CO EMISSIONS FROM PORTABLE PROPANE RADIANT HEATERS

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Prepared By David R. Tucholski

Directorate for Laboratory Sciences

United States Consumer Product Safety Commission

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EXECUTIVE SUMMARY

Portable propane radiant heaters are often referred to as camp heaters since the heaters were originally designed for use during outdoor activities such as camping, hunting, and fishing. The heaters use a disposable bottle of propane gas (e.g., 1-pound bottle) as their fuel source. Gas-fired radiant heaters are intended for use in large open areas where there is sufficient air available for the combustion process. When the heaters are operated in small enclosed areas that are poorly ventilated, such as a tent or trailer, the heaters present a carbon monoxide (CO) poisoning hazard to consumers, which could result in death or serious injury. Staff at the U.S. Consumer Product Safety Commission (CPSC) conducted in-depth investigations (IDIs) on 12 incidents that occurred between 1996 and June 2001 involving portable propane radiant heaters. The 12 incidents resulted in 18 deaths due to CO poisoning. All of the incidents occurred in tents, campers, trailers, or motor vehicles (passenger vans, passenger cars, and cabs of semi trucks).

To address this potential CO poisoning hazard, the voluntary standard for Portable Type Gas Camp Heaters (ANSI Z21.63) was revised in April 2000. Modifications to the standard were made based on work performed by CPSC staff in 1996. The revised standard specifies that when the heaters are operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0 and 1.5 air changes per hour (ACH), the CO concentration in the room cannot exceed 100 parts per million (ppm). The standard also specifies that the oxygen (O_2) concentration in the room cannot be depleted below 16 percent. The objective of this current CPSC project was to document the CO emissions from currently available portable propane heaters and to determine whether these heaters complied with the revised CO performance requirements of ANSI Z21.63 (2000).

Eight different heaters (denoted as Heaters A through H) were tested as part of this project. Based on the type of heater, the heaters can be divided into three different groups: (1) single burner radiant heaters, (2) radiant heater/cookers, and (3) radiant heaters equipped with an oxygen depletion sensor (ODS). Although not all of the heaters fell within the scope of ANSI Z21.63, all of the heaters could be used in typical camping situations. Therefore, all of the heaters were tested to the combustion requirements of ANSI Z21.63 (2000), since the standard provides guidelines for assessing whether a heater could present a CO poisoning hazard to consumers.

To evaluate the combustion characteristics of each propane heater, the heater was operated in a 100 ft^3 test chamber at the air exchange rates specified in ANSI Z21.63 (2000). Tests were also performed at other air exchange rates, since the maximum steady state concentration of CO did not necessarily occur at one of the air exchange rates specified in the standard. Gas samples were continually withdrawn from the test chamber and analyzed for carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and unburnt hydrocarbons (HC).

The following is a summary of CPSC staff's findings:

- Two *Single Burner Radiant Heaters* were tested (Heaters A and B) and neither heater complied with the combustion requirements in ANSI Z21.63 (2000). The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater A, 368 ppm at 0.92 ACH; and Heater B, 358 ppm at 0.77 ACH.

- Four *Radiant Heater/Cookers* were tested (Heaters C to F) and none of the heaters complied with the combustion requirements in ANSI Z21.63 (2000). The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater C, 687 ppm at 1.97 ACH; Heater D, 260 ppm at 3.07 ACH; Heater E, 2124 ppm at 1.52 ACH; and Heater F, 331 ppm at 2.93 ACH.

- Two *ODS-equipped Radiant Heaters* were tested (Heaters G and H) and both heaters complied with the combustion requirements in ANSI Z21.63 (2000). The ODS shut the heater off when the O_2 concentration ranged from 18.8 to 19.6 percent, which prevented the CO concentration from

exceeding 100 ppm in the chamber. The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater G, 39 ppm at 5.64 ACH; and Heater H, 38 ppm at 4.64 ACH.

- In general, the CO concentration did not exceed 100 ppm in the test chamber until the O_2 concentration was depleted below approximately 16 percent. In order to prevent the O_2 concentration from being depleted below 16 percent, the heater must either operate at an extremely low energy-input rate or the heater must incorporate some sort of safety shut-off device, like an ODS.
- None of the eight heaters tested were certified to ANSI Z21.63 (2000).
  - Three of the heaters were within the scope of the standard. One of the heaters was manufactured prior to the effective date of the revised standard. The remaining two heaters were manufactured overseas and the manufacturers may be unaware of the standard or have decided not to be certified to the voluntary standard.
  - The two heaters equipped with an ODS were outside the scope of the standard and were certified to a different standard, *CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and Commercial Use*. CSA 4.98 applies to gas-fired portable heaters for recreational and commercial use, that are equipped with an ODS.
  - Three of the heaters were outside the scope of the standard since the maximum energy-input rate of the heaters claimed by the manufacturers were greater than the maximum rate covered by the standard (12,000 Btu/hr). When the maximum energy-input rate of these heaters was determined experimentally, two of the three heaters had a rate that was within the energy-input rate covered by the standard. In addition, each of these units could be operated at lower energy-input rates that were within the scope of the standard.

Based on the test results, CPSC plans to:

1. Recommend to the *CGA/ANSI Z21 Joint Subcommittee on Refrigerators and Portable Camping Equipment* that the upper limit on the energy-input rate specified in the scope of the standard be removed from ANSI Z21.63. This will establish CO and O_2 requirements for portable type camp heaters that are exempt from the current standard because the products are rated by the manufacturer at rates greater than 12,000 Btu/hr. It is foreseeable that any portable gas camp heater could be brought into tents or other enclosed areas and pose a CO poisoning risk.
2. Recommend to the *CGA/ANSI Z21 Joint Subcommittee on Refrigerators and Portable Camping Equipment* that the scope of the ANSI Z21.63 should clearly state that the standard applies to both radiant heaters and radiant heater/cookers. This will eliminate the question of whether or not ANSI Z21.63 applies to heater/cooker combination units.

INTRODUCTION*

Background

Portable propane radiant heaters are often referred to as camp heaters since the heaters were originally designed for use during outdoor activities such as camping, hunting, and fishing. The heaters use a disposable bottle of propane gas (e.g., 1-pound bottle) as their fuel source. Gas-fired radiant heaters are intended for use in large open areas where there is sufficient air available for the combustion process. When the heaters are operated in small enclosed areas that are poorly ventilated, such as a tent or trailer, the heaters present a carbon monoxide (CO) poisoning hazard to consumers, which could result in death or serious injury. CPSC staff has conducted in-depth investigations (IDIs) on 12 incidents that occurred between 1996 and June 2001 involving portable propane radiant heaters. The 12 incidents resulted in 18 deaths due to CO poisoning. All of the incidents occurred in tents, campers/trailers, and motor vehicles (passenger vans, passenger cars, and cabs of semi trucks).

In the late 1990's, the heater industry worked with CPSC staff to revise the voluntary standard for portable type gas camp heaters to address the CO poisoning hazard that occurs when the heaters are used in enclosed areas that are poorly ventilated. The revised standard (ANSI Z21.63-2000) became effective April 1, 2000, and specifies that when the heater is operated in a 100 cubic foot room at air exchange rates of 0.5, 1.0, and 1.5 air changes per hour, the CO concentration inside the room cannot exceed 100 parts per million (ppm). The standard also specifies that the oxygen (O_2) concentration in the room cannot be depleted below 16 percent.

In 2001, CPSC staff began a project to document the CO emissions of currently available portable heaters and to determine if these heaters complied with the revised combustion section in ANSI Z21.63 (2000).

Types of Portable Propane Radiant Heaters

Currently, there are three types of portable propane radiant heaters available to consumers: (1) single burner radiant heaters, (2) radiant heaters that also function as cookers, and (3) radiant heaters equipped with an Oxygen Depletion Sensor (ODS). The single burner radiant heaters and the radiant heater/cookers are designed for outdoor use only. The ODS-equipped radiant heaters are designed for use in enclosed areas, or partially enclosed areas where the heater is protected from the wind. The ODS-equipped radiant heaters have a limited use in outdoor activities, since a pilot flame, which is part of the ODS, is easily extinguished in windy conditions. Although the ODS-equipped radiant heaters can be used in confined spaces such as a tent or trailer, the manufacturers still recommend that sufficient air be provided to the heater for the combustion process and for ventilation. Table 1 provides a summary of the different portable propane radiant heaters currently available to consumers. Figures 1 through 3 are photographs that are representative of each type of heater.

* The views expressed in this report are those of the CPSC staff and do not necessarily reflect the views of the Commission.

Table 1. Portable propane radiant heaters that could be used in camping situations

Heater Style	Intended Use	Typical Energy-Input Rate	Estimated Run Time[1]	
			1-pound bottle	20-pound tank[2]
Single Burner Radiant Heater	Outdoor	Up to 3,000 Btu/hr	7.5 hrs	N/A
Radiant Heater/Cooker	Outdoor	8,000 to 15,000 Btu/hr	1.5 - 2.8 hrs	29 – 55 –hrs
ODS-Equipped Radiant Heater	Indoor	4,000 to 9,000 Btu/hr	2.5 -5.7 hrs	49 – 110 hrs

1. Run time calculated assuming the following for propane gas: a heat content of 2,500 Btu/ft^3 and a density of 0.114 lb$_m$/ft^3.
2. A special hose assembly is required to attach the heaters to the bulk tank of propane gas.

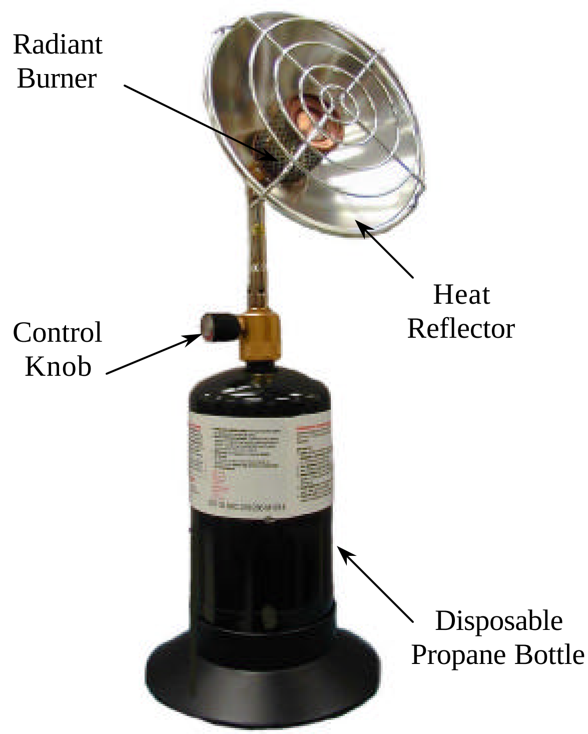

Figure 1. Single burner radiant heater

(a) Heater Position (b) Cooker Position

Figure 2. Radiant heater/cooker

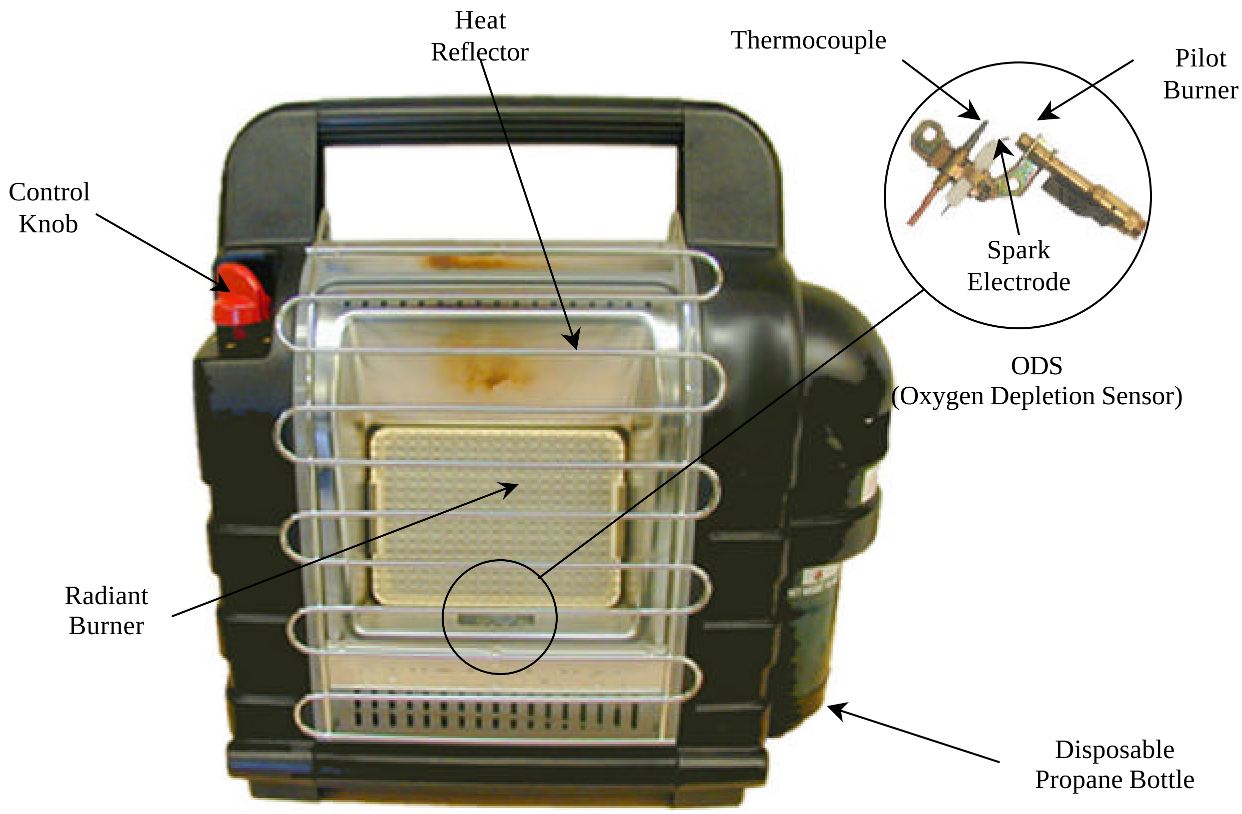

Figure 3. Radiant heater equipped with an oxygen depletion sensor (ODS)

Single Burner Radiant Heaters

Figure 1 is a photograph of a typical single burner radiant heater. This style of heater is similar to the products tested by CPSC staff in 1996 when staff was considering revisions to the ANSI standard for portable type gas camp heaters. The heater consists of a radiant burner surrounded by a heat reflector and a gas valve. A control knob on the gas valve allows for a variable setting of the heater's energy-input rate. The entire heater assembly attaches directly to the top of a disposable bottle of propane gas. Some single burner radiant heaters also have a thermally activated safety shutoff device that will stop the flow of gas if the flame is extinguished. The shutoff device consists of a solenoid gas valve and a thermocouple mounted above the burner. When the thermocouple is heated, it generates the voltage and current necessary to hold the solenoid valve open. When the flame is extinguished, the thermocouple cools, causing a decrease in the generated voltage and the closing of the gas valve.

Radiant Heater/Cookers

Figure 2 is a photograph of a typical radiant heater/cooker. In addition to being a heater (Figure 2a), the unit can also be used as a cooker (Figure 2b). The heater consists of a radiant burner surrounded by a heat reflector, a gas valve to control the flow of gas to the burner, and a stand on which to position the unit for either heating or cooking. Depending on the heater, the energy-input rate of the heater may be variable or it may have predefined settings (e.g., Low, Medium, and High). The control knob on the gas valve is used to set the energy-input rate of the heater. The heater has a thermally activated safety shutoff device, similar to the one previously discussed for the single burner radiant heaters. Several of the heaters also have an integral piezo-type electronic ignitor. Although the heaters are designed for use with a disposable bottle of propane gas, the heaters can also be attached to a bulk tank of propane gas using a hose assembly, which must be purchased separately.

ODS-Equipped Radiant Heaters

Figure 3 is a photograph of a radiant heater equipped with an Oxygen Depletion Sensor (ODS). The ODS is a thermally activated shutoff device that will stop the flow of gas to the burner when the O_2 concentration falls below a certain level (approximately 18 percent). The ODS differs from other thermally activated shutoff devices in that the thermocouple senses the temperature of a pilot flame instead of the main burner. The pilot flame is more sensitive to changes in the surrounding O_2 concentration than the flame on the main burner and will lift off quicker when the O_2 level decreases. When the flame lifts off the burner, the thermocouple will cool, causing the gas valve to close. ODS's have been used successfully for many years in unvented space heating applications, such as gas logs. Overall, an ODS-equipped radiant heater is similar to other radiant style heaters in that it has a single radiant burner, a heat reflector, and a gas valve to control the gas flow to the burner. A control knob on the gas valve is used to adjust the heater's energy-input rate to several predefined positions. The heaters also have an integral piezo-type electronic ignitor.

Voluntary Standards

The voluntary standard for camp heaters is ANSI Z21.62 (2000) – *American National Standard/CSA Standard for Portable Type Gas Camp Heaters*. The standard applies to unvented portable type gas-fired heaters, of the infrared type, that are intended for outdoor use, and have a maximum input rate up to and including 12,000 Btu/hr. Section 2.4 of the standard specifies that when the heaters are operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0, and 1.5 air changes per hour, the CO concentration in the room cannot exceed 100 ppm. In addition, the O_2 concentration in the room cannot be depleted below 16 percent.

Since the ODS-equipped radiant heaters are designed for indoor use, the heaters are not within the scope of ANSI Z21.63 (2000). Instead, the ODS-equipped radiant heaters are certified to a different standard, *CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and*

Commercial Use. CSA 4.98 is a supplemental standard to the voluntary standard for unvented gas-fired room heaters (*ANSI Z21.11.2-2000, Gas-Fired Room Heaters, Volume II, Unvented Room Heaters*). CSA 4.98 applies to gas-fired portable heaters for recreational and commercial use, having energy-input rates up to and including 10,000 Btu/hr. The standard requires that each heater be equipped with an ODS and that the ODS must shut the heater off when the O_2 concentration in the surrounding atmosphere is depleted to no lower than 18 percent. Section 2.4 of the standard specifies that when the heater is operated in a 500 ft^3 room with no air exchanges occurring, the CO concentration in the room cannot exceed 100 ppm when the O_2 concentration is depleted to 18 percent.

TEST EQUIPMENT* AND SETUP

Heater Samples

Eight portable propane radiant heaters were tested: two (2) single burner radiant heaters, four (4) radiant heater/cookers, and two (2) ODS-equipped radiant heaters. A summary of each heater is provided in Table 2. The Office of Compliance collected three of the eight heaters for evaluation. The remaining heaters were purchased over the Internet after visiting the Web sites of various camping stores. All of the test samples were collected after the revised voluntary standard became effective in April 2000. It should be noted that the manufacturer of Heater A has discontinued selling the heater as of January 2000, prior to the effective date for the revised standard of April 2000. However, the heater was still available to the public 9 months later when CPSC staff purchased the sample unit in September 2000. The standard requires that products manufactured after the effective date must comply with the standard. Products manufactured prior to the effective date can continue to be sold until supplies are exhausted.

Table 2. Summary of Portable Propane Radiant Heater Test Samples

Style of Heater	Test Sample	Energy-Input Rate[1] (Btu/hr)	Manufacturer	Certified to ANSI Z21.63	Within Scope of ANSI Z21.63
Single Burner	A	2,000 to 4,400	Domestic	No	Yes
	B	Up to 3,000	Foreign	No	Yes
Heater / Cooker	C	9,000/12,000/15,000	Domestic	No	No
	D	10,000/14,000	Domestic	No	No
	E	8,000/14,000	Domestic	No	No
	F	Up to 10,000	Foreign	No	Yes
ODS-Equipped	G	4,000/9,000	Domestic	No	No
	H	4,500/8,000	Foreign	No	No

1. Energy -input rate specified by manufacturer

As Table 2 illustrates, not all of the heaters tested were within the scope of ANSI Z21.63 (2000). Several of the radiant heater/cookers were outside the scope of the standard since the maximum energy-input rate of these heaters was listed by the manufacturers as greater than that covered by the standard. In addition, the ODS-equipped radiant heaters were not within the scope of the standard since these heaters are designed for indoor use. However, CPSC Staff believes that it is foreseeable that consumers could

* The test equipment described herein including specific manufacturers' products used to monitor or control testing, and/or record or obtain data, are specifically identified to allow others to attempt to re-produce this work should they so desire. Mention of a specific product or manufacturer in this report does not constitute approval or endorsement by the Commission.

use any of these heaters in the same type of environment as that of a typical camping heater. Therefore, all of the heaters were tested to the combustion requirements of ANSI Z21.63 (2000), since the standard provides guidelines for assessing whether a heater could present a CO poisoning hazard to consumers.

Propane Gas

The heaters were attached directly to a disposable 1-pound bottle of propane gas. Bottles from two different propane gas suppliers were used and the bottles were purchased locally at several different retail stores. A gas chromatograph analysis of gas samples taken from several bottles indicated that the propane gas consisted of approximately 90-95% propane, 2-9% ethane, 1-3% iso-butane, and less than 1% butane. A calorimeter was not available on site to measure the heating value of the propane gas, therefore a heating value of 2,500 Btu/ft^3 was assumed for the gas. A heating value of 2,500 Btu/ft^3 is often assumed for propane gas when the actual value is not known.[1]

Test Chamber

Experiments were conducted inside a 100 ft^3 test chamber with an interior height of 6.6 ft, a width of 3.9 ft, and a depth of 3.9 ft. The chamber was constructed from sheets of fire retardant boards supported by a metal framework. A chilled water heat exchanger system was used to maintain the temperature inside the chamber at a set temperature. The cooling system could maintain the chamber temperature at 70°F ± 5°F for heater's rated less than approximately 5,000 Btu/hr and at 80°F ± 5°F for heaters rated up to 15,000 Btu/hr. To enhance the heat transfer of the cooling system, fans were used to move air over the cooling coils of the heat exchanger. These fans also circulated the air within the chamber, which resulted in a well-mixed environment. The air exchange rate through the chamber could be varied from 0 to 6 air changes per hour (ACH) by controlling the speed of the supply fan and exhaust fan, and by changing the diameter of the opening for the supply air.

Gas Sampling System

Gas samples were continually withdrawn from the chamber through six equal length sample lines located within the chamber. The six sample lines were connected to a common manifold where the gas samples mixed. A pump conveyed the mixed gas sample to a series of gas analyzers. The gas sample was analyzed for CO, CO_2, O_2, and unburnt hydrocarbons measured as propane gas (C_3H_8). Table 3 provides a summary of the gas analyzers. Water vapor formed during the combustion process was removed from the gas sample prior to analysis using a chilled water heat exchange system.

Table 3. Summary of gas analyzers.

Gas Specie	Gas Analyzer			Measurement Range
	Measuring Technique	Manufacturer	Model	
CO	Non-Dispersive Infrared	Rosemount	880A	0 – 200 ppm 0 – 1,000 ppm 0 – 3,000 ppm
CO2	Non-Dispersive Infrared	Rosemount	880A	0 – 10 percent
O2	Paramagnetic	Rosemount	755R	0 – 20.9 percent
HC (C3H8)	Non-Dispersive Infrared	Rosemount	880A	0- 100 percent LEL1

1. LEL = Lower Explosive Limit; for propane gas, the LEL is 2.1 % propane in air.

[1] *Fundamentals of Gas Combustion*, 3rd edition, Catalog No. XH0105, American Gas Association, Washington, DC (2001).

Temperature

The air temperature in the chamber was measured at six locations in the chamber using K-type thermocouples (28-gauge, Omega). One thermocouple was located at the inlet of each sample tube.

Air Exchange Rate

The air exchange rate in the chamber was determined experimentally by measuring the exponential decay of a tracer gas once the heater shut off. Sulfur hexafluoride (SF_6) was used as the tracer gas for all tests. The concentration of SF_6 in the chamber was measured with an electron capture gas chromatograph analyzer (Largus Applied Technology, Model 101 Autotrac). The air exchange rates obtained from the decay of SF_6 were verified by the decay of CO, which occurred once the heater was off.

Energy-Input Rate of Heater

The energy-input rate of the heater was determined indirectly by measuring the amount of propane-fuel consumed by the heater over time. The mass of fuel consumed during a given time interval was measured using an electronic scale (Mettler, PM34 Delta Range).

Data Acquisition

A data acquisition system was used to collect and record the data. The system consisted of a personal computer, data acquisition interface hardware (Keithely), and data acquisition software (LABTECH® CONTROL). Gas concentrations and temperatures were recorded every 30 seconds by the data acquisition program. The program converted the voltage output from the gas analyzers into the appropriate concentration units (percent or parts per million). The only items not recorded by the data acquisition system were the concentration of SF_6 and the mass displayed on the electronic scale. The SF_6 analyzer contained an internal data acquisition program and recorded the concentration measurements directly to a 3.5-inch floppy disk located on the analyzer. The mass of fuel consumed was displayed on the electronic scale and recorded manually.

EXPERIMENTAL PROCEDURE

Chamber Tests

The gas analyzers were calibrated each morning prior to any tests being conducted. Each gas analyzer was calibrated according to the instructions specified by the manufacturer. In general, the CO, CO_2, O_2, and HC gas analyzers were zeroed with nitrogen gas. The CO, CO_2, and HC analyzers were then spanned using gases of known concentrations (EPA Protocol Standards). Since the CO analyzer had three different ranges available, the gas analyzer was spanned on each range using a gas appropriate for that range. The O_2 analyzer was spanned using room air, which was assumed to be 20.94 percent. The SF_6 analyzer was calibrated using a calibration gas supplied by the manufacturer of the SF_6 analyzer.

To begin a test, the air exchange rate of the test chamber was set by adjusting the speed of the inlet fan and the exhaust fan. The relationship between the fan speed (i.e., supply voltage) and the air exchange rate through the chamber was known prior to the tests. The chamber's cooling system was also started at this time.

After completing the initial setup of the chamber, the heater was attached to a disposable bottle of propane gas and the heater was placed on the electronic scale inside of the chamber. The propane gas to the heater was then ignited following the instructions specified by the manufacturer of each heater. The gas control valve on the heater was then adjusted to provide the desired energy-input rate of the heater. The door to the chamber was closed and the data acquisition program was then started.

As the test proceeded, the mass displayed on the electronic scale was recorded on a data sheet at various time intervals. As a back up to the data recorded electronically by the data acquisition system, the concentrations of CO, CO_2, O_2, and HC were periodically recorded manually on a data sheet.

The test proceeded until one of the following four events occurred: (1) the flame on the heater self-extinguished, (2) the heater produced a CO concentration greater than 3,000 parts per million (ppm), (3) the concentrations of CO, CO_2, and O_2 reached equilibrium (steady state), or (4) the HC exceeded approximately 40 percent of the lower explosive limit of propane (2.1 percent propane in air). If any of these events occurred, the heater was manually shut off by reaching into the chamber through a pair of glove ports and rotating the fuel control knob on the heater to the "Off" position. For tests in which the flame self-extinguished and the heater had an automatic safety shutoff device, it was not necessary to turn the control knob to the “Off” position. Once the heater was off, the SF_6 analyzer was started and a small volume of SF_6 tracer gas was injected into the chamber. The decay of the SF_6 gas was then monitored, with the concentration of the gas being recorded every two minutes.

DATA ANALYSIS

Air Exchange Rate

The equation describing the air exchange rate in the chamber can be derived from a simple mass balance of SF_6 in the chamber. The decay of SF_6 with time can be described by Equation 1:

$$C_t = C_o e^{-kt} \tag{1}$$

In Equation 1, C_t is the concentration of SF_6 at time t, C_o is the initial concentration of SF_6 at the start of the decay, k is the air exchange rate, and t is time. Equation 1 was derived based on the following assumptions: the air in the chamber is well mixed, the SF_6 does not get absorbed inside the chamber, and the background concentration of SF_6 is zero.

Equation 1 can be rearranged to solve for the quantity (kt) as follows:

$$\mathrm{Ln}\,(C_t/C_o) = -k\,t \tag{2}$$

Equation 2 indicates that a plot of the quantity Ln (C_t/C_o) versus time should be linear with time and that the air exchange rate (k) will be equal to the slope of this line. Since the line should be linear, linear regression can be used to fit a line to the data. An expression describing how well the line fits the data is the R^2 term, where R is the correlation coefficient. An R^2 value of 1.0 indicates that the line obtained by liner regression fits the data perfectly. For each test, a linear regression was performed on the SF_6 decay data and the air exchange rate was obtained from the slope of this line. The test was acceptable if the R^2 term was greater than 0.9.

CO Generation Rate

The rate at which the heater generated carbon monoxide, termed the CO source strength, can be derived from a simple mass balance of CO in the chamber. Between any two time intervals (t_i and t_{i+1}), the source strength can be calculated from the following equation,

$$S_{t_{i+1}} = \frac{Vk\left[C_{t_{i+1}} - C_{t_i} e^{-k\left(t_{i+1} - t_i\right)}\right]}{\left[1 - e^{-k\left(t_{i+1} - t_i\right)}\right]} \tag{3}$$

In Equation 3, $S_{t\,i+1}$ is the generation rate of CO at time t_{i+1}, V is the volume of the chamber, k is the air exchange rate, $C_{t\,i+1}$ is the concentration of CO at time t_{i+1}, and $C_{t\,i}$ is the concentration of CO at time t_i. Equation 3 was derived based on assuming that the air in the chamber is well mixed and that the CO is not absorbed inside the chamber.

Energy Input Rate

The energy-input rate of the heater, Q, was calculated indirectly from the mass of propane consumed by the heater over time. The energy-input rate was calculated as follows:

$$Q = \frac{C_1 HHV}{r}\frac{\Delta m}{\Delta t} \tag{4}$$

In Equation 4, C_1 is a conversion constant, *HHV* is the heating value of propane gas, r is the density of the propane gas, and *Dm* is the mass of propane fuel consumed during the time interval *Dt*. A HHV of 2,500 Btu/ft^3 was assumed for propane gas. The density of the propane gas used in the calculation was 0.114 lb$_m$/ft^3 and is based on a temperature of 70°F and a pressure of 14.7 lb$_f$/in^2.

RESULTS

A summary of the test data for each heater is provided in Appendix A. Tables A1 through A8 contain the following information: the test sequence number, the measured air exchange rate, the average energy-input rate of the heater, the peak concentrations of CO, CO_2 and HC, the minimum concentration of O_2, the time required to deplete the O_2 concentration to 16 percent O_2, the time required to increase the CO to 100 ppm, the length of each test, and the reason why the test was terminated. The tables also include a column to indicate whether the heater complied with the combustion requirements of ANSI Z21.63 (2000). Tests that were outside of the target air exchange rates of 0.5, 1.0, and 1.5 ACH by more then ± 0.1 ACH do not conform with the standard's test procedures and are therefore specified as a non-standard test. Tests were often conducted at air exchange rates other then those specified by the standard in order to determine the maximum CO that could be produced by the heater without extinguishing the flame. Finally, each table also includes information related to the rate that the heater generated CO.

Single Burner Radiant Heaters

Heater A

Heater A was a single burner radiant heater with a manufacturer's specified energy-input rate ranging from 2,200 Btu/hr to 4,400 Btu/hr. As the data in Table A1 indicates, the experimentally determined energy-input rate varied somewhat between tests for a given heater setting. Averaging the energy-input rate data in Table A1 yields the following average energy-input rates: 1,710 Btu/hr ± 220 Btu/hr at the heater's minimum setting and 3,720 Btu/hr ± 340 Btu/hr at the heater's maximum setting.

A review of the data in Table A1 indicates that Heater A did not comply with the combustion requirements of ANSI Z21.63 (2000) during a majority of the tests. Depending on the test conditions, the O_2 concentration inside the chamber was depleted to 16 percent within 38 minutes to 2.63 hours and the CO concentration inside the chamber was increased to 100 ppm within 50 minutes to 3.88 hours.

Figure 4 illustrates how the peak CO concentration in the chamber varied with both the air exchange rate and the energy-input rate of the heater. A line connects the data points for tests in which the heater continued to operate to steady state conditions, while the solid data points not connected with a line represent the tests in which the flame self-extinguished during the test. For all test conditions, the peak CO concentration ranged from 24 ppm to 716 ppm. The maximum CO concentration of 716 ppm occurred at an extremely low air exchange rate (0.1 ACH), which caused the flame on the heater to self-

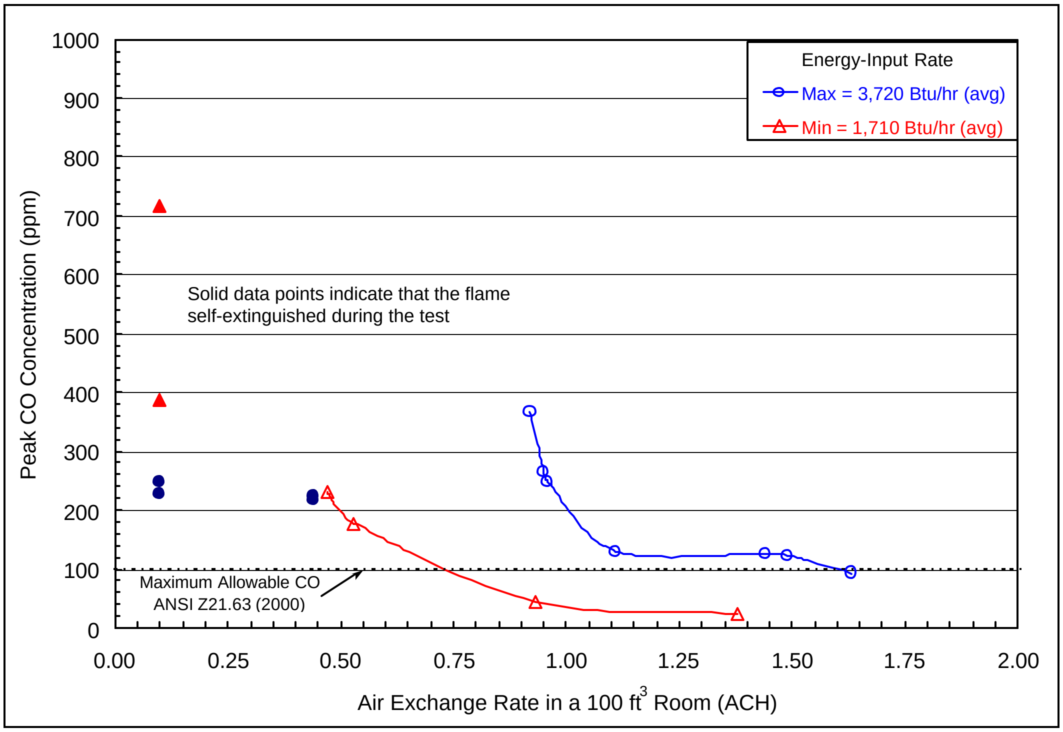

Figure 4. Peak CO concentration versus air exchange rate for Heater A (Single Burner Radiant Heater).

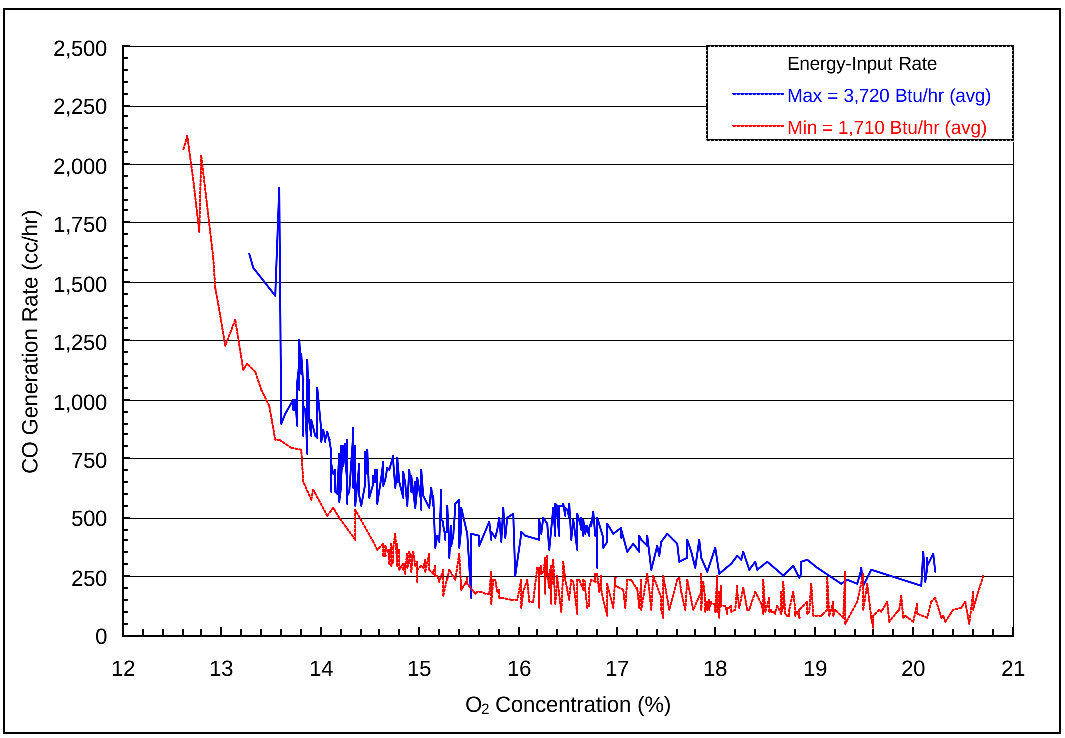

Figure 5. CO generation rate versus O_2 concentration for Heater A (Single Burner Radiant Heater). The figure includes data for all tests.

extinguish. The maximum CO concentration obtained without the flame extinguishing was 368 ppm and occurred when the heater was operated at its maximum energy-input rate and with the air exchange rate set to 0.92 ACH. At these test conditions, the CO concentration reached its peak value in approximately 4.50 hours and the heater would have continued to operate for an additional 2.15 hours before the fuel was totally consumed from a 1-pound disposable bottle of propane gas.

The air exchange rate at which the CO concentration exceeded the allowable CO limit of 100 ppm depended on the energy-input rate of the heater. When the heater was operated at its maximum energy-input rate, the peak CO concentration exceeded 100 ppm when the air exchange rate was between approximately 1.5 ACH to 1.6 ACH. When the heater was operated at its minimum energy-input rate, the peak CO concentration exceeded 100 ppm when the air exchange rate was between approximately 0.5 ACH to 0.9 ACH.

Figure 5 illustrates how the CO produced by Heater A was a function of the O_2 concentration in the chamber and the energy-input rate of the heater. The data shown in the figure is for all tests, which accounts for the scatter in the data. In general, the heater produced more CO when it was operated at its maximum energy-input rate than when the heater was operated at its minimum energy- input rate. As the O_2 concentration decreased in the chamber, the heater generated CO at a rate that steadily increased. After the O_2 concentration was depleted below approximately 16 percent, the heater produced CO more quickly. For all tests, the CO generation rate ranged from a minimum of 31 cc/hr to a maximum of 2,115 cc/hr.

When the O_2 concentration in the chamber was depleted below approximately 13.7 percent, the flame on the heater would self-extinguish. Since the heater did not have an automatic safety shut off system, the heater had to be manually turned off. Had the heater remained on, the concentration of propane would have eventually reached its lower explosive limit of 2.1 percent (propane in air), prior to the fuel being fully depleted from a 1-pound disposable bottle of propane gas.

Heater B

Heater B was a single burner radiant heater with a manufacturer's specified energy-input rate ranging up to 3,000 Btu/hr. Averaging the energy-input rate data in Table A2 yields the following average energy-input rates: 1,540 Btu/hr ± 670 Btu/hr at the heater's minimum setting and 3,050 Btu/hr ± 190 Btu/hr at the heater's maximum setting.

The data in Table A2 indicates that Heater B did comply with the combustion requirements of ANSI Z21.63 (2000) when the heater was operated at its minimum energy-input rate, but it did not comply when the heater was operated at its maximum energy-input rate. During tests in which the heater did not comply with the standard, the O_2 concentration was depleted to 16 percent within 1.04 to 3.27 hours and the CO concentration was increased to 100 ppm within 1.05 to 1.54 hours.

Figure 6 illustrates how the peak CO concentration measured in the chamber varied with the air exchange rate. For all tests, the peak CO concentration ranged from 19 ppm to 391 ppm. The maximum concentration of CO measured in the chamber was 391 ppm and occurred at an air exchange rate of 0.53 ACH, which caused the flame on the heater to self-extinguish. The maximum CO concentration obtained without the flame extinguishing was 358 ppm and occurred when the heater was operated at its maximum energy-input rate and with the air exchange rate adjusted to 0.77 ACH. At these conditions, the CO reached its peak concentration within 4 hours and the heater would have continued to operate for an additional 3.32 hours before the fuel was totally consumed from a 1-pound disposable bottle of propane gas.

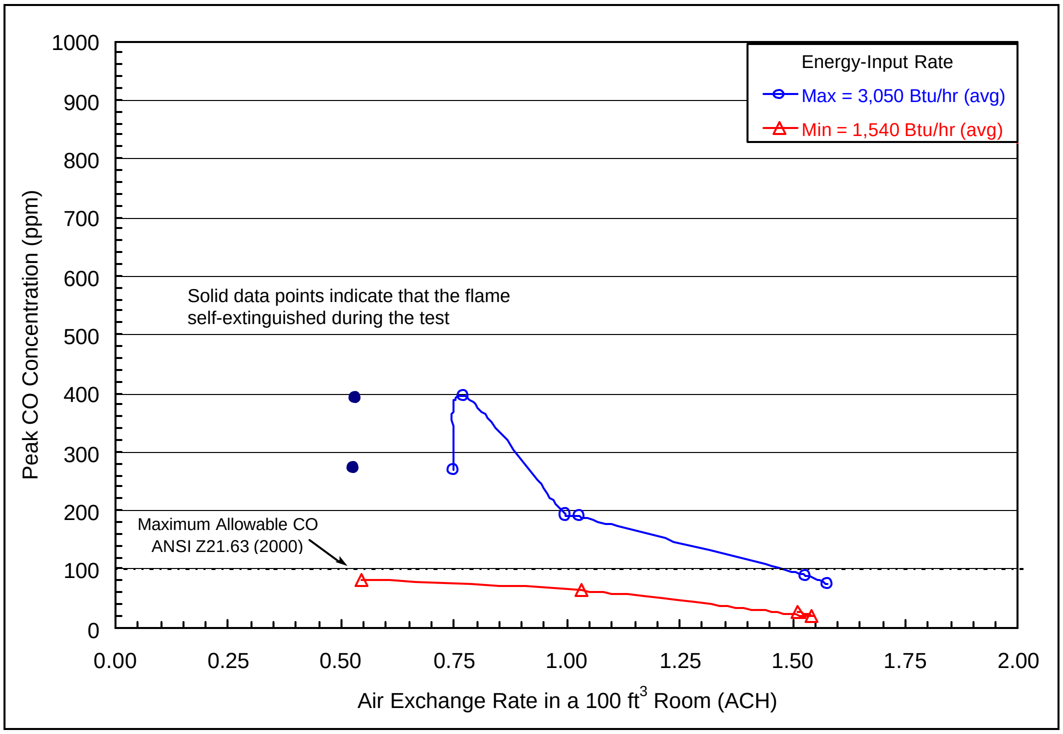

Figure 6. Peak CO concentration versus air exchange rate for Heater B (Single Burner Radiant Heaters).

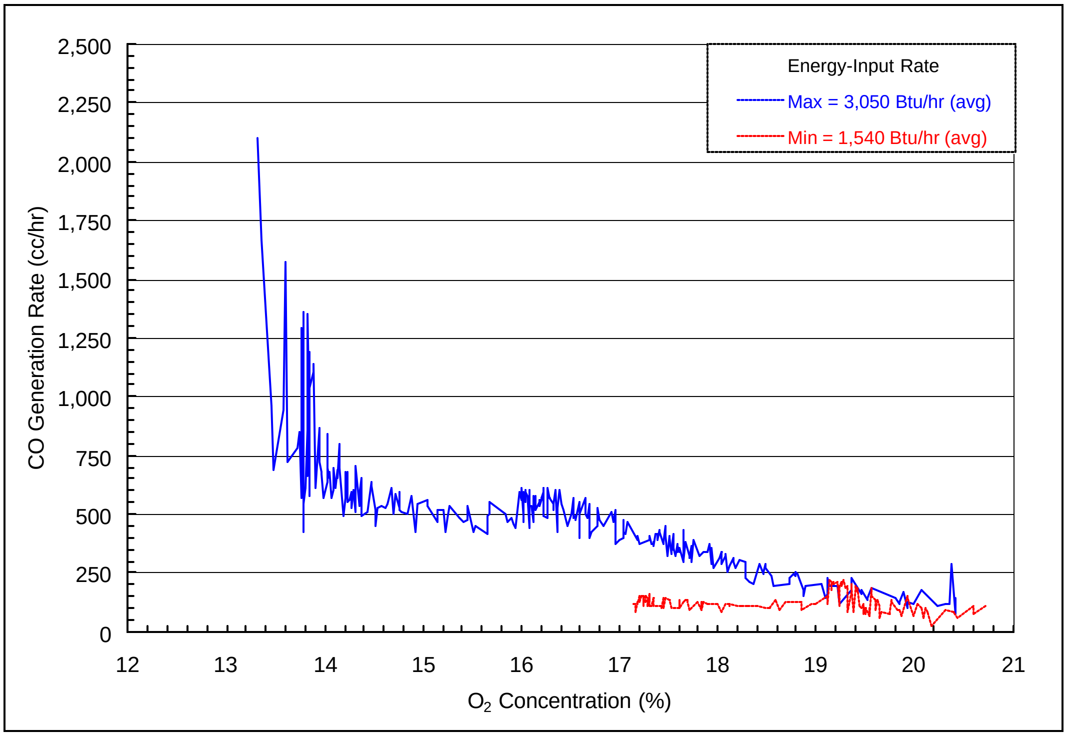

Figure 7. CO generation rate versus O_2 concentration for Heater B (Single Burner Radiant Heater). The figure includes data for all tests.

The air exchange rate at which the CO concentration exceeded the allowable CO limit of 100 ppm depended on the energy-input rate of the heater. When the heater was operated at its maximum energy-input rate, the peak CO concentration exceeded 100 ppm when the air exchange rate was less than 1.5 ACH. When the heater was operated at its minimum energy-input rate, the peak CO concentration never exceeded 100 ppm, although tests were not conducted below an air exchange rate of 0.5 ACH.

Figure 7 illustrates how the CO produced by the heater was a function of the O_2 concentration in the chamber and the heater's energy-input rate. Heater B was similar to Heater A, in that Heater B produced more CO when it was operated at its maximum energy-input rate than when it was operated at its minimum energy-input rate. In general, Heater B generated CO at a rate that steadily increased as the O_2 concentration decreased. The CO generation rate started to increase rapidly when the O_2 concentration was depleted below approximately 15 percent. For all tests, the CO generation rate ranged from 26 cc/hr to 2,097 cc/hr.

When the O_2 concentration in the chamber was depleted below approximately 13.5 percent, the flame on the heater would self-extinguish. Since the heater did not have an automatic safety shut off system, the heater had to be manually turned off. Had the heater remained on, the concentration of propane would have eventually reached its lower explosive limit of 2.1 percent (propane in air), prior to the fuel being depleted from a 1-pound disposable bottle of propane gas.

RADIANT HEATER/COOKERS

Heater C

Heater C was a radiant heater/cooker with a manufacturer's specified energy-input rate of 9,000 Btu/hr at the heater's minimum setting and 15,000 Btu/hr at the heater's maximum setting. As the data in Table A3 indicates, the experimentally determined energy-input rate varied somewhat between tests for a given heater setting. Averaging the energy-input rate data in Table A3 yields the following average energy-input rates: 7,790 Btu/hr $\pm$ 370 Btu/hr at the heater's minimum setting and 9,630 Btu/hr $\pm$ 190 Btu/hr at the heater's maximum setting.

A review of the data in Table A3 indicates that Heater C did not comply with the combustion requirements of ANSI Z21.63 (2000) during any tests at the air exchange rates specified in the standard. Depending on the test conditions, the O_2 concentration inside the chamber was depleted to 16 percent within 23 to 29 minutes, while the CO concentration inside of the chamber was increased to 100 ppm within 18 to 36 minutes.

Figure 8 illustrates how the peak CO concentration in the chamber varied with the air exchange rate and the energy-input rate of the heater. When the heater was operated at the air exchange rates specified in the standard, the flame on the heater would self-extinguish. Therefore, tests were conducted at air exchange rates greater than that specified in the standard to prevent the flame from going out. For all tests, the CO concentration ranged from 174 ppm to 687 ppm. The maximum CO concentration of 687 ppm was obtained when the heater was operated at its *minimum* energy-input rate and the air exchange rate was set to 1.97 ACH. At these test conditions, the CO concentration peaked within 3.00 hours, just prior to the fuel being totally consumed from a 1-pound disposable bottle of propane gas. Had the heater been connected to a 20-pound tank of propane gas, the heater would have continued to operate for well over 24 hours.

The rate at which Heater C generated CO was a function of the O_2 concentration and the heater's energy-input rate. Unlike the single burner radiant heaters, Heater C produced more CO when it was operated at its *minimum* energy-input rate than when it was operated at its *maximum* energy-input rate. As Figure 9 illustrates, the heater generated CO at a fairly constant rate as the O_2 concentration decreased. The CO generation rate started to increase rapidly when the O_2 concentration was depleted below

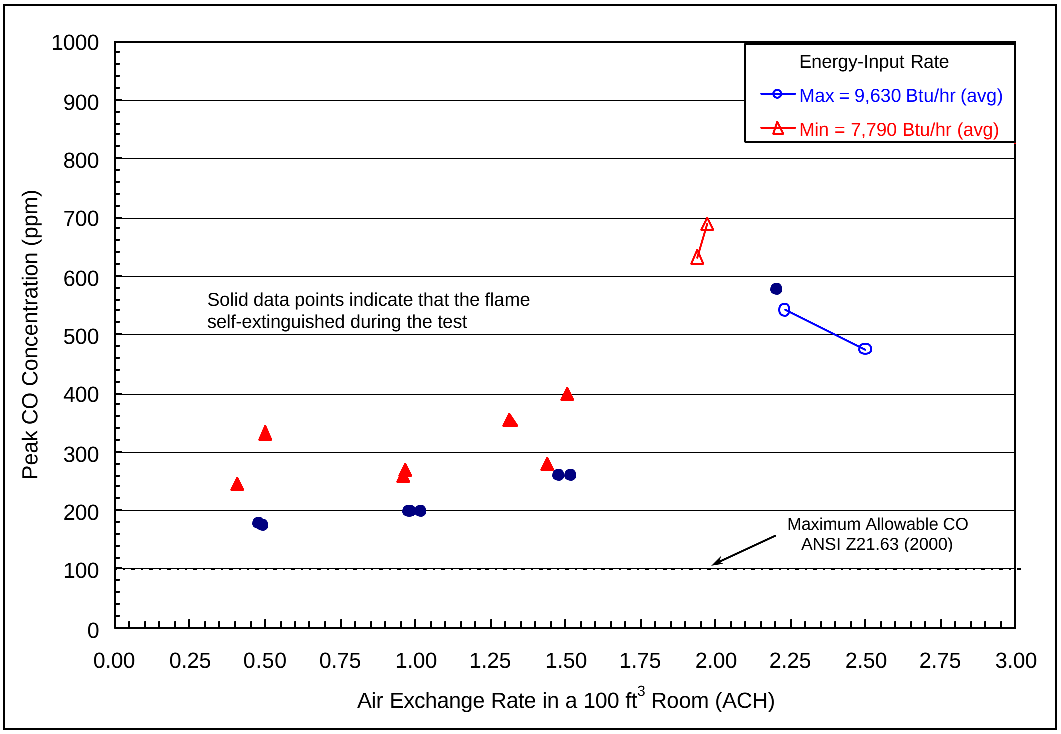

Figure 8. Peak CO concentration versus air exchange rate for Heater C (Radiant Heater/Cooker).

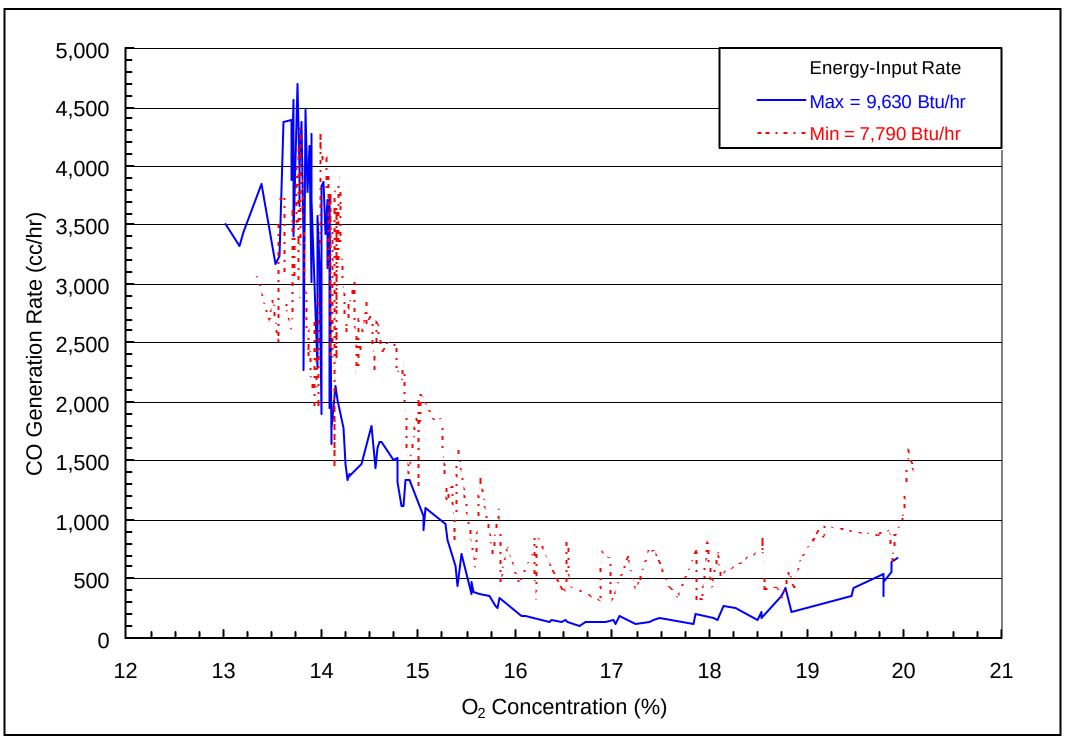

Figure 9. CO generation rate versus O_2 concentration for Heater C (Radiant Heater/Cooker). The figure includes data for all tests.

approximately 16 percent. The heater continued to operate in low O_2 conditions, down to approximately 13.5 percent, before the flame self-extinguished. For all tests, the CO generation rate ranged from 91 cc/hr to 4,694 cc/hr.

Heater D

Heater D was a radiant heater/cooker with a manufacturer's specified energy-input rate of 10,000 Btu/hr at the heater's minimum setting and 14,000 Btu/hr at the heater's maximum setting. Averaging the energy-input rate data in Table A4 yields the following average energy-input rates: 10,140 Btu/hr ± 320 Btu/hr at the heater's minimum setting and 12,510 Btu/hr ± 660 Btu/hr at the heater's maximum setting.

A review of the data in Table A4 indicates that Heater D did not comply with the combustion section of ANSI Z21.63 (2000) during any tests at the air exchange rates specified in the standard. Depending on the test conditions, the O_2 concentration inside the chamber was depleted to 16 percent within 13 to 21 minutes, while the CO concentration inside of the chamber was increased to 100 ppm within 18 to 26 minutes.

Figure 10 illustrates how the CO concentration in the chamber varied with the air exchange rate. Since the heater's flame would self-extinguish at the air exchange rates specified by the standard, tests were conducted at air exchange rates greater than that specified in the standard to prevent the flame from going out. For all tests, the CO concentration ranged from 160 ppm to 260 ppm. The maximum CO concentration of 260 ppm was obtained when the heater was operated at its *minimum* energy-input rate and the air exchange rate was set to 3.17 ACH. At these test conditions, the CO reached its peak within 2.28 hours, just prior to the fuel being totally consumed from a 1-pound disposable bottle of propane gas. Had the heater been connected to a 20-pound tank of propane gas, the heater would have continued to operate for well over 24 hours.

The rate at which the heater produced CO varied with the O_2 concentration, but did not appear to vary with the heater's energy-input rate. As Figure 11 illustrates, the heater generated CO at a fairly constant rate as the O_2 concentration decreased. The CO generation rate began to increase rapidly when the O_2 concentration fell below approximately 17 percent. The CO generation rate peaked between 14.5 and 15 percent O_2, and then leveled off. The rate of CO production started to increase more rapidly when the O_2 concentration fell below 13.4 percent. The flame finally self-extinguished when the O_2 concentration was less than 13.3 percent. For all tests, the CO generation rate ranged from 91 cc/hr to 5,152 cc/hr.

Heater E

Heater E was a radiant heater/cooker with a manufacturer's specified energy-input rate of 8,000 Btu/hr at the heater's minimum setting and 14,000 Btu/hr at the heater's maximum setting. Averaging the energy-input rate data in Table A5 yields the following average energy-input rates: 7,380 Btu/hr ± 310 Btu/hr at the heater's minimum setting and 11,050 Btu/hr ± 320 Btu/hr at the heater's maximum setting.

A review of the data in Table A5 indicates that Heater E did not comply with the combustion section of ANSI Z21.63 (2000) during any tests at the air exchange rates specified in the standard. Depending on the test conditions, the O_2 concentration inside of the chamber was depleted to 16 percent within 15 to 29 minutes. The CO concentration inside of the chamber was increased to 100 ppm within 24 to 40 minutes.

Figure 12 illustrates how the peak CO concentration in the chamber varied with the air exchange rate. When the heater was operated at its maximum energy-input rate, the flame on the heater self-extinguished at the air exchange rates specified by the standard. Therefore, tests were conducted at air

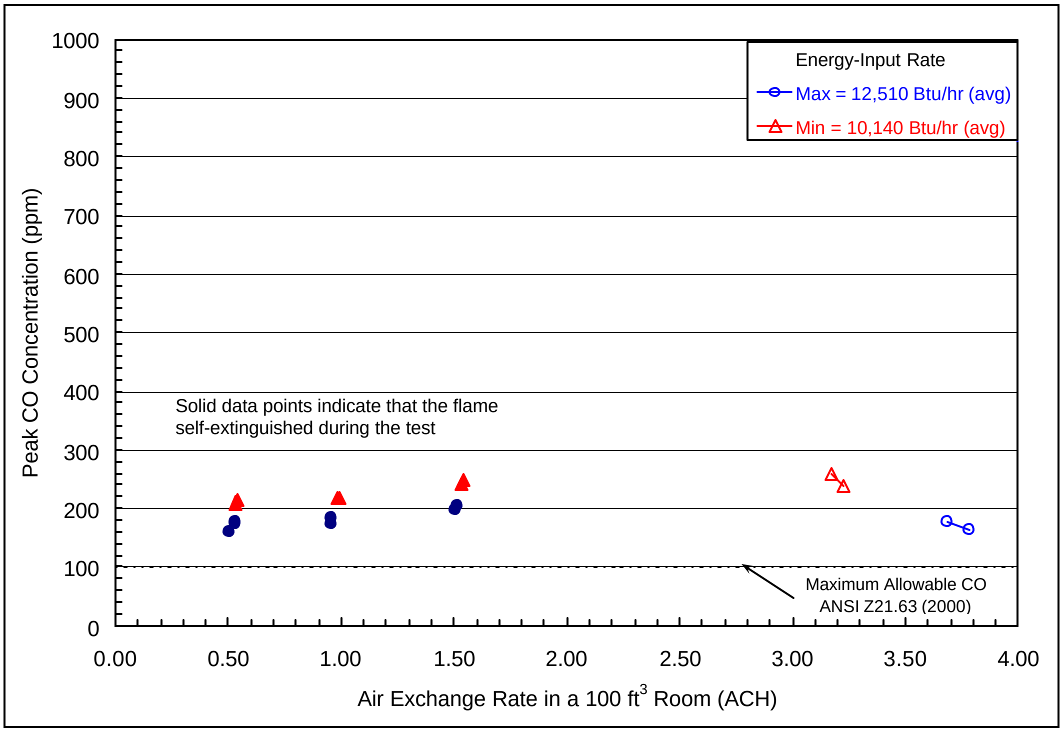

Figure 10. Peak CO concentration versus air exchange rate for Heater D (Radiant Heater/Cooker).

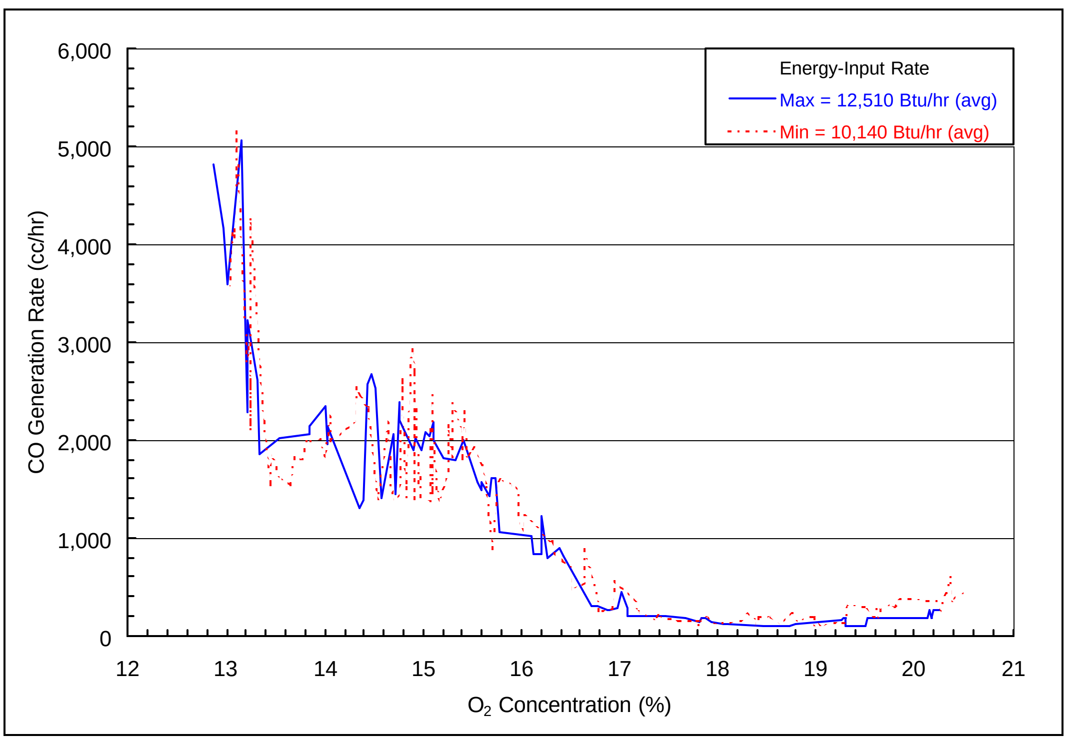

Figure 11. CO generation rate versus O_2 concentration for Heater D (Radiant Heater/Cooker). The figure includes data for all tests.

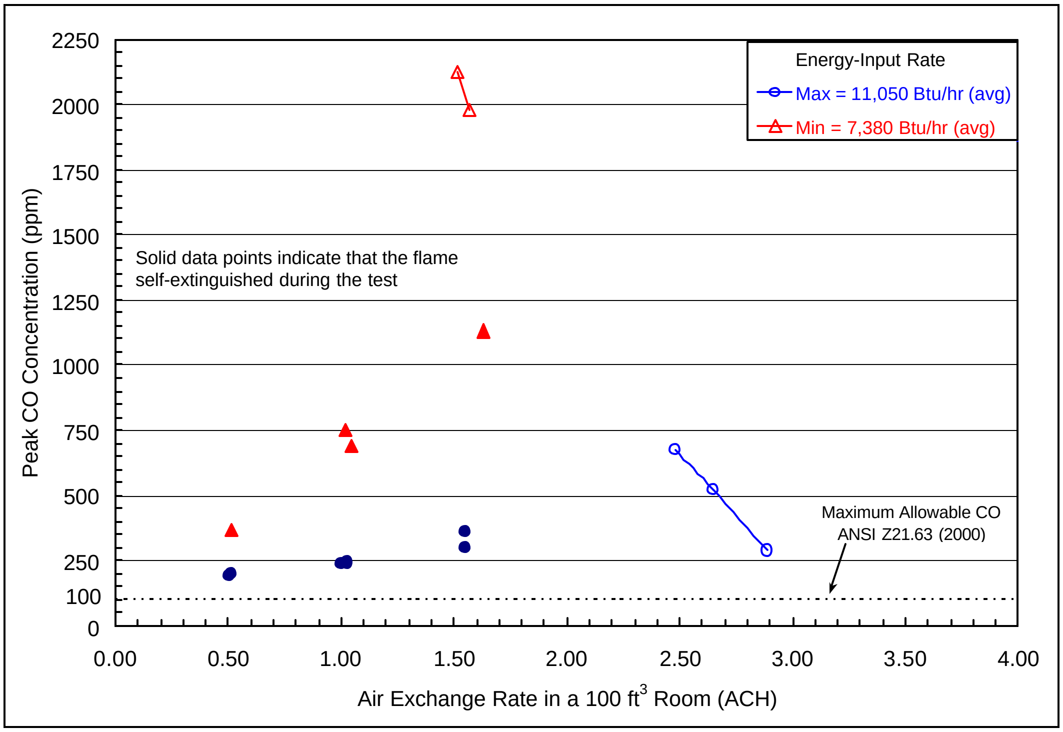

Figure 12. Peak CO concentration versus air exchange rate for Heater E (Radiant Heater/Cooker).

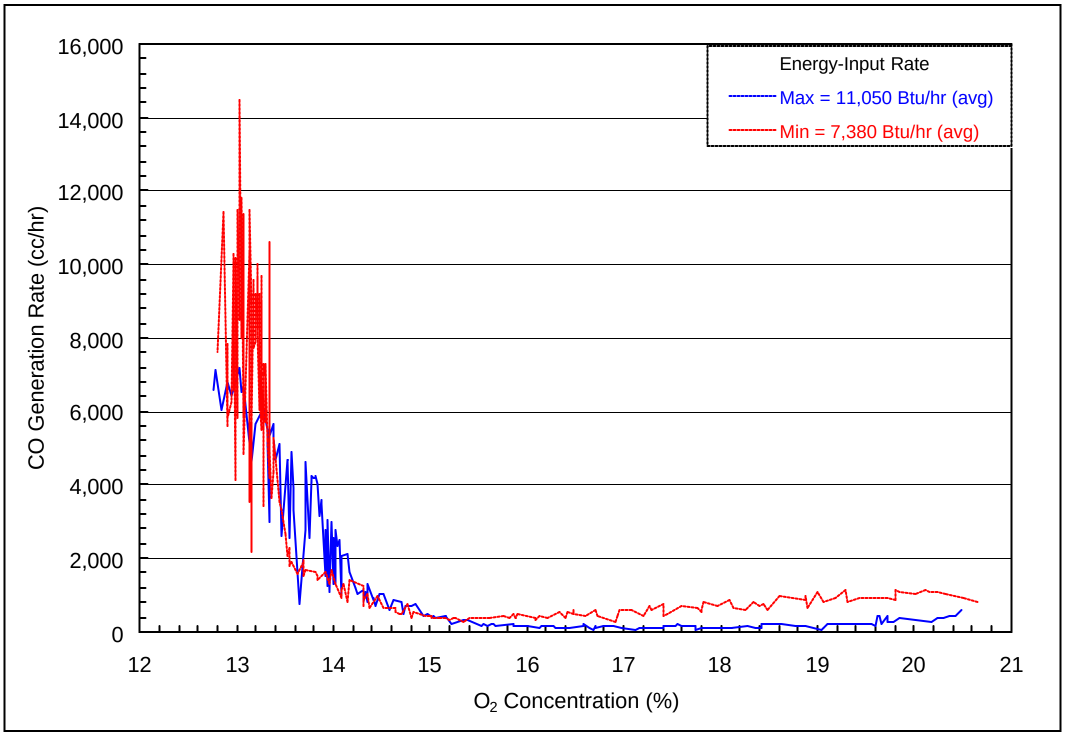

Figure 13. CO generation rate versus O_2 for Heater E (Radiant Heater/Cooker). The figure includes data for all tests.

exchange rates greater than that specified in the standard to prevent the flame from going out. For all tests, the CO concentration ranged from 191 ppm to 2,124 ppm. The maximum CO concentration of 2,124 ppm was obtained when the heater was operated at its *minimum* energy-input rate and the air exchange rate was set to 1.52 ACH. At these test conditions, the CO reached its peak within 3.13 hours, just prior to the fuel being totally consumed from a 1-pound disposable bottle of propane gas. Had the heater been connected to a 20-pound tank of propane gas, the heater would have continued to operate for well over 24 hours.

The rate at which Heater E produced CO varied with the O_2 concentration and to some extent, with the energy-input rate of the heater. As Figure 12 illustrates, the heater generated CO at a fairly constant rate as the O_2 concentration decreased. The CO generation rate began to increase rapidly when the O_2 concentration was depleted below approximately 15 percent. The CO generation rate continued to increase until the flame finally self-extinguished when the O_2 concentration was depleted below approximately 12.9 percent. For all tests, the CO generation rate ranged from 31 cc/hr to 14,471 cc/hr.

Heater F

Heater F was a radiant heater/cooker with a manufacturer's specified energy-input rate of up to 10,000 Btu/hr. The heater was tested only at its maximum energy-input rate setting, since the flame on the heater would self-extinguish when the control knob on the heater was adjusted to a lower setting. Averaging the energy-input rate data in Table A6 yields an average energy-input rate of 9,900 Btu/hr ± 1,210 Btu/hr.

A review of the data in Table A6 indicates that Heater F did not comply with the combustion section of ANSI Z21.63 (2000) during any tests at the air exchange rates specified in the standard. Depending on the test conditions, the O_2 concentration inside of the chamber was depleted to 16 percent within 14 to 25 minutes and the CO concentration inside of the chamber was increased to 100 ppm within 32 to 42 minutes.

Figure 14 illustrates how the peak CO concentration in the chamber varied with the air exchange rate. The flame on the heater self-extinguished when tests were conducted at the air exchange rates specified in the standard. Therefore, tests were conducted at higher air exchange rates to prevent the flame from going out. For all tests, the CO concentration ranged from 75 ppm to 402 ppm. The maximum CO concentration obtained in the chamber without the flame going out was 331 ppm and occurred at an air exchange rate of 2.93 ACH. This peak CO concentration occurred after operating the heater for 1.44 hours and the heater would have continued to operate for an additional 42 minutes before the fuel was totally consumed from a 1-pound disposable bottle of propane gas.

The rate at which Heater F produced CO was a function of the O_2 concentration. As Figure 15 illustrates, the heater generated CO at a fairly constant rate as the O_2 concentration decreased. The CO generation rate began to increase rapidly when the O_2 concentration fell below approximately 14 percent. The CO generation rate continued to increase until the flame finally self-extinguished when the O_2 concentration was depleted below 13.4 percent. For all tests, the CO generation rate ranged from 24 cc/hr to 6,157 cc/hr.

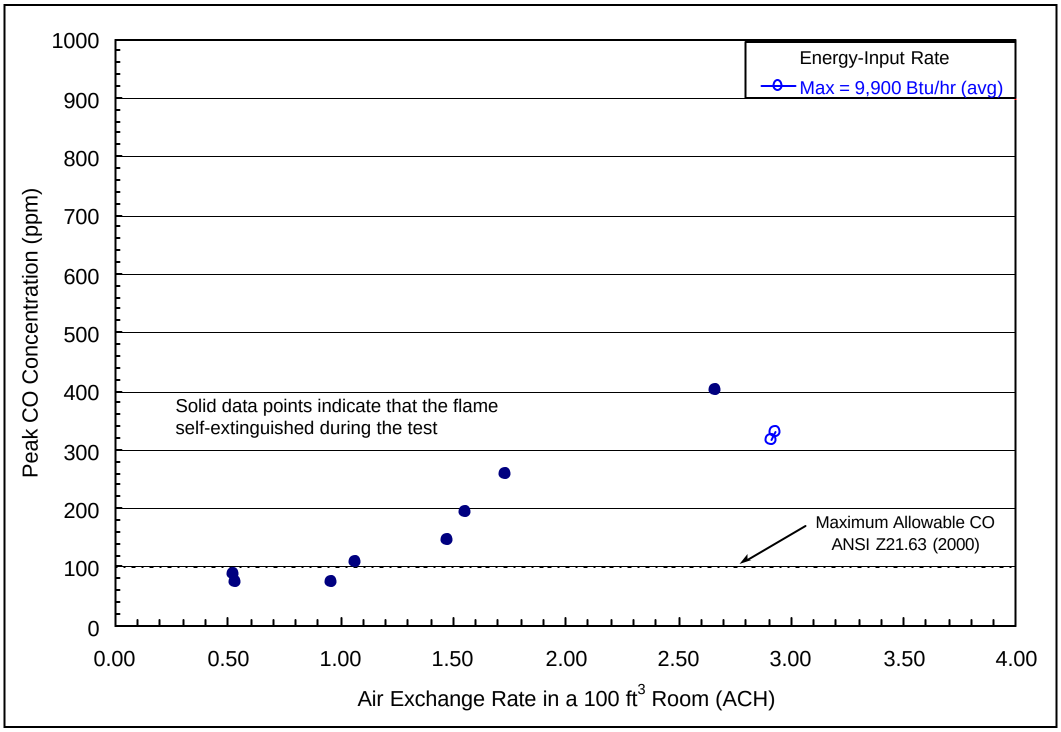

Figure 14. Peak CO versus air exchange rate for Heater F (Radiant Heater/Cooker).

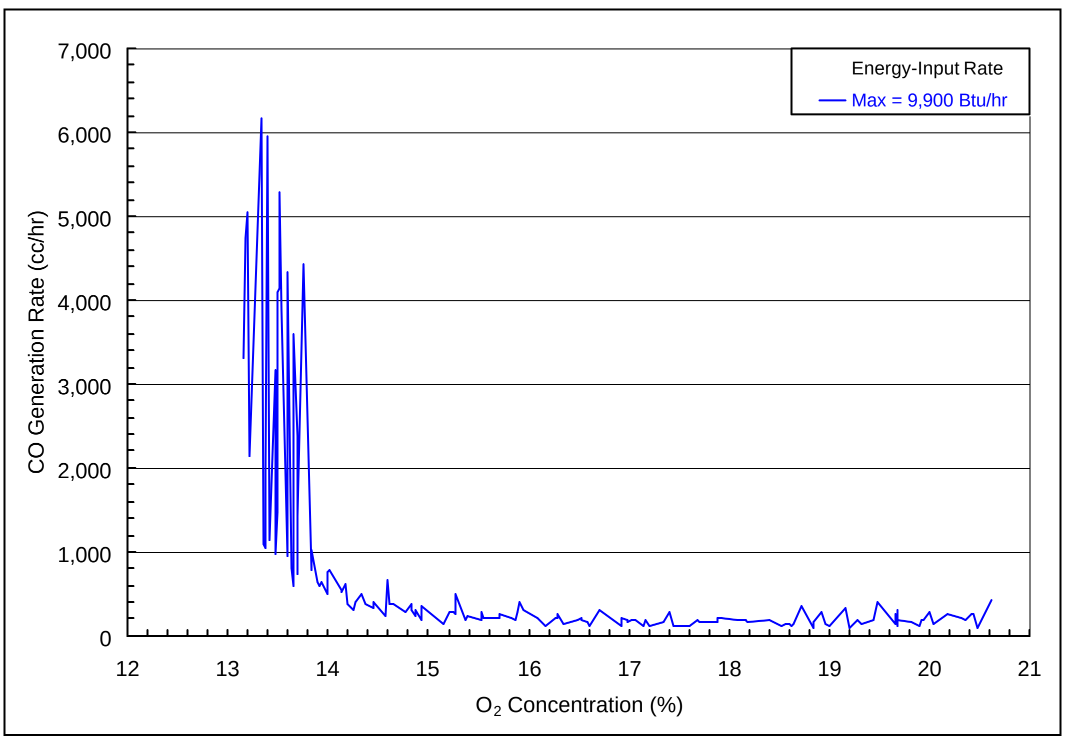

Figure 15. CO generation rate versus O_2 concentration for Heater F (Radiant Heater/Cooker). The figure includes data for all tests.

ODS-EQUIPPED RADIANT HEATERS

Heater G

Heater G was an ODS-equipped radiant heater with a manufacturer's specified energy-input rate of 4,000 Btu/hr at the heater's minimum setting and 9,000 Btu/hr at the heater's maximum setting. Averaging the energy-input rate data in Table A7 yields the following average energy-input rates: 4,720 Btu/hr ± 95 Btu/hr at the heater's minimum setting and 6,390 Btu/hr ± 130 Btu/hr at the heater's maximum setting.

A review of the data in Table A7 indicates that Heater G complied with the combustion section of ANSI Z21.63 (2000). The ODS shut the heater off when the O_2 concentration was between 19.0 to 19.6 percent, which prevented the CO concentration from reaching 100 ppm in the chamber.

Figure 16 illustrates how the peak CO concentration in the chamber varied with the air exchange rate and the energy-input rate of the heater. Tests were conducted at air exchange rates greater than those specified by the standard, to prevent the O_2 concentration from being depleted to a point that would cause the heater to shut off. For all tests, the CO concentration ranged from 18 ppm to 46 ppm. The maximum CO concentration of 46 ppm occurred during a test in which the heater shut off automatically. The maximum CO concentration obtained in the chamber without the heater turning off was 39 ppm and occurred when the heater was operated at its *minimum* energy-input rate and the air exchange rate was set to 5.64 ACH. The CO concentration peaked after operating the heater for approximately 35 minutes at these test conditions and the heater would have continued to operate for an additional 4.26 hours before the fuel was totally consumed from a 1-pound disposable bottle of propane gas.

Figure 17 illustrates how the CO generation rate varied with the O_2 concentrations and the energy-input rate of the heater. Heater G produced more CO at a given O_2 concentration when the heater was operated at its *minimum* energy-input rate compared to when the heater was operated at its maximum energy-input rate. As the O_2 concentration was depleted to the point that caused the heater to shut off, the heater produced CO a fairly constant rate. For all tests, the heater produced CO at rates up to 1,388 cc/hr.

Heater H

Heater H was an ODS-equipped radiant heater with a manufacturer's specified energy-input rate of 4,500 Btu/hr at the heater's minimum setting and 8,000 Btu/hr at the heater's maximum setting. Averaging the energy-input rate data in Table A8 yields the following average energy-input rates: 5,130 Btu/hr ± 260 Btu/hr at the heater's minimum setting and 6,860 Btu/hr ± 325 Btu/hr at the heater's maximum setting.

A review of the data in Table A8 indicates that Heater H complied with the combustion section of ANSI Z21.63 (2000). The ODS shut the heater off when the O_2 concentration was between 18.8 to 19.4 percent, which prevented the CO concentration from reaching 100 ppm in the chamber.

Figure 18 illustrates how the peak CO concentration in the chamber varied with the air exchange rate. Tests were conducted at air exchange rates greater than those specified by the standard, to prevent the O_2 concentration from being depleted to a point that would cause the heater to shut off. For all tests, the CO concentration ranged from 12 ppm to 38 ppm. The maximum CO concentration of 38 ppm occurred when the heater was operated at its *minimum* energy-input rate and the air exchange rate was set to 4.64 ACH. The CO concentration reached its peak concentration after operating the heater at these test conditions for approximately 50 minutes and the heater would have continued to operate for an additional 3.72 hours before the fuel was totally consumed from a 1-pound disposable bottle of propane gas.

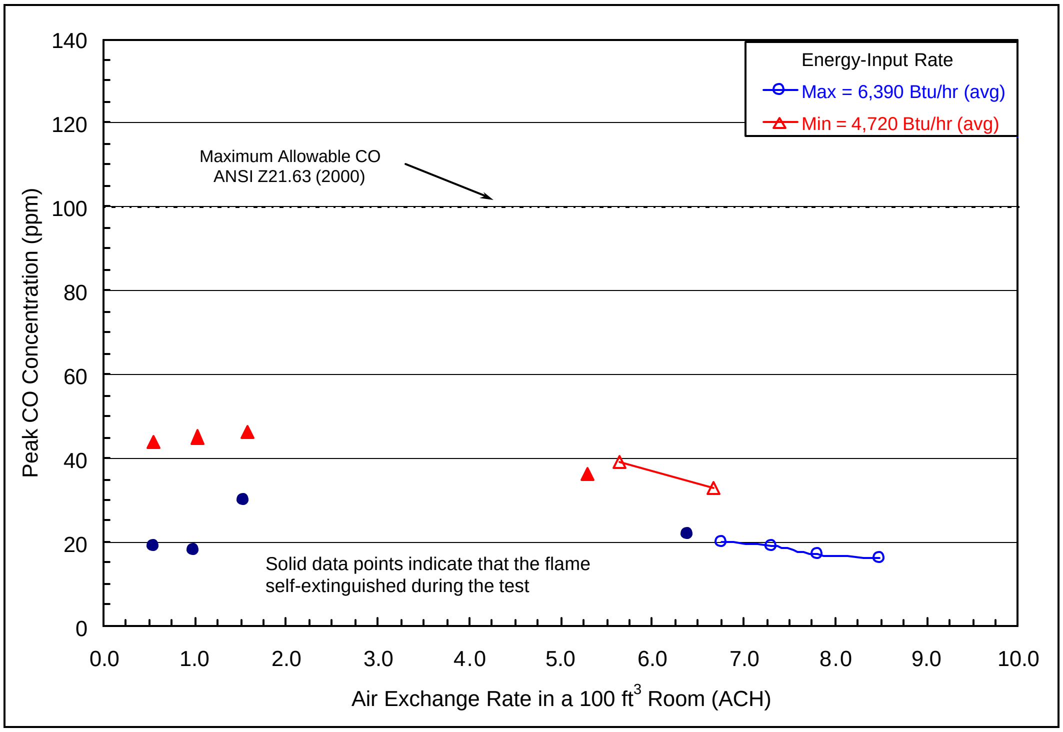

Figure 16. Peak CO versus air exchange rate for Heater G (ODS-equipped Radiant Heater).

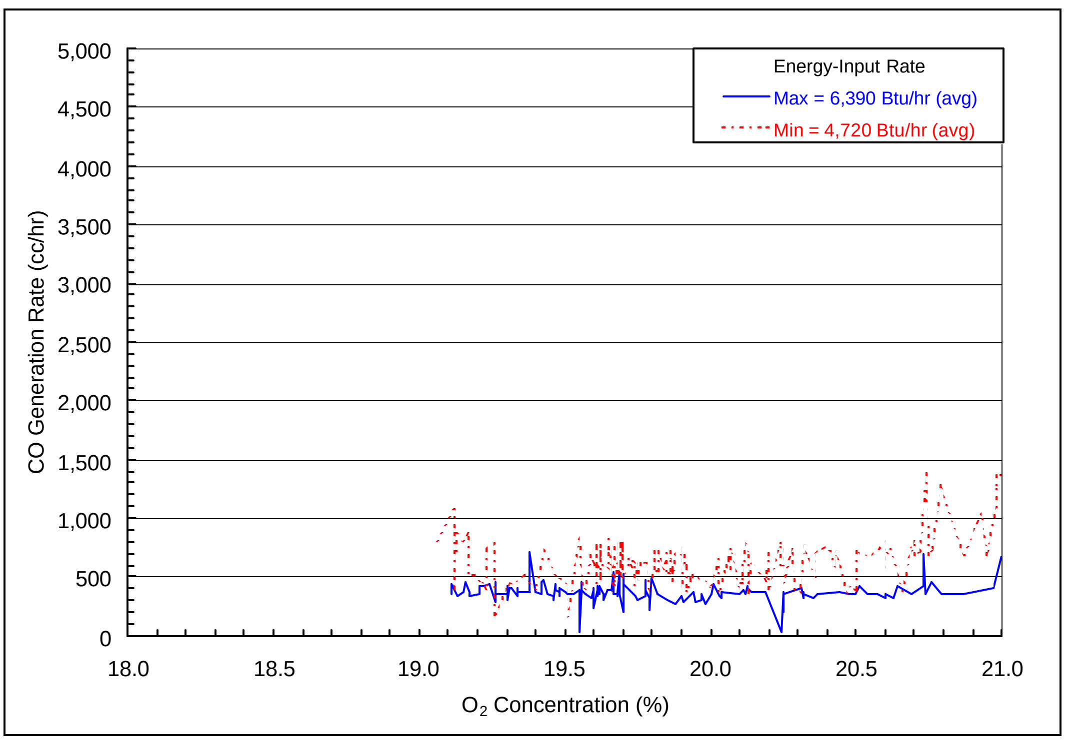

Figure 17. CO generation rate versus O_2 for Heater G (ODS-equipped Radiant Heater). The figure includes data for all tests.

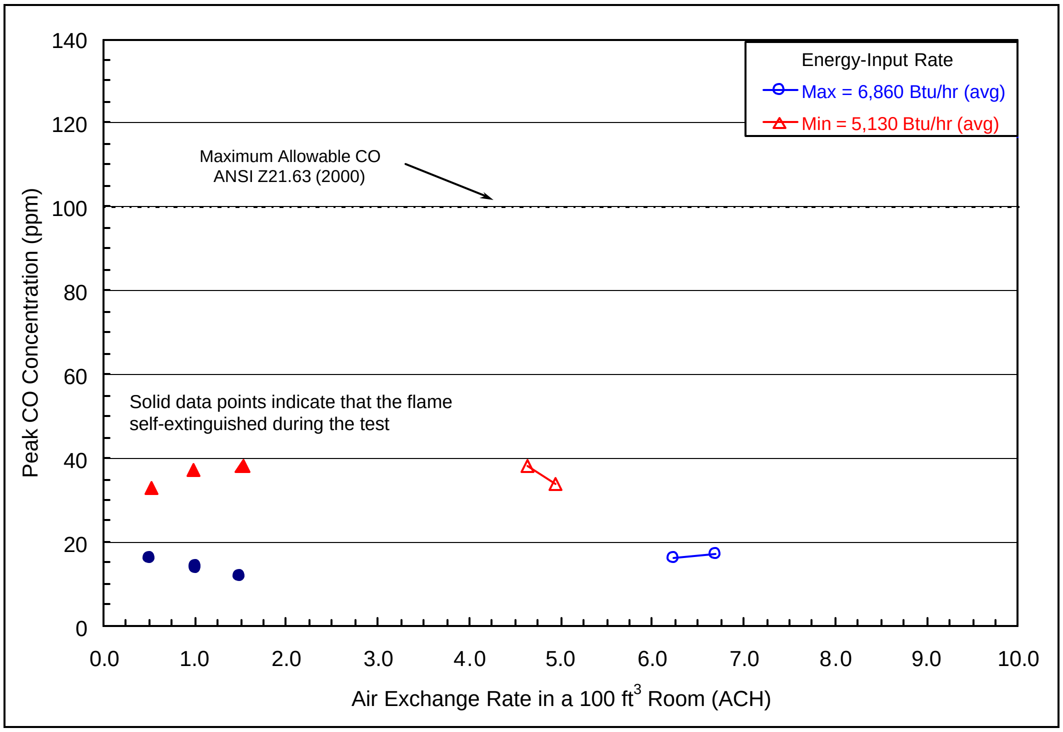

Figure 18. Peak CO concentration versus air exchange rate for Heater H (ODS-equipped Radiant Heater).

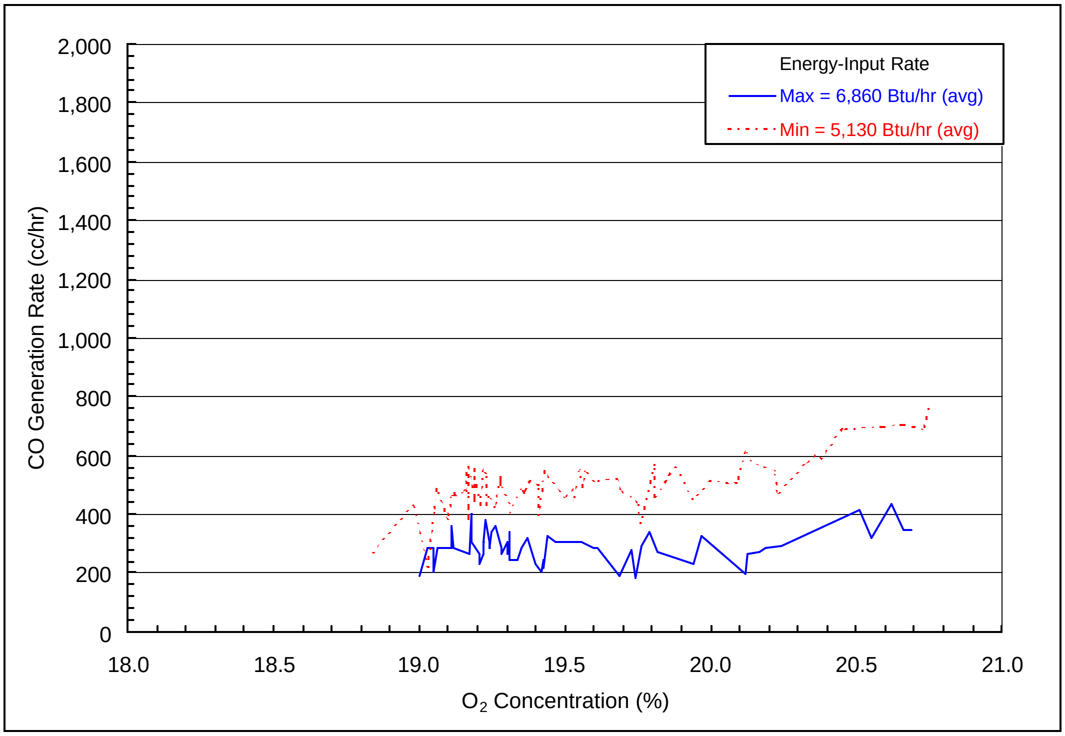

Figure 19. CO generation rate versus O_2 concentration for Heater H (ODS-equipped Radiant Heater). The figure includes data for all tests.

Figure 19 illustrates how the CO generation rate varied with the O_2 concentrations and the energy-input rate of the heater. Heater H produced more CO at a given O_2 concentration when the heater was operated at its *minimum* energy-input rate compared to when the heater was operated at its maximum energy-input rate. As the O_2 concentration was depleted to the point that caused the heater to shut off, the heater produced CO at a fairly constant rate. For all tests, the heater produced CO at rates up to 759 cc/hr.

DISCUSSION

Compliance with ANSI Z21.63 (2000)

The combustion section of ANSI Z21.63 was revised in April 2000 to address the potential CO poisoning hazard associated with operating portable gas-fired heaters in small areas that are poorly ventilated. The revised standard specifies that when a heater is operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0 and 1.5 ACH, the CO concentration in the room cannot exceed 100 ppm. Furthermore, the standard also specifies that the O_2 concentration in the room cannot be depleted below 16 percent.

Figures 20 and 21 provide graphical representations of how each heater performed with respect to the CO and O_2 requirements in the standard. Figure 20 compares the maximum CO concentration obtained in the chamber at the air exchange rates specified in the standard (0.5, 1.0, and 1.5 ACH) and at the air exchange rate that resulted in the maximum CO concentration at steady state conditions (ACH – Max CO_{ss}). Figure 21 compares the minimum O_2 concentration obtained in the chamber for each heater at the air exchange rates specified in the standard and at the air exchange rate that resulted in the maximum CO concentration at steady state conditions. Both figures clearly illustrate that only the ODS-equipped radiant heaters complied with the CO and O_2 requirements in ANSI Z21.63 (2000).

As Table 4 indicates, none of the heaters were certified to ANSI Z21.63 (2000). Of the eight heaters tested, three of the heaters were within the scope of the standard: both single burner radiant heaters (Heater A and B) and one radiant heater/cooker (Heater F). Heaters B and F were manufactured overseas and the manufacturers may be unaware of the standard or have decided not to be certified to the voluntary standard. The US manufacturer of Heater A has discontinued the heater as of January 2000, prior to effective date of revised standard (April 2000). Products manufactured prior to April 2000 can be sold until supplies are exhausted.

Table 4. Summary of the camp heater tests indicating which heaters complied with the revised standard

Heater Style	Test Sample	Complies with the Combustion Requirements of ANSI Z21.63 (2000)	Within the Scope of ANSI Z21.63 (2000)	Certified to ANSI Z21.63 (2000)	Certified to a Different Standard
Single Burner Radiant Heater	A	No	Yes	No	No
	B	No	Yes	No	No
Radiant Heater/Cooker	C	No	No[1]	No	No
	D	No	No[1]	No	No
	E	No	No[1]	No	No
	F	No	Yes	No	No
ODS-Equipped Radiant Heater	G	Yes	No[2]	No	Yes[3]
	H	Yes	No[2]	No	Yes[3]

1. Maximum energy-input rate reported by manufacturer exceeds the maximum rate of 12,000 Btu/hr covered by the standard.
2. ODS-equipped radiant heaters are designed for indoor use, which is currently not covered by ANSI Z21.63 (2000).
3. *CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and Commercial Use*

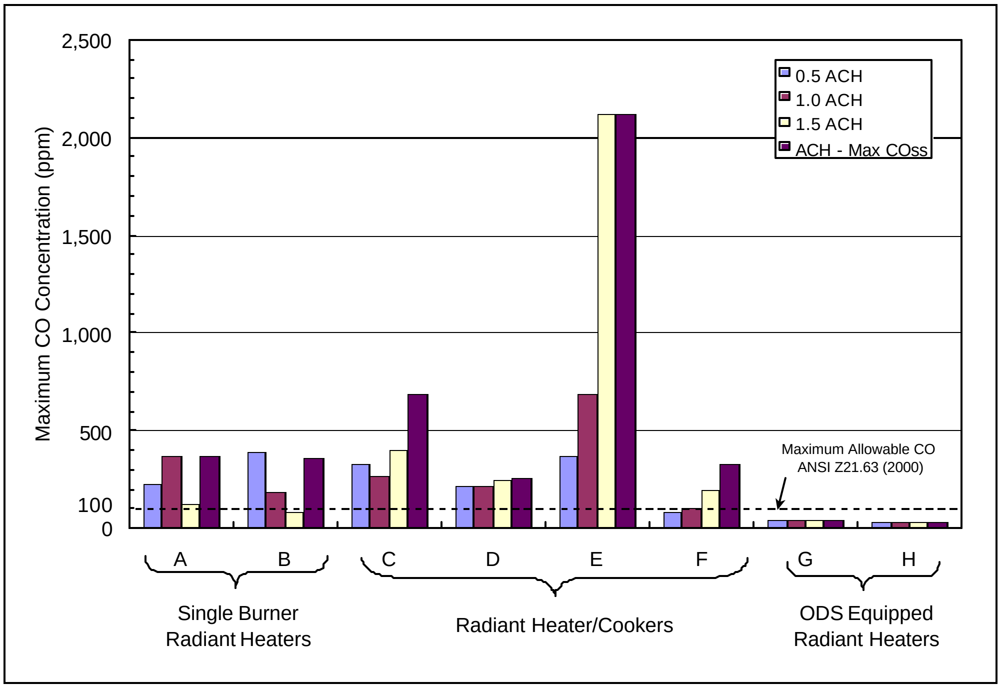

Figure 20. Comparison of the maximum CO concentration in the chamber for each heater at the air exchange rates specified in the standard and at an air exchange rate that produced the maximum CO without causing the flame to self-extinguish.

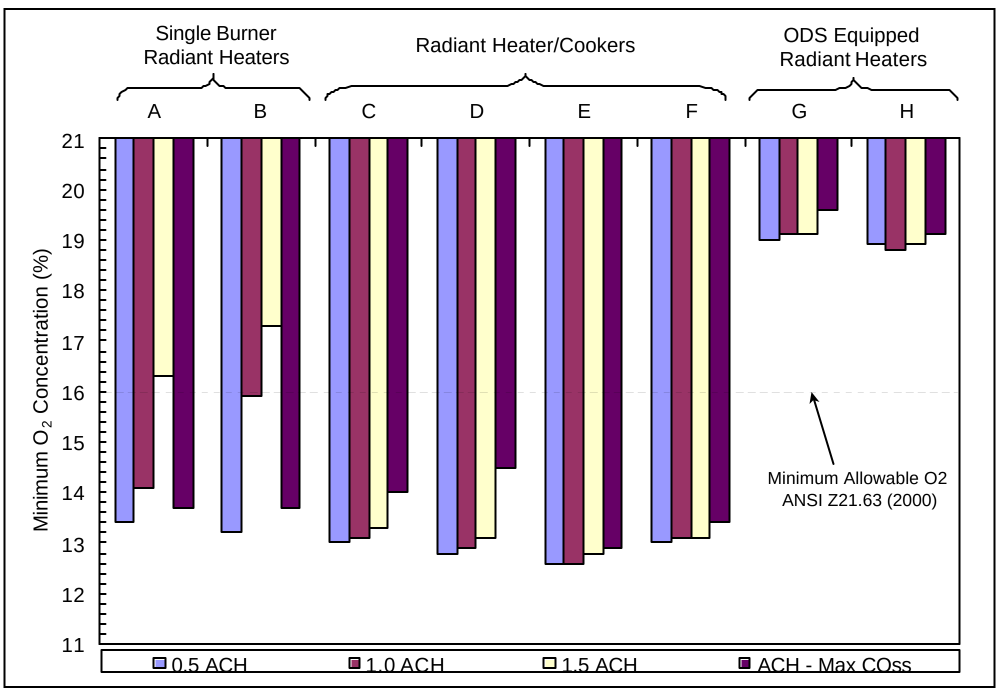

Figure 21. Comparison of the minimum O_2 concentration in the chamber for each heater at the air exchange rates specified in the standard (0.5, 1.0 and 1.5 ACH) and at an air exchange rate that produced the maximum CO without causing the flame to self-extinguish.

The two heaters equipped with an ODS were not certified to ANSI Z21.63 (2000), since the heaters were outside the scope of the standard. The ODS-equipped heaters are designed for indoor use, while ANSI Z21.63 (2000) applies to heaters designed for outdoor use. However, the ODS-equipped radiant heaters were certified to a different standard, *CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and Commercial Use*. CSA 4.98 is a supplemental standard to the standard for unvented gas-fired room heaters (*ANSI Z21.11.2-2000, Gas-Fired Room Heaters, Volume II, Unvented Room Heaters*). CSA 4.98 specifies that the CO concentration cannot exceed 100 ppm when the O_2 concentration is depleted to 18 percent in a 500 ft^3 room with no air exchanges occurring.

Three of the four radiant heater/cookers were also outside the scope of the standard, since the maximum energy-input rate of the heaters claimed by the manufacturers was greater than that covered by the standard (12,000 Btu/hr). However, CPSC staff believes that these heaters should also be covered by the standard for the following three reasons.

1. The heaters have the ability to operate at energy-input rates less than their maximum values. These lower energy-input rates are within the scope of the standard.
2. The heaters are designed for use with a 1-pound disposable bottle of propane gas, making them portable and ideal for use during outdoor activities, such as camping.
3. When the average maximum energy-input rate of these heaters was determined experimentally, two of the three heaters had a rate that was within the rate covered by the standard (Table 5). Although the method used to determine the energy-input rate was different than the method used by the manufacturers[2], it does not seem likely that the difference in methods would account for a 20 to 36 percent difference between the claimed rate and the experimental rate.

Table 5. Comparison of the maximum energy-input rates claimed by the manufacturers of Heaters C, D, and E, and the rates determined experimentally

Heater	Maximum Energy-Input Rate (Btu/hr)		
	Reported by Manufacturer	Experimentally Determined	Percent Difference
C	15,000	9,630	-35.8%
D	14,000	12,510	-10.6%
E	14,000	11,050	-21.1%

Note: The experimental rates listed are an average for all tests. Details of the energy-input rate calculation are given in Equation 4 on page 11.

Based on these observations, CPSC staff believes that the scope of the standard for ANSI Z21.63 should be revised to remove the upper limit of the energy-input rate. This action would prevent the exclusion of heaters from the standard that are well suited for camping and similar activities and that pose a CO poisoning hazard if used in tents or similar confined spaces. In addition, CPSC staff believes that the scope of the standard should be revised to include radiant heater/cookers, so that there is no confusion whether or not the standard applies to the heater/cooker combination units.

[2] The manufacturers calculate the energy-input rate of the heater by measuring the volumetric flow rate of propane gas over time. The manufacturers also measure the heating value of the gas with a calorimeter.

CO Emissions

As Figure 20 illustrated, only the ODS-equipped radiant heaters complied with the CO requirement in ANSI Z21.63 (2000). The remaining heaters generated sufficient CO to exceed 100 ppm in the chamber during some of the tests. The radiant heater/cookers generated the most CO, with levels inside the test chamber ranging from 260 ppm (Heater D) to 2,124 ppm (Heater E).

Figure 22 illustrates how the CO generation rate of each heater was a function of the O_2 concentration in the chamber. The figure was constructed by averaging the data of the CO generation rates for each heater, in increments of $\pm$ 0.25 percent O_2 about the values listed in the figure (13 to 20% O_2). Data for the heater operating at both its maximum energy-input rate and minimum energy-input rate were combined and averaged. Initially when the O_2 concentration was near 21 percent, several of the heaters generated CO at a relatively high rate. This appeared to be a function of the burner operation and not necessarily the O_2 concentration. This often occurs with radiant type heaters while the burner is warming up. Once the heaters warmed up, the CO generation rate decreased and did not increase until the O_2 concentration was depleted below approximately 16 percent. The exceptions to this were the ODS-equipped radiant heaters, which never depleted the O_2 concentration below approximately 19 percent.

Figure 23 illustrates the amount of time required for each heater to reach the following events: 100 ppm in the chamber, the maximum CO concentration in the chamber, and the depletion of a 1-pound bottle of propane gas. The data shown for each heater are for the specific test that yielded the maximum CO concentration at steady state conditions. As a reference, the maximum CO concentration obtained in the chamber for each heater is listed on the graph. Since the time intervals are a function of the heater's energy-input rate and the air exchange rate (O_2 concentration), different time intervals occur for different test conditions. In general, the CO concentration in the chamber reached 100 ppm within 0.5 to 1.25 hours of operating the heater. The exceptions to this were the ODS-equipped radiant heaters, which never reached 100 ppm. The time required to reach the maximum CO concentration in the chamber ranged from approximately 0.5 to 0.75 hours for the ODS-equipped radiant heaters, and from approximately 1.5 to 4.5 hours for the remaining heaters. The time to deplete a 1-pound disposable bottle of propane gas ranged from approximately 2.5 hrs to 7.25 hrs. It should be noted that the radiant heater/cookers could be attached to a bulk tank of propane gas, using a hose assembly. Attaching these heaters to a 20-pound tank would allow the heaters to operate continuously for more than 24 hours.

O_2 Depletion

As Figure 21 illustrated, only the ODS-equipped radiant heaters prevented the O_2 concentration from being depleted below 16 percent inside the 100 ft^3 test chamber. Based on the energy-input rate of the heaters, it was expected that most of the propane heaters would not comply with the O_2 requirement in ANSI Z21.63 (2000). This point is better illustrated by Figure 24, which shows how the steady state concentration of O_2 in the room is a function of the energy-input rate of the heater and the air exchange rate through the room. Figure 24 was constructed from a simple mass balance of O_2 in a 100 ft^3 room, assuming an initial O_2 concentration of 20.9 percent and a background O_2 concentration of 20.9 percent. It was also assumed that the propane heater consumed O_2 at a constant rate of 2 ft^3/hr for every 1000 Btu/hr of propane gas burned.[3]

Figure 24 illustrates that for a constant air exchange rate, the steady state concentration of O_2 in the room decreases as the energy-input rate of the heater increases. The point at which a constant air exchange line crosses the 16 percent O_2 line corresponds to the maximum energy-input rate that any propane heater can operate at without depleting the O_2 concentration below 16 percent.

[3] This assumes that 5 ft^3 of oxygen is consumed for 1 ft^3 of propane gas and the heating value of propane gas is 2,500 Btu/ft^3. Therefore, (5 ft^3 O_2/1 ft^3 C_3H_8)(ft^3 C_3H_8/2,500 Btu)(1,000 Btu/hr) = 2 ft^3 O_2/hr for every 1000 Btu/hr of propane gas burner.

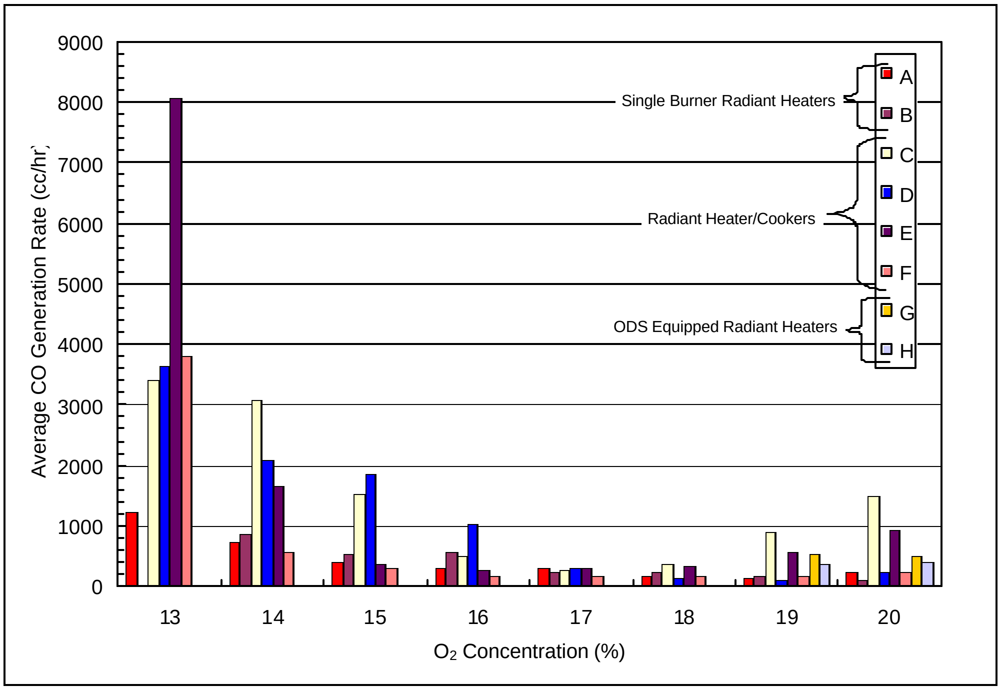

Figure 22. Average CO generation rate of each heater as a function of the O_2 concentration in the chamber.

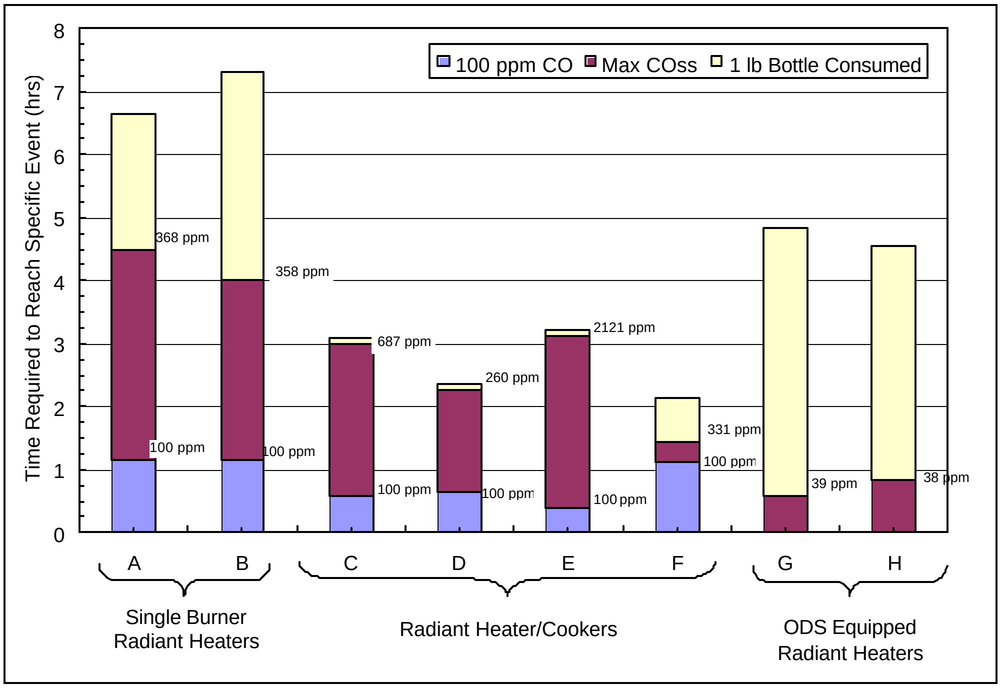

Figure 23. Time required for each heater to reach the following events: 100 ppm in the chamber, maximum CO in the chamber, and depletion of a 1-pound bottle of propane gas. For each heater, the data presented is for the test run that yielded the maximum CO level at steady state conditions. The length of time that each heater operated was a function of the heater's energy input rate and therefore varies between heaters.

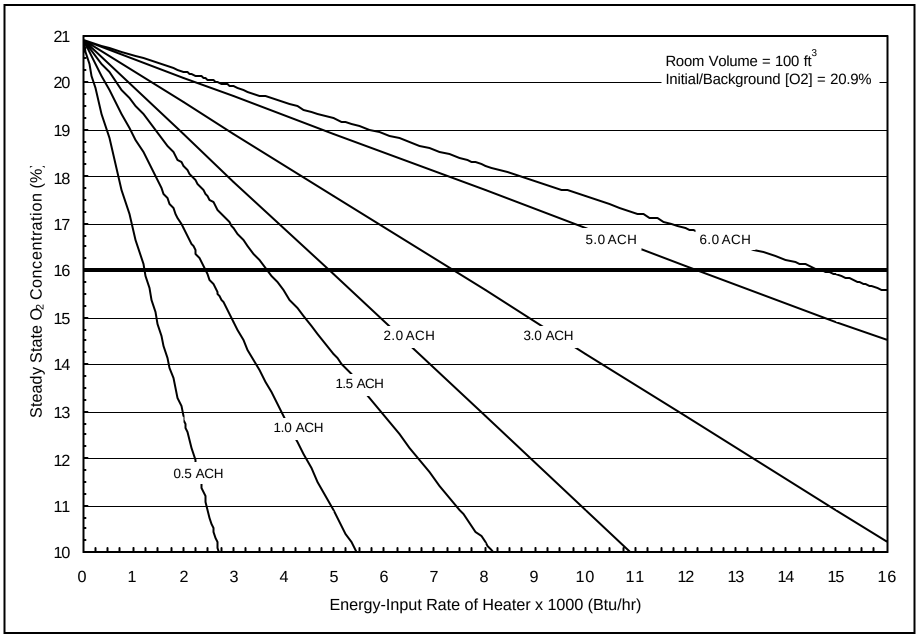

Figure 24. Predicted steady state O_2 concentrations in a 100 ft^3 room as a function of a propane heater's energy-input rate and the air exchange rate of the room.

Table 5 lists the maximum energy-input rates that result in a steady state O_2 concentration of 16 percent, for the three air exchange rates specified in the standard (0.5, 1.0 and 1.5 ACH). At the minimum air exchange rate of 0.5 ACH specified in the standard, the maximum energy-input rate that any propane heater can operate at is approximately 1,220 Btu/hr. In general, when any of the test samples were operated at an energy-input rate greater than that listed in Table 5, the O_2 concentration in the room was depleted below 16 percent. The exceptions to this were the ODS-equipped radiant heaters (Heaters G and H). The ODS turned the heaters off when the O_2 concentration fell below approximately 19 percent, allowing the heaters to comply with ANSI Z21.63 (2000). In contrast, the single burner radiant heaters (Heaters A and B) and the radiant heater/cookers (Heaters C, D, E, and F) were capable of depleting the O_2 concentration down to 13.5 to 14 percent before the flame on the heater self extinguished.

Table 5. Calculated energy-input rates that a propane heater can operate at without depleting the O_2 concentration below 16 percent in a 100 ft^3 room.

Air Exchange Rate (air changes per hour)	Energy-Input Rate (Btu/hr)
0.5	1,220
1.0	2,450
1.5	3,700

Assumptions: An initial O_2 concentration of 20.9 percent; a background O_2 concentration of 20.9 percent, and the propane heater consumes O_2 at a constant rate of 2 ft^3/hr for every 1000 Btu/hr of propane gas burned.

CONCLUSIONS

A series of tests were conducted on eight portable propane radiant heaters to determine if the heaters complied with the combustion requirements in the revised voluntary standard for portable type gas camp heaters (ANSI Z21.63-2000). In addition, the CO emissions from each heater were documented.

Eight different heaters (denoted as Heaters A through H) were tested as part of this project. Based on the type of heater, the heaters can be divided into three different groups: (1) single burner radiant heaters, (2) radiant heater/cookers, and (3) radiant heaters equipped with an oxygen depletion sensor (ODS). Although not all of the heaters fell within the scope of ANSI Z21.63, all of the heaters could be used in typical camping situations. Therefore, all of the heaters were tested to the combustion requirements of ANSI Z21.63 (2000), since the standard provides guidelines for assessing whether a heater could present a CO poisoning hazard to consumers.

To evaluate the combustion characteristics of each propane heater, the heater was operated in a 100 ft^3 test chamber at the air exchange rates specified in ANSI Z21.63 (2000). Tests were also performed at other air exchange rates, since the maximum steady state concentration of CO did not necessarily occur at one of the air exchange rates specified in the standard. Gas samples were continually withdrawn from the test chamber and analyzed for CO, CO_2, O_2, and HC.

The following is a summary of CPSC staff's findings:

- Two *Single Burner Radiant Heaters* were tested (Heaters A and B) and neither heater complied with the combustion requirements in ANSI Z21.63 (2000). The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater A, 368 ppm at 0.92 ACH; and Heater B, 358 ppm at 0.77 ACH.
- Four *Radiant Heater/Cookers* were tested (Heaters C to F) and none of the heaters complied with the combustion requirements in ANSI Z21.63 (2000). The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater C, 687 ppm at 1.97 ACH; Heater D, 260 ppm at 3.07 ACH; Heater E, 2124 ppm at 1.52 ACH; and Heater F, 331 ppm at 2.93 ACH.
- Two *ODS-equipped Radiant Heaters* were tested (Heaters G and H) and both heaters complied with the combustion requirements in ANSI Z21.63 (2000). The ODS shut the heater off when the O_2 concentration ranged from 18.8 to 19.6 percent, which prevented the CO concentration from exceeding 100 ppm in the chamber. The maximum CO concentration measured in the chamber at steady state conditions for each heater was as follows: Heater G, 39 ppm at 5.64 ACH; and Heater H, 38 ppm at 4.64 ACH.
- In general, the CO concentration did not exceed 100 ppm in the test chamber until the O_2 concentration was depleted below approximately 16 percent. In order to prevent the O_2 concentration from being depleted below 16 percent, the heater must either operate at an extremely low energy-input rate or the heater must incorporate some sort of safety shut-off device, like an ODS.
- None of the eight heaters tested were certified to ANSI Z21.63 (2000).
    - Three of the heaters were within the scope of the standard. One of the heaters was manufactured prior to the effective date of the revised standard. The remaining two heaters were manufactured overseas and the manufacturers may be unaware of the standard or have decided not to be certified to the voluntary standard.
    - The two heaters equipped with an ODS were outside the scope of the standard and were certified to a different standard, *CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and Commercial Use*. CSA 4.98 applies to gas-fired portable heaters for recreational and commercial use, that are equipped with an ODS.

- Three of the heaters were outside the scope of the standard since the maximum energy-input rate of the heaters claimed by the manufacturers were greater than the maximum rate covered by the standard (12,000 Btu/hr). When the maximum energy-input rate of these heaters was determined experimentally, two of the three heaters had a rate that was within the energy-input rate covered by the standard. In addition, each of these units could be operated at lower energy-input rates that were within the scope of the standard.

Based on the test results, CPSC plans to:

1. Recommend to the *CGA/ANSI Z21 Joint Subcommittee on Refrigerators and Portable Camping Equipment* that the upper limit on the energy-input rate specified in the scope of the standard be removed from ANSI Z21.63. This will establish CO and O_2 requirements for portable type camp heaters that are exempt from the current standard because the products are rated by the manufacturer at rates greater than 12,000 Btu/hr. It is foreseeable that any portable gas camp heater could be brought into tents or other enclosed areas and pose a CO poisoning risk.
2. Recommend to the *CGA/ANSI Z21 Joint Subcommittee on Refrigerators and Portable Camping Equipment* that the scope of the ANSI Z21.63 should clearly state that the standard applies to both radiant heaters and radiant heater/cookers. This will eliminate the question of whether or not ANSI Z21.63 applies to heater/cooker combination units.

ACKNOWLEDGMENTS

The following individuals contributed to the overall project: Chris Brown, Ron Reichel, Richard Schenck, Scott Snyder, and John Worthington.

REFERENCES

American National Standard/CSA Standard for Portable Type Gas Camp Heaters, ANSI Z21.63-2000/CSA 11.2-2000, First Edition, CSA International, Cleveland, OH (2000).

CSA International Requirement 4.98 U.S. for Gas-Fired Portable Heaters for Recreational and Commercial Use, June 1, 2000, Revised November 13, 2001, CSA International, Cleveland, OH.

Hazard Sketch of Portable Type Propane Camping Heaters, memo from J. Mah to D. Tucholski, Division of Hazard Analysis, Directorate for Epidemiology, U.S. Consumer Product Safety Commission, October 11, 2001.

Summary of Gas Fired Camping Heater Test Program, memo from J. Bertoch to R. Medford, Engineering Sciences, Directorate for Laboratory Sciences, U.S. Consumer Product Safety Commission, February 9, 1996.

APPENDIX A. SUMMARY OF TEST DATA

Table A1 – Summary of the test results for Heater A – Single Burner Radiant Heater.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
4	0.10	3,490	228	13.3	4.9	2	0.83	0.73	1.25	FSE	NST	1,620	219	537
10	0.10	3,530	247	13.3	4.9	2	1.25	0.72	1.25	FSE	NST	1,558	276	580
1	0.44	4,230	225	13.4	4.9	4	0.92	0.64	1.22	FSE	No	1,900	210	587
6	0.44	4,340	218	13.5	4.9	3	0.83	0.63	1.15	FSE	No	1,836	253	615
5	0.92	3,380	368	13.7	4.7	2	1.15	0.85	6.30	EQ	No	1,255	238	758
11	0.95	3,350	265	14.1	4.5	0	1.00	0.91	6.37	EQ	No	876	159	597
8	0.96	3,570	248	14.2	4.4	0	1.02	0.91	4.00	EQ	No	818	272	591
2	1.11	3,500	130	15.2	3.7	0	1.53	1.26	3.18	EQ	NST	480	209	388
7	1.44	3,680	126	16.3	2.9	0	1.37	N/A	2.60	EQ	No	592	293	485
9	1.49	3,930	123	16.3	2.9	0	1.48	N/A	2.52	EQ	No	560	287	475
3	1.63	3,870	93	16.4	2.8	0	N/A	N/A	2.52	EQ	NST	487	227	403
15	0.10	1,930	386	12.8	5.4	2	2.04	1.41	2.85	FSE	NST	2,034	69	398
17	0.10	1,520	716	12.5	5.6	3	1.82	1.90	4.15	FSE	NST	2,115	104	537
12	0.47	1,760	230	14.6	4.2	0	3.88	2.63	8.23	EQ	No	433	73	228
16	0.53	1,380	178	16.2	3.0	0	2.13	N/A	8.10	EQ	No	333	119	243
13	0.93	1,750	44	17.8	2.0	0	N/A	N/A	4.00	EQ	Yes	179	51	110
14	1.38	1,910	24	18.5	1.6	0	N/A	N/A	2.50	EQ	NST	126	31	90

1. FSE = Flame Self-Extinguished, EQ = Equilibrium of CO, CO_2, and O_2 Achieved
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A2 – Summary of the test results for Heater B – Single Burner Radiant Heater.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
6	0.53	2,940	391	13.2	5.1	1	1.05	1.12	2.88	FSE	Fail	2,097	158	597
4	0.53	3,240	273	13.5	4.9	2	1.11	1.04	2.15	FES	Fail	1,570	109	481
9	0.75	3,060	270	13.9	4.7	0	1.26	1.33	4.50	EQ	NST	701	76	476
7	0.77	3,070	358	13.7	4.8	0	1.15	1.12	4.50	EQ	NST	1,362	118	666
2	1.00	2,770	192	15.9	3.3	0	1.54	3.27	4.00	EQ	NST	615	117	455
5	1.03	2,830	189	16.2	3.2	0	1.38	NA	3.67	EQ	Fail	615	168	482
3	1.53	3,250	89	17.3	2.4	0	NA	NA	2.33	EQ	Pass	446	117	345
1	1.58	3,220	73	17.5	2.3	0	NA	NA	2.35	EQ	Pass	377	99	286
12	0.54	1,110	82	17.1	2.3	0	NA	NA	7.00	EQ	Pass	136	80	111
11	1.03	1,080	63	19.1	1.2	0	NA	NA	3.00	EQ	Pass	223	80	169
10	1.54	1,450	19	19.3	1.1	0	NA	NA	2.00	EQ	Pass	181	26	84
8	1.51	2,500	27	18.3	1.9	0	NA	NA	2.00	EQ	Pass	147	66	110

1. FSE = Flame Self-Extinguished, EQ = Equilibrium of CO, CO2, and O2 Achieved
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A3 – Summary of the test results for Heater C – Radiant Heater/Cooker.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hrs)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
16	0.49	9,750	174	13.2	5.2	2	0.45	0.30	0.50	FSE	Fail	3,436	125	1,064
14	0.48	9,770	178	13.0	5.2	4	0.44	0.29	0.50	FSE	Fail	3,505	91	1,212
13	0.98	9,670	197	13.1	5.2	3	0.48	0.33	0.57	FSE	Fail	3,318	110	1,222
11	1.02	9,650	197	13.4	5.1	2	0.51	0.34	0.57	FSE	Fail	3,852	114	1,067
10	1.48	9,640	259	13.5	5.0	4	0.56	0.38	0.69	FSE	Fail	4,376	143	1,142
12	1.52	9,550	259	13.3	5.0	3	0.58	0.38	0.73	FSE	Fail	3,243	131	1,220
17	2.20	9,380	577	13.7	4.8	8	0.78	0.48	1.83	FSE	NST	4,560	150	2,170
15	2.23	9,330	540	13.6	4.9	9	1.07	0.62	2.43	EB	NST	4,694	139	1,736
18	2.50	9,920	474	13.8	4.8	4	0.75	0.46	2.30	EB	NST	4,219	120	2,336
3	0.41	7,970	246	13.2	5.1	2	0.45	0.38	0.60	FSE	Fail	3,068	139	1,013
8	0.50	7,160	332	13.3	5.1	2	0.29	0.44	0.71	FSE	Fail	2,811	679	1,403
5	0.96	8,080	259	13.2	5.0	2	0.52	0.40	0.71	FSE	Fail	2,688	343	1,132
2	0.97	8,070	270	13.5	4.9	2	0.53	0.43	0.74	FSE	Fail	2,856	316	1,226
4	1.32	7,800	355	13.5	4.9	6	0.56	0.48	0.88	FSE	NST	3,730	414	1,267
1	1.44	8,250	278	13.5	4.9	3	0.60	0.45	0.84	FSE	Fail	3,259	307	1,202
6	1.50	7,890	398	13.5	4.9	7	0.58	0.48	1.03	FSE	Fail	3,722	412	1,595
9	1.94	7,410	632	13.7	4.8	7	0.52	0.73	3.03	EB	NST	4,315	729	2,316
7	1.97	7,440	687	14.0	4.6	8	0.59	0.72	3.00	EB	NST	4,266	676	2,561

1. FSE = Flame Self-Extinguished, EB = Empty propane bottle
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A4 – Summary of the test results for Heater D – Radiant Heater/Cooker.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
3	0.51	12,700	160	12.8	5.3	2	0.32	0.22	0.36	FSE	Fail	3,594	91	1,263
6	0.53	12,810	175	12.9	5.1	2	0.30	0.22	0.37	FSE	Fail	4,806	93	1,418
2	0.95	12,830	173	12.9	5.2	3	0.32	0.23	0.38	FSE	Fail	3,230	97	1,200
5	0.96	12,950	182	12.9	5.2	2	0.32	0.23	0.39	FSE	Fail	4,162	103	1,385
1	1.51	12,990	196	13.1	5.1	2	0.37	0.24	0.44	FSE	Fail	3,106	113	853
4	1.52	12,910	204	13.1	5.1	2	0.36	0.25	0.45	FSE	Fail	5,063	104	1,341
13	3.78	11,380	164	14.4	4.3	0	0.54	0.37	1.98	EB	NST	3,186	133	1,374
14	3.69	11,520	177	14.3	4.3	0	0.54	0.37	1.98	EB	NST	2,031	142	1,298
9	0.53	10,460	209	13.0	5.2	2	0.33	0.27	0.45	FSE	Fail	3,574	98	1,665
12	0.54	10,410	213	13.1	5.1	2	0.34	0.28	0.47	FSE	Fail	4,111	104	1,378
8	0.99	10,270	216	13.1	5.1	2	0.37	0.28	0.52	FSE	Fail	4,077	114	1,424
11	0.99	10,310	218	13.0	5.2	1	0.38	0.29	0.52	FSE	Fail	5,152	112	1,459
7	1.53	10,240	243	13.3	5.0	3	0.42	0.33	0.62	FSE	Fail	4,259	135	1,326
10	1.54	10,160	248	13.1	5.1	2	0.43	0.34	0.66	FSE	Fail	2,509	144	1,107
15	3.17	9,650	260	14.5	4.1	0	0.64	0.50	2.28	EB	NST	4,057	146	1,432
16	3.22	9,660	237	14.9	4.1	0	0.69	0.58	2.28	EB	NST	3,596	121	1,367

1. FSE = Flame Self-Extinguished, EB = Empty propane bottle
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A5 – Summary of the test results for Heater E – Radiant Heater/Cooker.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
8	0.51	11,250	191	12.6	5.4	0	0.42	0.25	0.45	FSE	Fail	6,022	101	986
5	0.52	10,870	197	12.6	5.4	0	0.43	0.28	0.48	FSE	Fail	6,586	105	1,345
4	1.00	10,790	235	12.8	5.4	0	0.48	0.30	0.54	FSE	Fail	6,445	45	1,229
2	1.03	11,430	240	12.6	5.4	2	0.45	0.27	0.52	FSE	Fail	7,125	32	1,392
3	1.55	11,020	359	12.8	5.4	2	0.55	0.33	0.68	FSE	Fail	6,801	83	1,631
1	1.55	11,800	297	12.9	5.2	2	0.48	0.28	0.58	FSE	Fail	7,179	31	1,582
12	2.48	10,660	676	13.3	5.0	6	1.01	0.43	2.10	EB	NST	5,643	140	2,518
14	2.65	10,820	519	13.7	4.8	3	0.93	0.44	2.13	EB	NST	4,630	128	2,268
11	2.89	10,840	286	13.9	4.6	1	1.12	0.44	2.10	EB	NST	3,022	139	1,336
							0.00	0.00						
13	0.51	7,150	369	12.6	5.4	2	0.40	0.43	0.78	FSE	Fail	7,524	322	1,287
10	1.02	7,070	754	12.8	5.2	7	0.38	0.48	1.08	FSE	Fail	11,917	322	2,254
15	1.04	7,700	688	13.0	5.3	6	0.66	0.45	0.94	FSE	Fail	14,471	284	2,268
9	1.52	7,070	2124	12.9	5.2	12	0.38	0.62	3.17	EB	Fail	11,823	391	4,849
7	1.57	7,610	1977	13.1	5.1	17	0.93	0.56	2.94	EB	Fail	10,598	359	5,374
6	1.63	7,660	1131	12.9	5.3	4	0.95	0.55	2.05	FSE	NST	7,302	268	2,278

1. FSE = Flame Self-Extinguished, EB = Empty propane bottle
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A6 – Summary of the test results for Heater F – Radiant Heater/Cooker.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
6	0.53	9,130	75	13.0	5.1	1	N/A	0.34	0.52	FSE	Fail	2,133	104	422
3	0.53	9,910	87	13.1	4.9	1	N/A	0.30	0.48	FSE	Fail	3,310	98	475
5	0.96	12,600	75	13.3	5.0	1	N/A	0.23	0.38	FSE	Fail	1,956	92	571
2	1.07	9,960	109	13.1	5.0	2	0.53	0.33	0.54	FSE	Fail	5,055	114	576
10	1.48	8,400	146	13.1	5.1	2	0.70	0.41	0.79	FSE	Fail	4,742	133	478
4	1.56	9,280	195	13.2	5.1	3	0.70	0.41	0.76	FSE	Fail	5,511	109	739
1	1.73	8,560	259	13.3	5.0	4	0.80	0.52	0.88	FSE	NST	6,157	118	926
7	2.66	10,300	402	13.4	4.9	5	1.06	0.47	1.37	FSE	NST	5,289	151	1,333
9	2.91	10,430	318	13.6	4.9	3	1.26	0.52	2.17	EB	NST	4,430	100	1,117
8	2.93	10,460	331	13.4	4.9	3	1.11	0.46	2.13	EB	NST	4,325	24	986

1. FSE = Flame Self-Extinguished, EB = Empty propane bottle
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A7 – Summary of the test results for Heater G – ODS-Equipped Radiant Heater.

Test #	Air Exchange Rate (1/hr)	Energy-Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
2	0.54	6,470	19	19.3	1.1	0	N/A	N/A	0.13	FSE	Pass	705	14	355
1	0.98	6,470	18	19.3	1.0	0	N/A	N/A	0.13	FSE	Pass	690	25	324
9	1.54	6,580	30	19.2	1.1	0	N/A	N/A	0.15	FSE	Pass	418	207	335
14	6.38	6,390	22	19.1	1.2	0	N/A	N/A	0.58	FSE	NST	459	275	369
13	6.75	6,310	20	19.2	1.1	0	N/A	N/A	0.60	EQ	NST	458	287	375
12	7.29	6,220	19	19.3	1.0	0	N/A	N/A	0.60	EQ	NST	467	302	377
11	7.80	6,470	17	19.5	1.0	0	N/A	N/A	0.58	EQ	NST	449	309	367
10	8.48	6,210	16	19.6	0.9	0	N/A	N/A	0.60	EQ	NST	542	202	378
5	0.55	4,850	44	19.0	1.3	1	N/A	N/A	0.22	FSE	Pass	1,361	359	577
4	1.03	4,810	45	19.1	1.2	0	N/A	N/A	0.23	FSE	Pass	1,035	373	576
3	1.57	4,750	46	19.1	1.2	0	N/A	N/A	0.25	FSE	Pass	1,367	155	624
8	5.29	4,640	36	19.6	1.0	0	N/A	N/A	0.42	FSE	NST	1,257	419	619
7	5.64	4,640	39	19.6	1.0	0	N/A	N/A	0.58	EQ	NST	1,277	445	678
6	6.67	4,640	33	19.7	0.8	0	N/A	N/A	0.58	EQ	NST	1,388	472	670

1. FSE = Flame Self-Extinguished, EQ = Equilibrium of CO, CO_2, and O_2 Achieved
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)

Table A8 – Summary of the test results for Heater H – ODS-Equipped Radiant Heater.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time CO Reached 100 ppm (hrs)	Time O_2 Reached 16% (hrs)	Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	Complies with ANSI Z21.63[2]	CO Generation Rate (cc/hr)		
												Max	Min	Avg
8	0.50	7,350	16	19.0	1.3	0	N/A	N/A	0.16	FSE	Pass	345	184	251
2	1.00	6,960	14	19.1	1.3	0	N/A	N/A	0.15	FSE	Pass	345	201	260
1	1.50	6,860	12	19.4	1.0	0	N/A	N/A	0.12	FSE	Pass	435	195	284
7	6.24	6,620	16	19.0	1.3	0	N/A	N/A	0.83	EQ	NST	411	247	294
6	6.70	6,520	17	19.2	1.2	0	N/A	N/A	1.08	EQ	NST	398	190	291
5	0.53	5,500	33	18.9	1.2	0	N/A	N/A	0.18	FSE	Pass	688	218	469
4	0.99	5,300	37	18.8	1.3	0	N/A	N/A	0.22	FSE	Pass	696	271	489
3	1.52	4,940	38	18.9	1.3	0	N/A	N/A	0.26	FSE	Pass	705	403	506
9	4.64	4,920	38	19.1	1.2	0	N/A	N/A	0.84	EQ	NST	759	394	498
10	4.95	4,980	34	19.1	1.2	0	N/A	N/A	0.84	EQ	NST	687	384	501

1. FSE = Flame Self-Extinguished, EQ = Equilibrium of CO, CO_2, and O_2 Achieved
2. NST = Non Standard Test = Any test conducted at an air exchange rate other then that specified by the standard (0.5, 1.0, 1.5 ACH ± 0.1 ACH)