards (JIS) have explicit performance requirements for vented gas water heaters, gas boilers, and gas space heaters that require shutoff of the appliance in response to CO levels above a certain threshold (*i.e.*, 300 ppm CO) (TAB D). The CO detection strategies used by Japanese manufacturers include detection of CO within the combustion chamber of the appliance and shutoff or combustion control in response to detection of hazardous levels of CO.

Gas boilers (Figure 6) are a common space heating appliance used throughout Europe in residential settings and are similar in design and function to residential gas boilers certified to ANSI Z21.13 and sold in the United States. The relevant CEN standards for residential gas boilers are:

- EN 15502 -1, Gas-fired heating boilers, Part 1: General requirements and tests
- EN 15502-2-1, Gas-fired central heating boilers, Part 2-1: Specific standard for type C appliances and type B2, B3 and B5 appliances of a nominal heat input not exceeding 1 000 kW
- EN 15502-2-2, Gas-fired central heating boilers, Part 2-2: Specific standard for type B1 appliances.

[16] JIS-S-2112 and JIS-S-2122 were not available in English. To confirm the existence of incomplete combustion preventive device requirements with these standards, the table of contents and sections of the standards pertaining to incomplete combustion, carbon monoxide, and CO were translated from Japanese to English using: https://www.bing.com/search?q=translate+from+japanese+to+english&form=IENTHT&mkt=en-us&httpsmsn=1&refig=ffc0d5a3070d45d3c5187baeb690b6dd&sp=1&ghc=1&qs=AS&pq=translate+from+japanese+to+english&sc=8-34&cvid=ffc0d5a3070d45d3c5187baeb690b6dd. Staff's partial translation and review of these standards confirmed that they both included requirements for devices to prevent incomplete combustion to protect against CO poisoning and that were consistent with the requirements in JIS-S-2109.

### E. Technological Considerations (TAB E)

Sometimes a lack of feasible technology can be a barrier to implementing a new or proposed standard. With that in mind, over the years, CPSC staff has sought to identify technologies that might be capable of implementing the CO shutoff/response proposals staff made to voluntary standards groups in 2000 and 2015. In addition, staff has also sought out international standards that required the same or similar performance requirements as staff's 2000 and 2015 proposals. Staff identified several gas-sensing technologies that were either being used for CO shutoff or combustion control of residential gas appliances in Japan and Europe. The CO-detection strategies used by Japanese manufacturers include detection of CO within the combustion chamber of the appliance and shutoff or combustion control in response. In Europe, residential gas boilers are required to meet certain combustion-efficiency requirements, as well as CO safety requirements (TAB D). The combustion-control strategies used by European gas boiler manufacturers are often accomplished by monitoring the gas/air mixture, the combustion flame, or the concentration of CO, oxygen, or carbon dioxide within the combustion products. The combustion-control strategies are also used to detect CO, but rather than causing shutdown of the appliance, CO production is either prevented or limited by modulating the appliance's operation. The Japanese and European standards do not specify a minimum lifespan for sensing devices used to implement their respective CO safety and combustion efficiency requirements.

## IV. REGULATORY AND OTHER ALTERNATIVES

The Commission could pursue one or more of the following alternatives to reduce the identified hazards associated with production and leakage of CO from gas furnaces and boilers:

1. **Information and education campaign.** The Commission could continue to issue annual and semi-annual news releases warning consumers about the dangers of CO and promoting the importance of consumers getting annual safety inspections of their fuel burning heating systems, instead of issuing a mandatory rule.

2. **Voluntary standard.** The Commission could continue to have staff work on the existing voluntary standards, ANSI Z21.13, ANSI Z21.47, and ANSI Z21.86, and continue to work with the Canadian Standards Association Group (CSA Group) to develop more effective requirements to address the identified hazards, instead of issuing a mandatory rule.

3. **Reliance on recalls.** The Commission has obtained recalls from gas furnace and boiler manufacturers related to CO leakage hazards. The Commission could continue to rely on recalls, both voluntary and mandatory, instead of promulgating a mandatory rule.

4. **Mandatory rule.** The Commission could develop a rule under the Consumer Product Safety Act (CPSA) establishing performance requirements and/or warnings and instructions for gas furnaces and boilers to prevent or reduce an unreasonable risk of death or injury associated with the production and leakage of CO from these products.

## V. STAFF RECOMMENDATIONS

Despite revisions to the voluntary standards since the 1980s, gas furnaces and boilers continue to be the second leading cause of CO deaths among all consumer products and the leading cause among heating systems. Staff's review of incidents indicates that "modern" gas appliances manufactured after the late 1980s continue to be associated with CO deaths and injuries. The current voluntary standards for gas appliances do not adequately address the risk of CO poisoning because the standards do not protect against many of the conditions that lead to production and leakage of dangerous levels of CO into the living space of a dwelling. Staff believes the most effective way to address the CO risk is to develop requirements that mitigate CO at the source of production. Staff recommends that the Commission approve publication of an ANPR in the *Federal Register* that will initiate rulemaking and work towards establishing performance requirements that address the risks of death and injury associated with CO production and leakage from central gas furnaces, boilers, wall furnaces and floor furnaces.

Staff recommends seeking input from stakeholders on mechanisms or performance requirements to mitigate more effectively the following hazard patterns that lead to CO production and leakage:

(1) Inadequate air for combustion supplied to the appliance;
(2) Too much fuel supplied to the appliance burner (*i.e.*, over-firing);
(3) Reduction of burner flame temperature below the ignition temperature of the combustion air-fuel mixture (*i.e.*, flame quenching);
(4) Disconnected or breached vent pipe, chimney, heat exchanger, or flue passageway;
(5) Partially blocked vent pipe, chimney, heat exchanger, or flue passageways;
(6) Snow blockage of side-wall vented gas appliances;
(7) Improperly sized vent pipes; and
(8) Depressurization of the room in which the gas appliance is installed.

The Office of the General Counsel (OGC) prepared a draft ANPR that would commence a rulemaking proceeding under the CPSA to protect consumers from the risks associated with CO leakage from gas furnaces and boilers. The draft ANPR discusses the products and their market, incident data, voluntary standards, technological considerations, and regulatory alternatives to address the risk of injury. The draft ANPR also solicits written comments from interested persons and seeks specific comments on the following:

1. Studies, tests, analysis, or surveys performed to evaluate the effectiveness of gas-sensing and shut-off devices and performance standards, laws, or codes in reducing carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters and other gas heating appliances in Europe and Japan;
2. Studies, tests, or analysis that demonstrate the ability and expected lifespan of gas sensing devices or combustion control systems operating within the combustion chamber, heat exchanger, or flue passageways of gas heating appliances
3. Studies or analysis of the costs of incorporating carbon monoxide sensors or combustion controls systems into residential gas furnaces, boilers, or water heaters in Japan, Europe, or the United States;

4. Studies or analyses that evaluate secondary cost impacts of using gas-sensing and shut-off devices in reducing carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters, and other gas heating appliances in Europe and Japan;
5. Studies or analyses that evaluate the impact of carbon monoxide fatalities and injuries associated with the use of domestic gas furnaces, boilers, water heaters and other gas heating appliances in Europe and Japan;
6. Data or analyses on the alternatives the Commission is considering, including the cost and effectiveness of the CO shutoff/response requirements under consideration;
7. Studies, test, or analyses that correlate the effects of incomplete combustion to carbon monoxide production and changes in the combustion efficiency of natural gas and propane appliances.
8. Standards, regulations, or manufacturer qualifications that specify a required lifespan, number of cycles, or operating hours that individual gas sensing devices or combustion control systems must achieve when used for CO shutoff and/or air/fuel ratio control in residential gas furnaces, boilers, and water heaters in Japan and Europe.

# TAB A *Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products. 2015 Annual Estimates, December 2018*

# Non-Fire Carbon Monoxide Deaths Associated with the Use of Consumer Products
## 2015 Annual Estimates

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*This analysis was prepared by the CPSC staff, and it has not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.*

## Table of Contents

## Executive Summary

This report provides information about the estimated number of unintentional non-fire deaths attributed to carbon monoxide (CO) poisoning that were associated with the use of consumer products in 2015, and companion statistics since 2005. Because U.S. Consumer Product Safety Commission (CPSC) staff continues to receive reports of CO poisoning deaths for 2015, the 2015 estimates may change in subsequent reports.[1]

Some of the key findings in this report are:

For 2015:

- There were 103 incidents resulting in an estimated 175 unintentional non-fire CO poisoning deaths associated with the use of consumer products under the CPSC's jurisdiction.
- Twenty percent of the 103 incidents involved multiple deaths, including an incident in which eight members of a family died while using a generator as a power source.
- Engine-Driven Tools (EDTs) were associated with more than half of non-fire CO poisoning deaths. This category includes generators. An estimated 94 deaths (54 percent) were associated with EDTs alone, while an estimated 98 deaths (56 percent) were associated with EDTs including multiple-product incidents[2] where at least one of the products was an EDT.[3] Ninety of the estimated 98 deaths involved generators.
- Heating Systems were associated with the second largest percentage of non-fire CO poisoning deaths. An estimated 37 deaths (21 percent) were associated with some type of heating appliance. An estimated 46 deaths (26 percent) were associated with heating systems when multiple-product incidents are considered where at least one of the products among the multiple was a heating appliance. Gas heating accounted for the largest share of the deaths, and within the gas-heating equipment, liquid petroleum (LP or propane) and natural gas heating equipment were the major contributors.
- Products other than EDTs or heating systems, were associated with an estimated 35 CO deaths (20 percent) in 2015.
- Seventy-six percent of the estimated 175 CO deaths in 2015 occurred in a home location. Included in these categories are 115 deaths occurring in fixed home locations (e.g., houses, mobile homes, apartments), 14 occurring in an external structure at a residence (e.g., detached garage), and 4 in non-fixed location domiciles used as home (e.g., camper trailers, tents) or a structure not designed for habitation used as a home (e.g., metal shed).

[1] Note that the estimates for individual categories may not sum to that of the broader category due to rounding effects.
[2] Nine deaths were associated with multiple fuel-burning products being used simultaneously. In these incidents, a single source of CO poisoning could not be identified.
[3] Numbers presented in this document represent national estimates of unintentional non-fire deaths attributed to CO poisoning that were associated with the use of consumer products and not observed counts as presented in the CPSC report *Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2005–2017.*

- In 2015, 73 percent of CO poisoning victims were males.

For 2013-2015:

- The estimated annual average from 2013 to 2015 was 162 deaths.
- The majority of CO deaths occurred in the colder months of the year, with slightly more than half of the deaths occurred during the 4 cold months of November, December, January, and February.
- Adults 45 years and older comprised an annual average of 63 percent of all non-fire, consumer product-related CO deaths, which was disproportionately higher than their representation in the U.S. population. Conversely, children younger than 15 years of age accounted for a disproportionately lower annual average of only 7 percent of the yearly CO poisoning deaths.
- In the 2013-2015 period, there is some statistical evidence that the proportion of deaths by race/ethnicity differs from the proportions of race/ethnicity in the U.S. population. The proportion of Hispanic victims (irrespective of race) is significantly lower than the proportion of Hispanic Americans in the U.S. population while the proportion of Black or African American victims was significantly greater than their percentage in the U.S. population.
- Among deaths with known location, during 2013-2015, an estimated 51 percent of all CO poisoning deaths occurred in non-urban locations. This is larger than the proportion of the U.S. population living in these areas.

For 2005-2015:

- There is a marginally significant downward trend in non-fire CO deaths from 2005 to 2015. However, it should be noted that the estimated number of consumer product-related CO deaths in 2015 is greater than any of the previous 6 years and has increased for the third straight year.
- Since 2005, portable generators have been associated with an estimated 788 non-fire CO poisoning deaths, accounting for 43 percent of all consumer product-related CO deaths under CPSC's jurisdiction.

## Introduction

Carbon monoxide (CO) is a colorless, odorless, and poisonous gas that results from the incomplete combustion of fuels, such as natural or liquefied petroleum (LP) gas, gasoline, oil, wood, coal, and other fuels. The health effects related to CO depend upon its concentration in blood, which, in turn, depends upon its concentration in air, an individual's duration of exposure, and an individual's general health. Carbon monoxide combines with the body's hemoglobin (Hb) with an affinity about 250 times that of oxygen, forming carboxyhemoglobin (COHb) and interfering with oxygen transport, delivery, and use. Generally, there are no perceptible health effects or symptoms in healthy individuals at COHb levels below 10 percent. Symptoms associated with blood levels at or above 10 percent COHb include headache, fatigue, nausea, and cognitive impairment. Loss of consciousness, coma, and death can occur at COHb levels greater than 20 percent; but for healthy adults, CO deaths typically require levels above 50 percent COHb.[4]

Some symptoms of CO poisoning may mimic common illnesses, such as influenza or colds. Thus, there likely is a high incidence of initial misdiagnosis by physicians and victims (Long and Saltzman, 1995). Frequently, patients are unaware of exposures, and health care providers may not always consider CO poisoning as a cause of such nonspecific symptoms. COHb formation is reversible, as are some clinical symptoms of CO poisoning. However, some delayed neurological effects that develop after severe poisonings, especially those involving prolonged unconsciousness, may not be reversible. Prompt medical attention is important to reduce the risk of permanent damage.

Any fuel-burning appliance can be a potential source of fatal or hazardous CO levels. Fuels, such as natural and LP gas, kerosene, oil, coal, and wood can produce large amounts of CO when there is insufficient oxygen available for combustion. Consumer products that burn kerosene, oil, coal, or wood (such as wood stoves, oil boilers, and kerosene heaters) often produce an irritating smoke that can alert the victim to a potentially hazardous situation. EDTs powered by gasoline engines produce large amounts of CO, even in locations where there is sufficient oxygen available for combustion; however, EDTs may not emit an irritating exhaust smoke. Other fuels, such as charcoal briquettes and pressed wood-chip logs produce relatively smokeless fires, even at times of inefficient combustion. In these cases, victims receive no obvious sensory warning that can alert the victim to a potentially hazardous situation. Another hazard scenario is present when gas appliances are not vented properly or are malfunctioning. Natural and LP gas burn more efficiently and cleanly, compared to other forms of fuel. However, in circumstances of poor maintenance, inadequate ventilation, or faulty exhaust pathways, natural and LP gas appliances may emit potentially lethal amounts of CO without any irritating fumes. Again, many victims may be unaware of a potential problem.

[4] Inkster S.E. *Health hazard assessment of CO poisoning associated with emissions from a portable, 5.5 kilowatt, gasoline-powered generator*. Washington, D.C.: U.S. Consumer Product Safety Commission, 2004.

**National Estimates of Non-Fire CO Poisoning Deaths Associated with Consumer Products**

The national estimates presented in this report are based on death certificate records obtained from all 50 states, the District of Columbia, New York City, and some territories directly, augmented by information collected in CPSC's In-Depth Investigations (IDIs), and to a lesser extent, news articles, and medical examiners' reports contained in the CPSC Injury or Potential Injury Incident (IPII) database. Death certificate data from some states can lag for months or even years, and may not be available in time for use in this report.

The 2015 and updated 2014 estimates of consumer product-related CO poisoning deaths presented in this report are based on reporting as of August 28, 2018. The National Center for Health Statistics (NCHS) has records of every death certificate filed in the United States and its territories. A comparison of CPSC records to NCHS records indicates that CPSC records have data on approximately 79 percent of all the fatal CO poisoning deaths that occurred in the United States in 2015. By comparison, for the 10 years, 2005 through 2014, CPSC records contain approximately 91 percent of all the fatal CO poisoning deaths that occurred in the United States reported to NCHS. The estimates presented here are based on the number of deaths for which CPSC has records, scaled to the NCHS totals to adjust for missing records. Appendix A of this report describes the detailed process used to generate the national estimates presented in this report.

During 2015, an estimated 175 CO poisoning deaths were associated with the use of a consumer product under the jurisdiction of the CPSC. This report does not include CO poisoning deaths involving products outside CPSC's jurisdiction, such as incidents where the CO gas resulted from a fire or a motor vehicle, were intentional in nature, or were directly work related. Over the prior 10 years, the annual average was 165 estimated non-fire CO deaths from consumer products. Please note that during the 11 years covered in this report, there were three incidents (one in 2007, one in 2013, and one in 2015) where the exhaust from a motor vehicle engine may have contributed to the victim's CO poisoning death in addition to a consumer product.

Although multiple factors may contribute to a CO poisoning death, the source of CO is virtually always a fuel-burning product. As mentioned before, poor product maintenance by professionals or consumers, inadequate ventilation, faulty exhaust pathways, and poor user understanding of the hazard or poor judgment in operating these products can result in fatal scenarios. CPSC staff produces the CO estimates associated with consumer products to identify and monitor product groups involved in these fatal CO scenarios. Within the individual product-specific CPSC projects, additional analysis is done to consider whether improvements are warranted in the areas of product design, ventilation safeguards, or user information and education.

The annual CO estimates for the years 2005 through 2015 are presented in two formats: by product category (Table 1) and by product within fuel type (Table 2). The data are presented as an average of the most recent 3-year period (2013 through 2015) followed by yearly estimates for each of the 11 years covered by this report. As already noted, data collection was only partially complete for 2015, and estimates for this year may change in the future when additional data become available. Therefore, data for 2015 are reported using italic font in the tables.

Because the numbers presented in this document represent national estimates of unintentional non-fire deaths attributed to CO poisoning associated with the use of consumer products, the generator and other EDT death estimates would not be expected to match the *observed* death counts presented in this report or in the CPSC report, "Incidents, Deaths, and In-Depth Investigations Associated with Non-Fire Carbon Monoxide from Engine-Driven Generators and Other Engine-Driven Tools, 2005–2017."

**By Product Category**

Table 1 shows the estimated average annual number of CO poisoning deaths associated with various consumer products for 2013 to 2015, as well as the annual estimated CO deaths for the individual years from 2005 through 2015. The annual average for this 3-year period is estimated to be 162 (with a standard error of approximately 8.5). The 95 percent confidence interval[5] for this estimated average ranged from 125 to 198 deaths. Appendix B contains a graph and the data point values for the annual estimates of CO poisoning deaths associated with a consumer product for 1980 through 2015.

The estimate for *Heating Systems*, which historically accounts for a large percentage of the deaths, is further broken down into heating system subcategories within various fuel types. Death estimates for the *Engine-Driven Tools* category were further distributed between generators and other engine-driven tools. The consumer product estimate and product distributions were derived using the methodology described in Appendix A.

In 2015, the *Heating Systems* category was associated with an estimated 37 deaths (21% of the total 175 CO poisoning deaths associated with consumer products). Of the 37 estimated deaths associated with heating systems, the majority (82% or 30 deaths) involved gas heating systems. Natural gas heating systems were associated with an estimated eight deaths (22% of all heating system-related deaths). LP gas[6] heating was associated with an estimated 14 deaths (38% of heating system-related deaths); and unspecified gas heating was associated with an estimated eight deaths (22% of heating system-related deaths).

Of the estimated eight deaths in 2015 that were associated with natural gas heating systems, seven involved installed freestanding furnaces, and one involved wall- or floor-mounted furnaces and heaters. Of the estimated 14 deaths in 2015 that were associated with LP gas heating systems, 10 (71%) involved unvented portable propane heaters. These unvented portable propane heaters were fueled by a propane tank and were not a component of an installed heating system. Unvented portable propane heaters were camping heaters that used disposable propane tanks, 1-pound propane bottles, or tank top heaters that used bulk tanks larger than 1 pound.

There were also an estimated three deaths (8% of heating system-related deaths) associated with oil-burning heaters and one death associated with kerosene-burning heaters (3%). In 2015, there were no reported wood-, coal-, or diesel-fueled heating system deaths. Additionally, in 2015, there were an estimated two CO deaths (5% of heating system-related deaths) associated with heating systems with unspecified fuel sources.

[5] The confidence interval is based on a t-distribution with two degrees of freedom.
[6] In this document, references to LP gas also include propane and butane gases, the two primary components of LP gas.

In 2015, an estimated 11 CO deaths (6% of the 175 total estimated deaths) were associated with charcoal or charcoal grills. In 2015, an estimated nine deaths (5%) were associated with water heaters – in all but one of these deaths, a type of gas water heater was involved but the type of gas type could not be determined. In the remaining case, it was unclear what type of fuel was involved. Additionally, there were an estimated 10 deaths (6%) associated with other LP-fueled devices including camping lanterns (5 deaths), grills or camp stoves (4 deaths), and one death involving an LP-fueled blacksmith forge and torch used at a private residence.

In 2015, an estimated nine deaths were associated with multiple appliances (5% of the total estimated deaths). The multiple-products category includes all incidents where multiple fuel-burning products were used simultaneously, such that a single source of the CO could not be determined. In all nine deaths, one of the products involved was some type of heating system. One incident may also have involved an automobile as a contributing factor.

An estimated 94 CO poisoning deaths (54% of the 175 estimated total deaths) were associated with the category of *Engine-Driven Tools*, which includes generators, lawn mowers, welding equipment and snow blowers/throwers. Additionally, four of the estimated nine *Multiple Product* deaths were associated with an engine-driven tool being used in conjunction with another fuel-burning product for an estimated total of 98 CO deaths (56% of the estimated total for 2015). Generator-associated deaths comprised the majority of deaths in this category. An estimated 90 CO poisoning deaths were associated with a generator, including four *Multiple Product* deaths involving an engine-driven tool in 2015 (92% of all engine-driven tool deaths and 51% of the total consumer product estimate).

In recent years, the *Engine-Driven Tools* category has been associated with more CO deaths than any other category. The estimated average number of CO deaths associated with engine-driven tools (75, not including multiple product incidents) for 2013 through 2015, is greater than the average number associated with heating systems (48 deaths), which is the category with the second most number. Over the 11 years covered in this report, the total number of estimated CO deaths associated with engine-driven tools (860) exceeds the estimates for heating systems (562). Estimated generator-related CO deaths alone exceed those for heating systems over these 11 years (740 generator-related deaths versus 562 heating system-related deaths). Generator-related deaths comprise the majority of engine-driven tool-related CO deaths, accounting for 86 percent of all engine-drive tool-related deaths over the entire 11 years covered by this report.

The availability of detailed information regarding the condition of products associated with CO deaths varies widely. Information collected often describes conditions indicative of compromised vent systems, flue passageways, and chimneys for furnaces, boilers, and other heating systems. Vent systems include the portion of piping that either connects the flue outlet of the appliance and exhausts air to the outside through a ceiling or sidewall, or connects to a chimney. According to the information available, some products had vents that became detached or were installed/maintained improperly. Vents were also sometimes blocked by soot caused by inefficient combustion, which, in turn, may have been caused by several factors, such as leaky or clogged burners, an over-firing condition, or inadequate combustion air.

Other furnace-related conditions included compromised heat exchangers or filter doors/covers that were removed or not sealed. Some products were old and apparently not well maintained. Other incidents mentioned a backdraft condition, large amounts of debris in the chimney, and the use of a product that was later taken out of commission by the utility company and designated not to be turned on until repaired.

**Table 1: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Associated Fuel-Burning Consumer Product, 2005–2015**

| | 2013–*2015*⁺ | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumer Product** | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*⁺** |
| **Total** | **162** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| **Heating Systems** | **48** | **30%** | **51** | **49** | **66** | **58** | **41** | **58** | **49** | **46** | **43** | **64** | ***37*** |
| **Furnaces (incl. Boilers)** | **22** | **14%** | **14** | **30** | **29** | **29** | **16** | **30** | **22** | **27** | **21** | **24** | ***21*** |
| Coal | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Liquid Petroleum (LP) Gas | 5 | 3% | 1 | 9 | * | 3 | 1 | 7 | * | 4 | 1 | 11 | *3* |
| Natural Gas | 6 | 4% | 6 | 19 | 20 | 18 | 10 | 15 | 6 | 15 | 5 | 6 | *7* |
| Oil | 3 | 2% | 2 | * | 5 | 1 | 3 | 1 | 2 | * | 5 | 1 | *3* |
| Unspecified Gas | 8 | 5% | 2 | * | 4 | 2 | 1 | 4 | 10 | 4 | 10 | 6 | *8* |
| Unspecified Fuel | < 1 | < 1% | 3 | 2 | * | 5 | 1 | 2 | 2 | 5 | * | * | *1* |
| **Portable Heaters** | **14** | **9%** | **23** | **14** | **17** | **13** | **8** | **19** | **13** | **11** | **12** | **18** | ***12*** |
| Kerosene | 1 | 1% | 2 | 3 | 3 | 4 | * | 1 | 2 | 1 | * | 2 | *1* |
| Liquid Petroleum (LP) Gas | 12 | 7% | 19 | 10 | 14 | 9 | 8 | 18 | 11 | 10 | 12 | 14 | *10* |
| Natural Gas | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Unspecified Gas | * | * | 1 | * | * | * | * | * | * | * | * | * | * |
| Unspecified Fuel | * | * | 1 | 1 | * | * | * | * | * | * | * | * | * |
| **Wall/Floor Furnaces** | **2** | **1%** | **2** | **2** | **9** | **3** | **6** | **5** | **1** | ***** | ***** | **5** | ***1*** |
| Liquid Petroleum (LP) Gas | * | * | * | * | 4 | 1 | 5 | 1 | * | * | * | * | * |
| Natural Gas | 1 | 1% | 2 | 2 | 5 | 2 | 1 | 2 | * | * | * | 2 | *1* |
| Unspecified Gas | 1 | 1% | * | * | * | * | * | * | * | * | * | 2 | * |
| Unspecified Fuel | * | * | * | * | * | * | * | 1 | 1 | * | * | * | * |
| **Room/Space Heaters** | **6** | **4%** | **8** | **1** | **6** | **5** | **9** | **1** | **5** | **5** | **9** | **8** | ***1*** |
| Coal | 1 | 1% | 1 | * | * | * | * | * | 2 | * | 1 | 1 | * |
| Liquid Petroleum (LP) Gas | 3 | 2% | * | * | 4 | 2 | 5 | 1 | 1 | 4 | 3 | 7 | * |
| Natural Gas | 1 | 1% | * | 1 | * | 2 | 2 | * | * | * | 2 | * | * |
| Wood | 1 | 1% | 2 | * | * | 1 | 2 | * | 1 | * | 2 | * | * |
| Unspecified Gas | * | * | 1 | * | 2 | * | * | * | 1 | * | * | * | * |
| Unspecified Fuel | < 1 | < 1% | 3 | * | * | * | * | * | * | 1 | * | * | *1* |
| **Unspecified Heater/System** | **4** | **2%** | **3** | **1** | **5** | **8** | **2** | **4** | **8** | **2** | **1** | **9** | ***1*** |
| Liquid Petroleum (LP) Gas | 3 | 2% | * | * | 1 | 2 | * | 1 | 3 | 1 | * | 8 | *1* |
| Natural Gas | * | * | * | * | 3 | * | * | * | 1 | * | * | * | * |
| Unspecified Gas | * | * | * | * | * | 2 | 1 | 1 | 1 | 1 | * | * | * |
| Unspecified Fuel | 1 | 1% | 3 | 1 | 1 | 4 | 1 | 1 | 2 | * | 1 | 1 | * |
| **Charcoal Grills, Charcoal** | **10** | **6%** | **6** | **10** | **8** | **7** | **7** | **17** | **10** | **6** | **11** | **7** | ***11*** |

**Table 1: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Associated Fuel-Burning Consumer Product, 2005–2015**

**(continued)**

| Consumer Product | 2013–*2015*+ | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Engine-Driven Tools** | **75** | **46%** | **102** | **104** | **79** | **82** | **76** | **56** | **73** | **64** | **68** | **62** | ***94*** |
| Generators - Gasoline | 65 | | 88 | 85 | 68 | 76 | 64 | 42 | 64 | 57 | 55 | 53 | *86* |
| Generators – LP | * | * | * | * | * | * | * | 2 | * | * | * | * | * |
| Generators - Unspecified Fuel | 1 | | * | * | * | * | * | * | * | * | 1 | 1 | * |
| Other Engine-Driven Tools | 10 | 6% | 13 | 18 | 11 | 6 | 12 | 14 | 10 | 6 | 13 | 8 | *8* |
| **Ranges or Ovens** | **5** | **3%** | **6** | ***** | **6** | ***** | **4** | **5** | **8** | **4** | **10** | ***** | ***5*** |
| Liquid Petroleum (LP) Gas | 1 | 1% | 1 | * | 1 | * | * | 1 | 1 | 1 | 1 | * | *3* |
| Natural Gas | 2 | 1% | 1 | * | 2 | * | 2 | 2 | 3 | * | 2 | * | *3* |
| Unspecified Gas | 1 | 1% | 3 | * | 3 | * | 2 | 1 | 3 | 2 | 2 | * | * |
| Unspecified Fuel | 2 | 1% | * | * | * | * | * | * | * | * | 5 | * | * |
| **Water Heaters** | **5** | **3%** | **6** | **4** | **2** | **6** | **5** | **2** | **8** | **5** | **2** | **5** | ***9*** |
| Liquid Petroleum (LP) Gas | 1 | 1% | 2 | * | 1 | 1 | 2 | * | 1 | * | 1 | 1 | * |
| Natural Gas | * | * | * | 3 | * | 1 | 1 | 2 | 4 | * | * | * | * |
| Oil | * | * | * | * | * | 1 | * | * | * | * | * | * | * |
| Unspecified Gas | 3 | 2% | 3 | 1 | 1 | 1 | 1 | * | 1 | 2 | * | 2 | *8* |
| Unspecified Fuel | 1 | 1% | * | * | * | 2 | 1 | * | 1 | 2 | 1 | 1 | *1* |
| **Lanterns** | **3** | **2%** | **6** | **3** | ***** | **4** | **1** | ***** | **2** | **2** | ***** | **5** | ***5*** |
| Liquid Petroleum (LP) Gas | 3 | 2% | 6 | 3 | * | 4 | 1 | * | 1 | 2 | * | 4 | *5* |
| Kerosene | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Unspecified Fuel | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| **Grills, Camp Stoves** | **4** | **2%** | ***** | **2** | **2** | ***** | ***** | ***** | **2** | ***** | **1** | **6** | ***4*** |
| Liquid Petroleum (LP) Gas | 2 | 1% | * | 1 | 1 | * | * | * | 2 | * | * | 2 | *4* |
| Wood | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Unspecified Fuel | 1 | 1% | * | 1 | 1 | * | * | * | * | * | 1 | 2 | * |

**Table 1: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Associated Fuel-Burning Consumer Product, 2005–2015 (continued)**

| | 2013–*2015*+ | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumer Product** | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*+** |
| **Other Products** | **5** | **3%** | **3** | ***** | **2** | **5** | **2** | **6** | **4** | **2** | **6** | **8** | ***1*** |
| Chimney – Unspecified Fuel | < 1 | < 1% | 1 | * | * | * | * | * | * | 1 | 1 | * | * |
| Fireplace – Unspecified Gas | * | * | * | * | 1 | * | * | * | * | * | * | * | * |
| Fireplace – Wood | * | * | * | * | 1 | * | * | * | * | * | * | * | * |
| Fireplace – Coal | * | * | * | * | * | * | * | 1 | * | * | * | * | * |
| Other Products – LP Gas | 2 | 1% | 1 | * | * | 3 | 1 | 2 | 2 | * | 1 | 4 | *1* |
| Other Products – Natural Gas | 1 | 1 % | 1 | * | * | * | 1 | * | * | * | 3 | 1 | * |
| Other Products – Unspecified Gas | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Other Products – Unspecified Fuel | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Unidentified Product | < 1 | < 1% | * | * | * | * | * | 2 | 1 | 1 | * | 1 | * |
| Unidentified Product – LP Gas | < 1 | < 1% | * | * | * | 2 | * | * | * | * | * | 1 | * |
| **Multiple Products** | **7** | **4%** | **12** | **8** | **20** | **12** | **11** | **15** | **8** | **5** | **5** | **7** | ***9*** |

\+ Data collection for 2015 is only partially complete and data are shown in italics. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC Injury or Potential Injury Incident File, CPSC In-Depth Investigation File,
National Center for Health Statistics Mortality File, 2005–2015.
Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

**By Fuel Type**

Table 2 (beginning on page 15) organizes the estimates by product within fuel type. The three major fuel types include *Gas-Fueled Products* (natural gas and liquid petroleum [LP including propane and butane] gas); *Solid-Fueled Products* (charcoal, coal, and wood); and *Liquid-Fueled Products* (gasoline, kerosene, and oil). Of these fuel types, *Gas-Fueled Products* were associated with 55 of the 175 (31%) estimated CO deaths in 2015. *Liquid-Fueled Products* were associated with 98 (56%) estimated deaths, and *Solid-Fueled Products* were associated with 11 (6%) estimated deaths in the same time period. An estimated seven (4%) deaths were associated with the *Multiple Products* category, where there were two or more different types of fuel used. Five (3%) deaths in 2015 were associated with consumer products where one or more of the fuel types were unknown. It should be noted that in multiproduct cases where the fuel types were the same for all involved products, the incident is counted in the respective category summary. For example, if an incident involved both a gasoline-fueled generator and a gasoline-fueled lawn mower, this incident would be included only once in the *Liquid-Fueled Products* category.

In the *Gas-Fueled Products* category, the majority of CO deaths in 2015 were associated with heating-related products. Of the estimated 55 gas-fueled appliance deaths in 2015, 30 (55%) were associated with heating systems or heaters, including furnaces, portable heaters, and room or space heaters. Additionally, the one Multiple Gas-Fueled Products death was associated with a heating-related product and another product raising the total involving heating-related products to 31 of the 56 *Gas-Fueled Products* category.

All but four of the estimated 98 liquid-fueled appliance-related deaths in 2015 were associated with engine-driven tools (*e.g.*, generators, lawn mowers/garden tractors). Generators accounted for 86 of the estimated 98 deaths (88%) in the *Liquid- Fueled Products* category for 2015.

In 2015, an estimated 11 deaths occurred in the *Solid-Fueled Products* category. All were associated with charcoal or charcoal grills.

**Table 2: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products Organized by Fuel Type, 2005–2015**

| | 2013–*2015*[+] | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumer Product** | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*** |
| **Total** | **162** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| **Gas-Fueled Products** | **59** | **36%** | **53** | **51** | **80** | **58** | **53** | **70** | **58** | **51** | **45** | **78** | ***55*** |
| **Natural Gas** | **11** | **7%** | **10** | **26** | **30** | **28** | **17** | **23** | **15** | 15 | 13 | 11 | *10* |
| Furnace (incl. Boilers) | 6 | 4% | 6 | 19 | 20 | 18 | 10 | 15 | 6 | 15 | 5 | 6 | *7* |
| Pool Heater | 1 | 1% | 1 | * | * | * | * | * | * | * | 3 | 1 | * |
| Portable Heater | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Range/Oven | 2 | 1% | 1 | * | 2 | * | 2 | 2 | 3 | * | 2 | * | *3* |
| Room/Space Heater | 1 | 1% | * | 1 | * | 3 | 2 | * | * | * | 2 | * | * |
| Wall/Floor Furnace | 1 | 1% | 2 | 2 | 5 | 3 | 1 | 2 | * | * | * | 2 | *1* |
| Water Heater | * | * | * | 3 | * | 1 | 1 | 2 | 4 | * | * | * | * |
| Unspecified Heater | * | * | * | * | 3 | * | * | * | 1 | * | * | * | * |
| Other Appliance | * | * | * | * | * | * | 1 | * | * | * | * | * | * |
| **Liquid Petroleum (LP) Gas** | **33** | **20%** | **30** | **23** | **26** | **31** | **23** | **35** | **23** | **22** | **20** | **52** | ***27*** |
| Furnace (incl. Boilers) | 5 | 3% | 1 | 9 | * | 3 | 1 | 7 | * | 4 | 1 | 11 | *3* |
| Generator | * | * | * | * | * | * | * | 2 | * | * | * | * | * |
| Grill/Camp Stove | 2 | 1% | * | 1 | 1 | * | * | * | 2 | * | * | 2 | *4* |
| Lantern | 3 | 2% | 6 | 3 | * | 4 | 1 | * | 1 | 2 | * | 4 | *5* |
| Other Products | 1 | 1% | * | * | * | 3 | 1 | * | * | * | * | 2 | *1* |
| Pool Heater | * | * | * | * | * | * | * | 1 | * | * | * | * | * |
| Portable Heater | 12 | 7% | 19 | 10 | 14 | 9 | 8 | 18 | 11 | 10 | 12 | 14 | *10* |
| Range/Oven | 1 | 1% | 1 | * | 1 | * | * | 1 | 1 | 1 | 1 | * | *3* |
| Refrigerator | 1 | 1% | 1 | * | * | * | * | 1 | 2 | * | 1 | 2 | * |
| Room/Space Heater | 3 | 2% | * | * | 4 | 3 | 5 | 1 | 1 | 4 | 3 | 7 | * |
| Unspecified Heater/System | 3 | 2% | * | * | 1 | 3 | * | 1 | 3 | 1 | * | 8 | *1* |
| Wall/Floor Furnace | * | * | * | * | 4 | 1 | 5 | 1 | * | * | * | * | * |
| Water Heater | 1 | 1% | 2 | * | 1 | 1 | 2 | * | 1 | * | 1 | 1 | * |
| **Unspecified Gas** | **13** | **8%** | **11** | **1** | **11** | **3** | **5** | **6** | **17** | **10** | **13** | **11** | ***16*** |
| Furnace (incl. Boilers) | 8 | 5% | 2 | * | 4 | 2 | 1 | 4 | 10 | 4 | 10 | 6 | *8* |
| Pool Heater | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Portable Heater | * | * | 1 | * | * | * | * | * | * | * | * | * | * |
| Range/Oven | 1 | 1% | 3 | * | 3 | * | 2 | 1 | 3 | 2 | 2 | * | * |
| Room/Space Heater | * | * | 1 | * | 2 | * | * | * | 1 | * | * | * | * |
| Fireplace | * | * | * | * | 1 | * | * | * | * | * | * | * | * |
| Wall/Floor Furnace | 1 | 1% | * | * | * | * | * | * | * | * | * | 2 | * |
| Water Heater | 3 | 2% | 3 | 1 | 1 | 2 | 1 | * | 1 | 2 | * | 2 | *8* |
| Unspecified Heater | * | * | * | * | * | 1 | 1 | 1 | 1 | 1 | * | * | * |

**Table 2: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products Organized by Fuel Type, 2005–2015 (continued)**

| | 2013–*2015*+ | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumer Product** | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*+** |
| **Multiple Gas-Fueled Products** | **2** | **1%** | **2** | **1** | **13** | **2** | **8** | **6** | **3** | **4** | * | **5** | ***1*** |
| **Liquid-Fueled Products** | **79** | **49%** | **108** | **108** | **89** | **95** | **81** | **60** | **79** | **65** | **73** | **67** | ***98*** |
| **Gasoline-Fueled** | 74 | 46% | **102** | **104** | **78** | **82** | **77** | **53** | **73** | **64** | **67** | **61** | ***94*** |
| Generator | 65 | 40% | 88 | 85 | 68 | 76 | 64 | 40 | 64 | 57 | 55 | 53 | *86* |
| Other Engine-Driven Tools | 10 | 6% | 13 | 18 | 11 | 6 | 12 | 14 | 10 | 6 | 13 | 8 | *8* |
| **Kerosene-Fueled** | **2** | **1%** | **2** | **3** | **3** | **4** | * | **1** | **2** | **1** | * | **4** | ***1*** |
| Grill/Camp Stove | * | * | * | * | * | * | * | * | * | * | * | * | * |
| Portable Heater | 1 | 1% | 2 | 3 | 3 | 4 | * | 1 | 2 | 1 | * | 2 | *1* |
| Lantern | < 1% | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| **Oil-Fueled** | **3** | **2%** | **2** | * | **5** | **2** | **3** | **1** | **2** | * | **5** | **1** | ***3*** |
| Furnace (incl. Boilers) | 3 | 2% | 2 | * | 5 | 1 | 3 | 1 | 2 | * | 5 | 1 | *3* |
| Water Heater | * | * | * | * | * | 1 | * | * | * | * | * | * | * |
| **Diesel-Fueled** | * | * | * | * | * | **1** | * | * | * | * | * | * | * |
| Water Heater | * | * | * | * | * | 1 | * | * | * | * | * | * | * |
| **Multiple Liquid-Fueled Products** | **1** | **1%** | **2** | **1** | **2** | **5** | **1** | **5** | **1** | * | **1** | **1** | * |
| **Solid-Fueled Products** | **11** | **7%** | **9** | **10** | **9** | **8** | **9** | **18** | **14** | **5** | **14** | **9** | ***11*** |
| **Charcoal-Fueled** | 10 | 6% | **6** | **10** | **8** | **7** | **7** | **17** | **10** | 5 | 11 | 7 | *11* |
| Charcoal / Charcoal Grills | 10 | 6% | 6 | 10 | 8 | 7 | 7 | 17 | 10 | 5 | 11 | 7 | *11* |
| **Coal-Fueled** | **1** | **1%** | **1** | * | * | * | * | **1** | **3** | * | **1** | **1** | * |
| Furnace (incl. Boilers) | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Room/Space Heater | 1 | 1% | 1 | * | * | * | * | * | 2 | * | 1 | 1 | * |
| Chimney / Fireplace | * | * | * | * | * | * | * | 1 | * | * | * | * | * |
| **Wood-Fueled** | **1** | **1%** | **2** | * | **1** | **1** | **2** | * | **1** | * | **2** | **1** | * |
| Chimney/Fireplace | * | * | * | * | 1 | * | * | * | * | * | * | * | * |
| Grill/Stove | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Room/Space Heater | 1 | 1% | 2 | * | * | 1 | 2 | * | 1 | * | 2 | * | * |

**Table 2: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products Organized by Fuel Type, 2005–2015 (continued)**

| | 2013–*2015*+ | | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Consumer Product** | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*+** |
| **Unspecified Fuel Products** | **7** | **4%** | **12** | **6** | **2** | **11** | **3** | **7** | **9** | **11** | **10** | **8** | ***4*** |
| Chimney | < 1 | < 1% | 1 | * | * | * | * | * | * | 1 | 1 | * | * |
| Furnace (incl. Boilers) | < 1 | < 1% | 3 | 2 | * | 5 | 1 | 2 | 2 | 5 | * | * | *1* |
| Generator | 1 | 1% | * | * | * | * | * | * | * | * | 1 | 1 | * |
| Grill/Camp Stove | 1 | 1% | * | 1 | 1 | * | * | * | * | * | 1 | 2 | * |
| Lantern | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Pool Heater | < 1 | < 1% | * | * | * | * | * | * | * | * | * | 1 | * |
| Portable Heater | * | * | 1 | 1 | * | * | * | * | * | * | * | * | * |
| Range/Oven | 2 | 1% | * | * | * | * | * | * | * | * | 5 | * | * |
| Room/Space Heater | < 1 | < 1% | 3 | * | * | * | * | * | * | 1 | * | * | *1* |
| Unspecified Heater | 1 | 1% | 3 | 1 | 1 | 4 | 1 | 1 | 2 | * | 1 | 1 | * |
| Wall/Floor Furnace | * | * | * | * | * | * | * | 1 | 1 | * | * | * | * |
| Unidentified Product | < 1 | < 1% | * | * | * | * | * | 2 | 1 | 1 | * | 1 | * |
| Water Heater | 1 | 1% | * | * | * | 2 | 1 | * | 1 | 2 | 1 | 1 | *1* |
| **Multiple Product - Different Fuels** | **4** | **2%** | **8** | **6** | **5** | **5** | **2** | **4** | **3** | **4** | **3** | **1** | ***8*** |
| Gas & Liquid | 2 | 1% | 7 | 6 | 5 | 3 | 1 | 1 | 2 | 2 | 3 | 1 | *7* |
| Gas & Solid | * | * | 1 | * | * | * | 1 | * | * | 1 | * | * | * |
| Liquid & Solid | * | * | * | * | * | 1 | * | 2 | 1 | * | * | * | * |
| Liquid & Unspecified | < 1 | < 1% | * | * | * | * | * | * | * | * | * | * | *1* |
| Gas & Liquid & Unspecified | * | * | * | * | * | 2 | * | * | * | * | * | * | * |

+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
# In 2011, there were an estimated three CO deaths associated with an LP-fueled welder/generator being used as a generator.

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC Injury or Potential Injury Incident File, CPSC In-Depth Investigation File,
National Center for Health Statistics Mortality File, 2005–2015.

Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

**Engine-Driven Tools**

Table 3 shows a breakdown of the death estimates for the 11-year period from 2005 through 2015 in the *Engine-Driven Tools* category. During 2015, engine-driven tools were associated with an estimated 98 carbon monoxide poisoning deaths (56% of the 175 total consumer product estimate). Table 3 totals differ from those in Tables 1 and 2 in that they also include the deaths associated with multiple potential CO-producing products, where at least one product was an engine-driven tool. Of the 98, four deaths were associated with an engine-driven tool and some other fuel-burning product; the remaining (92 percent) were associated with generators, or generators in conjunction with another fuel-burning product.

Lawnmowers were associated with slightly more than 50 percent (60 of 119) of the deaths in the *Other Engine-Driven Tools* category for the 11-year period. There were five other deaths associated with a lawnmower and another product in this period. There was an estimated average of four lawnmower-related CO deaths per year from 2013 to 2015 (13 deaths, excluding multi-product deaths). And to a lesser extent, CO deaths related to ATV exhaust, snow blowers, and power washers were other sizeable categories.

**Table 3: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Engine-Driven Tools, 2005–2015**

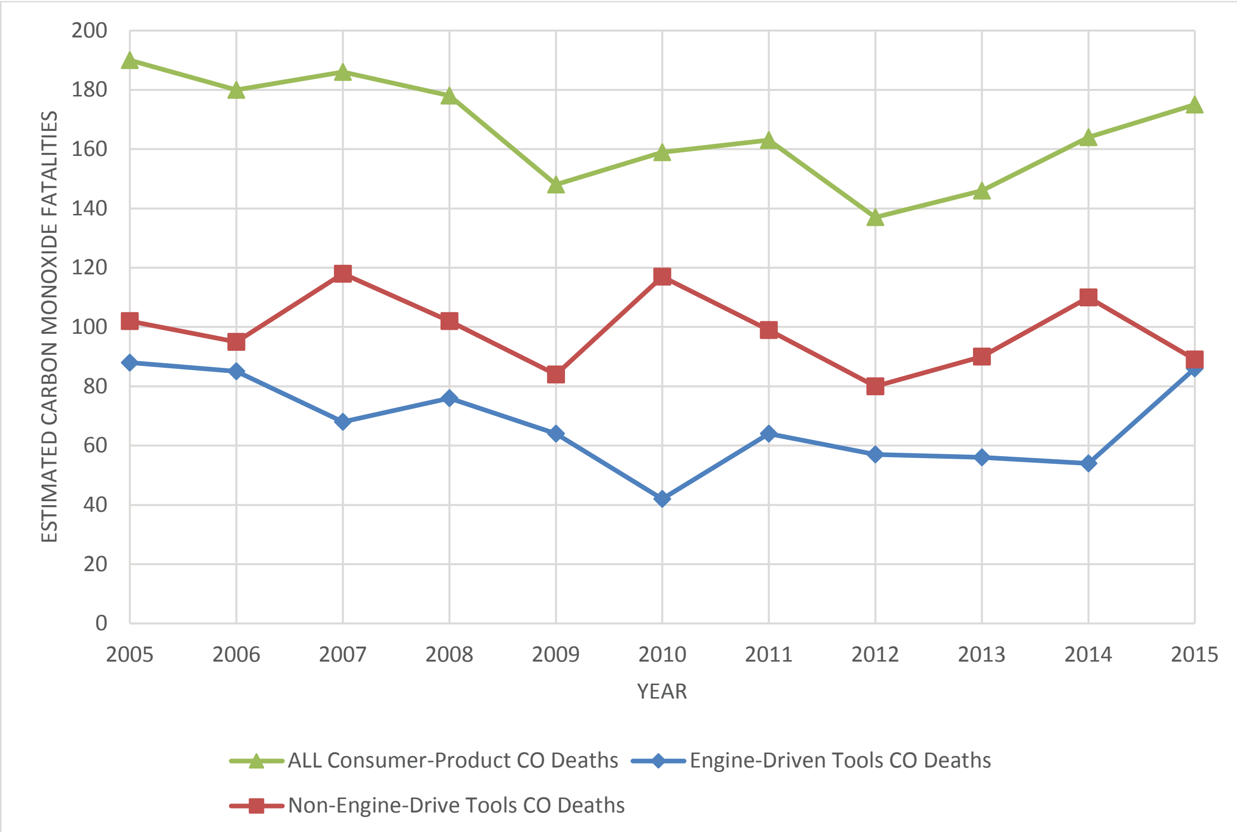
| Engine-Driven Tools | 2013-*2015*+ Average Estimate | Average Percentage | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2005 | 2006 | 2007 | 2008+ | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Total** | **79** | **100%** | **110** | **106** | **85** | **93** | **78** | **61** | **78** | **66** | **73** | **64** | ***98*** |
| **Generators** | **66** | **84%** | **88** | **85** | **68** | **76** | **64** | **42** | **64** | **57** | **56** | **54** | ***86*** |
| Gasoline-fueled | 65 | 82% | 88 | 85 | 68 | 76 | 64 | 40 | 64 | 57 | 55 | 53 | *86* |
| LP-fueled | * | * | * | * | * | * | * | 2 | * | * | * | * | * |
| Unspecified Fuel | 1 | 1% | * | * | * | * | * | * | * | * | 1 | 1 | * |
| **Other Engine-Driven Tools (OEDTs)** | **10** | **13%** | **13** | **17** | **11** | **6** | **12** | **14** | **10** | **6** | **13** | **8** | ***8*** |
| **Lawn Mowers** | **4** | **5%** | **9** | **11** | **5** | **2** | **6** | **7** | **3** | **4** | **7** | **2** | ***4*** |
| Riding Mowers | 3 | 4% | 9 | 8 | 4 | 2 | 6 | 5 | 3 | 2 | 6 | 1 | *3* |
| Unspecified Mowers | 1 | 1% | * | 3 | 1 | * | * | 2 | * | 1 | 1 | 1 | *1* |
| Paint Sprayer | * | * | * | * | * | * | * | * | 1 | * | * | * | * |
| Power Washer | 1 | 1% | 3 | 1 | 1 | * | 1 | * | 2 | * | * | 2 | * |
| Snow Blower/Thrower | 1 | 1% | * | 1 | 2 | * | 3 | 1 | 1 | * | 2 | 1 | *1* |
| ATV | 1 | 1% | 1 | * | * | 2 | * | 4 | 2 | 1 | 1 | 1 | * |
| Water Pump | < 1 | < 1% | * | 1 | 1 | * | * | 1 | * | * | 1 | * | * |
| Welder | 1 | 1% | * | * | 1 | 1 | * | * | * | * | * | * | *3* |
| Air Compressor | * | * | * | 1 | * | * | * | * | * | * | * | * | * |
| Concrete Saw | * | * | * | * | * | 1 | * | * | * | * | * | * | * |
| Tiller | * | * | * | * | * | * | 1 | * | * | * | * | * | * |
| Go-Cart | * | * | * | * | * | * | 1 | * | * | * | * | * | * |
| Small Engine | * | * | * | 1 | * | * | * | * | * | * | * | * | * |
| Snowmobile | * | * | * | 1 | * | * | * | * | * | * | * | * | * |
| Stump Grinder | < 1 | < 1% | * | * | * | * | * | * | * | * | 1 | * | * |
| Wood Splitter | < 1 | < 1% | * | * | * | * | * | * | * | 1 | * | 1 | * |
| **Multiple Product: Engine-Driven Tools Involved** | **4** | **5%** | **9** | **3** | **6** | **10** | **2** | **6** | **4** | **2** | **5** | **2** | ***4*** |
| Generator + OEDT | * | * | * | * | * | * | * | * | * | * | * | * | * |
| Generator + other Product | 3 | 4% | 9 | 3 | 6 | 8 | 2 | 6 | 3 | 2 | 3 | 2 | *4* |
| Multiple OEDT | * | * | * | * | * | 2 | * | * | 1 | * | * | * | * |
| OEDT + other product | < 1 | < 1% | * | * | * | * | * | * | * | * | 1 | * | * |

\+ Data collection for 2015 is only partially complete, and data are shown in italics. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC Injury or Potential Injury Incident File, CPSC In-Depth Investigation File, National Center for Health Statistics Mortality File, 2005–2015.
Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

## Comparison of Trends

Figure 1 provides a graphic representation of the CO death trends related to: (1) all consumer products; (2) engine-driven tools; and (3) non-engine-driven tool products. A regression analysis of the estimated number of all non-fire, consumer product-related CO poisoning deaths from 2005 to 2015 indicates that there is a marginally statistically significant evidence of a downward trend (p-value = 0.0700). However, it should be noted that the most recent year (2015) marks the third straight year where estimated CO deaths increased from the previous year from the current low of 2012. In addition, it should also be noted that the estimated 2015 CO deaths (175) is higher than the previous six years, since 2008.

**Figure 1: Comparison of Trends in Consumer Product-Related Carbon Monoxide Deaths–2005 to 2015**




## Number of Deaths per Incident Reported to CPSC

Table 4 presents a summary of the incident data distributed by the number of deaths per incident. It should be noted that this table does not provide estimates. The numbers presented are counts observed in the CPSC databases. Table 4 shows that in 2015, 82 of the 103 fatal CO incidents (80% of fatal CO incidents reported to the CPSC) involved a single death. Table 4 accounts for only the fatally injured victims in each CO poisoning incident. It is not uncommon for CO incidents involving one or more deaths to also result in one or more nonfatal CO poisoning injuries. However, the breakdown of these incidents was not quantified for analysis in this death-focused report. It should be noted that these are counts of incidents reported in CPSC databases and do not represent the national estimates of deaths per CO incident. Therefore, the counts presented in Table 4 should not be expected to add up to the estimated deaths in other tables. Additionally, note that occasionally, even though CPSC records indicate that there was more than one death in a specific incident, not all the deaths are used in the estimation process. Deaths for which CPSC does not have a death certificate are not used in the analyses, because the scaling estimation process accounts for missing records. Also, if an additional death that is work-related is indicated in the record, that death was not counted in the estimation process, because work-related deaths are out of scope for this report. However, both of these cases are included in Table 4 to highlight the danger of multiple deaths in CO poisoning cases.

Death certificates do not include information about other deaths for the same incident. Over the 11-year period covered by this report, CPSC records indicate that 19 percent of the incidents resulted in multiple deaths. Eighteen incidents resulted in four or more CO deaths including an incident in 2015 where eight people died. The number of deaths for a particular incident is based primarily on CPSC In-Depth Investigation (IDI) records. Some additional multiple-death incidents were identified by matching the incident date of death and location of death to death certificates, while others were identified from news articles contained in the CPSC Injury or Potential Injury Incident (IPII) database.

**Table 4: Number of Carbon Monoxide Poisoning Incidents Reported to CPSC by Number of Deaths per Incident, 2005–2015**

| Number of Deaths Reported in Incident | 2013–*2015*+ | | Annual Incidents | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Annual Average | Average Percent | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Total Incidents** | **106** | **100%** | **146** | **123** | **147** | **141** | **117** | **116** | **120** | **90** | **106** | **110** | ***103*** |
| 1 | 84 | 80% | 123 | 93 | 125 | 119 | 93 | 100 | 95 | 74 | 84 | 86 | *82* |
| 2 | 19 | 18% | 17 | 22 | 13 | 15 | 19 | 14 | 22 | 14 | 21 | 21 | *15* |
| 3 | 1 | 1% | 5 | 6 | 8 | 5 | 4 | 1 | 1 | 1 | * | 1 | *2* |
| 4 | 2 | 1% | * | 1 | 1 | 2 | 1 | 1 | 1 | * | 1 | 1 | *3* |
| 5 | < 1 | 1% | * | 1 | * | * | * | * | 1 | 1 | * | 1 | * |
| 6 | * | * | 1 | * | * | * | * | * | * | * | * | * | * |
| 7 | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 8 | < 1 | < 1% | * | * | * | * | * | * | * | * | * | * | *1* |

+ Data collection for 2015 is only partially complete, and data are shown in italics. Italicized counts may change in the future if more reports of deaths are received.

Note: Percentages do not add to 100% due to rounding.

Numbers presented here are counts based on records available to CPSC staff. These do not represent national estimates and should not be expected to match estimates presented elsewhere in this document.

Source: U.S. Consumer Product Safety Commission/EPHA.

## By Location of Death

Table 5 shows that, in 2015, an estimated 133 CO poisoning deaths occurred in home locations, including an estimated 14 deaths in detached structures at residential locations (*i.e.*, sheds, detached garages) and 4 in structures not intended originally as a permanent residence (*i.e.*, camper trailers, sea-land shipping containers). From 2013 to 2015, an annual average of 126 CO poisoning deaths (78% of all CO deaths) occurred at home locations. In 2015, an estimated 25 deaths took place in temporary shelters, such as campers, cabins, and trailers used for shelter. For 2013 to 2015, an annual average of 21 CO poisoning deaths (13%) took place in temporary shelters. Deaths due to CO poisoning in temporary shelters were most commonly associated with heating sources, generators, or lanterns.

A small percentage of the CO poisoning deaths occurred in vehicles (such as passenger vans, trucks, automobiles, or boats) where a consumer product was the CO producing product in use. In 2015, there were an estimated 12 CO deaths in this category. For the 3-year period 2013 to 2015, an annual average of eight CO poisoning deaths (5%) took place in vehicles. All of the vehicle location incidents in this 3-year period involved a generator, LP heater, LP lantern, or the burning of charcoal inside the vehicle.

**Table 5: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Location of Death, 2005−2015**

| Location of Death | 2013−*2015*+ | | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average Estimate** | **Average Percent** | **2005** | **2006** | **2007** | ***2008*** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | ***2015*+** |
| **Total** | **162** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| Home[1] | 106 | 65% | 120 | 119 | 138 | 124 | 109 | 125 | 122 | 107 | 104 | 100 | *115* |
| Home – External Structure[2] | 14 | 9% | 16 | 14 | 11 | 13 | 7 | 5 | 10 | 5 | 13 | 15 | *14* |
| Home – But Not House[3] | 6 | 4% | 6 | 4 | 4 | 6 | 1 | 5 | 5 | 1 | 3 | 12 | *4* |
| Temporary Shelter | 21 | 13% | 32 | 36 | 22 | 20 | 18 | 17 | 15 | 21 | 16 | 21 | *25* |
| Vehicles (including boats) | 8 | 5% | 14 | 6 | 8 | 9 | 12 | 6 | 9 | * | 7 | 6 | *12* |
| Other | 5 | 3% | 2 | 1 | 2 | 3 | * | 1 | 1 | * | 2 | 8 | *5* |
| Unknown | < 1 | < 1% | * | * | * | 2 | * | * | 1 | 2 | * | 1 | * |

\+ Data collection for 2015 is only partially complete, and data are shown in italics. Italicized estimates may change in the future if more reports of deaths are received.

* No reports received by CPSC staff.

Note: Percentages do not add to 100% due to rounding.

1 Traditional home (*e.g.*, detached house, townhouse, apartment, mobile home)

2 External structure at residential locations (*e.g.*, detached garage, shed)

3 Non-fixed structure or structure not originally designed for permanent occupation (*e.g.*, camper trailer, van, converted sea-land shipping container).

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File, National Center for Health Statistics Mortality File, 2005–2015.

## By Time of Year

CPSC data indicate that there were more CO deaths attributable to incidents that occurred in the cold months than in the warm months. This is most likely because of the use of furnaces and portable heaters in the cold months. Additionally, generators are often used in the cold months because of power outages due to snow and ice storms. Table 6 shows the annual estimated CO deaths categorized by month of death. In 2015, slightly less than half of the 175 estimated CO deaths (82, 47%) were attributable to incidents that occurred during the four cold months of November, December, January, and February. An estimated 63 deaths (36%) are attributable to incidents that occurred during the transition months of March, April, September, and October; and an estimated 30 deaths (17%) are attributable to the warm months of May, June, July, and August. The same pattern holds true for the 2013-2015 annual average estimates as well as the 11-year aggregated estimates.

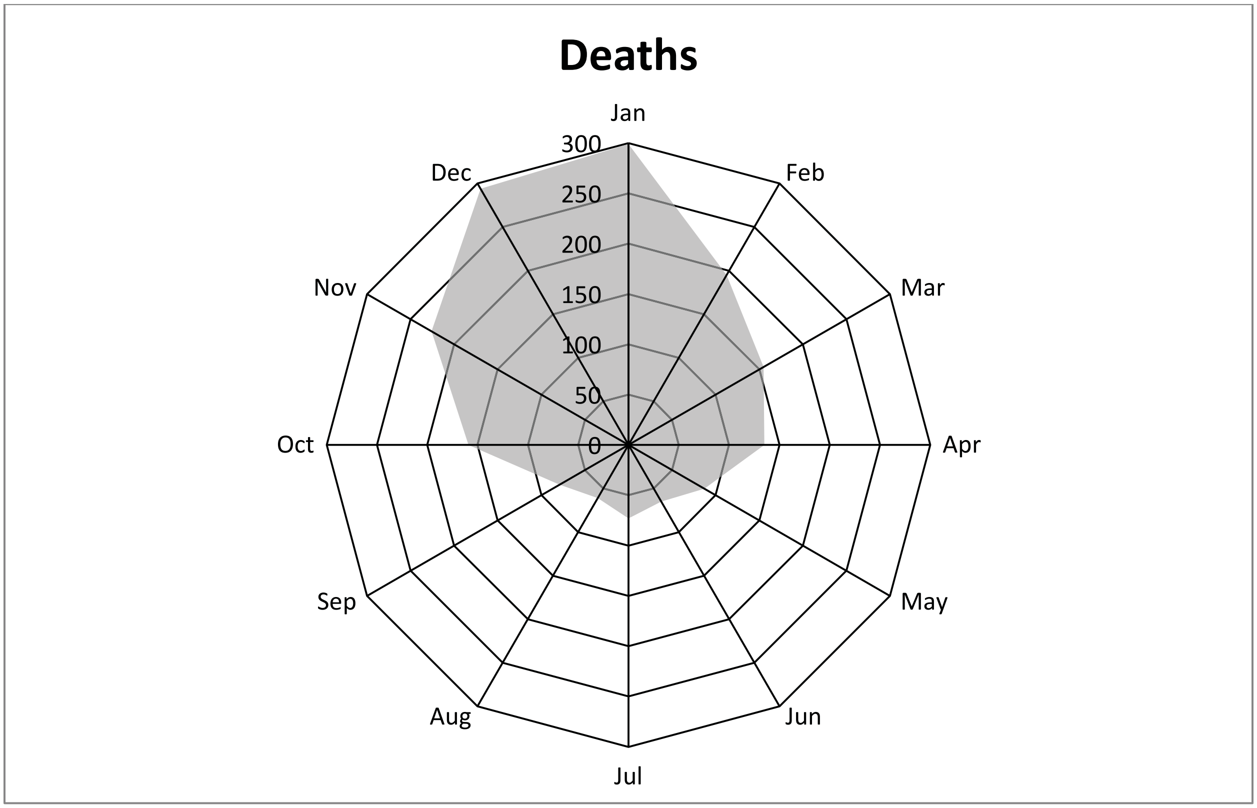
**Table 6: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Month and Year of the Death, 2005–2015**

| Month of Death | 2013−*2015*+ | | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Total** | **162** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| **Cold Months** | **82** | **51%** | **98** | **95** | **109** | **110** | **85** | **109** | **85** | **75** | **82** | **83** | ***82*** |
| November | 15 | 9% | 18 | 23 | 21 | 28 | 12 | 18 | 34 | 26 | 16 | 20 | *10* |
| December | 23 | 14% | 33 | 38 | 25 | 25 | 20 | 38 | 20 | 25 | 28 | 20 | *22* |
| January | 24 | 15% | 37 | 14 | 43 | 31 | 29 | 38 | 24 | 10 | 22 | 26 | *25* |
| February | 19 | 12% | 10 | 20 | 20 | 26 | 24 | 15 | 8 | 14 | 16 | 17 | *25* |
| **Transition Months** | **50** | **31%** | **62** | **56** | **49** | **34** | **41** | **33** | **55** | **46** | **43** | **44** | ***63*** |
| March | 14 | 9% | 19 | 19 | 19 | 7 | 12 | 22 | 9 | 6 | 12 | 10 | *20* |
| April | 16 | 10% | 9 | 16 | 15 | 7 | 8 | 6 | 11 | 14 | 6 | 14 | *29* |
| September | 7 | 4% | 17 | 7 | 1 | 7 | 4 | 2 | 13 | 6 | 5 | 6 | *11* |
| October | 13 | 8% | 17 | 14 | 14 | 13 | 17 | 2 | 23 | 20 | 21 | 14 | *4* |
| **Warm Months** | **29** | **18%** | **31** | **29** | **29** | **32** | **21** | **17** | **23** | **16** | **21** | **39** | ***30*** |
| May | 8 | 5% | 4 | 9 | 9 | 16 | 5 | 8 | 8 | 2 | 4 | 17 | *4* |
| June | 6 | 4% | 9 | 3 | 4 | 8 | 10 | 5 | 2 | 5 | 6 | 4 | *9* |
| July | 11 | 7% | 12 | 4 | 5 | 3 | 4 | 2 | 4 | 7 | 7 | 13 | *12* |
| August | 5 | 3% | 6 | 13 | 11 | 5 | 2 | 1 | 8 | 1 | 5 | 4 | *5* |

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
Source: U.S. Consumer Product Safety Commission / EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005– 2015
Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

Figure 2 graphically illustrates the relationship between the time of year and the estimated number of CO poisoning deaths from 2005 through 2015. The total estimated number of CO poisoning deaths is presented on the radar graph by month of death. The shaded area represents the estimated total number of deaths for the 11-year period, distributed by each month of a year. Notably, more CO deaths occur in the cold months, particularly, November, December, January, and February than in warm months. Additionally, as the months after the summer get colder, the number of CO deaths increases. Conversely, as the months after the winter get warmer, the number of deaths decreases.

**Figure 2: Estimated Number of Consumer Product-Related Carbon Monoxide Deaths by Month of Death, 2005–2015**




Source: U.S. Consumer Product Safety Commission / EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005– 2015

## Victim Demographics from Non-Fire Carbon Monoxide Poisoning Deaths Associated with the Use of Consumer Products

### Age of Victim

Table 7 shows the estimated number of CO poisoning deaths categorized by victim age for the 11 most recent years of data (2005–2015). From the data, it appears that consumer product-related CO deaths are skewed toward older individuals. For the three most recent years (2013–2015), children younger than 15 years of age accounted for an annual average of 6 percent (an estimated 10 of 162) of the yearly CO poisoning deaths, while this age group represents an average of about 19 percent of the U.S. population. For the same time frame, deaths among adults 45 years and older was 63 percent (102 of 162), while they represented about 41 percent of the U.S. population. Also in 2013-2015, adults 65 years and older accounted for an annual average of 23 percent of CO poisoning deaths, nearly double that age group's representation in the U.S. population (15 percent).[7] Statistical tests confirm the significance in the age-related differences in CO poisoning deaths

**Table 7: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Age of Victim, 2005–2015**

| Age | 2013–*2015*+ | | Estimated Percentage of U.S. Population# | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Total** | **162** | **100%** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **165** | ***175*** |
| Under 5 | 1 | 1% | 6% | * | 2 | 8 | 2 | 3 | 1 | * | 1 | * | 2 | * |
| 5 - 14 | 9 | 6% | 13% | 7 | 4 | 6 | 8 | 2 | 1 | 4 | 4 | 5 | 7 | *16* |
| 15 - 24 | 12 | 7% | 14% | 17 | 21 | 18 | 15 | 14 | 12 | 9 | 6 | 11 | 8 | *16* |
| 25 - 44 | 38 | 23% | 26% | 46 | 59 | 34 | 54 | 43 | 39 | 36 | 37 | 34 | 35 | *46* |
| 45 - 64 | 65 | 40% | 26% | 86 | 58 | 70 | 68 | 59 | 69 | 63 | 56 | 62 | 67 | *67* |
| 65 and over | 37 | 23% | 15% | 34 | 36 | 49 | 30 | 27 | 36 | 52 | 32 | 36 | 44 | *31* |

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
\# Based on estimated U.S. population statistics for the 3- year average (2013-2015). U.S. Census Bureau, 2017 Estimates, American FactFinder.
Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005 - 2015.

U.S. Census Bureau, Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2017
Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

### Gender of Victim

Table 8 presents the distribution of estimated CO deaths categorized by gender. In 2015, 73 percent of CO poisoning victims were males, and 27 percent were females. These percentages varied slightly from year to year over the 11 years of this report. However, every year there were many more male CO deaths than female. For 2013—2015, the average percentage of male CO victims was 78 percent, and the average percentage of female victims was 22 percent. By contrast, about 49 percent of the U.S. population is male, and 51 percent of the U.S. population is female.[8] The gender-related differences in CO Poisoning deaths were confirmed to be statistically significant (p-value = < 0.0001).

[7] Three-year average, 2013 to 2015 from June 2016 U.S. Census estimates of the U.S. population.
[8] Three-year average, 2013 to 2015, from March 2018 U.S. Census estimates of the U.S. population.

**Table 8: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Gender of Victim, 2005-2015**

| Gender | 2013–*2015*+ | | Estimated Percentage of U.S. Population# | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **Total** | **162** | **100%** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| Male | **126** | **78%** | 49% | 140 | 145 | 132 | 140 | 109 | 121 | 111 | 92 | 124 | 127 | *128* |
| Female | **35** | **22%** | 51% | 50 | 36 | 53 | 36 | 39 | 38 | 52 | 45 | 22 | 37 | *47* |

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.

\# Based on estimated U.S. population statistics for the 3-year average (2013-2015).

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File, National Center for Health Statistics Mortality File, 2005–2015.
U.S. Census Bureau, U.S. Census Bureau, 2013, 2014, and 2015 American Community Survey 1-Year Estimates

Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

## Victim Race/Ethnicity

Table 9 provides a summary of CO death victims characterized by race/ethnicity for the years 2005 through 2015. Because of the growing proportion of people of Hispanic descent, Hispanic victims were categorized separately, irrespective of their race. Estimates of the percentage of the U.S. population categorized into the various race/ethnicity groupings were based on single-race characterizations, as represented in the U.S. Census Bureau reports. Individuals reported as multi-race are included in the *Unknown/Other* category.

The estimated percentage of the 2013–2015 annual average CO deaths among non-Hispanic whites closely mirrors the percentage of the U.S. population[9] (62 percent and 63 percent, respectively). However, there appears to be a disproportionate number of Black or African American victims of CO poisoning, comprising 22 percent of all CO poisoning deaths, even though Blacks or African Americans represent only about 12 percent of the U.S. population. By contrast, the proportion of the CO poisoning death victims who were of Hispanic ethnicity (9%) is below the percentage of Hispanics in the U.S. population (17%). The race/ethnicity-based differences in CO poisoning deaths were statistically significant (p-value = < 0.0001)

[9] The "percentage of the U.S. population" is defined here as the 3-year average, 2013 to 2015 of the March 2018 U.S. Census estimates of the U.S. population.

**Table 9: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Race/Ethnicity, 2005−2015**

| Race/Ethnicity | 2013−*2015*+ | | Estimated Percentage of U.S. Population# | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | *2014* | *2015*+ |
| **Total** | **162** | **100%** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | ***164*** | ***175*** |
| White (non-Hispanic) | **101** | **62%** | 63% | 134 | 107 | 122 | 122 | 93 | 82 | 106 | 82 | 86 | *108* | *110* |
| Black or African American | **36** | **22%** | 12% | 36 | 36 | 35 | 30 | 20 | 43 | 38 | 31 | 35 | *26* | *48* |
| Hispanic (All races) | **15** | **9%** | 17% | 15 | 19 | 23 | 14 | 11 | 18 | 9 | 11 | 13 | *18* | *14* |
| Asian / Pacific[1] | **4** | **2%** | 5% | 2 | 13 | 3 | 1 | 3 | 4 | 3 | 5 | 7 | *6* | * |
| American Indian[2] | **1** | **1%** | 1% | * | 6 | 1 | 5 | 1 | 5 | 1 | * | 1 | *1* | * |
| Unknown / Other / Mixed[3] | **4** | **2%** | 2% | 2 | * | 2 | 4 | 19 | 8 | 6 | 7 | 5 | *5* | *3* |

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.
* No reports received by CPSC staff.
\# Based on estimated U.S. population statistics for the 3-year average (2013-2015).
1 Includes Asian, Pacific Islander, and Native Hawaiian
2 Includes American Indian, Native American, and Native Alaskan
3 Includes Unknown race, Other race, and Multiple races
Source: U.S. Consumer Product Safety Commission / EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005–2015.
U.S. Census Bureau, Source: 2011-2015 American Community Survey 5-Year Estimates
Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

## Population Density of Place of Death

Table 10 provides a breakout of the CO poisoning deaths characterized by population density of the incident location. The table is presented as three sections: (1) incidents occurring at all incident locations; (2) incidents occurring in locations identified as a permanent home (*e.g.*, house, apartment, mobile home); and (3) incidents occurring only in non-home locations (*e.g.*, camper trailer, tent, motel room). Please note that "Home Locations" and "Non-Home Locations" sum to "All Locations."

All fatal incidents were designated as occurring in one of four rural/urban categories based on the Rural-Urban Commuting Area (RUCA) codes developed by the Economic Research Service (ERS) of the U.S. Department of Agriculture (USDA) in conjunction with the Center for Rural Health, School of Medicine and Health Sciences, University of North Dakota. The categories are based on theoretical concepts used by the U.S. Office of Management and Budget (OMB) to define county-level metropolitan and micropolitan areas.[10] This 21-category classification system is based on measures of population density, urbanization, and daily commuting. The OMB methodology is based on a county-level delineation. ERS refined the methodology by applying it to smaller census tracts. ERS further delineated the characterization by cross-referencing each zip code in the United States to its RUCA code classification.[11] The development of the new update of the RUCAs to version 3.1 was developed by Center for Rural Health, School of Medicine and Health Sciences, University of North Dakota and ERS and is

[10] OMB BULLETIN NO. 13-01: Revised Delineations of Metropolitan Statistical Areas, Micropolitan Statistical Areas, and Combined Statistical Areas, and Guidance on Uses of the Delineations of these Areas. February 28, 2013.
[11] Version 3.10 of the ZIP code Rural-Urban Commuting Areas (RUCAs) geographic taxonomy, August 4, 2014. http://ruralhealth.und.edu/ruca/final310.csv.

funded by the HHS/HRSA Office of Rural Health Policy and the USDA Economic Research Service. The zip code cross-reference was used to characterize each of the CO deaths into one of four broad categories: Urban Core, Sub-Urban, Large Rural Town, and Small Town/Rural Isolated. The RUCA codes are updated approximately once every ten years. The last update was for the years 2010. It is unlikely that there would be a significant change in the urban-rural population distribution between 2010 and the 3-year period average of 2013 through 2015.

Table 10 also includes the estimated percentage of the U.S. population, per population density designation category. As can be seen in the *All Locations* section, the estimated average percentage of CO deaths during the 3-year period 2013 through 2015, in urban locations (48%), is smaller than the percentage of the U.S. population living in urban core locations (73%). The difference is offset by the larger percentages in the other three categories: sub-urban locations (21% versus 15% of the U.S. population), large rural town locations (9% versus 6%), and small town/rural isolated locations (20% versus 5%). Additionally, due to lack of detail in some of the death certificates that CPSC receives, the exact location of a small number of incidents (2%) could not be ascertained. However, looking at the *Non-Home Locations* category may help to identify some of the disparity for each of the non-urban location categories. An average of 40 percent of all non-home CO deaths occurred in small town/rural isolated locations, even though the U.S. population living in isolated locations is only 5 percent. In 2013 through 2015, an estimated average of 14 of 35 CO poisoning deaths in non-home locations occurred in small town/rural isolated locations. Two factors may help to explain the relatively high proportion of small town/isolated rural location CO deaths. Many non-home locations where CO deaths occurred were tents, camper trailers, or cabins in isolated locations, used during hunting or camping activities, where no local power utility is available. In these cases, individuals often resort to generators for power and use portable LP heaters, lanterns, and stoves.

## Table 10: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Population Density of Place of Death, 2005–2015

| RUCA Population Density Designation | 2013–*2015*+ | | Estimated Percentage of U.S. Population# | Annual Estimate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | *2015*+ |
| **All Locations** | **162** | **100%** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| Urban Core | 78 | 48% | 73% | 91 | 112 | 114 | 105 | 78 | 94 | 95 | 79 | 84 | 73 | *77* |
| Sub-Urban | 34 | 21% | 15% | 53 | 28 | 31 | 32 | 42 | 33 | 33 | 25 | 27 | 34 | *42* |
| Large Rural Town | 15 | 9% | 6% | 15 | 17 | 12 | 23 | 10 | 25 | 14 | 9 | 12 | 19 | *14* |
| Small Town/ Rural Isolated | 32 | 20% | 5% | 31 | 23 | 28 | 17 | 18 | 7 | 18 | 19 | 23 | 33 | *40* |
| Unknown Location | 3 | 2% | - | * | * | * | * | * | * | 2 | 6 | 1 | 6 | *1* |
| **Home Locations** | **127** | **100%** | **100%** | **141** | **138** | **153** | **143** | **117** | **135** | **137** | **113** | **121** | **127** | ***133*** |
| Urban Core | 66 | 52% | 73% | 74 | 99 | 96 | 89 | 66 | 88 | 78 | 71 | 73 | 63 | *63* |
| Sub-Urban | 31 | 24% | 15% | 32 | 19 | 22 | 27 | 30 | 24 | 28 | 20 | 24 | 29 | *40* |
| Large Rural Town | 11 | 9% | 6% | 14 | 13 | 11 | 16 | 10 | 19 | 14 | 6 | 7 | 14 | *12* |
| Small Town/ Rural Isolated | 18 | 14% | 5% | 21 | 7 | 24 | 11 | 11 | 4 | 15 | 11 | 15 | 21 | *18* |
| Unknown Location | < 1 | < 1% | - | * | * | * | * | * | * | 2 | 5 | 1 | * | * |
| **Non-Home Locations** | **35** | **100%** | **100%** | **49** | **42** | **32** | **34** | **30** | **24** | **26** | **24** | **26** | **37** | ***42*** |
| Urban Core | 12 | 34% | 73% | 17 | 13 | 18 | 16 | 11 | 6 | 18 | 7 | 11 | 11 | *15* |
| Sub-Urban | 3 | 9% | 15% | 21 | 9 | 9 | 5 | 12 | 8 | 5 | 5 | 2 | 5 | *1* |
| Large Rural Town | 4 | 11% | 6% | 1 | 3 | 1 | 7 | * | 6 | * | 2 | 5 | 5 | *3* |
| Small Town/ Rural Isolated | 14 | 40% | 5% | 10 | 17 | 4 | 6 | 7 | 4 | 3 | 7 | 8 | 11 | *22* |
| Unknown Location | 2 | 6% | - | * | * | * | * | * | * | * | 1 | * | 6 | *1* |

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.

* No reports received by CPSC staff.

\# Estimated 2010 U.S. population categorized by Rural Urban Commuting Area (RUCA 3.1) designation. U.S. population estimates by RUCA classification were determined by cross-referencing the Center for Rural Health, School of Medicine and Health Sciences, University of North Dakota/Economic Research Service, Department of Agriculture RUCA3.1 zip code table with the 2010 U.S. Census population estimates by zip code area.

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005–2015.
Center for Rural Health, University of North Dakota School of Medicine and Health Sciences, ZIP code RUCA Version 3.10

## Geographical Region of Incident

Table 11 provides a breakout of the CO poisoning deaths characterized by geographic region where the incident occurred. As can be seen in the table, for the most part, the percentage of CO deaths in each of the regions reflects the percentage of the U.S. population living in these regions. This would indicate that geographic location has little effect on the likelihood of fatal CO poisoning incidents. The states that comprise each of the regions is given in Appendix D.

**Table 11: Estimated Non-Fire Carbon Monoxide Poisoning Deaths by Geographical Region of Incident, 2005–2015**

| Region‡ | 2013–*2015*+ | | Estimated Percentage of US Population# | Annual Estimates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average Estimate | Average Percent | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | *2013* | 2014 | *2015*+ |
| **Total** | **162** | **100%** | **100%** | **190** | **180** | **186** | **178** | **148** | **159** | **163** | **137** | **146** | **164** | ***175*** |
| **Northeast** | **34** | **21%** | **18%** | **33** | **24** | **44** | **28** | **14** | **23** | **43** | **25** | **34** | **37** | ***30*** |
| New England | 12 | 7% | 5% | 7 | 8 | 10 | 12 | 5 | 5 | 16 | 1 | 14 | 8 | *13* |
| Middle Atlantic | 22 | 14% | 13% | 26 | 16 | 34 | 16 | 9 | 18 | 27 | 24 | 20 | 29 | *17* |
| **South** | **50** | **31%** | **37%** | **74** | **57** | **61** | **51** | **55** | **55** | **55** | **55** | **43** | **42** | ***64*** |
| East South Central | 8 | 5% | 6% | 9 | 10 | 9 | 10 | 19 | 12 | 13 | 7 | 3 | 9 | *12* |
| South Atlantic | 24 | 15% | 20% | 41 | 26 | 25 | 21 | 13 | 26 | 23 | 31 | 20 | 21 | *30* |
| West South Central | 18 | 11% | 12% | 24 | 21 | 27 | 21 | 23 | 17 | 19 | 17 | 20 | 12 | *22* |
| **Midwest** | **44** | **27%** | **21%** | **46** | **54** | **47** | **58** | **48** | **49** | **33** | **31** | **48** | **40** | ***44*** |
| East North Central | 25 | 15% | 15% | 31 | 40 | 25 | 39 | 28 | 40 | 27 | 26 | 27 | 22 | *27* |
| West North Central | 19 | 12% | 7% | 15 | 14 | 22 | 18 | 20 | 10 | 6 | 5 | 21 | 18 | *17* |
| **West** | **34** | **21%** | **24%** | **33** | **46** | **33** | **40** | **31** | **31** | **32** | **25** | **23** | **44** | ***37*** |
| Mountain | 16 | 10% | 7% | 18 | 21 | 17 | 25 | 16 | 11 | 9 | 13 | 9 | 26 | *15* |
| Pacific | 18 | 11% | 16% | 15 | 24 | 17 | 15 | 14 | 20 | 23 | 12 | 14 | 18 | *22* |

‡ Region designation is based on U.S. Census Bureau reporting practices. See Appendix C for identification of specific regional designation of state of occurrence.

\+ Data collection for 2015 is only partially complete. Italicized estimates may change in the future if more reports of deaths are received.

\# Based on estimated U.S. population statistics for the three year average (2013-2015).

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, CPSC Injury or Potential Injury Incident File,
National Center for Health Statistics Mortality File, 2005–2015.
U.S. Census Bureau, Population Division Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico:
April 1, 2010 to July 1, 2017 (NST-EST2017-01)

Note: Reported annual estimates and estimated averages and percentages may not add to subtotals or totals due to rounding.

## Appendix A: Methodology

This appendix describes the data sources and methodology used to compute the national estimate of non-fire carbon monoxide (CO) poisoning deaths associated with the use of consumer products and the estimates by product, victim age, and incident location.

All death certificates filed in the United States are compiled by the National Center for Health Statistics (NCHS) into a multiple cause of mortality data file. The NCHS Mortality File contains demographic and geographic information, as well as the International Statistical Classification of Diseases and Related Health Problems codes for the underlying cause of death. Data are compiled in accordance with the World Health Organization instructions, which request that member nations classify causes of death by the current Manual of the International Statistical Classification of Diseases and Related Health Problems. The International Classification of Diseases, Tenth Revision (ICD-10) was implemented in 1999. Although the NCHS data contain cause of death codes that are helpful in identifying deaths due to CO poisoning, the records do not contain any narrative information that might indicate the involvement of a consumer product.

CPSC staff purchases death certificates from the 50 states, New York City, the District of Columbia, and some territories. Specifically, CPSC staff purchases death certificates with certain cause-of-death codes for which there is a high probability that consumer products are involved. In addition to the cause-of-death codes and demographic and geographic information, the death certificate contains information about the incident location and a brief narrative describing the incident. Any references to consumer products are usually found in these narratives. As resources allow, CPSC staff conducts follow-up In-Depth Investigations (IDIs) on selected deaths to confirm and expand upon the involvement of consumer products. These data from CPSC complement the NCHS mortality data.

ICD-10 classifies deaths associated with CO poisoning with the codes listed below. The focus of this report is accidental CO poisoning deaths, and the report concentrates on deaths coded as X47 and Y17. Deaths coded under Code X67, intentional CO poisonings, are excluded from this analysis.

| **ICD-10 Code** | **Definition** |
|---|---|
| X47 | **Accidental–** Poisoning by and exposure to other gases and vapors. Includes: carbon monoxide, lacrimogenic gas, motor (vehicle) exhaust gas, nitrogen oxides, sulfur dioxide, utility gas. |
| X67 | **Intentional–** Poisoning by and exposure to other gases and vapors. Includes: carbon monoxide, lacrimogenic gas, motor (vehicle) exhaust gas, nitrogen oxides, sulfur dioxide, utility gas. |
| Y17 | **Undetermined intent–** Poisoning by and exposure to other gases and vapors. Includes: carbon monoxide, lacrimogenic gas, motor (vehicle) exhaust gas, nitrogen oxides, sulfur dioxide, utility gas. |

The first step in compiling the annual estimates is computing the total estimates of CO poisoning deaths associated with consumer products. The CPSC's Death Certificate (DTHS) File and the CPSC's Abbreviated Death Certificate (ABDT) File were searched for cases associated with ICD-10 codes X47 and Y17.

Each case in the CPSC's DTHS File that was coded as X47 or Y17 was reviewed by an analyst and categorized as in-scope, out-of-scope, or source of CO unknown or questionable. In-scope cases are unintentional, non-fire CO poisoning deaths associated with a consumer product under the jurisdiction of the CPSC. Out-of-scope cases are cases that involve CO sources that are not under the jurisdiction of the CPSC, fire or smoke-related exposures, or intentional CO poisonings. Examples of out-of-scope cases include poisonings due to gases other than CO (*i.e.*, natural gas, ammonia, butane); motor vehicle exhaust- or boat exhaust-related poisonings; and work-related exposures. The source of CO was classified as unknown or questionable in cases where a consumer product was possibly associated with the incident, but the exact source of CO was unknown.

The CPSC's ABDT File contains death certificates for CO poisonings (X47 and Y17) that involve motor vehicle exhaust, cases where the source of the CO is unknown, or where the death certificate does not mention a consumer product. Other examples of cases that may appear in the abbreviated file are cases associated with farm accidents, smoke inhalation from a structural fire, or other gas poisonings. Occasionally, newer information from CPSC IDIs may be matched with ABDT cases that were originally classified as having no known source or did not mention a consumer product. If information from IDIs indicated that an ABDT case should be considered in-scope, then it was included with the DTHS database files. For example, in 2005 data, one case from the ABDT File was reclassified as an in-scope case. For the 2006 data, three cases from the ABDT were reclassified. For 2007, three more cases were reclassified. For 2008, 2009, 2010, and 2011, no ABDT records were reclassified as in-scope. For the three most recent years, eight cases were reclassified: three cases for 2012; one case for 2013; four cases for 2014; and two cases in 2015.

Since the release of the previous annual report, additional records have been entered into the CPSC databases; and therefore, the resulting initial categorization for 2014 through 2015 has been recalculated and is presented in Tables A.1.a through A.1.b.

**Table A.1.a: Initial Categorization for 2014 Data**

| ICD-10 Code | NCHS Total | DTHS File & ABDT File | | | | Number of Cases to be Imputed[1] |
|---|---|---|---|---|---|---|
| | | In-Scope | Unknown Scope | Out-of-Scope | Total | |
| X47 | 803 | 137 | 19 | 542 | 698 | 124 |
| Y17 | 106 | 1 | 10 | 60 | 71 | 45 |
| **Total** | **909** | **138** | **29** | **602** | **769** | **169** |

**Table A.1.b: Initial Categorization for 2015 Data**

| ICD-10 Code | NCHS Total | DTHS File & ABDT File | | | | Number of Cases to be Imputed[1] |
|---|---|---|---|---|---|---|
| | | In-Scope | Unknown Scope | Out-of-Scope | Total | |
| X47 | 847 | 133 | 34 | 516 | 683 | 198 |
| Y17 | 91 | 1 | 3 | 52 | 56 | 38 |
| **Total** | **938** | **134** | **37** | **568** | **739** | **236** |

[1] "NCHS Total" cases, minus "Total in CPSC Database," plus "Unknown Scope" from DTHS.
Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, Abbreviated Death Certificate File,
National Center for Health Statistics Mortality File, 2014–2015.

The proportion of death certificates found in the CPSC database associated with non-fire, unintentional X47 or Y17 deaths and associated with consumer products was applied to the NCHS totals to calculate the total estimated number of non-fire CO poisoning deaths associated with consumer products. In theory, the NCHS totals comprise all death certificates in the United States, and the same proportion of in-scope cases should exist in the death certificates that are missing from the combined CPSC Death Certificate and Abbreviated Death Certificate files or are from an unknown source. Applying the proportion of in-scope cases to the NCHS database totals, therefore, should provide an estimate of in-scope cases nationwide. This was done in the following way for ICD-10 codes X47 and Y17, separately:

1. The number of in-scope deaths in the CPSC's two death certificate files coded under the specific ICD10 code that were associated with an accidental non-fire CO poisoning and a consumer product were identified ($n_1$).

2. The total number of deaths in the CPSC's Death Certificate File and the Abbreviated Death Certificate File coded under the specific ICD10 code were summed separately, excluding cases with an unknown or highly questionable source ($n_2$).

3. The total number of deaths in the NCHS data associated coded under the specific ICD10 code was counted ($n_3$).

4. The estimate of the number of non-fire CO poisoning deaths associated with consumer products under the specific ICD10 code was calculated, using the formula:

$$N= (n_1 / n_2) * n_3$$

The proportion ($n_1 / n_2$) represents the number of in-scope cases found in the CPSC's files, divided by the total of in-scope and out-of-scope cases.

5. The estimates of the number of non-fire CO poisoning deaths associated with consumer products under the specific ICD10 codes were summed to calculate the total estimate of non-fire CO poisoning deaths.

$$\text{Total Estimate} = N_{X47} + N_{Y17}$$

The ratio ($n_3 / n_2$) represents the weighting factor used to calculate the annual estimates. The CPSC's Death Certificate File does not contain death certificates for all deaths listed in the NCHS file; therefore, a weighting factor was calculated to account for death certificates that are missing. The weighting factor allows the computation of national estimates of CO deaths by consumer products and by other characteristics collected by CPSC about each death.

Table A.2 contains the values for the variables used in the calculation, as well as the final computed 2014 and 2015 estimates of CO poisoning deaths.

**Table A.2.a: Calculation Detail of the Final Computed 2014 Estimate of Non-Fire CO Poisoning Deaths Associated with Consumer Products**

| **Variable** | **ICD-10 Code** | |
|---|---|---|
| | **X47** | **Y17** |
| **$n_1$** | 137 | 1 |
| **$n_2$** | 698 - 19 = 679 | 71 - 10 = 61 |
| **$n_3$** | 803 | 106 |
| ***Weighting Factor*** *($n_3 / n_2$)* | 1.1826 | 1.7377 |
| **N** | 162.0191 | 1.7377 |
| **Total Estimate** | {162.0191 + 1.7377 = 163.7568 ~ 164} | |

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, Abbreviated Death Certificate File, National Center for Health Statistics Mortality File 2014-2015.

**Table A.2.b: Calculation Detail of the Final Computed 2015 Estimate of Non-Fire CO Poisoning Deaths Associated with Consumer Products**

| Variable | ICD-10 Code | |
|---|---|---|
| | X47 | Y17 |
| $n_1$ | 133 | 1 |
| $n_2$ | 683 - 34 = 649 | 56 - 3 = 53 |
| $n_3$ | 847 | 91 |
| ***Weighting Factor*** *($n_3$ / $n_2$)* | 1.3051 | 1.7170 |
| N | 173.5763 | 1.7170 |
| **Total Estimate** | {173.5763 + 1.7170 = 175.2933 ~ 175} | |

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, Abbreviated Death Certificate File, National Center for Health Statistics Mortality File 2014-2015.

Death certificates received by NCHS are routinely checked for accuracy of state personnel-identified ICD-10 coding. On occasion, NCHS staff will correct codes before entering the data into their databases. CPSC staff has no way of correcting CPSC records to mesh with NCHS records. CPSC receives death certificate facsimiles or electronic death certificates directly from the states, prior to any possible corrections deemed necessary per NCHS procedures. As a consequence, there may be slight discrepancies between final NCHS counts and CPSC records. For this report, CPSC staff has made the assumption that, over time, the number of death certificates with ICD-10 codes changed by NCHS staff to the codes of interest (X47 and Y17), would approximately equal those changed to codes other than X47 or Y17 thereby having little long-term effect on the estimates.

Table A.3 shows the weighting factors used to calculate the estimates for the years 2005–2015, based on the information available to CPSC staff.

## Table A.3: CO Death Cases and Weighting Factors Used to Calculate the Estimates for the Years 2005–2015

| Year | NCHS Total | Total in CPSC Databases* | In-Scope Cases+ | Weighting Factor |
|---|---|---|---|---|
| 2005 | | | | |
| X47 | 650 | 590 | 171 | 1.1017 |
| Y17 | 92 | 70 | 1 | 1.3143 |
| 2006 | | | | |
| X47 | 585 | 527 | 161 | 1.1101 |
| Y17 | 74 | 53 | 1 | 1.3962 |
| 2007 | | | | |
| X47 | 605 | 580 | 173 | 1.0431 |
| Y17 | 89 | 68 | 4 | 1.3088 |
| 2008 | | | | |
| X47 | 677 | 660 | 166 | 1.0258 |
| Y17 | 68 | 54 | 6 | 1.2593 |
| 2009 | | | | |
| X47 | 734 | 769 | 145 | 1.0000 |
| Y17 | 72 | 52 | 2 | 1.3846 |
| 2010 | | | | |
| X47 | 675 | 567 | 125 | 1.1905 |
| Y17 | 98 | 68 | 7 | 1.4412 |
| 2011 | | | | |
| X47 | 786 | 730 | 143 | 1.0767 |
| Y17 | 89 | 76 | 8 | 1.1711 |
| 2012 | | | | |
| X47 | 736 | 591 | 109 | 1.2453 |
| Y17 | 114 | 84 | 1 | 1.3571 |
| 2013 | | | | |
| X47 | 704 | 608 | 123 | 1.1579 |
| Y17 | 76 | 60 | 3 | 1.2667 |
| 2014 | | | | |
| X47 | 803 | 679 | 137 | 1.1826 |
| Y17 | 106 | 61 | 1 | 1.7377 |
| 2015 | | | | |
| X47 | 847 | 649 | 133 | 1.3051 |
| Y17 | 91 | 53 | 1 | 1.7170 |

+ For some years, the number of in-scope cases has changed slightly from the previous report, due to either newly obtained information or a recharacterization of a few cases.

* This is the total number of deaths in the Death Certificate File and Abbreviated Death Certificate File, excluding deaths associated with an unknown or questionable source of CO.

Source: U.S. Consumer Product Safety Commission/EPHA.
CPSC Death Certificate File, CPSC In-Depth Investigation File, Abbreviated Death Certificate File, National Center for Health Statistics Mortality File, 2005–2015.

Incidents with unknown or highly questionable CO sources were excluded from the denominator (the number of deaths in the CPSC databases) of the weighting factor. The group of cases with unknown or highly questionable sources was assumed to contain the same proportion of cases associated with a consumer product as the group of cases within the CPSC database with known CO sources (this is the same assumption that is made for those cases where the death certificate is missing). To include these cases within the denominator assumes that these cases can be classified as in-scope or out-of-scope cases, when actually their scope status is unknown. Therefore, for weighting purposes, cases where the source was unknown, or highly questionable, were treated in the same way as missing cases were treated.

In-scope cases were examined further to determine which product was associated with the incident. Further information on the CO deaths was obtained from review of the CPSC's IDI File.

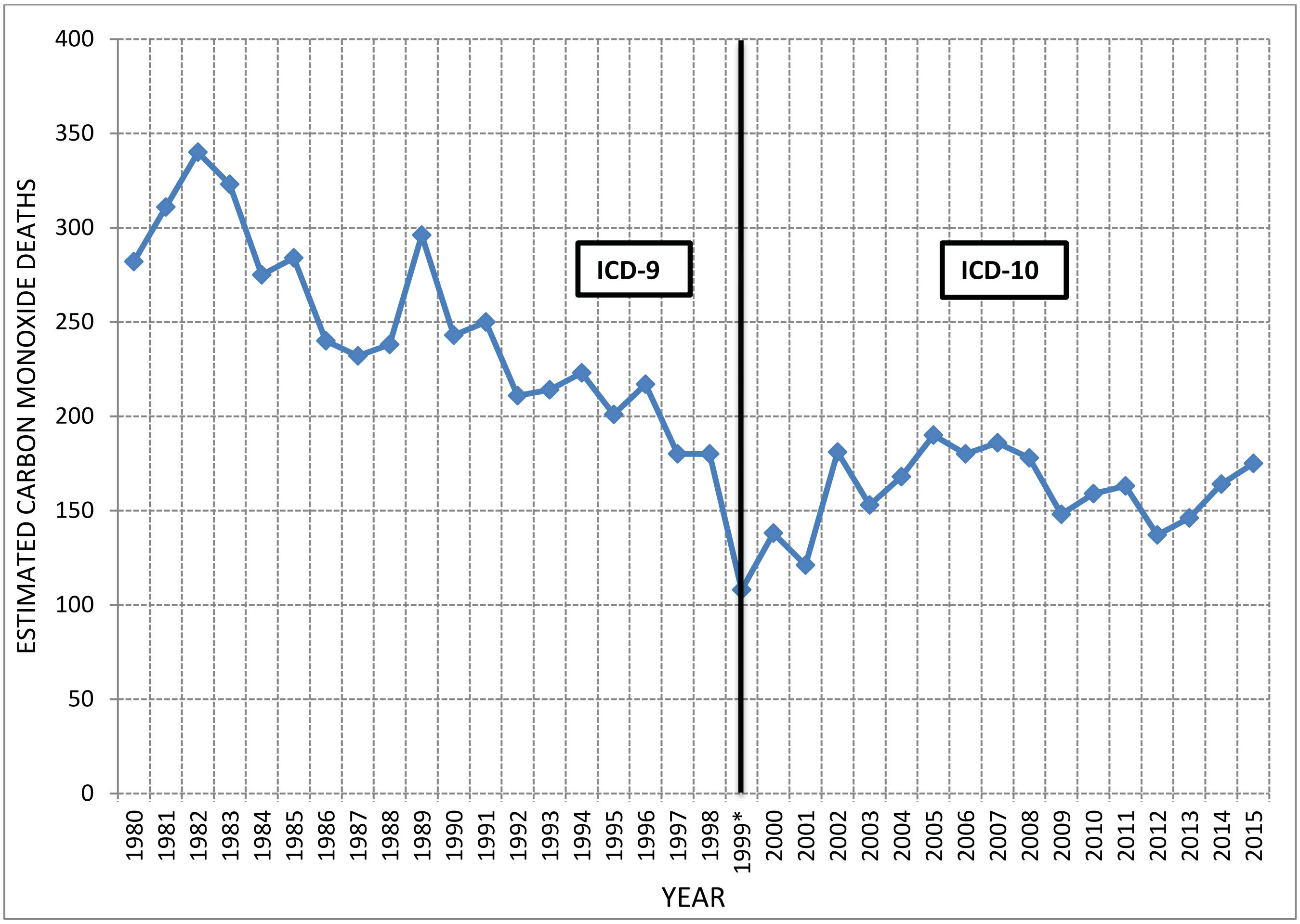
Reports of non-fire CO poisoning deaths were retrieved from the DTHS and ABDT files based on the following criteria: date of death between 1/1/2005 and 12/31/2015, and ICD-10 code of X47 or Y17. Death certificates entered into the CPSC's database before July 10, 2018, were included in this analysis. Whenever possible, each CO death was reviewed and coded by the author, according to the consumer product and type of fuel involved, incident location, and whether multiple deaths were associated with the same incident. If information about the product's condition, venting system, or installation environment was provided in the IDI report, then this information was coded for informational purposes.

In Table 1 of this report, the *Heating Systems* category includes CO poisoning deaths from subcategories for furnaces and boilers (combined under the heading of *Furnaces*), vented floor and wall heaters, unvented room/space heaters, unvented portable heaters, and other miscellaneous heating systems. Each subcategory is further delineated by fuel type used. Deaths associated with charcoal being burned alone and in the absence of an appliance (*e.g.*, in a pail or in the sink) were presented with *Charcoal Grills*, even though this practice usually was done for heating purposes. Examples of products historically included in the *Other Products* category include LP gas refrigerators and gas pool heaters. LP gas grill, LP fish cooker, and other LP gas portable cooking appliance incidents are classified in the *Grills, Camp Stoves* category. Deaths where multiple fuel-burning products were used simultaneously, such that a single source of the fatal CO could not be determined, were classified under *Multiple Products*. *Engine-Driven Tools* included generators and power gardening equipment, such as power lawn mowers, garden tractors, concrete cutters, gasoline-powered water pumps, and snow blowers. Generators that were original equipment installed on a recreational vehicle (RV), trailer, camper, or boat were considered out of scope because they are outside the jurisdiction of the CPSC.

## Appendix B: National Estimates and Mortality Rates of Consumer Product-Related CO Poisoning Deaths, 1980 to 2015

Figure B.1 below graphically suggests a trend of the estimated CO deaths from 1980 to 2015. Before the implementation of the ICD-10 coding in 1999, the estimated number of non-fire, consumer product-related CO poisoning deaths decreased from the early 1980s to the late 1990s, from a high of 340 in 1982, to a low of 180 in both 1997 and 1998. In 1999, there were an estimated 108 consumer product-related CO deaths, well below the estimated 180 deaths in each of the two previous years. The difference may be due, in part, to the change from ICD-9 coding to ICD-10 coding, where product identification could be assessed more accurately.

**Figure B.1: Estimated Non-Fire CO Poisoning Deaths Associated with Consumer Products: 1980–2015**




* Implementation of ICD-10.

**Estimated CO Mortality 3-Year Trends**

Table B.1 presents the annual estimates from 1980 to 2015, and the 3-year average mortality rates associated with each year, where three years of data were available. The 3-year average mortality rate is presented in the table for the mid-point year. The estimated 3-year average mortality rate decreased from the 1982 high of 14.02 per 10 million population to a 3-year average rate of 4.34 per 10 million in 2000, a reduction of 69 percent. Subsequently, the 3-year average rate increased annually through 2006, to a rate of 6.21. Since 2006, the rate has been slowly dropping to the 2013 estimate of 4.71 before rising in the 2014 estimate to a rate of 5.07. The year 2014 is the last year for which data are available to calculate a 3-year average.

**Table B.1: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products, 1980−2015**

| Year | Estimate | U.S. Population Estimates (thousands) | 3-Year Average Mortality Rate per 10 Million Population |
|---|---|---|---|
| 1980 | 282 | 227,225 | |
| 1981 | 311 | 229,466 | 13.55 |
| 1982 | 340 | 231,664 | 14.02 |
| 1983 | 323 | 233,792 | 13.38 |
| 1984 | 275 | 235,825 | 12.47 |
| 1985 | 284 | 237,924 | 11.19 |
| 1986 | 240 | 240,133 | 10.49 |
| 1987 | 232 | 242,289 | 9.77 |
| 1988 | 238 | 244,499 | 10.44 |
| 1989 | 296 | 246,819 | 10.49 |
| 1990 | 243 | 249,623 | 10.53 |
| 1991 | 250 | 252,981 | 9.27 |
| 1992 | 211 | 256,514 | 8.77 |
| 1993 | 214 | 259,919 | 8.31 |
| 1994 | 223 | 263,126 | 8.08 |
| 1995 | 201 | 266,278 | 8.02 |
| 1996 | 217 | 269,394 | 7.40 |
| 1997 | 180 | 272,647 | 7.05 |
| 1998 | 180 | 275,854 | 5.66 |
| 1999* | 108 | 279,040 | 5.09 |
| 2000 | 138 | 282,172 | 4.34 |
| 2001 | 121 | 285,082 | 5.15 |
| 2002 | 181 | 287,804 | 5.27 |
| 2003 | 153 | 290,326 | 5.76 |
| 2004 | 168 | 293,046 | 5.81 |
| 2005 | 190 | 295,753 | 6.06 |
| 2006 | 180 | 298,593 | 6.21 |
| 2007 | 186 | 301,580 | 6.01 |
| 2008 | 178 | 304,375 | 5.61 |
| 2009 | 148 | 307,007 | 5.27 |
| 2010 | 159 | 309,338 | 5.06 |
| 2011 | 163 | 311,644 | 4.91 |
| 2012 | 137 | 313,993 | 4.74 |
| 2013 | 146 | 316,235 | 4.71 |
| 2014 | 164 | 318,623 | 5.07 |
| 2015 | 175 | 321,040 | |

Note: The 3-year average mortality rate is reported at the mid-point year.
* The Tenth Revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) was implemented.
Source: U.S. Consumer Product Safety Commission/EPHA.
U.S. Census Bureau, Population Division Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2017 (NST-EST2017-01)

Before implementation of ICD-10 in 1999, generating estimates for an important category of products—generators and other engine-driven tools—was not possible.[12] With the advent of ICD-10 coding, generation of estimates of deaths associated with generators and other engine-driven tools is now possible. Table B.2 presents a summary of the mortality rates associated with generators, which steadily increased from 1999 through 2006, but has retracted somewhat from the 2006 high point. However, the 3-year average mortality rate from 2013 to 2015 reached its highest (2.05) is the highest level for six years. This 3-year average mortality rate range for generators alone is nearly four times greater than the 3-year average rate in 2000.

**Table B.2: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Generators, 1999−2015***

| Year | Estimate | U.S. Population (thousands) | 3-Year Average Mortality Rate per 10 Million Population |
|---|---|---|---|
| 1999 | 7 | 279,040 | |
| 2000 | 19 | 282,172 | 0.54 |
| 2001 | 20 | 285,082 | 0.95 |
| 2002 | 42 | 287,804 | 1.29 |
| 2003 | 49 | 290,326 | 1.52 |
| 2004 | 41 | 293,046 | 2.02 |
| 2005 | 88 | 295,753 | 2.41 |
| 2006 | 85 | 298,593 | 2.69 |
| 2007 | 68 | 301,580 | 2.53 |
| 2008 | 76 | 304,375 | 2.28 |
| 2009 | 64 | 307,007 | 1.98 |
| 2010 | 42 | 309,338 | 1.83 |
| 2011 | 64 | 311,644 | 1.74 |
| 2012 | 57 | 313,993 | 1.88 |
| 2013 | 56 | 316,235 | 1.76 |
| 2014 | 54 | 318,623 | 2.05 |
| 2015 | 86 | 321,040 | |

* Estimates are based on single source product incidents as multiple source incidents could be included in multiple categories.
+ Estimates in this table do not include multiple product-related deaths because a generator was not the sole product associated with the death.
Note 1: The 3-year average mortality rate is reported using the mid-year population estimates.
Note 2: Mortality rate changes from last year's report are due to changes in CPSC CO death estimates and changes in U.S. Census population estimates.

[12] See Appendix B of Mah (2001) for details.

Table B.3 shows the CO poisoning mortality rates associated with all consumer products, excluding generators. The data indicate that, when generators are excluded, there does not appear to be a trend in the mortality rate for consumer products related CO deaths. The 2000, 3-year annual average mortality rate was 3.60. The 2014, 3-year average mortality rate was 2.80, a decrease of 22 percent. However, the 3-year averages did not change much from 2008 through 2014, the, hovering in the 2.66 to 2.88 range after dropping from a 2003 high of 3.93.

**Table B.3: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products, 1999–2015 (Excluding Generator-Related Deaths)***

| Year | Estimate | U.S. Population (thousands) | 3-Year Average Mortality Rate per 10 Million Population |
|---|---|---|---|
| 1999 | 95 | 279,040 | |
| 2000 | 117 | 282,172 | 3.60 |
| 2001 | 93 | 285,082 | 3.93 |
| 2002 | 126 | 287,804 | 3.65 |
| 2003 | 96 | 290,326 | 3.93 |
| 2004 | 120 | 293,046 | 3.48 |
| 2005 | 90 | 295,753 | 3.35 |
| 2006 | 87 | 298,593 | 3.07 |
| 2007 | 98 | 301,580 | 3.04 |
| 2008 | 90 | 304,375 | 2.86 |
| 2009 | 73 | 307,007 | 2.88 |
| 2010 | 102 | 309,338 | 2.87 |
| 2011 | 91 | 311,644 | 2.87 |
| 2012 | 75 | 313,993 | 2.66 |
| 2013 | 85 | 316,235 | 2.77 |
| 2014 | 103 | 318,623 | 2.80 |
| 2015 | 80 | 321,040 | |

* Estimates are based on single source product incidents as multiple source incidents could be included in multiple categories.
+ Excludes estimates of deaths associated with a generator only.

Note 1: The 3-year average mortality rate is reported at the mid-year population estimates.
Note 2: Mortality rate changes from last year's report are due to changes in CPSC CO death estimates and changes in U.S. Census population estimates.

Table B.4 shows the 3-year average mortality rates of all engine-driven tools, including generators, through 2014. Though the average mortality rates for 2007 through 2011 have dropped slightly since the 2006 high (3.18), in 2014 rate (2.34) increased to the highest rate since 2008 rate of 2.60. The table shows that the 3-year average mortality rate has more than tripled from the 2000 (0.72), to 2014 (2.34).

**Table B.4: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Generators and Other Engine-Driven Tools, 1999–2015***

| Year | Estimate | U.S. Population (thousands) | 3-Year Average Mortality Rate per 10 Million Population |
|---|---|---|---|
| 1999 | 13 | 279,040 | |
| 2000 | 26 | 282,172 | 0.72 |
| 2001 | 22 | 285,082 | 1.17 |
| 2002 | 52 | 287,804 | 1.51 |
| 2003 | 56 | 290,326 | 1.88 |
| 2004 | 56 | 293,046 | 2.43 |
| 2005 | 102 | 295,753 | 2.95 |
| 2006 | 104 | 298,593 | 3.18 |
| 2007 | 79 | 301,580 | 2.93 |
| 2008 | 82 | 304,375 | 2.60 |
| 2009 | 76 | 307,007 | 2.32 |
| 2010 | 56 | 309,338 | 2.21 |
| 2011 | 73 | 311,644 | 2.06 |
| 2012 | 64 | 313,993 | 2.18 |
| 2013 | 68 | 316,235 | 2.04 |
| 2014 | 62 | 318,623 | 2.34 |
| 2015 | 94 | 321,040 | |

* Estimates are based on single source product incidents as multiple source incidents could be included in multiple categories.

+ Estimates in this table do not include multiple product-related deaths because an EDT was not the sole product associated with the death. The one exception to this is the 2001 estimate that includes one estimated death associated with a generator and another EDT.

Note 1: The 3-year average mortality rate is reported at the mid-year population estimates.

Note 2: Mortality rate changes from last year's report are due to changes in CPSC CO death estimates and changes in U.S. Census population estimates.

Table B.5 shows the CO mortality rates associated with all consumer products, excluding generators and other engine-driven tools. The data indicate that the annual average, 3-year mortality rate decreased by 27 percent of non-engine-driven tool consumer products (*i.e.*, excluding generator and other engine-driven tools), from the 2000 rate of 3.44 to 2015 rate of 2.51.

**Table B.5: Estimated Non-Fire Carbon Monoxide Poisoning Deaths Associated with Consumer Products, 1999−2015 (Excluding Generator- and Other Engine-Driven Tool-Related Deaths)***

| Year | Estimate | U.S. Population (thousands) | 3-Year Average Mortality Rate per 10 Million Population |
|---|---|---|---|
| 1999 | 89 | 279,040 | |
| 2000 | 110 | 282,172 | 3.44 |
| 2001 | 92 | 285,082 | 3.72 |
| 2002 | 116 | 287,804 | 3.44 |
| 2003 | 89 | 290,326 | 3.56 |
| 2004 | 105 | 293,046 | 3.07 |
| 2005 | 76 | 295,753 | 2.81 |
| 2006 | 68 | 298,593 | 2.58 |
| 2007 | 87 | 301,580 | 2.64 |
| 2008 | 84 | 304,375 | 2.54 |
| 2009 | 61 | 307,007 | 2.53 |
| 2010 | 88 | 309,338 | 2.49 |
| 2011 | 82 | 311,644 | 2.55 |
| 2012 | 68 | 313,993 | 2.37 |
| 2013 | 73 | 316,235 | 2.49 |
| 2014 | 95 | 318,623 | 2.51 |
| 2015 | 72 | 321,040 | |

* Estimates are based on single source product incidents as multiple source incidents could be included in multiple categories.

\+ Excludes estimates of deaths associated with EDTs only. Multiproduct-associated incidents are included here because an EDT could not be identified as the only product involved. The one exception to this is the 2001 estimate, which excludes one estimated death associated with a generator and another EDT.

Note 1: The 3-year average mortality rate is reported at the mid-year population estimates.

Note 2: Mortality rate changes from last year's report are due to changes in CPSC CO death estimates and changes to U.S. Census estimates.

## Summary

When all consumer products are included, there has been a 9 percent increase in the CO mortality rate from the 2000 average rate, increasing from 3-year average mortality rate of 4.34 in 2000, to 5.07 in 2014, as shown in Table B.1. Engine-driven tools and generators, in particular, have had a substantial impact on the CO poisoning mortality rate involving consumer products.

## Appendix C: Chi-Squared Test Results

### Age Group Test Result

Table 7 shows the estimated number of CO poisoning deaths categorized by victim age for the 11 most recent years of data (2005–2015). For the Chi-Square statistical analysis, the two younger groups ("Under 5" and "5−14") were combined, due to their small estimated averages. Chi-Square goodness-of-fit test results indicate that there is a statistically significant difference (p-value = < 0.0001) between the proportion of CO victims in each age group from that of the general U.S. population. Each age group was analyzed separately, versus the expected proportion of the respective age group, based on U.S. population figures (assuming there was no age group effect on the CO poisoning death rate), to determine which age group proportions were significantly different from expectation. Binomial tests indicate that all individual groups, with the exception of the "25−44" group, were found to be significantly different from what would be expected if there was no population group effect:

1. The "Under 15" group[13] was significantly lower (< 0.0001);
2. The "15–24" group was significantly lower (0.0156);
3. The "45–64" group was significantly higher (< 0.0001); and
4. The "65 and older" group was significantly higher (0.0052).

### Gender Group Test Result

Table 8 presents the distribution of estimated CO deaths categorized by gender. For 2013—2015, the average percentage of male CO victims was also 78 percent, and the average percentage of female victims was 22 percent. By contrast, about 49 percent of the U.S. population is male, and 51 percent of the U.S. population is female.[14] The gender-related differences in CO Poisoning deaths were confirmed to be statistically significant (p-value = < 0.0001).The gender-related differences in CO Poisoning deaths were confirmed to be statistically significant (p-value = < 0.0001). Chi-square goodness-of-fit test results

### Ethnicity/Race Group Test Result

Table 9 provides a summary of CO death victims characterized by race/ethnicity for the years 2005 through 2015. Estimates of the percentage of the U.S. population categorized into the various race/ethnicity groupings were based on single-race characterizations, as represented in the U.S. Census Bureau reports. Individuals reported as multi-race are included in the *Unknown/Other* category.

Chi-square goodness-of-fit test results indicate that there is a significant statistical difference (p-value = < 0.0001) between the proportion of CO victims categorized by race/ethnicity from that of the general U.S. population. Each race/ethnicity group was analyzed separately, versus the expected proportion of the respective race/ethnicity group based on U.S. population figures, assuming there was no race/ethnicity group effect on the CO poisoning death rate, to determine which race/ethnicity group proportions were significantly greater than or less than the expectation. For the Chi-Square statistical analysis, the three smaller groups ("Asian/Pacific," "American Indian," and "Unknown/Other/Mixed") were combined, due to their relative small proportion of the U.S. population. Binomial tests indicate that two race/ethnicity groups were statistically significantly different from the expected proportion based on the U.S. population. The observed proportion of Hispanic CO deaths was significantly lower (p-value of 0.0087) than the proportion of Hispanics in the U.S. population. Additionally, the observed

[13] "Under 5" and "5–14" groups were combined due to small sample sizes.
[14] Three-year average, 2013 to 2015, from March 2018 U.S. Census estimates of the U.S. population.

proportion of Black or African American CO deaths was significantly higher (p-value = < 0.0001) than the proportion of Black or African Americans in the U.S. population.

## Appendix D: Regional Definitions

1) Northeast comprises New England and Middle Atlantic states.
   a) New England: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut.
   b) Middle Atlantic: New York, New Jersey, and Pennsylvania.
2) Midwest comprises East North Central and West North Central states.
   a) East North Central: Ohio, Indiana, Illinois, Michigan, and Wisconsin.
   b) West North Central: Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas.
3) South comprises South Atlantic, East South Central and West South Central states.
   a) South Atlantic: Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, and Florida.
   b) East South Central: Kentucky, Tennessee, Alabama, and Mississippi.
   c) West South Central: Arkansas, Louisiana, Oklahoma, and Texas.
4) West comprises Mountain and Pacific states.
   a) Mountain: Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada.
   b) Pacific: Washington, Oregon, California, Alaska, and Hawaii

Source: U.S. Census Bureau 2012 Statistical Abstract
http://www.census.gov/compendia/statab/cats/population.html

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# **TAB B** *Gas Furnaces and Boilers ANPR: Preliminary Discussion of the Market and Number in Use*

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

Date:

| | | |
|---|---|---|
| TO | : | Ronald Jordan<br>Directorate for Engineering Sciences |
| THROUGH | : | Gregory B. Rodgers, Ph.D.<br>Associate Executive Director<br>Directorate for Economic Analysis<br><br>Robert Franklin<br>Senior Staff Coordinator<br>Directorate for Economic Analysis |
| FROM | : | Bretford Griffin, Ph.D.<br>Economist<br>Directorate for Economic Analysis |
| SUBJECT | : | Gas Furnaces and Boilers ANPR: Preliminary Discussion of the Market and `<br>Number in Use |

The Commission is considering whether to issue an advance notice of proposed rulemaking (ANPR) to address the risk of non-fire carbon monoxide (CO) poisonings associated with residential heating systems. If the Commission issues the ANPR, it will initiate a rulemaking procedure that could potentially result in a product safety rule. This memorandum provides information on the market for gas furnaces and other heating equipment, including the number of units in use. , The memorandum also discusses the information that would be needed to prepare a preliminary analysis of the benefits and costs of a rule were the Commission to issue a proposed rule pursuant to section 9 of the CPSA. The scope of the draft ANPR covers residential, gas-fired central furnaces, boilers, wall furnaces, and floor furnaces (gas furnaces and boilers). These appliances are fueled by natural gas or propane (gas).

## Residential Heating Equipment Associated with CO Poisonings

This section provides information on the types of heating equipment that are involved in CO poisonings. Estimates of the annual sales, the number in use, and other relevant information are also provided. Estimates of the number of units in use are from the Residential Energy Consumption Survey (RECS), which is a national representative survey of housing units conducted by the Energy Information Agency of the Department of Energy about every 5 years. The most recent data available are from the 2015 survey. The types of heating equipment discussed include central warm-air furnaces, boilers, wall and floor furnaces, and room or space heaters. Because the ANPR is not intended to cover portable equipment, portable equipment is not discussed in this memorandum.

## Central Warm-Air Furnaces and Boilers

Central warm-air furnaces are a type of space-heating equipment in which natural gas, propane or fuel oil is burned within an enclosed combustion chamber to heat air surrounding the chamber. The heated air is provided to the living spaces through ducts. Most modern central warm air furnaces include a blower or fan that forces the air through the ducts. These are usually referred to as forced-air furnaces. However, some furnaces, referred to as gravity furnaces, do not have blowers and rely on the natural flow of warm air up and cold air down to circulate the air through the living space.

In 2015, according to the RECS, about 50.3 million housing units used central warm-air furnaces fueled by natural gas or propane as their primary heating equipment; and another 3.5 million central warm-air furnaces were fueled by fuel oil or kerosene. According to the Air-Conditioning, Heating and Refrigeration Institute (AHRI), a trade association representing manufacturers of heating, ventilation, and air conditioning equipment, between 2.6 million and 3.1 million natural gas or propane furnaces were shipped annually between 2013 and 2017. Shipments of oil- or kerosene-based warm air furnaces were between 32,000 and 38,000 annually during the same period.

Boilers are a type of residential heating equipment that heat water and then circulate the heated water, or in some cases steam, through pipes to heat living spaces. The most common type of boiler supplies steam or hot water to conventional radiators or baseboard radiators. Boilers can also supply radiant heat through pipes inlaid in a concrete slab floor that carry hot water.

In 2015, according to the RECS, boilers were the main heating equipment in about 9.1 million households. Of these boilers, 6.8 million used natural gas or propane, and 1.7 million used fuel oil or kerosene. The remainder used other fuels, including electricity and wood. Shipments of boilers (all fuel types) were about 390,000 in 2016 (Freedonia, 2017).

According to *Appliance* magazine, the average product life of gas furnaces (including boilers) ranges from 15 to 20 years (Appliance, 2009). Similarly, a recent article in the trade publication *Air Conditioning, Heating & Refrigeration News* also estimated that furnaces last about 15 to 20 years (Taylor, 2019).

## Floor and Wall Furnaces

Floor and wall furnaces are less common than central furnaces and boilers, but they are nevertheless used as the main heating equipment in some housing units. These are ductless heating equipment, and fuel is burned within an enclosed combustion chamber to heat surrounding air that then warms the living spaces. A floor furnace is located below the floor, typically between the wooden floor joists, and it delivers heated air to the room or rooms above, through gravity. A wall furnace is installed in a wall, typically between the wooden framing members, and it delivers heated air to the rooms on one or both sides of the wall.

In 2015, according to the RECS, there were about 800,000 homes with floor, wall, or pipeless furnaces fueled by natural gas or propane and about 100,000 fueled by fuel oil or kerosene. Additionally, about 2.8 million housing units had other types of built-in room heaters fueled by natural gas or propane and another 300,000 had built-in room heaters that were fueled by fuel oil or kerosene. These types of heating equipment can also be used as secondary or supplemental heat sources in some housing units, such as in an addition or garage. We have not located recent shipment data for floor, wall, or pipeless furnaces, or other types of room heaters. We would welcome public comments that could provide information on the total number of these types of units that might be in use and their annual shipments.

**Manufacturers and Importers of Residential Heating Equipment that Could Be Affected by a Product Safety Standard or Rule**

Manufacturers of combustion heating equipment can be classified in one of several North American Industrial Classification System (NAICS) categories. NAICS category 333415 (Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing) includes warm-air furnaces, but also covers many types of equipment that would not be within the scope of this potential rulemaking activity. NAICS category 333414 (Heating Equipment, (except Warm Air Furnaces) Manufacturing) includes manufacturers of boilers and other types of room heating equipment, including some types that would unlikely be considered in-scope for this possible rulemaking proceeding (*e.g.,* wood stoves and solar heating systems). Although the U.S. Bureau of the Census reports that there are more than 1,000 firms in these two categories, based on a market report published by Freedonia (2017), we believe that there are about 65 manufacturers and importers that supply the types of residential heating equipment that potentially could be impacted by this rulemaking proceeding.

The U.S. market for *residential* and *commercial* heating equipment was estimated to be $4.1 billion in 2016. In terms of revenue, the largest 10 of these firms account for approximately 80 percent of the market. The majority of these firms produce at least some types of *residential* equipment that could be in the scope of this potential rulemaking proceeding, including warm-air furnaces, boilers, and other types of combustion heating equipment, such as room heaters or wall furnaces. By value, about one-quarter of the heating market consists of imports, mostly from Mexico and Canada. However, we do not have specific information on the types of heating equipment that are imported or the unit quantities.

We would welcome public comments that provide information on manufacturers and importers of residential heating equipment that could be within the scope of this rulemaking proceeding, including the annual shipments of residential combustion heating equipment by type. We would also welcome comments on small manufacturers or importers that could be impacted by this rulemaking proceeding.

**Preliminary Estimate of Non-Fire CO Injuries Associated with Gas Furnaces and Boilers**

This section estimates the medically-attended, non-fire carbon monoxide (CO) poisonings involving residential heating systems, and reported through the National Electronic Injury Surveillance System (NEISS). Our focus is on the injuries associated with *natural gas or LP central warm-air furnaces and boilers* because that is the equipment of primary interest. However, the same procedures would be used to estimate the emergency department (ED)-treated injuries associated with other types of heating equipment or furnaces and boilers using other fuel sources.

CO-Related Deaths and Injuries Involving Furnaces and Boilers

From 2013 through 2015, there were a total of 57 non-fire CO deaths associated with natural or LP gas-burning central furnaces and boilers, or an average of 19 deaths per year (Hnatov, 2018).

National estimates of nonfatal CO-poisonings involving furnaces and boilers treated in U.S. hospital emergency departments were derived from the National Electronic Injury Surveillance System (NEISS), a stratified national probability sample of hospital emergency departments that allows CPSC staff to make national estimates of product-related injuries. The sample consists of about 100 of the approximately 5,400 U.S. hospitals that have at least six beds and provide 24-hour emergency service.

To develop injury estimates, an interdisciplinary agency team selected and evaluated all NEISS cases that met the following criteria:

- The treatment date was in the years 2013 through 2015[17];
- A product code of 308 (boilers), 310 (gas furnaces), 322 (unspecified furnaces), or 392 (gas heaters), or 393 (unspecified heaters); and
- A diagnosis code of 65 (anoxia) or 68 (poisoning).

The team first reviewed the short narratives of the gas furnace cases (NEISS product code 310) to make sure incidents were non-fire related and CO poisoning related. Cases for which there was strong evidence that they were in scope were assigned to Tier 1; cases that were likely in scope, but we could not rule out the possibility that they were not, were assigned to Tier 2. Cases where available information indicates that the product was out of scope, such as cases that had a non-gas fuel type (*e.g.*, oil or wood), or cases that were fire-related or otherwise not involving CO poisoning, were excluded from the analysis.

The team then reviewed the cases involving boilers and unspecified furnaces (product codes 308 and 322). Cases that specified natural or LP gas as the fuel were assigned to Tier 1, and cases that did not mention gas as a fuel were assigned to Tier 2. The remaining cases were excluded from the analysis.

For gas heaters (product code 392) and unspecified heating systems (product code 393) the screening criteria were more difficult because we also had to establish that the heating appliances were either a furnace or a boiler. Cases that identified the product as a furnace or boiler, and identified the fuel type as natural or LP gas were assigned to Tier 1. Cases that identified the product as a furnace or boiler, but did not specify a fuel, were assigned to Tier 2. The remaining cases were excluded from the analysis.

Based on this analysis, there was an annual average of about 700 Tier 1 injuries and another 1,150 Tier 2 injuries that were treated in U.S. hospital EDs and reported through NEISS during the 2013 through 2015 period. Both Tier 1 and Tier 2 cases are used in the analysis that follows; consequently, for purposes of this analysis, there was an average of about 1,850 CO-related furnace and boiler injuries treated in U.S. hospital EDs annually.

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[17] These years were chosen to be consistent with the fatality data being used.

In addition to injuries treated in EDs, the CPSC's Injury Cost Model (ICM) uses empirical relationships between the characteristics of injuries and victims initially treated in hospital EDs and those initially treated elsewhere to estimate the number of medically attended injuries treated outside of hospital EDs, such as in physician's offices, urgent care centers, or patients who were admitted directly into a hospital bypassing the ED (Lawrence et al., 2018). Based on the annual estimate of about 1,850 injuries treated in hospital EDs, the ICM projects another 5,740 non-fire furnace injuries treated outside of hospital EDs, for a total of about 7,590 Tier 1 and Tier 2 injuries annually.[18]

**Evaluating Possible Safety Remedies**

If the Commission initiates a regulatory proceeding by issuing the ANPR, and develops a notice of proposed rulemaking, the Directorate for Economic Analysis will conduct a preliminary regulatory analysis of the proposed rule. That process would begin by estimating present value of societal costs per furnace or boiler in use and within scope of the proposed rule over the useful life of the furnace or boiler. That present value figure would represent the maximum benefits, per furnace or boiler, that would be attainable if the proposed rule prevents all of the deaths and injuries it was intended to address. Once a safety remedy is identified, the benefits of the proposal, per furnace or boiler within scope of the proposed rule, would be determined by the remedy's expected effectiveness. Seldom, if ever, are safety remedies fully effective. Consequently, the benefit of the proposal would be some proportion of the present value of the societal costs per furnace or boiler.

The expected benefits would then be compared to the expected costs which would include the cost of modifying the design of the furnaces or to incorporate components that might be needed to conform to the standard. The costs would also include changes in the operating or maintenance cost of the equipment over its expected useful product life and any qualitative costs that would be incurred as a result of the rule.

To address these issues, CPSC requests the information described below:

1. We request information on any factors or trends that, independent of any CPSC rulemaking, could act to reduce (or increase) CO poisonings associated with gas furnaces, boilers, wall furnaces, and floor furnaces described in the draft ANPR.

2. We request information on any feasible means of addressing this hazard, along with the specific costs that might be involved, including information on the costs associated with the maintenance over the service life of the equipment that would likely result from potential remedies. We also request information on how effective the different remedies would be in reducing the hazard.

3. We understand that there are standards in Japan and some European Union countries that require some gas appliances to have a means by which CO production or perhaps fuel

[18] The ICM estimates nonfatal injuries treated in non-ED hospital settings using treatment location ratios derived from the Medical Expenditure Panel and the National Inpatient Sample, respectively.

consumption is measured. We request information on those standards, the means by which compliance with the standards is achieved, the impact of the standards on the cost of equipment, including the maintenance costs, and the effectiveness of the standards at achieving their intended purpose.

4. We request any information available on the distribution of CO emissions of natural or LP gas furnaces in use. Or in other words, the number of gas furnaces that are not in compliance with the 400 ppm air-free standard at any given time and the degree to which they might be producing CO in excess of that standard. We also request information on the causes of equipment producing excessive CO and their frequency of occurrence, such as improper installation, changes in installation, poor maintenance of the equipment, and so forth.

6. We understand that furnaces and other equipment that are producing excessive CO emissions may also be consuming excessive fuel or not burning fuel completely. We request any available information on the relationship between excessive CO production and fuel consumption and complete/incomplete combustion.

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# TAB C *Hazard Patterns - Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and "Modern" Gas Furnaces and Boilers, September 2012*

U.S. CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, D.C. 20207
September 14, 2012

**TO:** DeWane Ray
Assistant Executive Director,
Hazard Identification and Reduction (EXHR)

**THROUGH:** George Borlase
Associate Executive Director
Directorate for Engineering Sciences (ES)

**THROUGH:** Patricia Adair
Director, Division of Combustion & Fire Sciences (ESFS)
Directorate for Engineering Sciences

**FROM:** Ronald Jordan
Project Manager, Vented Gas Appliance CO Sensors
Division of Combustion & Fire Sciences (ESFS)
Directorate for Engineering Sciences

**SUBJECT:** Updated Review of In-Depth Investigations Associated with Carbon Monoxide Poisoning and "Modern" Gas Furnaces and Boilers

## PURPOSE

The purpose of this memorandum is to (1) report the results of a review of In-Depth Investigations (IDIs) associated with non-fire-related carbon monoxide (CO) incidents and gas furnaces and boilers and (2) provide an update of previous CO incident reviews involving these types of products.[1,2] The current and previous reviews address assertions by some within the gas appliance industry and voluntary standards community that most of the CO poisoning incidents reported to the CPSC involved older appliances, not "modern" appliances.

## BACKGROUND

"Modern" furnaces are furnaces that, based on: (1) their date of manufacture, installation, or certification; or (2) the safety components they were equipped with (*e.g.*, Blocked Vent Shutoff Switches (BVSS)/pressure switches or spill switches/thermal switches designed to shutdown the appliance when the vent became blocked), would have been certified to the 1986 (effective date 1987) or later versions of ANSI Z21.47, *Standard for Gas-Fired Central Furnaces* (Except

[1] "In-Depth Investigations of Carbon Monoxide (CO) Incidents Associated with "Modern" Gas-Fired Furnaces," R. Jordan and S. Vagts (2002).
[2] "In-Depth Investigations Associated with Certain Vented Gas Appliances," R. Jordan and S. Vagts (2002).

Direct Vent Furnaces) or the 1989 (effective date 1992) or later versions of ANSI Z21.64 (Z21.64b-1989), *Standard for Direct Vent Central Furnaces*. ANSI Z21.47 provided coverage for draft hood-equipped furnaces, while ANSI Z21.64 provided coverage for direct vent furnaces. In 1993, ANSI Z21.47 and ANSI Z21.64 were combined into one standard and designated, ANSI Z21.47, *Standard for Gas-Fired Central Furnaces*. These versions of the furnace standards were the first to adopt the current set of construction and performance requirements that address some of the operating, installation, or usage conditions that could result in CO leakage into the living space.

"Modern" boilers are boilers that, based on: (1) their date of manufacture, installation, or certification; or (2) the safety components they were equipped with (*i.e.*, BVSS/pressure switches or spill switches/thermal switches designed to shutdown the appliance when the vent became blocked), would have been certified to the 1989 or later versions of ANSI Z21.13, *Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers*. This version of the boiler standard was the first to adopt the current set of construction and performance requirements that address some of the operating, installation, or usage conditions that could result in CO leakage into the living space.

In 1996, CPSC staff proposed to the ANSI Z21.47 furnace subcommittee that a performance provision be added to the furnace standard, ANSI Z21.47, *Standard for Gas-Fired Central Furnaces*, that would require furnaces to shut down in the event that their vents became disconnected or partially blocked. The standard in effect at that time did not include provisions that protected consumers from those conditions. In 2000, CPSC staff reiterated that proposal and also proposed an additional, alternative provision that would: (1) require a means to prevent a furnace from producing CO levels in excess of 400 ppm (air free)[3], or (2) require the furnace to shut down if CO levels exceeded 400 ppm (air free). To support these proposals, in 1997 and 2000, staff conducted reviews of incidents reported to the CPSC involving CO poisonings associated with gas furnaces and disconnected or blocked vents, and provided the results of those reviews to the furnace subcommittee.[4,5] The reviews demonstrated that disconnected and partially blocked vents were failure conditions that contributed to the CO poisonings.

Representatives from the Gas Appliance Manufacturers Association (GAMA) and other subcommittee members asserted that the incidents discussed in these reviews did not involve "modern" furnaces, but rather, older appliances. They also asserted that "modern" furnaces did not pose the CO exposure risks from the failures or conditions reported in the CPSC incident reviews. Because the 1997 and 2000 IDI reviews focused primarily on vent conditions, not the vintage of the appliance, staff was unable to confirm whether the furnaces involved in those cases met the criteria (described in the following paragraph) for "modern" furnaces. In order to respond to industry's assertions, a review of CO exposure incidents that identified not only vent conditions, but also appliance vintage, was necessary. In 2002, CPSC staff conducted additional IDI reviews with a focus on the vintage of the appliance, in addition to vent and operating conditions, to determine whether "modern" furnaces (or boilers, for that matter) were involved in

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[3] "Air-free" is a means to express a flue gas sample of CO that has not been diluted by excess air added to the burners during the combustion process.
[4] "Review of Selected Investigation Reports Involving Vent Disconnection from Gas-Fired Central Furnaces," R. Jordan (1997).
[5] "Review of Selected Investigation Reports Involving Gas-Fired Central Furnaces and Disconnected and Blocked Vents," R. Jordan (2000).

CO poisoning incidents. The results of these reviews demonstrated that "modern" furnaces and boilers had been, and continue to be, involved in CO exposure incidents.[6, 7]

Despite their intended purpose, the performance requirements for furnaces and boilers do not provide consumers protection from CO leakage under a number of conditions that commonly occur in the field and that have been associated with CO deaths, injuries, and potential exposures. These conditions include: disconnected vents, partially blocked vents, over-fired furnace/boilers, and furnace/boilers that have inadequate air for combustion. The safety devices (*e.g.*, Blocked Vent Shutoff Systems and spill switches) required by the ANSI Z21 standards were not designed to respond to these conditions, and thus, they are unable to protect consumers from CO exposure under these conditions. The scenarios described in these incidents underscore the need for requirements that provide more comprehensive protection against CO poisoning for consumers.

**METHODOLOGY**

This memorandum provides an update of staff's previous reviews of furnaces and boilers and summarizes CO incidents associated with modern furnaces and boilers from the CPSC IDI files for the years 2002 through 2009. For the purposes of this review, CO incidents were comprised of cases in which a gas furnace or boiler reportedly leaked CO into the home or other structure. CPSC staff from the Directorate for Engineering Sciences reviewed the IDIs to compile the information within this memorandum. This review focused on reported conditions associated with furnace or boiler components, installation and operation, as well as deaths and medical treatment information associated with the incidents.

The incidents included in this review were from the CPSC's In-Depth Investigation (INDP) File. Data from the CPSC INDP files are not a statistical sample, and national totals may not be derived from the number of incidents investigated. However, the data does provide minimum case count examples of actual incidents and anecdotal information. See Appendix A for the codes and keywords used in the database searches. The initial database search identified 435 IDIs from January 2002 through December 2009, involving carbon monoxide poisonings or exposures associated with gas furnaces and boilers. After the initial database search, staff screened the incidents to determine if they were within scope. Incidents were considered out of scope or indeterminate for the following reasons:

- Furnace or boiler was converted to or from solid fuel or oil to natural or liquefied petroleum (LP) gas;
- Furnace was not a gas-fired central furnace;
- Furnace or boiler was manufactured prior to 1987;
- The furnace's age or vintage could not be determined or estimated from available information;
- The incident was associated with a fire or a gas leak; or
- No evidence was provided within the investigation that CO leakage or exposure was related to furnace or boiler malfunction or failure.

[6] "In-Depth Investigations of Carbon Monoxide (CO) Incidents Associated with "Modern" Gas-Fired Furnaces," R. Jordan and S. Vagts (2002).

[7] "In-Depth Investigations Associated with Certain Vented Gas Appliances," R. Jordan and S. Vagts (2002).

In addition to screening out incidents that were not relevant, staff also verified the occurrence of reported conditions that were associated with CO leakage into the home or other structure. This memorandum only includes CO leakage-related information that was corroborated by at least one authoritative, investigating source. Acceptable sources included: the fire department, gas utilities, HVAC or plumbing service technician, forensic engineer, medical records, product manufacturer, housing authority, police, and local, state, or federal health officials. This review includes cases that were collected through the following means:

- Investigative reports collected by CPSC field investigators from the sources; or
- Investigative findings recorded by CPSC field investigators through telephone or in-person interviews of the sources; or
- Investigative findings of the sources reported to CPSC field investigators through interviews or investigative reports of third parties.

In addition to counting the number of CO-related deaths associated with each incident, staff also provides counts of the number of probable CO injuries, as well as the number of potential CO exposures related to each incident. Staff collected information on the type of medical treatment that each consumer received that was associated with CO exposure reported in the incidents. Based on the available information, each consumer's condition or disposition during or following the incident was characterized as either:

- Diagnosed injury,
- Given medical treatment for physical symptoms of CO exposure, or
- On-Site at time of the incident (no medical treatment given, requested, or cited).

"Probable injuries" were defined as consumers who were cited as having been either diagnosed with CO poisoning or given medical treatment for physical symptoms of CO exposure. This memorandum only includes a count of probable injuries that were corroborated by at least one authoritative, medical source. "Potential exposures" were defined as exposures to consumers who were on-site at the time of the incident but were not diagnosed with, or given medical treatment for, CO exposure. This memorandum only includes a count of potentially exposed consumers, whose exposure was corroborated by at least one authoritative technical or medical source.

Acceptable sources included: hospital/medical center records; doctors, nurses, and other health care professionals; emergency medical technicians (EMTs), fire fighters, and other first responders; federal, state, and local health officials. To be characterized as having sustained a carbon monoxide poisoning injury, the consumer would have had to have a carboxyhemoglobin (COHb) level above 10 percent or received supplemental hyperbaric oxygen (HBO) in a pressurized chamber (*i.e.*, hyperbaric chamber). To be characterized as having a high likelihood of CO exposure, a consumer would have had to exhibit at least one of the following physical symptoms OR received one of the following medical treatments or test results:

- loss of consciousness,
- loss of responsiveness,

- nausea/vomiting,
- disorientation,
- dizziness,
- headaches,
- received supplemental normobaric oxygen.

Staff counted the number of consumers who were on-site at the time of the incident and: (i) received medical treatment as a result, or (ii) did not receive medical treatment. Staff believes it was important to include this category because it provides an indication of the potential CO poisoning risk to consumers presented by the conditions that led to the incident. These conditions and the presence of other consumers on-site during the incident could have resulted in more deaths and injuries. The ultimate goal of the Vented Gas Appliance CO Sensor project is to reduce the number of CO-related deaths and injuries associated with these types of products (*i.e.,* furnaces and boilers) and to reduce the risk of CO poisoning incidents associated with them.

This memorandum only includes medical treatment information that was corroborated by at least one medical source, and which satisfied the following criteria:

- Medical reports were collected by CPSC field investigators from the medical source, or
- Medical findings or treatments were recorded by CPSC field investigators through telephone or in-person interviews of the medical sources, or
- Medical findings or treatments of the medical sources were reported to CPSC field investigators through interviews or investigative reports of third parties or consumers.

**RESULTS**

In-scope CO incidents

CPSC's epidemiology database was queried through the EPIdemiology Retrieval (EPIR) using the search criteria listed in Appendix A, resulting in identification of a total of 435 IDIs involving CO poisoning and either gas furnaces or boilers (Table 1). The screening criteria described under the Methodology section were applied to determine which cases were within the scope of this study. As shown in Table 1, the product vintage could not be determined in three-fifths (261 out of 435) of the IDIs, and as a result, ES staff was unable to determine whether the appliances involved in those incidents were "modern" units or older units. This is a common problem encountered with IDIs involving CO poisoning and gas furnaces or boilers. Thus, valuable incident data from cases in which the vintage could not be determined were not included in this review.

**Table 1. CO Incidents Involving All Furnaces and Boilers (2002–2009)**

| Year of Incident | Total Number of Incidents | Incidents without Furnace/Boiler Vintage Info | Incidents with Furnace/Boiler Vintage Info | Incidents with Out-of-Scope Vintage Info | Incidents with In-Scope Vintage Info |
|---|---|---|---|---|---|
| 2002 | 73 | 57 | 16 | 7 | 9 |
| 2003 | 41 | 25 | 16 | 9 | 7 |
| 2004 | 71 | 35 | 36 | 21 | 15 |
| 2005 | 56 | 32 | 24 | 15 | 9 |
| 2006 | 45 | 28 | 17 | 6 | 11 |
| 2007 | 71 | 42 | 29 | 17 | 12 |

**Table 1. CO Incidents Involving All Furnaces and Boilers (2002–2009)**

| Year of Incident | Total Number of Incidents | Incidents without Furnace/Boiler Vintage Info | Incidents with Furnace/Boiler Vintage Info | Incidents with Out-of-Scope Vintage Info | Incidents with In-Scope Vintage Info |
|---|---|---|---|---|---|
| 2008 | 44 | 25 | 19 | 10 | 9 |
| 2009 | 34 | 17 | 17 | 6 | 11 |
| **Totals** | **435** | **261** | **174** | **91** | **83** |

*** Note.** Data from the CPSC In-depth Investigation File are not a statistical sample and national totals may not be derived from the number of incidents investigated. The data does provide examples of actual incidents and anecdotal information.

Many of the IDIs reviewed did not include details concerning the product's manufacturer, model number, dates of manufacture, certification, or installation of the furnace or boiler. The IDIs also often do not include a report or statement from an authoritative technical source confirming that a furnace or boiler was the source of the CO production. Finally, many of the IDIs did not include photographs of key components, such as the vent pipe, pressure switch, or the unit's rating plate. In the absence of other specific forms of information on appliance vintage, photographs of these components, at times, have helped determine appliance vintage. Of the 435 IDIs initially identified, only about one-fifth of them (83 out of 435) were found to be within scope (see Table 1A).

**Table 1A. In-Scope Incidents (2002–2009)**

| Year of Incident | Total Number of Incidents | Incidents with In-Scope Vintage Info |
|---|---|---|
| 2002 | 73 | 9 |
| 2003 | 41 | 7 |
| 2004 | 71 | 15 |
| 2005 | 56 | 9 |
| 2006 | 45 | 11 |
| 2007 | 71 | 12 |
| 2008 | 44 | 9 |
| 2009 | 34 | 11 |
| **Totals** | **435** | **83** |

<u>CO Deaths, Probable Injuries, and Potential Exposures</u>

As shown in Table 2, there were a total of 44 CO-related deaths and 207 probable CO-related injuries involving "modern" gas furnaces and boilers during the review period from 2002–2009. It is important to note that these deaths and probable injuries are a subset of all the furnace and boiler CO incidents and likely do not reflect all of the cases involving "modern" furnaces and boilers but only those cases that included adequate descriptive information from which appliance vintage could be determined. In addition to counting deaths and probable injuries, staff also considered potential CO exposures. For purposes of this review, "potential CO exposures" were a count of consumers who were on-site at the time of the incident, and therefore, were potentially at risk of being exposed to, and affected adversely by, leakage of CO from the appliance. This category was included because it provides a means to measure other potential impacts of the incident and potential benefits of the Vented Appliance CO Sensor project. Only information that was corroborated by authoritative medical sources was included.

**Table 2. CO Deaths, Injuries, and Potential Exposures Associated with "Modern" Gas Furnaces and Boilers (2002–2009)[8,9] ***

| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2002–2009 Totals | 2002–2009 Averages |
|---|---|---|---|---|---|---|---|---|---|---|
| **Incidents** | **9** | **7** | **15** | **9** | **11** | **12** | **9** | **11** | **83** | **10.4** |
| **Deaths** | 9 | 4 | 7 | 4 | 8 | 4 | 4 | 4 | 44 | 5.5 |
| **Probable Injuries** | 3 | 16 | 82 | 51 | 11 | 8 | 9 | 27 | 207 | 25.9 |
| **Potential Exposures** | 27 | 15 | 111 | 67 | 302 | 48 | 144 | 56 | 770 | 96.3 |

*** Note.** Data from the CPSC In-depth Investigation File are not a statistical sample and national totals may not be derived from the number of incidents investigated. The data does provide examples of actual incidents and anecdotal information.

Failure modes that led or contributed to CO leakage and associated deaths, injuries, and potential exposures

As shown in Table 3, the investigating authorities were able to determine the primary failure modes that led to or contributed to CO leakage from the furnace or boiler in 73 out of 83 cases. The reported failure modes included: disconnected or breached vents; blocked vents, heat exchangers (HEX), or chimneys; depressurization of the space or back drafting of exhaust products; improper venting; and miscellaneous failure modes. The failure mode was unknown in 10 of the incidents.

**Table 3. Failure Modes that Led or Contributed to CO Incidents Associated with "Modern" Furnaces and Boilers (2002–2009).***

| Primary failure mode reported | Incidents Citing the Failure Mode | | Deaths | Probable Injuries | Potential Exposures |
|---|---|---|---|---|---|
| | # | % | # | # | # |
| Vent, Chimney, or Heat Exchanger Breach or Disconnect | 16 | 19.3% | 8 | 41 | 62 |
| Vent, Chimney, or Heat Exchanger Blockage | 15 | 18.1% | 10 | 55 | 96 |
| Depressurization or Back drafting | 3 | 3.6% | 1 | 8 | 11 |
| Improper Venting | 3 | 3.6% | 0 | 2 | 21 |
| Miscellaneous | 14 | 16.9% | 4 | 26 | 104 |
| Multiple Failure Modes | 22 | 26.5% | 12 | 60 | 181 |

[8] A spike in the number of injuries reported in 2004 occurred because out of a total of 20 in-scope incidents, two occurred in commercial/institutional settings, each involving more than 10 injuries (10 injuries associated with IDI No 041025HNE1836 and 28 injuries associated with IDI No. 041026HWE3016).

[9] A spike in the number of injuries reported in 2005 occurred because out of a total of 10 in-scope incidents, two occurred in commercial/institutional settings, each involving more than 10 injuries (19 injuries associated with IDI No. 050321HCN0534 and 15 injuries associated with IDI No. 051206HNE0282).

**Table 3. Failure Modes that Led or Contributed to CO Incidents Associated with "Modern" Furnaces and Boilers (2002–2009).***

| Primary failure mode reported | Incidents Citing the Failure Mode | | Deaths | Probable Injuries | Potential Exposures |
|---|---|---|---|---|---|
| | # | % | # | # | # |
| Unknown | 10 | 12.0% | 9 | 15 | 295 |
| **Totals*** | **83** | **100.0%** | **44** | **207** | **770** |

*** Note.** Data from the CPSC In-depth Investigation File are not a statistical sample and national totals may not be derived from the number of incidents investigated. The data does provide examples of actual incidents and anecdotal information.

For the purposes of this study, a disconnected vent or chimney described the condition cited in the IDI report in which there was either a partial or complete separation between two adjoining sections of vent pipe or chimney or between a section of vent pipe and the adjoining flue outlet of a furnace or boiler. A breached vent, chimney, or heat exchanger described a condition cited in the IDI report in which a hole or some other opening was present in the wall of the component. These components (*i.e.*, vents, chimneys, and heat exchangers) and conditions (*i.e.* disconnect and breach) were grouped under the broader category "Vent, Chimney, or Heat Exchanger Breach or Disconnect" because despite the various causes that led to the condition, they all created a leakage path that allowed CO to enter the living space. When complete or partial blockage of vents, chimneys, and heat exchangers was reported, these components were grouped under the broader category, "Blocked Vents, Chimneys, or Heat Exchangers." Again, despite the various causes, locations, and degrees of blockage of these components, they all caused or contributed to leakage of CO into the living space.

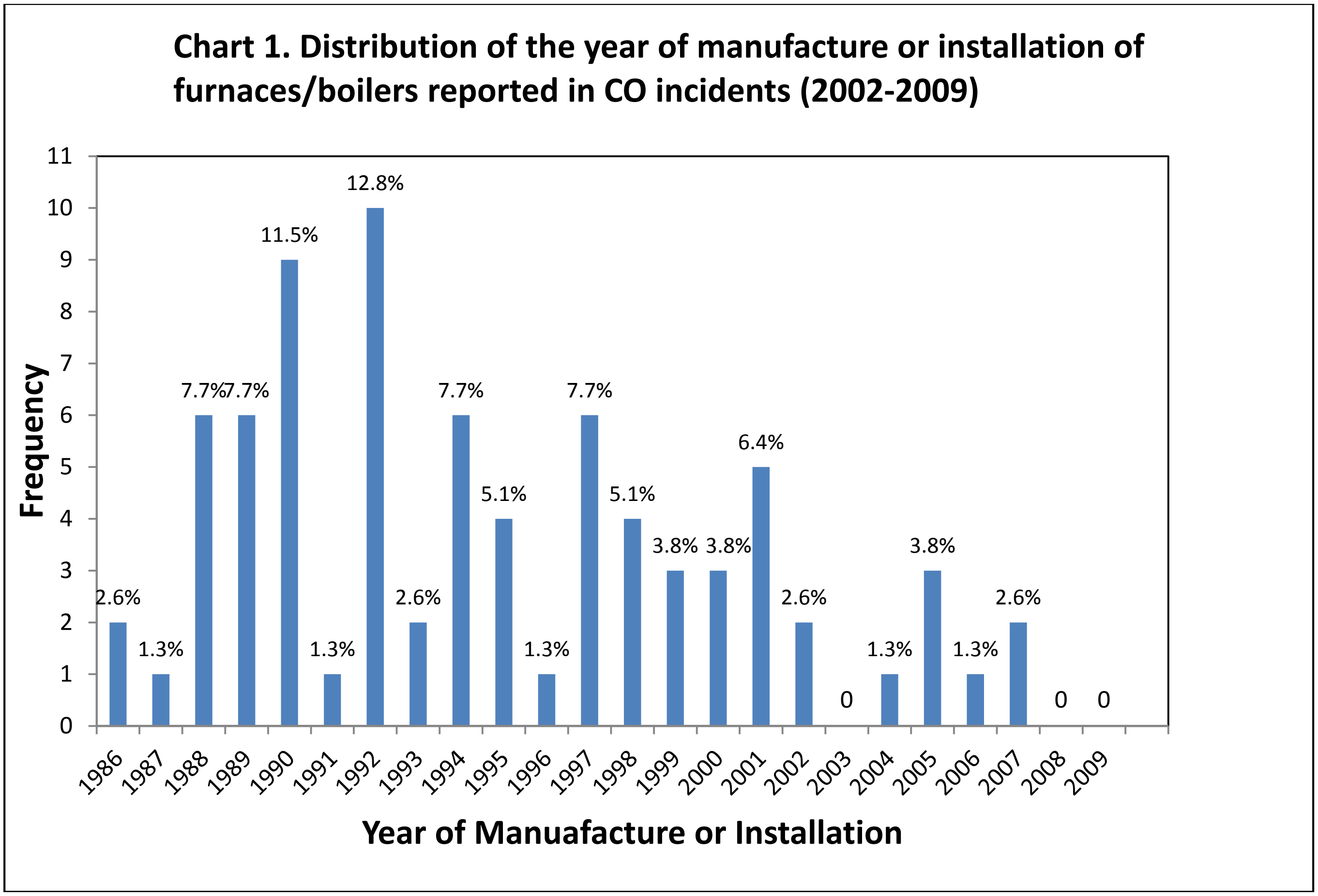
"Depressurization" described the conditions reported in the IDI reports in which air was exhausted from the home or other structure through exhaust fans or other mechanical means, possibly at greater rates or larger volumes than air infiltration into the home or air exhausted through the vent system of the furnace or boiler, causing a negative pressure locally at the appliance flue collector or burner compartment. "Back-drafting" described a condition reported in the IDI in which exhaust product flow reversed back through the appliance flue collector or burner compartment and into the living space, instead of through the vent system to the outdoors. This condition may or may not have been a consequence of depressurization. "Improper Venting" described conditions cited in the IDI reports in which the vent system was installed in a manner that was in violation of the instructions and requirements of the appliance manufacturer, the vent manufacturer, and/or the local building codes. "Miscellaneous" failure modes included reported conditions that did not meet the descriptive criteria of the preceding failure modes. Incidents in which the cause of the failure mode was not reported were classified as Unknown. When more than one cause for CO leakage was reported, the incident was classified as having had "Multiple" failure modes.

Disconnected/breached vents, chimneys, or heat exchangers were reported most frequently, accounting for 19.3 percent of the primary failure modes cited (16 out of 83 cases), followed by blocked vents, air intakes, heat exchanger, or chimneys, which were cited in 18.1 percent of the cases (15 out of 83 cases). Scenarios in which a vent/flue damper failed to open were also counted among the blocked vent cases. There were 8 deaths and 41 injuries associated with the cases that cited a disconnected or breached vent as the primary failure mode. The cases that involved a blocked vent as the primary failure mode accounted for 10 deaths and 55 injuries. Overall, disconnected and blocked vents were cited as the primary failure mode in more than a third of the cases (*i.e.*, 31 out of 83 or 37%) involving "modern" furnaces and boilers and were associated with 41 percent of the deaths (*i.e.*, 18 out of 44 deaths) and 46 percent of the injuries (96 out of 207 injuries). Of the 22 cases involving multiple failure modes, disconnected vents were cited as one of the failure modes 12 times, improper venting was cited 11 times, blocked vents were cited 6 times, and depressurization only once. Miscellaneous failure modes were cited as one of the failure modes in 19 of the 22 multiple failure mode cases.

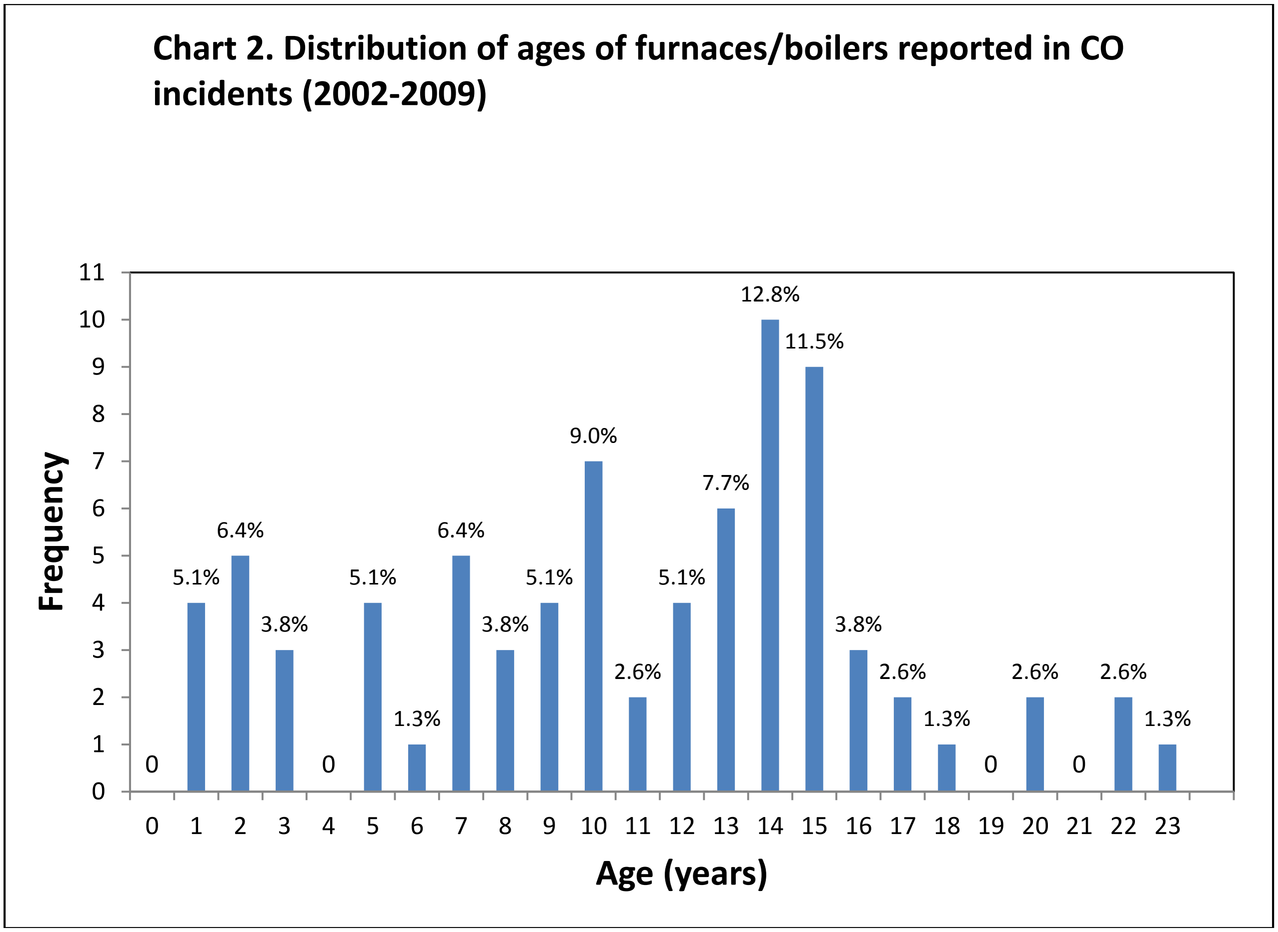
Failure mechanisms that led to or contributed to production of elevated CO levels.
Although the incident reports often identified the leakage path of CO into the living space, they rarely provided information about the failure mechanism/s that either led to or contributed to a furnace or boiler producing elevated levels of CO. Only 19 out of the 83 incident reports included this type of information. When the failure mechanisms were reported, they were almost evenly divided between inadequate/blocked combustion/ventilation air (10 citations) and over-firing (7 citations). There were two reports of the appliance having been converted improperly to or from natural or LP-gas. In two of the cases, more than one failure mode was reported.

Determination of the vintage of furnaces and boilers involved in CO incidents
The vintage of the appliances involved in each incident was based on the reported age, date of manufacture, or date of installation; or the reported age or date of construction of the residence or building structure the appliance was installed in. In some incidents, when the age of the appliance or its date of manufacture or installation were not reported, the vintage was based on whether the appliance was reported to have been equipped with component/s or materials indicative of a "modern" furnace or boiler design. Components indicative of a "modern" furnace or boiler design included blocked vent shutoff switches (BVSS), flame rollout switches, spill switches, and blower door interlock switches (for central furnaces only). Materials indicative of a "modern" furnace or boiler design included polyvinyl chloride (PVC) used for vent pipe and other forms of plastic used for inducer motors.

The information provided in the incident reports was sufficient to determine the year of manufacture or installation and age of furnaces and boilers in 78 of the 83 incidents. For those incidents in which the year of manufacture or installation of the product could be determined, the distribution is provided in Chart 1. The distribution of product age at the time of the incident is provided in Chart 2. Neither chart reflects distribution data for products involved in incidents in which the year of manufacture or installation or age of a product was not reported.




As shown in Chart 1, the years of manufacture or installation of the appliances involved in these incidents ranged from 1986 to 2007. The age of these appliances ranged from less than 1 year to 23 years old. The average appliance age was 12 years old, with a mode of 14 years old. The median appliance age was 11 to 12 years old.




Despite the gas appliance industry's expected life of 15 to 20 years for furnaces and boilers, Chart 2 shows that the majority (86 percent) of the CO incidents occurred in appliances that were reported to have been 15 years old or less at the time of the incident. Thus, although the life expectancy of a furnace or boiler may be at least 15 years, this data shows that failure modes and conditions that allow CO leakage into a living space can occur well before the appliance exceeds its expected lifespan. For this data set, the average age of appliances involved in a CO incident was 9.6 years.

**CONCLUSION**

This study demonstrates that CO deaths and injuries continue to occur involving "modern" furnaces and boilers. It also confirms and underscores staff's concern that the current ANSI standards do not adequately protect consumers from common appliance failure modes and conditions that allow leakage of CO into a living space. The cases involving disconnected vents demonstrate that consumers who experience this mode of failure can be exposed to hazardous levels of CO. There are no provisions in the furnace or boiler standards to address this failure scenario. The cases involving blocked vents demonstrate that "modern" furnaces or boilers equipped with a pressure sensing means (e.g., measuring the static pressure within the vent) or a temperature sensing means (*e.g.*, measuring the temperature of exhaust gases spilling past a measurement point in a draft hood) do not always protect against real world conditions, such as a disconnected or partially blocked vent, that can lead to leakage of hazardous levels of CO into the living space.

# **TAB D** *Existing Voluntary Standards and Voluntary Standards Development with Carbon Monoxide Hazards Associated With Gas Furnaces and Boilers*

**TO :** Gas Appliance CO Sensor ANPR File

**THROUGH:** Joel Recht, Associate Executive Director
Directorate for Engineering Sciences
Mark Kumagai, Director
Division of Mechanical and Combustion Engineering

**FROM :** Ronald Jordan, Project Manager
Directorate for Engineering Sciences

**SUBJECT :** Existing Voluntary Standards and Voluntary Standards Development with Carbon Monoxide Hazards Associated With Gas Furnaces and Boilers

# I. VOLUNTARY STANDARDS ASSESSMENT

## A. BACKGROUND

The standards development organization (SDO) for performance and safety standards for residential gas appliances and accessories sold in the United States and Canada is the Canadian Standards Association Group (CSA Group). These standards are accredited by the American National Standards Institute (ANSI) and administered by the ANSI/CSA Z21/83 Technical Committee (TC), which has oversight over subordinate Technical Subcommittees (TSC), and Working Groups (WG). The TSCs develop performance and safety standards for individual gas appliances and accessories. Staff recommends that the Commission issue an advance notice of proposed rulemaking (ANPR) to address carbon monoxide (CO) hazards posed by certain residential gas appliances. The ANPR would cover residential, gas-fired central furnaces, boilers, wall furnaces, and floor furnaces (gas furnaces and boilers). These appliances are fueled by natural gas or propane (gas). This memorandum discusses relevant voluntary standards.

The voluntary standards for residential gas furnaces, boilers, wall furnaces and floor furnaces are:

- ANSI Z21.13, Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers
- ANSI Z21.47, Standard for Gas-fired central furnaces
- ANSI Z21.86, Standard for Vented Gas-Fired Space Heating Appliances

The ANSI/CSA Technical Subcommittees that oversee the development of these standards are:

- ANSI/CSA Joint Technical Subcommittee on Standards for Gas-Fired, Low-Pressure Steam and Hot Water Boilers (for gas boilers, ANSI Z21.13)
- ANSI/CSA Joint Technical Subcommittee on Standards for Gas-Fired Central Furnaces (for gas furnaces, ANSI Z21.47)
- Z21/CSA Joint Technical Subcommittee on Standards for Vented Gas-Fired Warm Air Heaters (for gas wall furnaces and gas floor furnaces, ANSI Z21.86)

<u>ANSI Z21.13, Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers</u>

This standard specifies the construction and performance requirements for gas-fired low-pressure steam and hot water boilers with input ratings of less than 12,500,000 Btu/hr (3,663 kW). This standard was published in 1982, and has been revised several times, culminating in the latest 6th edition published in 2017.

ANSI Z21.47, Standard for Gas-fired central furnaces
This standard specifies the construction and performance requirements for gas-fired central furnaces with input ratings up to and including 400,000 Btu/hr (117 kW). This standard was first published in 1982, harmonized with Canadian standard requirements in 1993, and the latest 7th edition was published in 2016.

ANSI Z21.86, Standard for Vented Gas-Fired Space Heating Appliances
This standard specifies the construction and performance requirements for vented gas-fired space-heating appliances with input ratings up to and including 400,000 Btu/hr (117 kW), including vented room heaters (Parts III and IV), gravity and fan-type direct-vent wall furnaces (Parts V and VI), gravity and fan-type wall furnaces (Part VII), gravity and fan-type vented wall furnaces (VIII), and gravity and fan-type floor furnaces for the United States only (Parts IX and X). The scope of this ANPR only includes gravity and fan-type direct-vent wall furnaces (Parts V and VI), and gravity and fan-type floor furnaces (IX and X), since these types of appliances do not have certain protections from CO exposure. This standard was first published in 1998, and the latest 6$^{th}$ edition was published in 2016.

B. ADEQUACY OF EXISTING U.S. STANDARDS

Based on the hazard patterns identified in the review of fatal CO poisoning incidents involving gas appliances (TAB C), CPSC staff believes requirements to address CO risk at the source of production, before potentially deadly levels of CO can enter the living space, will reduce the occurrence of CO-related deaths, injuries, and exposures associated with gas furnaces, boilers, wall, and floor furnaces.

The primary carbon monoxide safety provisions for U.S. and Canadian gas appliances certified to the above standards are as follows:

**Table 1.**

| | ANSI STANDARD | | |
|---|---|---|---|
| | **ANSI Z21.13** | **ANSI Z21.47** | **ANSI Z21.86** |
| **PERFORMANCE REQUIREMENTS** | **SECTION/SUBSECTION; CLAUSE DESCRIPTION; SHUTOFF** | | |
| **Combustion** | 5.5.1; CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. | 2.8.1; CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. | 6.3.1 and 10.3.1; CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. |

| | | | |
|---|---|---|---|
| **Flame Roll-Out Safety Shut-Off Means** | 5.10; shall shut off the main burner gas in the event the flow of combustion products through the boiler flueway (s) is reduced.<br>At no time during this test shall flames issue outside the face of the jacket; Shutoff. | 2.13; The means specified in 1.2.4 shall shut off main burner(s) gas in the event the flow of combustion products through the furnace flue-way(s) is reduced. At no time during this test shall flames issue outside the exterior of the casing; Shutoff. | Not applicable. |
| **Blocked Vent Shutoff System (BVSS)** | 5.21; shutoff when vent is totally blocked; units less than 300,000 Btu/hr (88 kW) equipped with draft hood; Shutoff. | 2.20; shutoff when vent is totally blocked; Shutoff. | Not applicable. |
| **Flue blockage of Draft Hoods** | 5.22.1; With the outlet of the draft hood blocked, the concentration of carbon monoxide in an air-free sample of the flue gases shall not exceed 0.04 percent when the boiler is tested in an atmosphere having a normal oxygen supply; No prevention or shutoff requirement. | 2.21.1; with draft hood outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. | 10.10.1; with flue outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. |
| **Flue blockage for furnaces not equipped with draft hoods (shutoff provisions are optional)** | Not applicable. | 2.23.1; with flue outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. | 6.3.2; With the flue outlet blocked to any degree up to and including complete closure, the concentration of carbon monoxide in an air-free sample of the flue gases shall not exceed 0.04 percent;<br>No prevention or shutoff requirement.<br>10.11.1; with flue outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. |

| | | | |
|---|---|---|---|
| **Flue blockage of Direct Vent Systems (shutoff provisions are optional)** | 5.25.5; With the flue outlet or air inlet blocked in accordance with part the Method of test below, the concentration of carbon monoxide in an air-free sample of the flue gases shall not exceed the amount prescribed in the Method of test below on an air free basis when the boiler is tested in an atmosphere having a normal oxygen supply; No prevention or shutoff requirement. | 4.4.6; with flue outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. | 6.3.2; with flue outlet blocked, CO not to exceed 0.04 percent in an air-free sample;<br>No prevention or shutoff requirement. |
| **Blocked vent test for boilers equipped with forced or induced draft burners and without draft hoods or regulators** | 5.23; CO not to exceed 0.04 percent in an air-free sample; No prevention or shutoff requirement. | Not applicable (see Sections 2.21.1 and 2.23.1 for similar coverage). | Not applicable. |
| **Blower door interlock** | Not applicable. | 1.5.6; means shall be provided to prevent the operation of the main gas control valve and fan or blower if an access door or panel covering an opening to a circulating air compartment is not in place; Shutoff. | Not applicable. |

The combustion requirements cited above in Table 1 are common CO emissions performance requirements found in all of the ANSI Z21 standards for gas-burning appliances. This requirement specifies the maximum concentration of CO (0.04 percent[19] in an air-free flue sample) that can be produced by a gas-burning appliance while being subjected to certification testing at the manufacturing plant or at a testing agency. Although this provision specifies maximum CO emission limits for new appliances during certification testing, it does not address CO emissions throughout the lifespan of the appliance. Furthermore, the provision does not specify a means or mechanism that ensures that appliance CO emissions remain below the maximum limit during long-term use of the

[19] In ANSI Z21 standards, CO emissions are always cited in units of percent in an air-free sample of the flue gases. Another unit of measure for CO concentration, commonly used by first responders and utility personnel, is "parts per million (ppm)," which can be calculated by multiplying the percent of CO level by 10,000. The maximum permissible CO emissions for gas furnaces, gas boilers, gas wall furnaces (gravity and fan type direct vent wall furnaces), and gas floor furnaces (gravity and fan type floor furnaces) is 0.04 percent CO in an air free flue sample (400 ppm).

product once installed in a dwelling and the various conditions that can lead to CO production and leakage. Carbon monoxide production in excess of the emission limits is always present in the hazard patterns observed by CPSC staff during review of CO incident data involving gas furnaces and boilers (see TAB C). The most effective strategy to address production of hazardous levels of CO is to ensure that gas appliances either: (1) do not produce CO above an acceptable emission limit (through continuous monitoring and response to the combustion process), or (2) shut off response when a hazardous CO emission limit is exceeded. Therefore, staff concludes that the existing combustion requirements in the voluntary standards do not adequately address the CO hazard in gas appliances.

The Combustion requirements are the only standards provisions that address CO production, albeit not over the lifespan of the appliance after it has been installed in a dwelling. The other requirements listed above in Table 1 address one leakage mechanism common to all vented gas appliances (*i.e.*, a totally blocked vent) and a leakage mechanism that only occurs in gas-fired central furnaces (*i.e.*, an uninstalled blower access door). Either of these mechanisms would result in spillage or circulation of combustion products, including CO, into the living space of a dwelling. The weaknesses of these requirements are that they do not include provisions that protect against a number of other conditions known to cause or contribute to the production of dangerous levels of CO or the leakage of CO into the living space of a dwelling (TAB C). These conditions include, but are not limited to:

- disconnected or breached flues, vents, and chimneys
- partially blocked heat exchangers, flues, vents, and chimneys
- over-fired appliances, and
- inadequate combustion air to appliances.

To summarize, ANSI Z21.47, ANSI Z21.13 and, ANSI Z21.86 all require the appliances:

- not to produce CO in excess of 400 ppm (but not to shut off when this limit is exceeded)
- to shut off when vent or flue is fully blocked
- to shut off when blower door is not properly sealed (central furnaces only)
- to shut off if flames issue outside of jacket.

In 2000 and 2015, CPSC staff presented the voluntary standards organizations with proposals for CO shutoff/response requirements to eliminate or reduce the occurrence of CO-related deaths, injuries, and exposures associated with gas furnaces, boilers, wall, and floor furnaces. Those proposals addressed the CO risk at the source of production, before potentially deadly levels of CO can enter the living space, regardless of conditions that cause or contribute to the appliance's production and leakage of CO into the living space.

## D. PAST WORK - HISTORY

### CPSC Staff's 2000 CO Shutoff/Response Recommendation to the ANSI Z21.47 Furnace Committee

In 2000, CPSC staff determined that the ANSI Z21 standards for gas appliances did not adequately address hazards posed by disconnected or partially blocked vents, based on tests conducted by CPSC staff. Staff determined that the voluntary standards did not account for the long-term use of the appliances once installed in a dwelling and the various conditions that can manifest to affect CO production and leakage. Therefore, staff determined an effective means to reduce incidents associated with CO hazards in gas appliances was to address the CO at the source of production before leakage into the living space occurred. Accordingly, CPSC staff recommended to the ANSI Z21.47 furnace committee that the committee should adopt the following:

1. Require a means to prevent furnace CO emissions from exceeding the standard limits once installed in the field; or
2. Require a means, once installed in the field, to shut down the furnace if CO emissions exceed the standard limits.

In 2001, CPSC staff identified and acquired examples of two carbon monoxide-sensing technologies (*i.e.,* catalytic bead and Mixed Metal Oxide Semiconductor or MMOS) and began a test program to demonstrate the concept (*i.e*., "proof of concept") of using sensor technology to detect elevated CO production within a gas furnace and initiate furnace shutdown in response. The tests successfully demonstrated the concept of using sensor technology for shutdown response to hazardous CO levels within a furnace. In 2001, staff provided the test results[20] to the ANSI Z21.47 Central Furnace Subcommittee in support of the 2000 "CO Shutoff" proposal[21].

From 2002 to 2004, the ANSI Z21/83 TC established the Ad Hoc WG for CO/Combustion Sensor (AHWG) and evaluated the use of gas sensors to shut down gas appliances in response to excessive CO production. However, after several efforts to develop a work plan, the Technical Committee abandoned the effort in 2005. At the September 2005 Technical Committee meeting, the Z21/83 Technical Committee cited deficiencies in CO-sensing technology to: (1) withstand the harsh environments of furnace flue passageways, and (2) match the 15-year life expectancy of furnaces. The Technical Committee disbanded the Ad Hoc working group, because the Committee felt that it had fulfilled its mission. CPSC staff disagreed with the Technical Committee's determinations and began exploring technical means to address the concern about CO sensor durability in harsh environments.

<u>CPSC Staff's 2015 CO Shutoff/Response Proposal to ANSI Z21 Technical Subcommittees</u>

In 2007, CPSC staff conducted tests on multiple CO sensors in various locations within gas furnaces to evaluate their durability under those harsh operating conditions. The results of this test program demonstrated that the CO sensors and the $CO_2$ sensors were durable enough to withstand the harsh, operating environment of a gas furnace. The results[22] were published in 2012, on CPSC's Research Report website and shared with the Z21/83 Technical Committee, the Z21.47 Central Furnace TAG, and the Z21.13 Boiler TAG.

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[20] Furnace Combustion Sensor Test Results, R.A. Jordan, Directorate for Engineering Sciences, CPSC, September 2001.
[21] Jordan, R., CO shutoff/response proposal letter Canadian Standards Association International, CPSC. November 2000.
[22] Evaluation of the Durability and Longevity of Chemical Sensors Used In-Situ For Carbon Monoxide Safety Shutdown of Gas Furnaces, R.A. Jordan. R. Butturini, Directorate for Engineering Sciences, CPSC, September 2012.

CPSC staff continued to monitor CO incidents and the state of technology and standards development. Surveillance of annual CO death estimates, as well as anecdotal review of In-Depth Investigations, revealed that CO deaths persisted among this class of products. CO deaths associated with gas furnaces, boilers, wall, and floor furnaces continued to be the second leading cause of non-fire related-CO deaths among all consumer products.

In September 2015, CPSC staff developed an updated CO shutoff/response voluntary standards proposal for gas-fired central furnaces, boilers, and wall furnaces, and floor furnaces. In the new proposal, CPSC staff requested that the governing ANSI Z21 Technical Subcommittees (TSC) for these appliances adopt the following performance and safety requirements:

1. Require a means to limit gas furnace, boiler, wall furnace, and floor furnace:
    a. CO emissions to below 0.04 percent; or
    b. combustion conditions that result in CO emissions at or in excess of 0.04 percent; or

2. Require a means to shut-off a gas furnace, boiler, wall furnace, and floor furnace in response to:
    a. CO emissions at or in excess of 0.04 percent; or
    b. combustion conditions that result in CO emissions at or in excess of 0.04 percent; or

3. Require a means to modulate gas furnace, boiler, wall furnace, and floor furnace operation to reduce CO emissions in response to:
    a. CO emissions at or in excess of 0.04 percent; or
    b. combustion conditions that result in CO emissions at or in excess of 0.04 percent.

Staff's research also found that voluntary standards for gas appliances in Japan and Europe included requirements that were similar to staff's proposed requirements. CPSC staff recommended that the ANSI Z21/83 TC, the relevant TSCs, and the WG review the Japanese and European standards as possible models or benchmarks for the proposed CO shutoff/response requirements. The ANSI Z21/83 TC and the TSCs established the ANSI Z21/83 Cross-Functional WG on Carbon Monoxide Detector Sensors in Gas Appliances in October 2015. The objectives of the WG were to evaluate the feasibility of incorporating sensors in residential gas heating appliances:

(1) *Determine the current availability of sensors for measuring carbon monoxide either directly or indirectly and the technological feasibility of incorporating sensors into residential vented gas space heating appliances.*

(2) *Evaluate the impact that such sensors may have had internationally by studying the results in:*
- *a) Japan (Japanese Industrial Standards, "JIS"), which has implemented sensor requirements in JIS-S-2109 Gas Burning Water Heaters for Domestic Use*
- *b) Europe (Committee for European Standardization, "CEN"), which has implemented EN16340, Safety and Control Devices for Burners and Appliances Burning Gaseous or Liquid Fuels.*

(3) *Determine the costs and benefits of implementing a requirement for such sensors to be installed, which accounts for:*

- *a) The cost of currently available sensors*
- *b) The demonstrated or projected lifespan of sensors*
- *c) The costs associated with replacing sensors (appliance maintenance by the appliance owner) in the appliance*
- *d) The estimated impact on CO poisoning mortality rates due to the implementation of sensors into residential vented gas space heating appliances.*

In an email to WG members, dated May 22, 2019, the WG chair announced that the WG was being disbanded. The email stated that a status report had been drafted and will be forwarded to the TC announcing the decision. Following is a summary of the status of the WG objectives that are being reported to the TC:

*Status of WG progress on Objective 1*. The WG has not received any new information or any reports of improvements in technologies since the WG considered the above question during its September 21, 2017 meeting. The WG has not been able to identify a clear path forward regarding objective #1.

*Status of WG progress on Objective 2*. The type of sensors used in Europe are designed as an operating device intended to adjust the fuel/air ratio to optimize the combustion process and keep the appliance operating efficiently. The system is not designed as a safety shutoff system to shut down an appliance if/when the CO level exceeds a certain threshold.

In Japan, different types of systems are being used, including a sensor mounted in the combustion chamber that is designed to shut down the appliance if high levels of CO are detected. In addition, combustion control systems are also being used to maintain proper combustion, thereby limiting production of high levels of CO. Japanese gas water heaters, boilers, and space heaters apparently started using these systems around 2001, but there are no standards for the sensor or the control system itself. The appliance, sensor, and combustion control systems are tested in combination on the appliance and must meet the requirements of JIS-S-2109. There may be other technologies in use which staff lacks information on. Staff seeks comments on what these technologies are and whether they may be applicable to residential gas furnaces and boilers

It is still unknown if, and/or how often, sensors are being replaced, or how they are performing in the application. The WG continued to collect and disseminate any relevant information from Japan, the EU, and sensor manufacturers that might be beneficial in further understanding the current state of sensor technology for use in this application.

*Status of WG progress on Objective 3*. Due to the lack of progress and the lack of funding for objective #3 over the past 10 months, the WG considered this objective to be closed.

## II. REVIEW OF INTERNATIONAL STANDARDS

### A. Review of Japanese gas appliance standards

Standards Development Organization
In Japan, the SDO that develops safety and performance standards for gas appliances is the Japanese Standards Association (JSA) and the accrediting body is the Japanese Industrial Standards (JIS).

Relevant Gas Appliance Standards
Although gas water heaters are not within the scope of the draft ANPR, the Japanese standard, JIS-S-2109, is relevant because the combustion process and technology involved in heating water is similar to the combustion process and technology used for gas furnaces and boilers sold in the United States. In addition, the Japanese standard's CO shutoff requirements are similar to CPSC staff's 2000 and 2015 CO shutoff/response proposals; and the CO detection and combustion components are applicable to gas furnaces and boilers sold in the United States. Japanese gas water heaters come in three basic types: instantaneous water heaters, storage water heaters, and bath water heaters. Other distinguishing factors include the function of the water heater and how it is vented. Water heaters can be designed to heat water only, or to heat water and the living space. Water heaters in Japan can be vented or unvented, including instantaneous, bath tub (with and without hot water supply), space heating, space and water heating, and water storage types. The voluntary standard for these appliances is the Japanese Industrial Standard, JIS-S-2109, Gas-burning water heaters for domestic use. This standard covers all of the aforementioned types of gas water heaters.

To gain a better understanding of these standards, CPSC staff purchased the standards and posed questions to the JSA directly through email and through a collaboration with the ANSI Z21/83 CO sensor WG, as another avenue to pose questions to JSA. For the purposes of comparing U.S. gas furnaces and boilers that would be impacted by the CPSC staff's 2015 & 2000 CO shutoff/response proposals, the relevant types of Japanese gas water heaters are the space and water heating, space heating, and instantaneous water heating types.

Requirements for Combustion and Carbon Monoxide
To protect against CO exposure, JIS-S-2109 includes requirements that vented gas water heaters be equipped with what they call an "Incomplete Combustion Prevention Device" (ICPD). A gas appliance experiencing incomplete combustion means that the fuel is not being burned or combusted completely, and as a result, can produce elevated concentrations of CO. Section 7.7.6 of JIS-S-2109, Incomplete Combustion Preventive Device of FE includes requirements that the water heater shut off when CO concentrations reach 0.03 percent (300 ppm)[23] in:

i) the room in which the water heater is installed, and
ii) the adjacent room.

According to JSA, the Incomplete Combustion Preventative Device provisions have been required in JIS-S-2109 since 2001. A minimum life span for the device is not required, and these devices are replaced, if necessary, based on use and functionality. JSA also indicated that there

[23] 0.03 percent converts to 300 ppm CO by multiplying 0.03 percent by 10,000.

are not separate performance standards for ICPDs required by JIS-S-2109; all of the performance requirements for ICPDs are specified in JIS-S-2109. In addition, JIS-S-2109 also includes flame rollout and blocked vent requirements at Section 6.3.5, Combustion gas outflow safety device, and 6.3.6, Exhaust air shut-off safety device (respectively, similar to the Flame Roll-Out and Blocked Vent Safety requirements in ANSI Z21.13 and ANSI Z21.47).

Table 2 summarizes the requirements in JIS-S-2109 and provides CPSC staff's assessment of how the requirements relate to staff's 2000 and 2015 CO shutoff/response proposals.[24]

Table 2

| Requirements in JIS-S-2109 to address CO Hazard | Staff Assessment of Requirement |
|---|---|
| Shut off required for FE class water heaters | Shut off or preemptive response requirement is similar to CPSC staff's CO shutoff/response proposal[25]. |
| Shut off threshold at or below 0.03 percent (300 ppm) CO | Shut off or response threshold at or below 0.04 percent (400 ppm) CO in an air free flue sample. |

Another similarity between the incomplete combustion preventive device requirements of JIS-S-2109 and CPSC staff's 2000 and 20015 CO shutoff/response proposals is that they both necessitate locating a device within the harsh environment of appliance combustion chamber, flue passageways, or vent system.

B. Review of European gas appliance and combustion sensor standards

Standards Development Organization

In Europe, the SDO that develops performance and safety standards for gas appliances and equipment is the European Committee for Standardization (CEN). CEN is comprised of the National Standardization Bodies of 34 European countries and is recognized by the European Union (EU) and European Free Trade Association (EFTA) in its function of developing and defining voluntary standards within Europe.

Relevant Gas Appliance Standards

Gas boilers are a common space-heating appliance used throughout Europe in residential settings, and they are similar in design and function to residential gas boilers certified to ANSI Z21.13 and sold in the United States. The relevant CEN domestic gas boiler standards are:

- EN 15502 -1, Gas-fired heating boilers, Part 1: General requirements and tests
- EN 15502-2-1, Gas-fired central heating boilers, Part 2-1: Specific standard for type C appliances and type B2, B3 and B5 appliances of a nominal heat input not exceeding 1 000 kW, and
- EN 15502-2-2, Gas-fired central heating boilers, Part 2-2: Specific standard for type B1 appliances.

The CEN technical committee that oversees the development of these standards is CEN/TC 109, Central heating boilers using gaseous fuels. These standards are the European analogs to ANSI

[24] CPSC staff's 2015 and 2000 CO Shutoff/Response proposals.

[25] Ibid.

Z21.13, and the CEN/TC 109 is the European equivalent to ANSI/CSA Z21/CSA Joint Technical Sub-Committee on Standards for Gas-Fired Low Pressure Steam and Hot Water Boilers.

These standards (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2) include requirements to ensure the proper supply of combustion air and gas to the combustion process (*i.e*., air proving) through the use of one of the following mechanisms:

1. Carbon Monoxide (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2);

2. Supervision of the combustion air pressure or the combustion products pressure (EN 15502 -1);

3. Supervision of the combustion air rate or the combustion products rate (EN 15502-2-1 and EN 15502-2-2);

4. Gas/air ratio control (EN 15502 -1, EN 15502-2-1, and EN 15502-2-2); or

5. Indirect supervision (*e.g.*, fan speed supervision) (EN 15502 -1).

As discussed below, the second and third requirements, Supervision of the combustion air rate or the combustion products rate, and Gas/air ratio control, are the most similar to CPSC staff's 2000 and 2015 CO Shutoff proposals to the ANSI Z21/83 Technical committee and furnace and boiler subcommittees.

In addition, these standards include performance requirements for blocked vents (Section 8.12.5, Supplementary test for low temperature boilers and condensing boilers of EN 15502 -1; 8.11.102, Combustion products discharge safety device, and 8.12.101, Supplementary test for natural draught boilers of EN 15502-2-2).

These standards also have combustion product discharge provisions, which are similar to the Flame Roll-Out provisions of the ANSI standards (*i.e*., ANSI Z21.13 and ANSI Z21.47). These requirements are found in Section 8.11.102 Combustion products discharge safety device of EN 15502-2-2.

Requirements for Combustion and Carbon Monoxide
<u>Carbon Monoxide</u>
Section 8.12, Carbon Monoxide, of EN 15502 -1 (EN 15502-2-1 and EN 15502-2-2 by reference), specifies all of the general requirements for CO emissions for gas boilers.

> Section 8.12.1, requires that the CO concentration in a gas boiler be measured and specifies how the CO concentration is to be measured.

Section 8.12.2, Limit conditions, of EN 15502 -1, specifies that the maximum permissible CO concentration not exceed 0.10 percent (1,000 ppm).[26]

Section 8.12.3.1, Incomplete combustion, of EN 15502 -1, specifies test conditions designed to cause incomplete combustion and specifies that the maximum permissible CO concentration during incomplete combustion not exceed 0.20 percent (2,000 ppm).

In addition to the common requirements for all three of the standards, EN 15502-2-1 also includes test conditions and CO emissions limits for: Boilers without gas/air ratio controls (Section 8.12.2.101) and Boilers using gas/air ratio controls (Section 8.12.2.102). Both requirements specify that the maximum permissible CO concentration not exceed 0.10 percent (1,000 ppm).  EN 15502-2-2 includes a provision, Section 8.12.101, Supplementary test for natural draught boilers that specifies that the maximum permissible CO concentration not exceed 0.10 percent (1,000 ppm).

Supervision of the combustion air rate or the combustion products rate

The provisions for "supervision of the combustion air rate[27] or the "combustion products rate"[28] are found in EN 15502-2-1 and EN 15502-2-2 and are identical in both standards. In EN 15502-2-1, the "supervision of the combustion air rate or the combustion product rate" provisions are located under Section 8.11.101, Air proving Device. In EN 15502-2-2, these provisions, with the same numbering (8.11.101.2), are located under Section 8.11.101, Air proving device for type B12 and B13 boilers. Following is an excerpt of those provisions from EN 15502-2-1 and EN 15502-2-2:

***"8.11.101.2 Supervision of the combustion air rate or the combustion products rate***

*Requirements*
*At a reduced flow rate the CO concentration (dry, air-free) may not exceed a specific value.*
*The following methods of flow reduction are to be examined:*

*a) progressive blockage of the air inlet;*

*b) progressive blockage of the combustion products evacuation ducts;*

*c) progressive reduction of the fan speed, for example by reduction of the fan voltage.*

[26] Although the maximum CO limits in the European standards are higher than the U.S standards (*i.e*., 1,000 ppm compared to 400 ppm CO), if the European performance provisions were adopted for use in the United States, the maximum CO limit could be reduced to the limits already specified in the ANSI standards. The measurement range of most CO/combustion sensors can be readily adjusted between those CO limits.
[27] Supervision of the combustion air rate requires monitoring and response to changes to the combustion air provided to the burner that are below a desired value.
[28] Supervision of the combustion product's rate requires monitoring and response to changes in combustion products, particularly CO, when they are in excess of a specified limit.

*There are two alternative supervision strategies for the air proving; a startup supervision or a continuous supervision. Based on the supervision strategy the boiler shall at a reduced flow rate meet one of the following two requirements:*

*d) continuous supervision: Shut down before the CO concentration exceeds 0,2%, or*

*e) Start-up supervision: Not start if the CO concentration exceeds 0,1%.*

*<u>Test conditions</u>*
*The test is carried out when the boiler is in thermal equilibrium, at the nominal heat input, or for modulating boilers, at the maximum and the minimum heat input and at the heat input corresponding to the arithmetic mean of these two inputs. When several rates are provided, supplementary tests are needed at each of these rates. The CO and $CO_2$ concentrations are measured continuously. The means of carrying out the blockage shall not give rise to recirculation of the products of combustion."*

There are additional "supervision of the combustion air rate or the combustion product rate" provisions located under Section 8.11.101.3, Gas/air ratio controls. This set of provisions has slight differences from those found earlier in EN 15502-2-1 and EN 15502-2-2. An excerpt of those provisions are provided below:

***"8.11.101.3.2 Supervision of the combustion air rate or the combustion products rate***
*<u>Requirements</u>*
*At a reduced flow rate the CO concentration may not exceed a specific value. The following methods of flow reduction are to be examined:*

*a) Progressive blockage of the air inlet;*

*b) Progressive blockage of the combustion products evacuation ducts;*

*c) If internal recirculation can occur then an additional test shall be carried out by progressive reduction of the fan speed, for example by reduction of the fan voltage.*

*There are two alternative supervision strategies for the air proving; a startup supervision or a continuous supervision. Based on the supervision strategy the boiler shall at a reduced flow rate meet one of the following two requirements:*

*d) Continuous supervision:*

*Shutdown before the CO concentration (dry, air free) exceeds:*

*1) 0,20 % over the range of modulation specified in the installation instructions), or*

*2) $CO_{mes} \times Q / Q_{KB} \leq 0,20\%$ below the minimum rate of the modulation range.*
*where:*

*Q is the instantaneous heat input, in kW;*
*$Q_{KB}$ is the heat input at the minimum rate, in kW;*
*$CO_{mes}$ is the measured CO concentration (dry, air free).*

*e) Start up supervision:*

*Not start if the CO concentration (dry, air free) exceeds 0.1%.*

*Test conditions*
*The test is carried out when the boiler is in thermal equilibrium, at the nominal heat input, or for modulating boilers at the maximum and the minimum heat input.*
*When several rates are provided, supplementary tests are needed at each of these rates. The CO and $CO_2$ concentrations are measured continuously. The means of carrying out the blockage to achieve a reduced flow rate shall not give rise to recirculation of the products of combustion. It is checked that for each of the 3 methods of flow reduction at least the requirement of one the alternative supervision strategies is met."*

Similarities to CPSC Staff's CO Shutoff/Response Proposals
The "continuous supervision" provisions are similar to CPSC staff's proposals because they require: (1) in-flue monitoring of CO concentrations, and (2) shutdown of the appliance in response to a specified elevated CO concentration in the flue. The "gas/air ratio control" provisions are similar to CPSC staff's proposals because they require a modulating response of adjusting the gas flow, air flow, or both, to maintain the proper air/fuel ratio, which ensures combustion efficiency, good combustion quality, and prevents or limits CO production.

Relevant Combustion Control Device Standards
Unlike the JIS standards, the CEN includes separate standards for combustion monitoring devices and controls that are used in domestic gas boilers. The relevant CEN standards are:

- EN 13611, Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements
- EN 12067-2, Gas/air ratio controls for gas burners and gas burning appliances-Part 2: Electronic types
- EN 16340, Safety and control devices for burners and appliances burning gaseous or liquid fuels— Combustion product sensing devices.

The CEN technical committee that oversees the development of these standards is CEN/TC 58, Safety and control devices for burners and appliances burning gaseous or liquid fuels.

EN 13611, Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements
This standard specifies the general safety, design, construction, and performance requirements and testing for safety, control, or regulating devices use for burners or appliances burning gaseous or liquid fuels. This standard specifies the general product requirements for the following types of controls devices:

- Automatic shut-off valves

- Automatic burner control systems
- Flame supervision devices
- Gas/air ratio controls
- Pressure regulators
- Manual taps
- Mechanical thermostats
- Multifunctional controls
- Pressure sensing devices
- Valve proving systems
- Automatic vent valves
- Combustion product sensing devices.

This standard is designed to be used in conjunction with the various CEN standards that govern the above types of control devices. Because they address combustion process monitoring and modulation, EN 12067-2 and EN 16340 are of particular interest to this discussion.

EN 12067-2, Gas/air ratio controls for gas burners and gas burning appliances-Part 2: Electronic types

This standard specifies the safety, construction and performance requirements for closed loop electronic gas/air ratio control systems (GARCs) for use with gas burners and gas burning appliances. A GARC provides the electromechanical interface to the burner or the gas valve and the combustion air supply that allows these devices to be modulated or controlled to increase or decrease gas flow or combustion air flow. This allows the GARC to maintain the combustion efficiency of the appliance by monitoring and maintaining an optimal gas/air ratio. An optimal gas/air ratio ensures that the gas/air mixture supplied to the appliance burner is burned completely, thereby maintaining combustion efficiency. This standard includes the following burner interface and safety shut-down provisions for GARCs:

> ***7.2 Burner control interface***
> *The electronic GARC shall be interfaced and interlocked with the burner control system in order to ensure that the requirements of the burner control system according to EN 298 and this standard are fully maintained.*
>
> ***7.3 Safety shut-down initiated by the electronic GARC***
> *The electronic GARC shall initiate one of the following safety actions:*
>
> *a) safety shut-down followed by restart. The number and the interval of subsequent restarts shall comply with the requirements of the application.*
> *b) safety shut-down followed by lock-out."*

EN 16340, Safety and control devices for burners and appliances burning gaseous or liquid fuels— Combustion product sensing devices

This standard specifies the safety, construction, and performance requirements for combustion product-sensing devices (CPSD) designed to measure combustion products, as part of combustion control systems for burners and appliances that operate by burning gaseous or liquid fuels. This standard covers sensing devices that measure the following flue gases:

- Oxygen ($O_2$)
- Carbon dioxide ($CO_2$)
- Carbon monoxide (CO)
- Hydrogen ($H_2$)
- Various hydrocarbons ($C_xH_y$)
- Nitrogen oxide ($NO_x$)
- Sulfur Dioxide ($SO_2$)
- Or a combination of these gases.

This standard is designed to be used in conjunction with EN 13611, Safety and control devices for burners and appliances burning gaseous and/or liquid fuels — General requirements.

<u>Similarities to CPSC Staff's Voluntary Standards CO Shutoff/Response Proposals</u>
EN 16340 is compatible with CPSC staff's CO shutoff/response proposals because it establishes performance requirements for a device that monitors: (1) within the same parameters (*i.e*., combustion gases, including CO); (2) within the same harsh environment (*i.e*., the combustion chamber). Consequently, these devices are subject to the same harsh operating conditions (*i.e*., high operating temperature, relative humidity, combustion gases, thermal cycling) that the Z21/83 Technical Committee and its subordinate technical subcommittees (for gas furnaces and boilers) and CO/combustion sensor working groups raised questions about in response to CPSC staff's 2000 and 2015 CO shutoff/response proposals.

# **TAB E** *Technological Considerations for a Standard on Carbon Monoxide Shutoff/Response Requirements for Residential Gas Furnaces and Boilers*

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

| | |
|---|---|
| **TO :** | Gas Appliance CO Sensor ANPR File |
| **THROUGH:** | Joel R. Recht, Associate Executive Director<br>Directorate for Engineering Sciences<br><br>Mark Kumagai, Director<br>Division of Mechanical and Combustion Engineering |
| **FROM :** | Ronald Jordan, Project Manager<br>Directorate for Engineering Sciences |
| **SUBJECT :** | Technological Considerations for a Standard on Carbon Monoxide Shutoff/Respons<br>Requirements for Residential Gas Furnaces and Boilers |

Staff is recommending that the Commission issue an advance notice of proposed rulemaking that would cover residential, gas-fired central furnaces, boilers, wall furnaces, and floor furnaces (gas furnaces and boilers). These appliances are fueled by natural gas or propane (gas). The governing standards for this class of gas appliances are ANSI Z21.13, Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers, ANSI Z21.47, Standard for Gas-fired central furnaces, and ANSI Z21.86, Standard for Vented Gas-Fired Space Heating Appliances. The only provisions within these standards that are designed to provide protection from CO exposure for appliances installed in residential dwellings are the Blocked Vent Shutoff System (BVSS), Flame Roll-Out Safety Shut-Off, and Blower Door Interlock Switch (gas-fired central furnaces only) requirements. This memorandum discusses technologies that can be used in gas furnaces and boilers to protect against CO exposure.

## TECHNOLOGIES USED IN GAS FURNACES AND BOILERS IN THE UNITED STATES

<u>Blocked Vent Shutoff System</u>
A blocked vent shutoff system (BVSS) monitors increases in the static pressure within the heat exchanger, flue passageways, or vent system of a gas appliance and shuts off the appliance when the static pressure increases beyond a preset value. Increased static pressure is typically caused by totally blocked or, depending on the type of gas appliance, partially blocked passageways within the heat exchanger, flue passageways, or vent system. This condition can also cause combustion products, including CO, to spill out into the living space. The BVSS function in gas furnaces and boilers is typically accomplished through the use of a pressure switch.

Pressure switches are typically used to implement the BVSS requirements of the ANSI gas appliances standards for furnaces, boilers, wall furnaces, and floor furnaces. A pressure switch is a pressure-actuated, normally closed (*i.e.*, the electrical circuit is closed, allowing current to flow) device designed to sense an increase in pressure in the environment being monitored and open the circuit at a threshold level. Pressure switches are comprised of a flexible diaphragm contained within a sealed enclosure and is part of an electrical circuit connected to either the gas valve or the appliance control board. Pressure switches are mechanically connected to the outer wall of a vent, heat exchanger, or flue passageway by a rubber or plastic tube that is fitted over a port opening in the wall, exposing the flexible diaphragm to pressure changes within the environment. When the static pressure within the environment increases beyond the set point, the switch opens, stopping the flow of current through the electrical circuit and to the gas valve or control board, which shuts off the appliance.

Pressure switches are limited in their effectiveness because they do not directly protect against CO, because they are only protect against one of the conditions that can lead to elevated CO production: a totally blocked vent, heat exchanger, or flue passageway; they do not protect against other common CO leakage paths/mechanisms involved in CO incidents that result in the death, injury, and exposure of consumers.

<u>Flame Roll-Out Safety Shutoff Switch</u>
A flame roll-out safety shutoff switch monitors temperature rise in the burner vestibule of a gas appliance at the inlet opening of the appliance's primary heat exchanger and shuts off the appliance when the temperature increases beyond a preset value. Temperature rise can be caused by a blocked heat exchanger or a breach in the heat exchanger that allows air, at a higher pressure, to flow into the heat exchanger, causing the burner flame to "roll-out" of the heat exchanger inlet openings into the burner vestibule. The heat from this "flame roll-out" can damage critical safety control wiring. This condition can also cause combustion products, including CO, to spill out into the living space. The flame roll-out safety shut-off switch function in gas furnaces and boilers is typically accomplished through the use of a thermal limit control of the fusible link or bimetal disc type.

The following discussion describes devices used to implement the Flame Roll-Out Safety Means requirements of the ANSI gas appliances standards for furnaces, boilers, wall furnaces, and floor furnaces.

A thermal limit control is a device that limits the temperature in the burner vestibule of a gas appliance. It is electrically connected to the gas valve or the appliance control board and is normally in the closed position (*i.e.*, the electrical circuit is closed, allowing current to flow). When a flame rolls out into the burner vestibule, the rise in temperature causes the contacts in the thermal limit control to open, breaking the circuit and stopping the flow of current to the gas valve or the appliance control board, shutting off the appliance.

A fusible link (also known as a thermal spill switch) is a temperature-sensitive fuse that is electrically connected to the gas valve or the appliance control board. When the burner vestibule becomes overheated, the fusible link melts and breaks the electrical circuit with the gas valve or control board, shutting off the appliance.

A bimetal disc is a device that consists of two different types of metal, or bimetals, fastened together along their entire length. One metal will have a high coefficient of expansion, the other a low coefficient of expansion. When the bimetals are heated by exposure to a thermal source (*i.e*., hot combustion gases spilling from the heat exchanger opening) the bimetals bend because they have different coefficients of thermal expansion and are connected. The portion of the bimetal that bends is electrically connected to a normally closed switch (*i.e*., the electrical circuit is closed, allowing current to flow), which is connected to the gas valve or the gas appliance control module. When this happens, the flow of gas to the gas valve is stopped and the appliance is shut down.

Flame roll-out safety shutoff switches are limited in the same way that BVSS switches are; they address one condition that can lead to elevated CO production: a totally blocked vent, heat exchanger, or flue passageway; but they do not protect against other common CO leakage paths/mechanisms involved in CO incidents that result in the death, injury, and exposure of consumers.

<u>Blower Door Interlock Switch (gas-fired central furnaces only)</u>
A blower door interlock switch is a device designed to shut off a gas-fired central furnace when the blower door is not in place. This prevents the large capacity blower within the blower compartment from depressurizing the heat exchanger and causing combustion products, including CO, to back-flow out of the heat exchanger and into the blower compartment and being circulated throughout the dwelling through the duct system. Blower door interlock switches are only located on gas-fired central furnaces because they are the only gas heating appliance that is connected to and that circulates its heated air through a duct system. A blower door interlock switch is a spring-loaded electrical switch located at the top, outside edge of the blower door compartment and is electrically connected to the gas valve or the appliance control module and is normally in an open (*i.e*., the electrical circuit is open, preventing current flow) position. The blower door is positioned so that when the blower door is put in place, the door comes into contact with the switch, causing it to be depressed, thus, closing the switch and the electrical circuit, allowing current to flow and the gas appliance to be energized and operate. When the blower door is removed, or is not in place, the blower door is not depressed, causing the switch to remain in the open position and causing current not to flow, and thus, de-energizing the gas valve or the gas appliance control module.

Blower door interlock switches are limited in the same way that BVSS and flame roll-out safety shutoff switches are; they respond to one of the conditions that can lead to elevated CO production: a totally blocked vent, heat exchanger, or flue passageway, but they do not protect against other common CO hazards.

All of the proceeding devices are only designed to protect against exhaust gas leakage caused by a limited subset of hazard patterns: totally blocked heat exchangers, flue passageways, and vent pipes and exhaust gas circulation caused by an uninstalled blower compartment access door (for gas-fired central furnaces only). The key limitation of these devices is that that they do not protect against CO production or other common CO leakage paths/mechanisms involved in CO incidents that result in the death, injury, and exposure of consumers. Other typical CO leakage paths/mechanisms not covered pressure switches, include:

- disconnected or breached vents, flues, and chimneys
- partially blocked vents
- snow blockage of side-wall vented appliances.

Blower door interlock switches do not protect against other common failure mechanisms that cause excessive CO production, such as:

- incomplete combustion caused by overfiring
- incomplete combustion caused by inadequate combustion air.

**CARBON MONOXIDE SENSOR AND COMBUSTION MONITORING TECHNOLOGIES USED IN GAS APPLIANCES IN JAPAN AND EUROPE**

In the Voluntary Standards memorandum, ESMC staff discussed the Japanese and the European voluntary standards for residential gas boilers and water heaters, as well as the voluntary standards for combustion-sensing devices in Europe. In this section of this memorandum, ESMC staff will discuss some of the technologies used to implement the standards requirements in Japan and Europe.

**Combustion Background**

To understand the relevance and possible application of Japanese and European standards and technologies to the gas furnaces and boilers sold in the United States, and the governing U.S. voluntary standards, it is important to understand the relationship between complete and incomplete combustion, combustion efficiency, excess air, fuel/air ratio, combustion quality, and carbon monoxide. Hydrocarbon-based fuels, such as natural gas and propane, are used to heat dwellings through the release of thermal energy when the fuel is burned. To completely burn natural gas or propane, the fuel has to be mixed with an ideal amount of oxygen (or air), and the flame to burn this mixture of fuel and air has to be at a certain temperature.

In gas appliances, such as furnaces and boilers, the fuel (natural gas or propane) is supplied to the burner by a gas valve. Air that provides the oxygen that is consumed for combustion of the fuel (*i.e*., combustion air) must be mixed with the fuel at the proper ratio to ensure stoichiometric combustion. Stoichiometric combustion is ideal combustion in which the fuel air mixture is burned completely, with just enough, but not excessive, oxygen present for all carbon atoms in the fuel to be fully oxidized to $CO_2$. Combustion air is provided to the burner as primary air and secondary air. In the case of direct-vent gas appliances, combustion air is supplied directly to the burner vestibule or the combustion chamber through a dedicated plastic pipe that leads to and draws air from the outdoors. Primary air makes up approximately 50 percent of the air needed for stoichiometric combustion and is supplied directly to the burner through venturi openings in the burner. Primary air is mixed with the fuel before the fuel leaves the burner port opening for combustion. The remaining air supplied for stoichiometric combustion is known as secondary air. Secondary air is provided to the burner flame from the air that surrounds the burner flame, after the primary air and fuel mixture has been ignited.

The stoichiometric air-fuel ratio ($AFR_{ideal}$) is the ratio of the ideal mass of air to the ideal mass of fuel needed to completely burn an air/fuel mixture, and depends on the chemical composition of the fuel, the molar masses of the various constituent elements in the fuel molecules, and the number of oxygen molecules needed to react fully with each fuel molecule. For methane, this ratio is 17.19:1.[29]

Because stoichiometric combustion doesn't take place in practice, excess air is needed to ensure that the air/fuel mixture burns completely, which ensures combustion efficiency and quality and prevents or limits CO production. Excess air is provided from the volume within the gas appliance cabinet and the surrounding volume of the room in which the appliance is located. The actual AFR used to burn an air/fuel mixture is the ratio of the actual mass air to the actual mass of fuel, and can be described by the equation: [30]

$$\mathbf{AFR_{actual} = m_a/m_f}$$

The ratio of the actual air/fuel ratio ($AFR_{actual}$) to the stoichiometric, or ideal air/fuel ratio ($AFR_{actual}$) is called the equivalence ratio or lambda ($\lambda$) and is given by the equation: [31]

$$\boldsymbol{\lambda} = \mathbf{AFR_{actual}/AFR_{ideal}}$$

Lambda values below 1 are referred to as "rich," because there is excess fuel present, while lambda values above 1 are referred to as "lean," because there is extra oxygen available. Excess air described above is thus, an example of lean burning or $\boldsymbol{\lambda<1}$.

Complete combustion of the air/fuel mixture not only ensures optimal combustion efficiency, but also combustion quality and prevents or limits the production of CO. Carbon monoxide is formed when the air fuel mixture is not burned completely. This is known as incomplete combustion. Rich mixtures are one source of CO production. Combustion efficiency is a measure of how well fuel being burned is used in the combustion process. Residential water heater and space heater manufacturers in Japan meet their safety standards requirements by using technologies that provide shutdown or modulation of the gas appliance in response to the presence of carbon monoxide or incomplete combustion. In Europe, gas boiler and water heater manufacturers meet their efficiency and safety standards requirements by maintaining an optimal gas/air ratio through modulation of the gas appliance in response to gas/air ratios that are out of tolerance or other indicators of incomplete combustion, including production of elevated concentrations of CO. This type of modulation is akin to how electronic fuel-ignition systems for internal combustion engines modulate the AFR to achieve efficient and quality combustion to drive an engine.

[29] https://x-engineer.org/automotive-engineering/internal-combustion-engines/performance/air-fuel-ratio-lambda-engine-performance/

[30] "…"

[31] "…"

Failure conditions and mechanisms that are typically involved in CO incidents, lead to incomplete combustion that results in an increase in the concentrations of CO produced and a decrease in combustion efficiency. The Japanese standards include requirements that protect against CO exposure, while the European standards include requirements that protect against CO exposure, as well as provisions to optimize combustion efficiency and combustion quality by controlling the air/fuel ratio of gas appliances. Three technologies used to accomplish these goals are standalone gas-sensing technology, and flame-monitoring and combustion-control systems.

**Gas Sensing Technology**

A gas sensor is a device that detects the presence of a particular target gas and converts the gas concentration measurement into a proportional electrical signal. When used as a safety device in a gas appliance to detect and protect against a certain gas concentration threshold, the sensor's electrical signal that corresponds to that threshold can be sent to the appliance control system (*e.g.*, control board, burner control, gas valve) to elicit a shutdown or modulation response by the appliance. Shutdown of the appliance stops the combustion process, thereby preventing the gas concentrations from continuing to increase and reducing the gas concentration back to safer, ambient levels.

There are a variety of methods to detect directly or indirectly and protect against dangerous levels of CO within the heat exchanger, flue passageways, and vent systems of gas furnaces and boilers. A direct method to accomplish this would be to deploy CO sensors within those regions of the appliance to measure and respond to elevated CO concentrations. An indirect approach would be to use other gas- or combustion-sensing technologies to measure and respond to combustion gases or parameters that can be correlated to excessive CO production in those areas. Some of those technologies include: catalytic CO sensors, nondispersive infrared (NDIR) $CO_2$ sensors, and Lambda $O_2$ sensors.

<u>Catalytic CO sensors</u>

A catalytic CO sensor measures the concentration of CO it is exposed to. The sensors consist of a wire coil coated with a catalyst that is electrically heated to a temperature that is high enough to burn (catalyze) the target gas (*i.e.*, CO). When CO is catalyzed by the wire, heat is released, increasing the temperature and the electrical resistance of the wire. A Wheatstone Bridge circuit measures the resistance and converts it to an output voltage that is proportional to the concentration of CO the sensor detected. A second wire, known as a compensator, is used to compensate for temperature, pressure, and humidity. Catalytic CO sensors are used in the combustion chamber of vented tankless gas water heaters manufactured and sold in Japan. These devices meet the Incomplete Combustion Prevention requirements in JIS-S-2109 and that were discussed in the voluntary standards memorandum (TAB D). The image below depicts the operating principle of catalytic sensors.[32]

[32] https://www.bing.com/images/search?view=detailV2&id=0EB0F94C5A4139C5AD42F1AAA8D375CCDE99F815&thid=OIP.7hk42NgjoEgCG5Sv2OFV-gHaEk&mediaurl=http%3A%2F%2F4.bp.blogspot.com%2F-2DUjjq5qhk4%2FUEbzBZtDxQI%2FAAAAAAAAGCM%2Fvu88tVRf9GA%2Fs640%2F553667_346642178745594_686417155_n.jpg&exph=274&expw=444&q=Catalytic+Bead+Sensor&selectedindex=8&ajaxhist=0&vt=0&eim=1,2,6

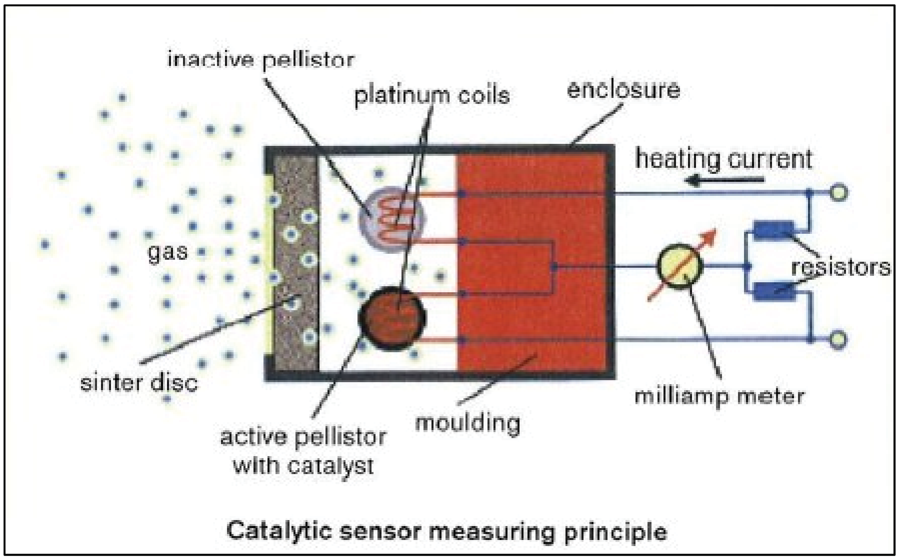


**Figure 1.** Catalytic sensor

<u>Nondispersive Infrared $CO_2$ Sensors</u>

Gas emits thermal energy that is within the electromagnetic spectrum. The electromagnetic spectrum is the range of frequencies of electromagnetic radiation and their respective wavelengths and photon energies.[33] Infrared radiation is electromagnetic radiation with frequencies that range from roughly 300 GHz to 400 THz (which correspond to wavelengths of 1 mm to 750 nm). Non-Dispersive Infra-Red (NDIR) is a technique that relies on the emittance of a beam of infrared light from a light source that does not "disperse" or become scattered by substances between the light source and a detector. An NDIR gas sensor measures the concentration of a particular gas in a sample chamber that passes between an infrared light source and a detector. In a non-dispersive system, the light from the infrared light source is absorbed by the gases. The amount of light absorbed is a function of how much gas is between the light source and the light detector.

An NDIR sensor is comprised of an infrared light source, a gas sample chamber with an inlet and outlet for gas to enter and exit, an absorption infrared detector, a spectral filter for the absorption infrared detector, a reference infrared detector, and a spectral filter for the reference infrared detector. Combustion gases enter the sample chamber through diffusion. The infrared light source is directed through the sample chamber and through the combustion gases inside the sample chamber to the absorption detector and its filter and the reference detector and its filter.

The absorption detector is designed to detect the target gas (in this case, $CO_2$) at its characteristic infrared wavelength. The filter for this detector filters out the infrared radiation of other combustion gases, only allowing the wavelength of the target gas to be detected. The reference infrared detector is designed to detect a reference gas at its characteristic infrared wavelength. The NDIR sensor converts the infrared energy detected by the absorption infrared detector and the reference infrared detector into electrical signals proportional to the concentration of gas detected and measured.

[33] https://en.wikipedia.org/wiki/Electromagnetic_spectrum.

Figure 2 is a depiction of an NDIR gas sensor designed to detect the gas carbon dioxide ($CO_2$). The infrared light source is installed at one end of the sample chamber and the light detector is installed at the opposite end. The light detector has a filter so it specifically only detects light in the electromagnetic spectrum that is related to $CO_2$. An inlet and outlet between the light source and detector allows $CO_2$ to flow freely in and out of the sample chamber. The image below depicts the operating principle of a NDIR sensor.[34]

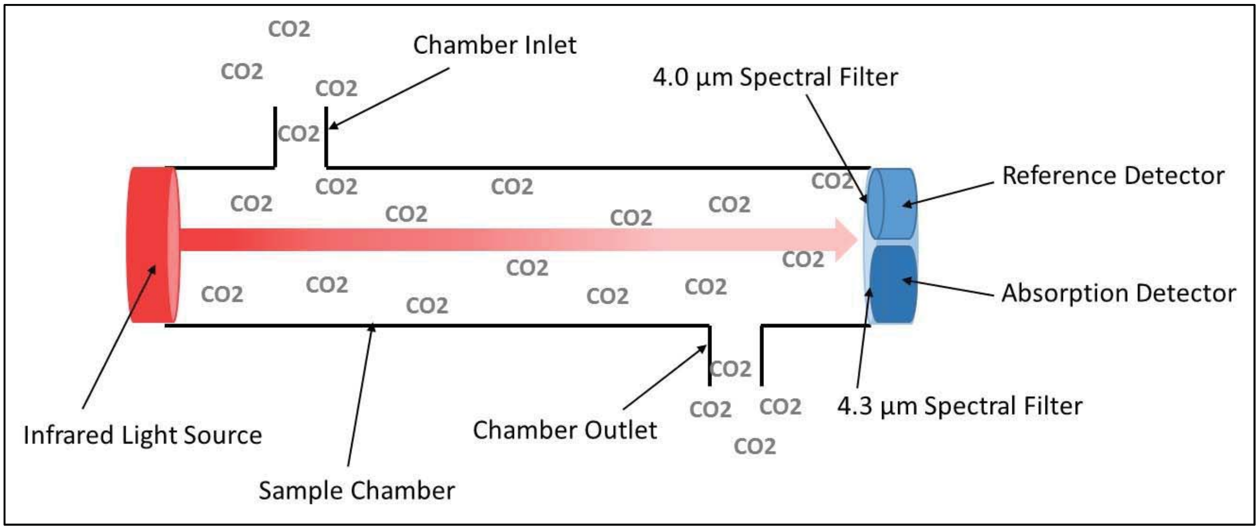


**Figure 2.** Nondispersive infrared sensor

The amount of infrared light absorbed is proportional to the concentration of $CO_2$ in the sample chamber. As $CO_2$ concentration increases, more infrared light is absorbed, and less light is detected. A known mathematical equation is used to calculate the $CO_2$ concentration, in parts per million (ppm) or as a percent (%), present in the sample chamber."[35] NDIR $CO_2$ sensors are currently used as a shutdown mechanism in kerosene heaters to comply with indoor air quality requirements in France, in accordance with AFNOR 128, *Duty Mobile Auxiliary Space Heaters Burning Deodorised Kerosene and not Connected to a Flue or Special Device for the Evacuation of Combustion Products*.

Zirconium dioxide ($ZrO_2$) Oxygen Sensors

A zirconium dioxide ($ZrO_2$) oxygen sensor (also known as a lambda sensor) determines the oxygen concentration of a gas or mixture of gases by measuring the partial pressure of an unknown concentration of oxygen within a gas or mixture of gases (*e.g*., the exhaust gases of an air/fuel mixture being burned) that flows past the exterior surface of the sensor. The sensor also measures the partial pressure of a known concentration of oxygen from a reference source (*e.g*.,

[34] https://www.bing.com/images/search?view=detailV2&id=0EB0F94C5A4139C5AD42F1AAA8D375CCDE99F815&thid=OIP.7hk42NgjoEgCG5Sv2OFV-gHaEk&mediaurl=http%3A%2F%2F4.bp.blogspot.com%2F-2DUjjq5qhk4%2FUEbzBZtDxQI%2FAAAAAAAAGCM%2Fvu88tVRf9GA%2Fs640%2F553667_346642178745594_686417155_n.jpg&exph=274&expw=444&q=Catalytic+Bead+Sensor&selectedindex=8&ajaxhist=0&vt=0&eim=1,2,6

[35] https://www.edaphic.com.au/knowledge-base/articles/gas-articles/ndir-explained/.

air) that flows through the interior surfaces of the sensor. At temperatures greater than 650ºC, the $ZrO_2$ exhibits two characteristics:

1) $ZrO_2$ partially dissociates (separates), producing oxygen ions that can be transported through the material when a voltage is applied.
2) $ZrO_2$ behaves like a solid electrolyte for oxygen. If two different oxygen pressures exist at the exterior and interior surfaces of a $ZrO_2$ element, a Nernst voltage can be measured across the element.

The greater the difference in the oxygen ion concentrations at the interior and exterior surfaces of the sensor, the greater the Nernst voltage. With air as the reference gas, the Nernst voltage is a direct measure of the oxygen concentration in the air/fuel mixture surrounding the exterior surfaces of the sensor.

A typical plug-type zirconium dioxide oxygen sensor setup used in a motor vehicle is shown in the image below.[36] The primary parts of the sensor and the operating environment include:

1. zirconium dioxide ceramic coating
2. interior and exterior electrodes
3. electrical contacts
4. housing contacts
5. exhaust pipe (sensor is inserted through exhaust pipe wall)
6. ceramic support shield
7. exhaust gas
8. ambient air.

The plug-type, zirconium dioxide oxygen sensor is inserted through exhaust pipe wall (5) into the exhaust gas stream (7). Zirconium dioxide is a ceramic unit (1), which serves as a solid-state electrolyte that allows oxygen ions to pass from a volume of higher oxygen concentration (8), to a volume of lower oxygen concentration (7) when it is heated above 350ºC. The sensor is open to ambient air (8) on one end and closed on the other. Mounted on both the interior and exterior surfaces, are gas-permeable platinum electrodes (2). The exterior platinum electrode serves as a catalyst that allows the exhaust gases that flow past the exterior surface of the sensor to react and generate a voltage when heated. The interior platinum electrode is exposed to the atmosphere, allowing in ambient air. The side that is exposed to the exhaust gases (7), also has a porous ceramic layer (Spinell coating) to protect against contamination. A metal tube with numerous slots (6) guards the ceramic body (1) against impacts and thermal shocks. The inner cavity is open to the atmosphere, which serves as the unit's reference gas.

[36] https://wbo2.com/lsu/oxygen13-17.pdf.

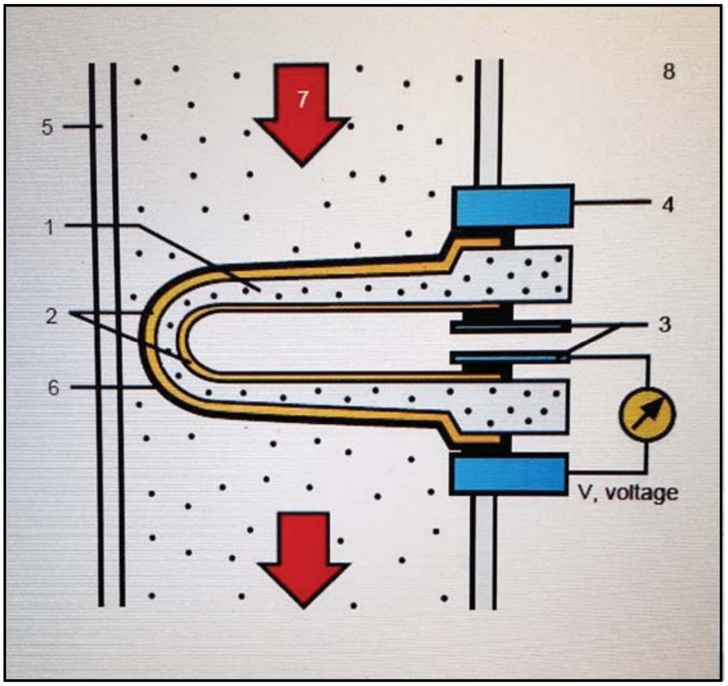


**Figure 3.** Zirconium Dioxide Oxygen sensor

The two-state sensor operation is based in the Nernst Principle. The sensor's ceramic material conducts oxygen ions at temperatures 350$^o$C and above. Disparities in oxygen levels on the respective sides of the sensor will result in the generation of electrical voltage (*i.e*., Nernst voltage) between the two surfaces. This voltage serves as the index of how much the oxygen levels vary on the two sides of the sensor. The amount of residual oxygen in the exhaust fluctuates sharply in response to the variation in the induction mixture's air/fuel ratio.

Zirconium Dioxide COe Sensors

Like zirconium dioxide oxygen sensors, zirconium dioxide COe sensors function on the principle of solid-state electrolysis and also use the zirconium dioxide ceramic material as the solid-state electrolyte. However, unlike the oxygen sensors, COe sensors are mixed-potential devices, and by varying the sensing element geometry, material and electrical wiring can measure unburned flammable gases, including CO, hydrogen ($H_2$), and a variety of hydrocarbons ($C_xH_y$). These gases are also referred to as CO equivalent (COe) and are an indication that the air fuel mixture was not burned completely.

Measurement of COe is accomplished by using three measurement electrodes that make up the units' sensing element: (1) one electrode for COe measurement, (2) one for a redundant COe measurement, and (3) one reference electrode to measure ambient air. COe sensors must be heated to operating temperature. This is accomplished through the use of a heating element attached to the back of the sensing element. COe sensors are mixed-potential solid electrolyte sensors. Different electrochemical reactions (between $O_2$-molecules and combustibles) occur at the two different electrode types (reference and measurement electrode), due to their different electrocatalytic materials. This results in different electrochemical potentials (voltages) between the two electrodes. The potential difference between the two electrodes is the measured sensor signal voltage. The signal voltage is a function of combustible COe. A diagram of a zirconium dioxide COe sensor is depicted below.[37]

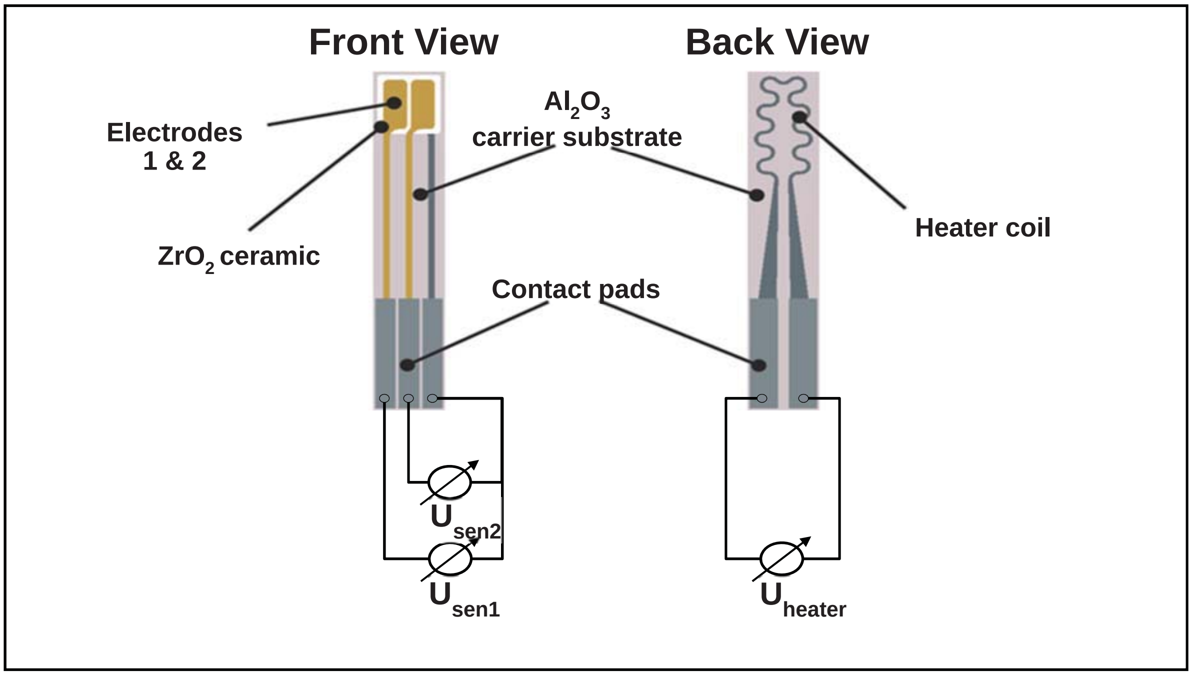


**Figure 4a.** Zirconium Dioxide COe sensing element

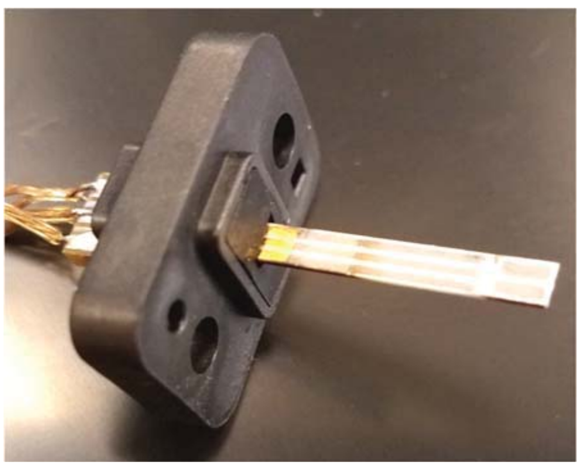

**Figure 4b.** Sensing element and sensor housing.

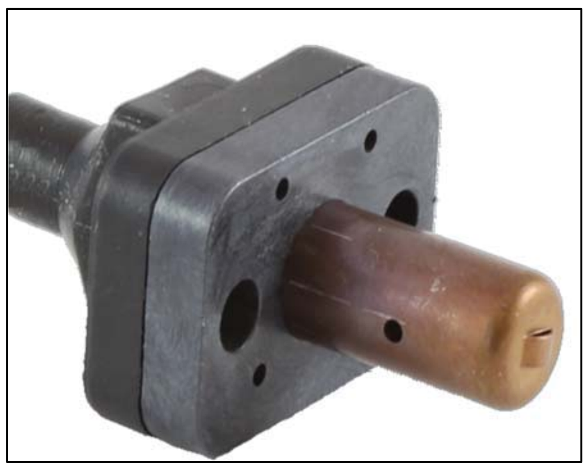

**Figure 4c.** Protective housing over element.

**Flame Sensing Technology**

A flame sensor is a device that detects the condition of a flame and generates an electrical signal that is proportional to the flame condition being detected. The condition of the burner flame in a gas appliance can be detected in the following ways:

[37] Technical Data for Lamtec CarboSen 1000 ST Sensor, TD-CarboSenST-DLT5800-10-aEN-009, LAMTEC Leipzig GmbH & Co. KG.

- Temperature detection. An example is a thermocouple connected to the gas valve. In case of flame failure, the gas valve will close when the temperature is not high enough.
- Flame radiation. Radiation is in the IR or UV wavelengths. The signal depends on fuel and flame temperature.
- Flame ionization.

Flame-Ionization Sensors

Combustion of hydrocarbon fuels can be detected through the presence of ions in the combustion flame. The ion concentration is dependent upon the ratio of fuel to air and the position of the detection device in the flame. In gas appliances, flame ionization is the electrical phenomenon that occurs when a voltage is applied between the burner and an electrode rod positioned in the burner flame. When this occurs, the ions within the flame become either positively or negatively charged, generating an ionization current that is proportional to the ratio of fuel to air in the mixture (*i.e.*, air/fuel ratio) being burned. The air/fuel ratio is also known as the equivalence ratio. The ionization current flows through the electrode rod, which is part of an electrical control circuit, and is used in the circuit to either shutoff the appliance or modulate appliance performance to maintain the proper air/fuel ratio.

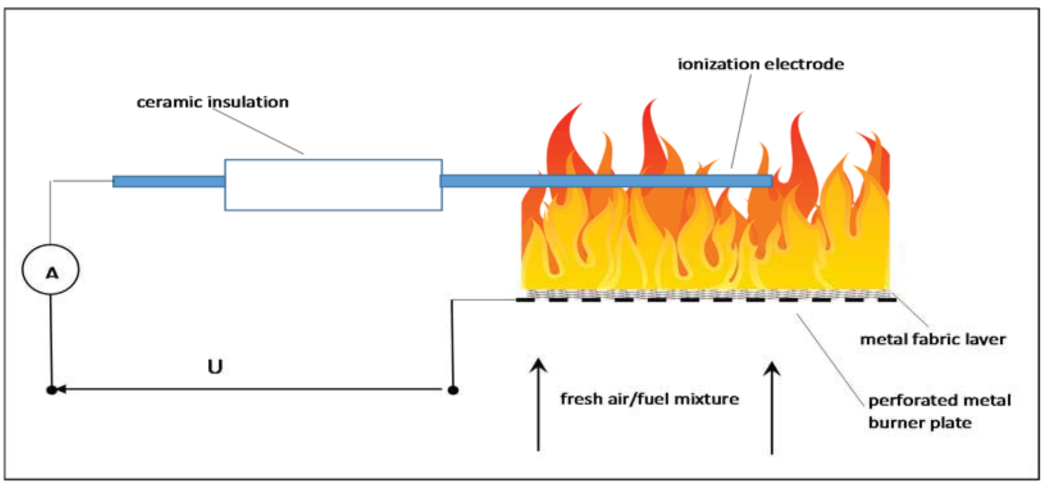


**Figure 5.** Flame-Ionization Sensor

**Combustion Control Systems**

Combustion control systems used in gas appliances are designed to maintain the proper air/fuel mixture of the fuel and air being burned within the combustion chamber of a gas appliance. As discussed earlier, maintaining the proper air/fuel mixture of hydrocarbon fuels ensures that the mixture is burned completely (*i.e.*, complete combustion). Complete combustion of the air/fuel mixture ensures combustion efficiency and combustion quality, which either prevents or limits the production of carbon monoxide. Simply stated, maintaining the proper the air/fuel mixture with a combustion control system can also prevent or limit production of CO.

Combustion control systems used in gas appliances are typically based on flame ionization or flue gas monitoring.[38] There are a variety of gas-sensing and combustion-control technologies currently on the market and being used in Japan and Europe for in-situ monitoring of the combustion process for shutdown or gas/air ratio control of residential gas appliances.
A combustion-control system based on gas monitoring or flame ionization would use the same technologies described earlier in the Gas-Sensing Technology section. As part of a combustion-control system, the signal from gas-sensing or flame-ionization technology would be used to modulate appliance performance.

The technologies for this application include catalytic CO sensors, nondispersive infrared $CO_2$ sensors, non-Nernst COe (or zirconia dioxide sensors), flame ionization sensors, and UV sensors. The electrical signal generated by these technologies can be used in an electrical control circuit to either shut off the appliance or modulate appliance performance to maintain the proper air/fuel ratio, as well prevent or limit CO production.

Shutdown of the appliance stops the combustion process, thereby preventing the gas concentrations from continuing to increase and reducing the gas concentration back to safer, ambient levels. Modulation of the appliance involves either increasing the combustion air or decreasing the fuel provided to the burner for combustion. This ensures a proper gas/air ratio that allows the gas/air mixture to be burned completely, thus optimizing combustion efficiency and preventing or limiting the production of CO. Increasing the combustion air provided to the burner can be accomplished by increasing the fan speed of the inducer motor either mechanically or electronically. Decreasing the fuel provided to the burner can be accomplished by mechanically or electronically decreasing the gas flow rate or supply at the gas valve.

**Summary**

To achieve optimal combustion efficiency of natural gas or propane furnaces and boilers, it is important to ensure the proper mixture of air and fuel (*i.e.*, air fuel ratio) at the burner. This ensures complete combustion of the air fuel mixture and that the production of CO will either be prevented or limited. There are a variety of gas sensing technologies and combustion control systems currently being used for shutdown or modulation of Japanese and European gas boilers and water heaters in response to elevated CO, sub-optimal air fuel mixtures, or other inefficient combustion conditions within the combustion chamber or flue passageways of these appliances. Staff believes that the use of these technologies in natural gas or propane furnaces and boilers manufactured in the U.S. would protect consumers from many of the CO hazards that are currently not addressed in the U.S. voluntary standards for these appliances.

[38]"Combustion control in domestic gas appliances: Fuel gases containing hydrogen", Danish Gas Technology Centre (2014).

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