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Standard Guide for Field Investigation of Carbon Monoxide Poisoning Incidents[1]

This standard is issued under the fixed designation E2292; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers collection and preservation of information and physical evidence related to incidents involving the poisoning of individuals by carbon monoxide.

1.2 This guide is not intended to address the medical effects of carbon monoxide exposure.

1.3 This guide is not intended to be a guide for investigating carbon monoxide poisoning caused by hostile fires, or contamination in closed air systems or confined spaces. Guidance on the investigation of carbon monoxide poisonings related to fire can be found in NFPA 921.

1.4 This guide is not intended for an investigation where equipment is removed from the incident site and conducted in a more controlled setting.

1.5 This guide is intended to be used by a wide range of investigators, including first responders, appliance technicians and engineers.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E860 Practice for Examining And Preparing Items That Are Or May Become Involved In Criminal or Civil Litigation

E1459 Guide for Physical Evidence Labeling and Related Documentation

E2713 Guide to Forensic Engineering

2.2 *NFPA Standards:*[3]

NFPA 54 National Fuel Gas Code

NFPA 921 Guide for Fire and Explosion Investigations

2.3 *UL Standard:*[4]

UL 2034 Single and Multiple Station Carbon Monoxide Alarms

2.4 *IFGC Publication:*[5]

IFGC International Fuel Gas Code

3. Significance and Use

3.1 This guide is intended for use by individuals who investigate incidents involving carbon monoxide poisoning. If this guide is followed, the cause for the carbon monoxide poisoning incident may be determined, and corrective action may be identified to prevent future incidents.

3.2 When attempting to identify the source of carbon monoxide, consider that it is produced at some level in virtually every fuel-burning engine, boiler, furnace, burner, stove or fire. All carbon-based fuels (for example, gasoline, diesel fuel, natural gas, propane, coal, wood, paper products, plastics) produce carbon monoxide as a result of incomplete combustion. When there is insufficient air for complete combustion, carbon monoxide can become a major product of combustion. In properly-operating fuel-fired combustion appliances (for example, residential furnaces and water heaters), the level of carbon monoxide produced may be as little as a hundred parts per million or less (that is, 0.01 %). In those same appliances, malfunctions can potentially result in significantly higher carbon monoxide concentrations (10 000 ppm to

[1] This practice is under the jurisdiction of ASTM Committee E58 on Forensic Engineering and is the direct responsibility of Subcommittee E58.05 on Industrial Processes.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[4] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

[5] Available from International Code Council (ICC), 500 New Jersey Ave., NW, 6th Floor, Washington, DC 20001, http://www.iccsafe.org.

100 000 ppm, or higher). Properly-operating internal combustion engines may also generate carbon monoxide concentrations on the order of 10 000 ppm or higher.

3.3 Be aware of the effects of carbon monoxide on humans and pets. Carbon monoxide acts as a central nervous system depressant. With increasing dosage (combination of concentration and time of exposure) symptoms may include headache, dizziness, weakness, upset stomach, vomiting, chest pain, and confusion, and may lead to death. Carbon monoxide is especially hazardous because it is colorless and odorless, providing no warning of its presence. When inhaled, carbon monoxide binds with hemoglobin in the blood, creating carboxyhemoglobin (COHb). The affinity of carbon monoxide for hemoglobin is approximately 200 times greater than the affinity of oxygen for hemoglobin. Therefore, the blood can accumulate dangerous levels of COHb, depriving the body of oxygen.

3.4 Since there is the potential for investigators to become victims of elevated carbon monoxide levels themselves, extreme care should be taken to assure the safety of investigators and anyone else at risk of continuing carbon monoxide exposure. Carbon monoxide monitoring and measurement equipment is required to ensure life safety of those present, as well as to determine the cause of the problem and its solution.

4. Equipment

4.1 The following is a listing of basic measurement equipment that may be useful in diagnosing a carbon monoxide problem and determining the source, cause, and validating corrective actions:

4.1.1 *Electronic Carbon Monoxide Monitor*—A properly calibrated direct reading electronic monitor having a range of 0 to 1000 or 2000 ppm (that is, 0.1 to 0.2 %) is preferred in that its output provides almost instantaneous concentration data, and it therefore has the capability to warn the investigator if carbon monoxide levels are reaching dangerous concentrations. The carbon monoxide monitor may also be used to survey different areas of a building to locate the area of highest concentration, helping to identify the source. Monitors with data logging capabilities are preferred to assist in assessments of dosage.

4.1.2 *Carbon Monoxide Alarms (compliant with UL 2034)*—These alarms may be used as warning devices (see Section 5). Alarms with digital readouts should not be used as primary investigative monitors since their range is typically limited to ~100 ppm (that is, 0.01 %).

4.1.3 *Combustion Gas Analyzer*—Because malfunctioning combustion equipment is sometimes found to be the source of excessive carbon monoxide, portable gas analyzers are useful to check the combustion products produced by fuel burning equipment. These instruments indicate carbon monoxide as well as other exhaust gases. Combustion gas analyzers are used to determine whether the combustion equipment is operating within its normal limits for carbon monoxide in the exhaust. A measurement range up to 10 % carbon monoxide (100 000 ppm) may be required.

4.1.4 *Manometer*, or equivalent instrument, capable of determining positive and negative pressures in the combustion air supply, exhaust stack, and inside the living space while fuel burning equipment is operating.

4.1.5 *Ventilation Equipment*—A fan, blower, or similar device should be available to provide air movement in the space around equipment between tests to lower the carbon monoxide level to the baseline. Monitor the carbon monoxide level in the area before running each test.

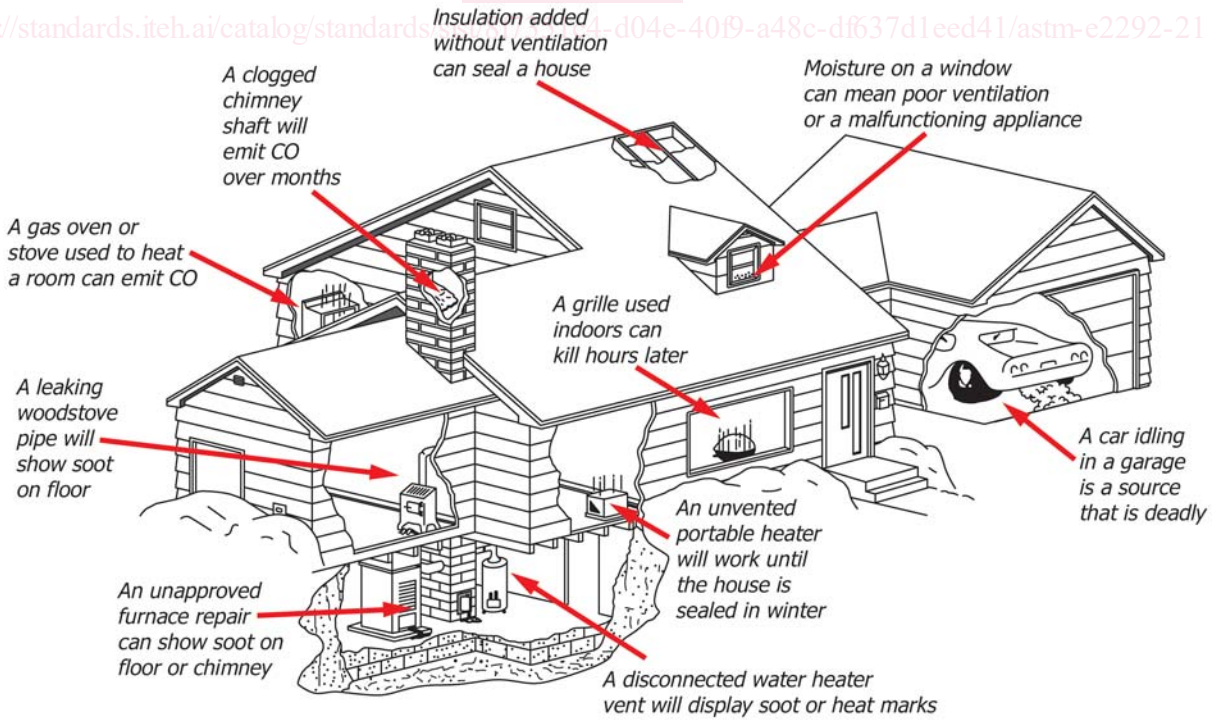

FIG. 1 Common Locations of Carbon Monoxide Build-Up

4.1.6 *SCBA (self contained breathing apparatus)* may be used if entering a highly contaminated area while conducting tests.

4.1.7 All indicating equipment should be calibrated at least annually or in accordance with the manufacturer's recommendations, and checked prior to each use. The equipment may be checked against a standard reference gas. Selection of calibration gas concentrations should reflect both low and high range for gas measurement equipment.

5. Safety

5.1 Entering spaces and testing of equipment suspected of causing carbon monoxide poisoning may yield definitive results that cannot be obtained any other way. Testing of equipment that may have injured individuals, however, is a potentially dangerous undertaking, in that the investigator runs the risk of becoming exposed to carbon monoxide being produced by improperly functioning equipment.

5.2 Safe testing procedures are of the utmost importance. Before any testing is undertaken, a safety officer should be identified. The safety officer's responsibilities are to protect the safety and health of the investigator and any individuals who may be affected by the testing.

5.3 Stable communications should be assured between the site and emergency service providers.

5.4 Audible carbon monoxide alarms, compliant with UL 2034, may be used as warning devices to warn participants of hazardous conditions. Such alarms are not substitutes for carbon monoxide monitors or analyzers, which may be worn on-person and can be configured to alert the user at different thresholds.

5.5 Until its safe operation has been verified, the minimum number of participants should be in the space where a piece of equipment is being tested for carbon monoxide output that the potentially interested parties will agree upon. Those persons inside should remain within sight of the safety officer or another individual capable of rescuing that individual from the space. SCBAs may be used if necessary.

5.6 All testing should be discussed in detail with all individuals involved in the testing, prior to the beginning of any test. A written test protocol may be advisable, as discussed in 6.11 below.

5.7 Permissible levels of carbon monoxide concentration depend on the time of exposure. The U.S. Environmental Protection Agency (EPA) advises a threshold of 50 ppm averaged over 8 hours. Higher concentrations or longer exposures at lower levels, or both, are also hazardous.

6. Procedure

6.1 *Scene Security*—If the carbon monoxide concentration is elevated in the area, the first priority is to evacuate the scene and prevent further injuries or loss of life.

6.1.1 After evacuation, the scene should be secured. If possible, field measurements of carbon monoxide levels in various locations around the scene should be taken.

6.1.2 The fuel supply to the scene should be turned off. This may require the switching off of internal combustion engines, or the closing of valves for gaseous or liquid fuels.

6.2 Notify individuals who have been identified as potentially having an interest in the testing of the time that the tests are going to take place. Prior to the testing, provide each of these individuals a copy of the testing protocol developed for their information and comment. For additional guidance on notification, see Guide E2713, E860, and NFPA 921 at 7.10 and 12.3.5. The advice of legal counsel may be advisable.

6.2.1 Such individuals may include the property owner, representatives of the victim(s), equipment manufacturers, fuel suppliers, equipment service personnel, law enforcement officers, code enforcement officers, and the insurance carrier for any of the parties listed above.

6.2.2 Keep a record of individuals who have been notified of the proposed testing.

6.2.3 Notification of other interested parties may not be necessary if the investigation is going to be limited to observations that do not change the condition of any of the structures or equipment.

6.3 *Documentary Information*—The following information may be of interest; not all of the information ultimately obtained will be available at the time of the initial field investigation. Nevertheless, the collection process should begin as soon as practical.

6.3.1 Emergency phone line recordings and medical records, particularly those that describe the blood gas analysis of the victims.

6.3.2 Obtain statements as early as possible from all individuals associated with the incident.

6.3.2.1 Determine if the occupants (including small animals) have exhibited prior signs of carbon monoxide exposure; for example, flu like symptoms.

6.3.2.2 First responders' test protocols and data.

6.3.2.3 First responders' actions to correct defects or remove carbon monoxide sources.

6.3.3 Weather data prior to and at the time of the incident; wind speed and direction, temperature, precipitation (snow, rain).

6.3.4 Altitude of the site if over 2000 ft; see NFPA 54 regarding high altitude installations.

6.3.5 Maintenance/service records for any fuel burning equipment, including maintenance contracts.

6.3.6 Equipment manuals or other related information regarding operation, service, maintenance, and input ratings.

6.3.7 Activities prior to the incident that may have affected the fuel sources, fuel burning equipment or ventilation of combustion products.

6.3.8 Information about the status of carbon monoxide alarms and monitoring systems.

6.3.9 Layout of the rooms and their dimensions. If the structure contains more than one heating appliance, indicate which appliances service each room.

6.3.10 Heating, ventilation, and air conditioning (HVAC) system configurations and settings. For structures, this may include thermostat setpoint, supply duct locations, and louver

positions. For vehicles, this may include settings such as fresh-air mode or recirculation mode, and fan speed.

6.3.11 Window and door positions.

6.4 Identify all fuel-burning equipment in the site. Determine when and how often the equipment operates.

6.4.1 Fuel gas burning equipment is operated on natural gas or propane. This equipment includes boilers, furnaces, water heaters, dryers, forklifts, gas fireplaces, stoves, ovens, etc. This equipment may be vented to the outside or unvented (discharging combustion products to the living or working space).

6.4.2 Liquid burning equipment is operated on gasoline, diesel, kerosene or fuel oil. This equipment includes internal combustion engines, kerosene heaters and fuel oil burning furnaces. The equipment is usually unvented if it is portable and vented if it is stationary.

6.4.3 Solid burning equipment includes wood stoves, fireplaces and pellet stoves. These are usually stationary and vented. If applicable, note position of fireplace dampers (open or closed) as well as door and window positions.

6.5 Identify all ventilation equipment, not associated with fuel burning equipment. This equipment includes power vents for bathrooms or gas ranges, electric dryers, and heat recovery ventilators.

6.6 Determine and document the condition of the equipment at the time of the incident.

6.6.1 Determine the condition of the flues on ventilated equipment. Look for sooting that would indicate incomplete combustion. Look for corrosion that might permit the recirculation of combustion products as combustion air. For appliances or vehicles which have internal combustion engines, listen for exhaust leaks and look for sooting emanating from junctions.

6.6.2 If the equipment includes a heat exchanger, determine whether there is a crack or break that might permit combustion products being introduced into the living/working space.

6.6.3 Measure the pressure to fuel gas appliances during operation, as well as the regulated pressure within those appliances.

6.6.4 If the equipment is convertible (for example, natural gas to propane), determine whether it is properly configured and adjusted.

6.6.5 If the altitude is above 2000 ft above sea level, determine whether the equipment is adjusted in accordance with the appliance instructions or NFPA 54.

6.6.6 Establish the condition of valves and/or switches. Systems within an appliance may be tested individually or in combination with the overall function of the appliance.

6.7 Determine the source of fuel, combustion air, and ventilation of each piece of equipment.

6.7.1 Determine whether any of the equipment is located in an enclosure that can be defined as a ‘confined space.’ Confined spaces are defined in NFPA 54 as, “a space whose volume is less than fifty cubic feet per 1000 BTU per hour (4.8 m^3 per kW) of the aggregate input of all appliances installed in that space.”

6.7.2 Determine whether the equipment has an adequate supply of air for combustion and ventilation as specified in NFPA 54, Chapter 9, or the International Fuel Gas Code (IFGC), Section 304.

6.7.2.1 Where combustion air is obtained directly from the outdoors, determine whether openings comply with NFPA 54 (or IFGC); including reduction due to louvers, grills and screens.

6.7.2.2 Where combustion air is mechanically supplied, determine whether openings comply with NFPA 54 (or IFGC).

6.7.2.3 Determine whether there is a separation between the return air and combustion air supply in HVAC installations in accordance with NFPA 54 (or IFGC).

6.7.2.4 Document whether safety switches such as spill switches have been bypassed or tampered with.

6.8 Determine whether the equipment, if venting is required, is vented to safely carry the products of combustion outside, as required by NFPA 54, Chapter 12; IFGC, Section 503; and relevant building codes.

6.8.1 Determine whether any temporary obstruction of the equipment ventilation, including obstructions of the return vents, have been moved. Verify that this has not changed since the incident (for example, melting snow or remedial measures taken by emergency responders).

6.9 For incidents involving generators, document the generator settings, surroundings (including potential ingress locations into structures), and loads or appliances that are connected to the generator. For connected loads or appliances, identify and document whether they are in use along with any pertinent settings.

6.10 For incidents involving internal combustion engines in vehicles, document the status of any malfunction indicator lights, including the check-engine light if it is present on the vehicle. If possible, connect to the vehicles diagnostic port (for example, OBD-II port) for assessment.

6.11 *Planning the Test*—Develop a plan for safely testing the potential sources of carbon monoxide at the scene. This planning will involve preparation of a written protocol for tests to be carried out.

6.11.1 A written protocol should be prepared for each investigation and tailored to the particular incident.

6.11.2 This plan will typically include turning on suspected equipment and observing and recording its performance ‘as found’ using the carbon monoxide measurement devices described in Section 4. In addition to testing equipment ‘as found’ it may also be desirable to test the equipment in accordance with the appropriate appliance standard.

6.11.2.1 A basic protocol may be derived from that described in Appendix X2 for first responders.

6.11.2.2 The suggested basic protocol in Appendix X2 does not address the impact of misuse, whereas the forensic protocol may address the impact of that misuse; and, a steady state carbon monoxide level will require time to attain a particular level from a cold start.

6.11.2.3 The protocol may include operation of the multiple fuel burning items (for example, a furnace in combination with

a fireplace) or in combination with other power vents, or both, as well as door/window positions determined in 6.5.

6.11.2.4 More detailed protocols would include a flue gas analysis for individual appliances or the impact of negative pressures on an appliance's performance, or both.

6.11.2.5 The protocol may include operation of the equipment before and after removing the defects determined above.

6.11.3 Identify the individuals who will be conducting the tests and the safety officer.

6.12 Operate each piece of equipment in accordance with the protocol; with changes as agreed to by the attending parties.

6.13 Identify and document all carbon monoxide alarms in the space at the time of the incident. Consider retaining some or all of the detectors for future analysis.

7. Collection of Physical Evidence

7.1 Once all parties to the investigation are satisfied that sufficient testing has been accomplished on site, items of physical evidence pertinent to the matter may be secured for future examination or testing.

7.2 Label according to Practice E1459.

7.3 Frequently, the device that is identified as having produced the carbon monoxide can be restored to a safe operating condition, and left in place after the condition that led to the poisoning event has been sufficiently documented. If left in place, a qualified appliance technician should make repairs and take responsibility for safe operation of the equipment.

8. Report

8.1 The report of test results should include the following information:

8.1.1 Location of test,

8.1.2 Names of those present, and

8.1.3 The test results.

8.2 The format of the report should be appropriate for inclusion in a separate final opinion report, if necessary.

9. Keywords

9.1 carbon monoxide; CO; combustion; monoxide; poisoning

APPENDIXES

(Nonmandatory Information)

X1. FLOWCHART FOR INVESTIGATING CARBON MONOXIDE INCIDENTS

X1.1 This overview describes the basic process for preventing further harm, diagnosing the problem, and determining steps for corrective action.

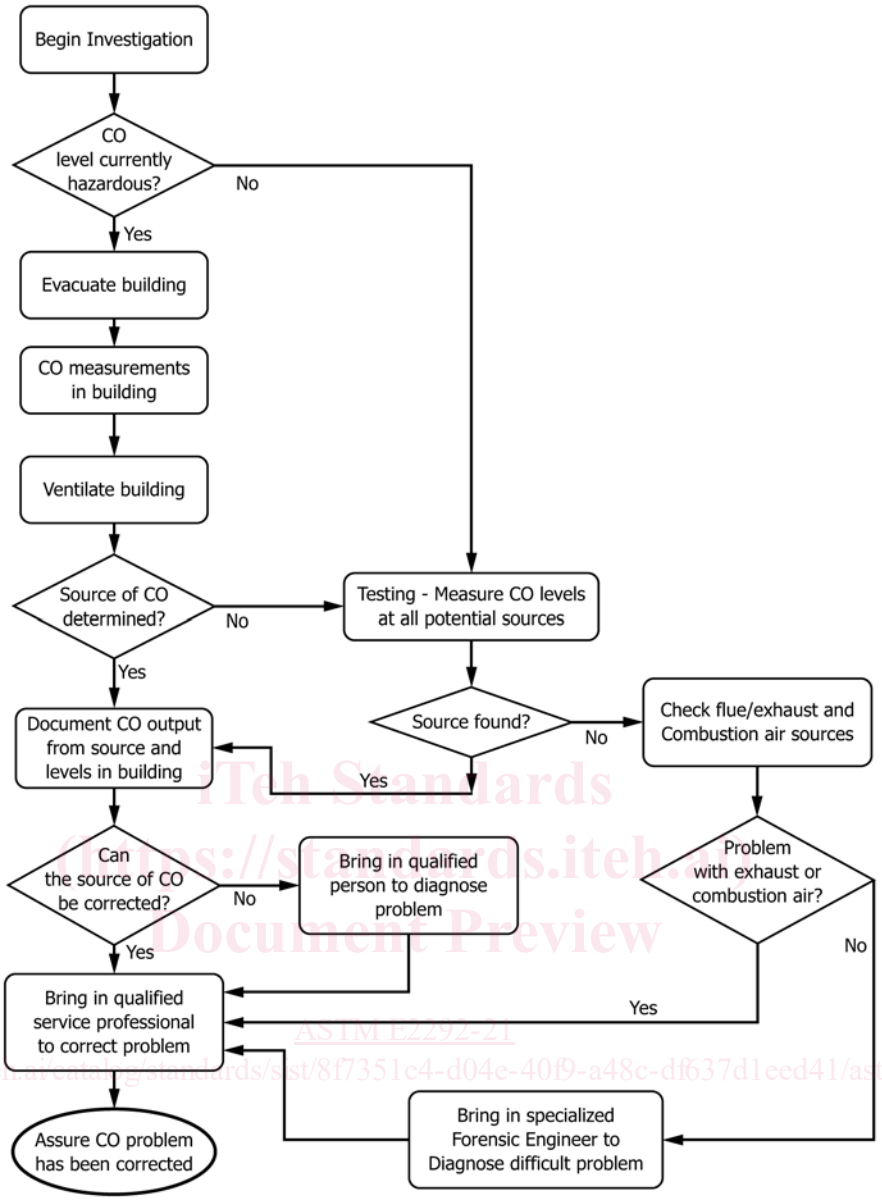

FIG. X1.1 Flowchart for Investigating Carbon Monoxide Incidents

X2. SAMPLE TEST PROTOCOL

X2.1 Test protocol for first responders:

TABLE X2.1 Test Protocol for First Responders[A]

Step 1: Identify Potential Sources of Elevated Carbon Monoxide in the Home and Attached Garage

Potential sources of carbon monoxide include: automobiles; motorcycles; trucks; golf carts; RVs; gasoline, propane, or diesel-fueled appliances; lawn mowers; power generators; furnaces; water heaters; clothes dryers; natural gas or propane refrigerators; ranges; ovens; space heaters; fireplaces; gas logs; wood and coal stoves; charcoal or gas grills; kerosene heaters; wood stoves; and any other equipment or appliance that burns fuel.

(*A*) List the potential sources of elevated carbon monoxide in the home that were in operation at the time of the call or were in use in the 24 hours before the call. Note their location in the building, and if they are unvented or vented to the outside of the building. These potential sources can be improperly installed, used, or maintained, leading to elevated levels of carbon monoxide. Improper remodeling can cause carbon monoxide problems by interfering with combustion air supplies, for example. It is important to note whether you see any indication of this. For example, gasoline generators improperly used indoors and gas ovens improperly used for heating or lined tightly on the bottom with aluminum foil can increase carbon monoxide emissions and lead to carbon monoxide buildup in homes, garages and other buildings.

Potential Source (Example) Kerosene Heater	Location Living Room	Vented or Unvented
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

(*B*) Examine flues, vents, and chimneys for blockage by birds' or other animals' nests or by debris, such as chipped or cracked masonry. Note any loose or disconnected vent or chimney connections, any loose or missing furnace panels, and any debris or soot in the chimney. Advise occupants to have flues, vents, and chimneys professionally serviced if problems are indicated.

(*C*) If there is an attached garage, answer the following questions:

Were any vehicles in the garage in the last 12 hours? Yes No

Were any vehicles' engines on in the last 12 hours? Yes No

Step 2: Take Carbon Monoxide Measurements

(*A*) Before taking indoor carbon monoxide measurements, take a measurement of the ambient air carbon monoxide concentration in an open area for reference.

(*1*) Plan to take one set of carbon monoxide measurements in areas or rooms of the building where there are potential sources of elevated carbon monoxide that were in operation at the time of the call or were in use in the 24 hours before the call. Take outdoor measurements around chimneys and exhaust vents with combustion devices operating.

(*2*) Plan to record your measurements on a carbon monoxide Measurement Form such as the example below.

(*3*) To complete the entire investigation, you will need to take one set of measurements. These measurements will help you assess whether there are elevated levels of carbon monoxide in the building and what the source(s) of those elevated levels might be.

(*B*) Taking indoor measurements

(*1*) If you have not already taken (and recorded) a carbon monoxide reading outside and at the entry to the home, then return to **Step 2A**, and follow those instructions. After taking indoor readings, you will need to subtract the outdoor reading from the indoor reading in order to determine the contribution that indoor sources make to any measured carbon monoxide indoors. For example, if the outdoor reading is 25 ppm and the indoor reading is 40 ppm, then the contribution from indoor sources is 15 ppm.

(*2*) Close all windows and doors. Turn on the fuel-burning appliances and other carbon monoxide sources that have been in operation in the past 24 hours and let them reach operating temperature (about 15 minutes). Keep them on during the measurements. Be sure to put pots with water in them on all range-top burners that have been used in the past 24 hours because cold pots on the burner can elevate carbon monoxide readings.

(*3*) Measure and record indoor carbon monoxide levels throughout the house. IMPORTANT: Take measurements in the ambient air in the center of each room, standing back approximately 5 ft from any potential carbon monoxide source. Do NOT take measurements in or near vents or flue pipes.

(*4*) Check for proper draft in all fuel-burning appliances by using a smoke test. Hold a lit match near the draft hood of the appliances that you turned on. Blow the match out. The smoke will be drawn into the hood if there is proper draft.

(*5*) When you have finished taking all measurements and if you measured elevated carbon monoxide levels, then open all doors and windows of the residence so that the home will be ventilated.

[A] This test protocol for first responders is adapted from Consumer Product Safety Commission (CPSC), *Responding to Residential Carbon Monoxide Incidents*, pp. 6–9, http://www.cpsc.gov//PageFiles/121994/coguide.pdf.