Field Protocol for Gas Range Carbon Monoxide Emissions Testing

Annotated Version

(Annotations and additions to the original protocol are in blue, bold, italics)

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For the
Chicago Regional Diagnostics Working Group

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Notice
This protocol and its emission limits are based on an approximation of *Household Cooking Gas Appliances* (ANSI Standard Z21.1) by the American Gas Association. ANSI Standard Z21.1 is a laboratory test conducted by manufacturers of gas ranges, not a field test. Because this protocol is intended for field use, it cannot precisely match the ANSI Standard.

The author of this protocol has attempted to base it on the latest research, practice, and technology. However, the author and the funding organizations cannot accept any responsibility for injury to a field analyst, house occupant, or anyone else caused by the use of this protocol. Any individual or organization using this protocol does so at their or its own risk.

☞ This icon indicates a policy decision might be required by program funders.

👓 This icon indicates a maximum level of emissions from a burner. Additional study and field research may result in adjustment of the emission levels of this protocol.

Introduction

The purpose of this protocol is to guide the field analyst through a systematic procedure of gas range testing. This protocol is intended to determine whether a gas range burner(s) is emitting unacceptable levels of carbon monoxide.

The burner limits for this protocol for carbon monoxide emissions are 35 ppm CO, as-measured[1] for range top burners[2] and 800 ppm CO air-free[3] for oven bake burners. Oven broil burners are not required to be tested.

These emission standards comply with ANSI Standard Z21.1. It is difficult – if not impossible – to equate the ANSI Standard, generally performed by manufacturers technicians under laboratory conditions, with this field protocol. Efforts have been made to equate this field protocol with the ANSI Standard as closely as possible.

Using a single-zone, mass balance model to predict the ambient room concentrations at the protocol emission levels for all the range burners, except a separate oven broil burner, results in room CO concentrations of 28 ppm after one hour and 45 ppm after two hours of combustion. Refer to Assumptions for Single-Zone Mass Balance Model near the end of this document for more information.

These emission levels are based on field and laboratory research, as well as on consultation with scientists and air quality experts. As more research is conducted in the areas of combustion emissions from gas ranges and assessment of human health risk factors related to CO, these allowable emission levels might change.

This method covers residential grade floor-mounted gas ranges, drop-in range top burners, and built-in ovens only. If drop-in range top burners or built-in ovens are encountered, follow the appropriate sections of this protocol for these appliances. This protocol is not intended for use with 1) outdoor gas grilles; 2) ovens in catalytic cleaning mode; 3) ovens vented into flues or chimneys; or 4) range/ovens with a closely located, down-vented, and operating exhaust fans, e.g., JennAir down-vented exhaust fan.

This protocol is not intended to determine whether gas ranges operate acceptably during misuse, such as using a range for space heating.

Accurately measuring CO emissions in the field is difficult due to the complex nature of combustion and dilution airflow patterns. Use of this protocol can increase the accuracy of measurements to, perhaps, $\pm$30 percent. This means that the protocol will sometimes result in false failures and false passes.

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[1] CO as-measured is a part-per-million (ppm) or percentage reading that is *not* adjusted (normalized) with corresponding O_2 or CO_2 readings from the same combustion gas sample.

[2] For the average test, this value is approximately 800 ppm CO air-free allowable emissions from each range top burner.

[3] CO air-free is a CO as-measured reading that has been adjusted (normalized) with corresponding O_2 percentage readings from the same combustion gas sample. CO air-free is usually expressed as a parts-per-million (ppm) value, but it is actually an emission rate, not a percentage.

The ±30 percent value in the above paragraph is based on Reuther's estimates (1996, p. 13) of the accuracy of emissions measurements in various settings. He states, "In a field setting, [reproducibility] is unknown, in a factory setting [for manufacturers] it is about ±33%."

Because there is a broad variety of gas ranges in the field, there is the possibility that range characteristics not addressed in this protocol will be encountered. When problems are discovered that are beyond the scope of this protocol, it is important that the field analyst use his or her good judgment when deciding whether to pass or fail a burner or range.

This protocol has two parts. Phase 1 includes range inspection and client education. Phase 2 includes instrumented emissions testing of the range top and oven burners. Complete Phase 1 before moving on to Phase 2.

Phase 1: Visual Inspection and Client Education[4]

A. Gas Range Inspection

1. **Range top inspection:**
    a. Inspect the range top burner area for cleanliness. If the burners or burner area are dirty enough to *adversely impact the combustion process*, inform the client that the range should be cleaned to reduce the possibility of unacceptable emissions. Do not test for CO emissions until the problem is corrected.
    b. Inspect the burners for proper alignment and seating.
    c. All cooking vessel support grates should 1) be in place, 2) fit properly in the burner well, and 3) be in one piece with no broken parts.
    If these grates are not seated properly or missing, CO emissions might increase because of increased flame quenching from impingement.
    d. If any of the grates are missing or in unsatisfactory condition, the client should not use the affected range burner(s) until the substandard or missing grate is replaced. If a grate(s) cannot be repaired or replaced, the decision whether to replace the range should be made by those funding the program, with appropriate input from the client.
    e. If the range top burners are ignited with a standing pilot light, verify that the pilot flame is present, is about 5/16 in length, and is soft blue in color (not yellow). When properly adjusted, a standing pilot uses about 75 Btuh.
2. **Oven area inspection:**
    a. Inspect the oven for cleanliness. If the burners or oven area are dirty enough to *adversely impact the combustion process*, inform the client that the range should be cleaned to reduce the possibility of unacceptable emissions. Do not test for CO emissions until the problem is corrected.
    b. Check the oven for blockage of the oven-bottom vents. These vent holes must not be blocked by anything in the oven, such as aluminum foil. The vent openings must ***never*** be obstructed because they are an important part of the oven combustion venting system.
    Studies by the United States Consumer Product Safety Commission (2000a, 2000b, 2000c) demonstrated that CO emissions from oven bake burners increase when oven-bottom vents are blocked.

[4] This phase requires from five to ten minutes of the analyst's time.

c. Check for air blockage at the bottom of the range and drawer and/or broiler compartment under the oven. Dust, lint, pet hair, rugs, or any other obstruction blocking free airflow to the oven bake burner must be removed.

   Can have the same impact as foil blockage of oven-bottom vents.

d. Check the oven bake-burner spreader plate (burner baffle). Most bake burners (the one at the bottom of the oven compartment) have a flame spreader plate just under the oven compartment bottom and above the bake burner flame (typically, this plate is attached to the oven bottom). Warped or detached spreader plates can result in flame impingement and quenching (cooling) of the gas flame, causing increased production of carbon monoxide. Many spreader plates are intentionally bent into curved or angular shapes, or dimpled, to add strength. Inspect carefully with a flashlight and inspection mirror to determine if the spreader plate has distorted from its original shape or has detached from the oven bottom. Ignite the bake burner to inspect the flame. The flame should not extend beyond the edge of the spreader plate. Also, inspect for carbon buildup on the spreader plate and the oven bottom. Any carbon buildup can be an indication of incomplete combustion caused by flame quenching or a fuel-rich gas mixture.

   Increased impingement resulting from bent or detached spreader plates can increase CO emissions from oven burners.

e. If the range also has a broil burner at the top of the oven compartment, check its flame for proper size and color.

f. Inspect the oven compartment and under the oven compartment for any other defects that could lead to unacceptable CO emissions.

g. If the oven burner(s) is ignited with a standing pilot light, verify that the pilot flame is present, is about 5/16 in length, and is soft blue in color (not yellow). When properly adjusted, a standing pilot uses about 75 Btuh.

3. **Inspect gas range installation for code compliance.** Refer to the latest edition of the *National Fuel Gas Code* (NFPA 54), section 6.15: Household Cooking Appliances.
4. **Verify that the range is set up for the supply gas.** When a gas range is setup for natural gas but has propane piped to it, dangerous over-firing of the burners results. Although this is not a common occurrence, each range should be checked. Natural gas piped to a range setup for propane is not as hazardous because it results in under-firing.
   a. Gas characteristics:
      i. Propane (LPG) contains 2500 Btu per cubic foot. Gas ranges using propane usually operate at a gas pressure of 7 – 11 inches of water. Because of these characteristics, propane requires a smaller orifice size at each burner and a higher pressure than natural gas.
      ii. Natural gas (methane) contains 1000 Btu per cubic foot. Gas ranges using natural gas usually operate at a gas pressure of 3.5 to 6 inches of water. Because of these characteristics, natural gas requires a larger orifice size than propane at each burner and a lower gas pressure.
   b. If a range is setup for natural gas but has propane piped to it, it will be over-firing, probably creating unacceptable levels of CO. ***A gas range in this condition must not be used until the problem is corrected.***

Symptoms of this problem include noisy flames, yellow flames, large flames rising above the cooking vessel support grates on the range top burners, carbon (smoke) emissions, or unacceptable carbon monoxide emissions.

c. If a range is setup for propane but has natural gas piped to it, it will be under-firing. In this case, the client might complain of the long period required to boil water or the amount of time required for baking. This condition is usually not hazardous, but it should be corrected.
d. Methods for verifying supply gas type and range setup:
    i. Client interview
        1. Ask client about the history of the gas range. Is it new? Is it a recently acquired used range? If so, do they know where it was obtained? The client's answers might indicate the gas for which the range was setup at its last location.
        2. Ask client if they have noticed any flame irregularities. Flames too big, yellow, or noisy? Flames very small, cooking or baking taking too long?
    ii. Flame inspection
        1. Range top burner flames should appear normal on the high setting, in size, color, and sound. If the flames appear over-fired or under-fired, it is likely that there is a setup/gas supply mismatch.
    iii. Determine gas type piped to gas range
        1. Ask client. Verify by checking for natural gas meter or propane tank and corresponding piping to the appliance.
    iv. Determine gas range setup: natural gas or propane
        1. The best way to determine which gas the range is setup to burn is by inspection of orifice sizes or settings, inspection of pressure regulator settings, and measurement of gas pressure. However, because such an inspection is beyond the scope of this protocol, base your appraisal on the performance of the burners, that is, if it appears that all or most of the burner flames are over- or under-firing, assume the range setup does not match the supply gas.
e. ***If it is determined that the range setup gas does not match the supply gas, the client must not use the range until the mismatch is corrected.***

5. **Check for flexible connector**. If the flexible gas connector can be inspected without moving the range, or if the range is moved out for replacement, make sure the flexible connector is 1) not brass, 2) is not a two-piece connector, and 3) has no pre-1973 rings (in some cases, the date can be found on the flare nuts rather than the date rings). Do not move the range for the sole purpose of inspecting the flexible connector; this movement might crack or otherwise damage it.
6. **Check for gas leaks** at the range top burner area, oven area, and any accessible gas lines with an appropriate combustible gas detector. Check for propane leaks below connections (propane settles) and for natural gas leaks above connections (natural gas rises***). If any gas leaks are found, specify repair. Shut off the gas to the appliance and do not proceed with testing until the leak is repaired.***

☞ 7. ***If the gas range fails any of these items above or if the field analyst believes, for any reason beyond the scope of this protocol, that the range burners or the oven bake burner are emitting unacceptable levels of carbon monoxide 1) specify repair of the gas range or 2) specify replacement of the gas range, depending on the character of the problem(s).*** Proceed with Phase 2.

   The important phase in the above paragraph is "for any reason beyond the scope of this protocol." This paragraph could be interpreted as undermining the protocol, for it gives control to the analyst. The intention of the paragraph is to 1) recognize that the protocol probably does not cover every possible item related to the condition of gas ranges and emissions testing and 2) in the case when an analyst discovers something outside of the scope of the protocol, that he should use his good judgment in determining whether to pass the range.

B. Client Education

Educating the client is a very important. Give a copy of *Carbon Monoxide Questions and Answers* to the client (U.S. Consumer Product Safety Commission publication # 466, http://www.cpsc.gov/CPSCPUB/PUBS/466.html), or other appropriate instructional document on the health impact of carbon monoxide. **Always take the time to explain the following to the client:**

1. **The holes in the oven bottom must never be blocked** with aluminum foil or anything else. Blockage of the vent holes can also occur from storing too much in the broiler or drawer area under the bake oven. Blockage of the oven bottom vent holes can result in unacceptable carbon monoxide emissions.

   Studies by the United States Consumer Product Safety Commission (2000a, 2000b, 2000c) demonstrated that CO emissions from oven bake burners increase when oven-bottom vents are blocked.
2. **Do not use the range top burners or the oven burner(s) as a space heater**. Use of a gas range for space heating is against the manufacturer's recommendations; gas ranges are not designed for such use.

   A hospital study (Heckerling et al 1987) of 89 patients diagnosed with CO poisoning found that 39 percent used gas ranges for supplemental heat. It is probably significant that the hospital was in a disadvantaged area of Chicago and that many of the patients were indigent. Other estimates range from 12 percent (Reuther, 1996) to 60 percent (Tureil, 1985). More research is needed regarding the percentage of people that use their gas range as a space heater on a regular basis. During an electricity outage, the percentage is probably higher than otherwise.
3. **Install a CO alarm** in the house according to the alarm manufacture's instructions. Make sure the alarm complies with the current UL Standard 2034. ☞ (Whether to provide and install a CO alarm for the client should be determined by those funding the program.)

   Some of the resource people involved with the development of this protocol thought that this should not be recommended to clients because CO alarms are unreliable. Chances are high that CO alarms will become more reliable in the future, so the primary author of this protocol based this recommendation on the assumption of increased future quality.
4. **Have the range checked and tuned once every two years** by a technician with an instrument capable of measuring carbon monoxide. This checkup and tuning should include:

   As a combustion appliance, the gas range needs periodic maintenance. At least

one study (Tikalsky et al. 1987, p. iii) suggested regular servicing: ". . . routine service adjustments on the 10 range set resulted in statistically significant decreases in CO and NO_2 following servicing. This finding implies that some servicing of the gas range may be desirable and have an impact on indoor levels of NO_2 and CO, and should be investigated further on a larger data set to determine if this initial indication holds true for a larger population."

a. Adherence to this protocol
b. Testing of range gas pressure
c. Making all necessary adjustments for the acceptable operation of all burners. The level of carbon monoxide emissions from a burner can only be determined with an instrument that measures CO and O_2; it cannot be determined by visual inspection of the flames.

5. **The oven should be kept clean at all times.** There is evidence that dirty ovens emit more CO than clean ovens.

   Little is known about the emissions from high temperature oven cleaning. The author of this protocol has measured high CO emissions (over 2000 ppm as-measured) from an electric oven in cleaning mode. It is probably a valid assumption that dirty ovens produce more CO than clean ovens. More study is needed here.

6. **The flames from gas burners, both natural gas and propane, should burn steadily with a clear, blue flame.** The flame normally makes a slight hissing sound, but it should not sound like a blowtorch. If the flames burn yellow and/or burn loud or irregularly, the gas range should be serviced as soon as possible. Avoid using a bad burner until it is properly adjusted or repaired.

   Sometimes the incorrect gas pressure or orifice can be visibly or audibly detected. Rudimentary client knowledge of telltale flame problems can be helpful in informing them when to call for service. A resource will be supplying some flame color charts and related information that might be appropriate to add to this section.

Phase 2: Measurement of Emissions[5]

A. Safety During the Test Period

1. While performing the emissions testing, monitor CO concentrations in the kitchen. Shut down the burner(s), discontinue testing, and open windows and/or doors if indoor air concentrations rise above 35 ppm.
2. Be cautious not to burn hands or other body parts on hot test equipment or the range. Also, be mindful not to damage test equipment by open flames or hot surfaces.
3. Do not damage client's counters, floors, carpeting, or furniture with hot equipment or open flames.
4. This protocol calls for range top burners to "warm up" for at least six minutes before recording emissions. Make sure that the open flame is not left unattended during this burn period. If the analyst wishes to attend to other tasks during the burner warm-up period, ask the client to watch the burners during warm up.

[5] Phase 2 requires as much as 50 minutes of the analyst's time if the analyst attends the range during "warm up" for all five burner tests, or as little as 10 minutes if the analyst works on other tasks during burner warm up and only attends the five burners to record the readings. Do not leave the ignited range top burners unattended (a viable option is to ask the client to attend them while the analyst attends to other auditing tasks). The oven does not require attendance during warm up.

B. Emission Testing Equipment

1. Emission test equipment shall comply with the following:
    a. Digital display capable of measuring CO in 1 - 2 ppm increments with ± 10 percent accuracy at 500 ppm.
    b. Give readings for a range of at least 0 – 2000 ppm CO.
    c. Reach 90 percent of final reading within one minute.
    d. Capability of continuous sampling.
    e. Probe/hose assembly for flue gas sampling capable of withstanding high temperatures and the ability to passively, chemically, or mechanically remove water vapor from the combustion emissions.
    f. Instrument memory and/or printing capabilities are recommended, but not required.
    g. From the same piece of equipment or a separate piece of equipment, must have the capability of measuring percentage of O_2. Measurement of emission gases with the same instrument is preferred over two instruments because of the advantage of synchronicity.[6]

C. Preparation for Burner Testing

1. Always calibrate the emissions measurement instrument according the manufacturer's recommendations*. Before using the instrument, make sure that the most recent calibration is valid* (check for the calibration label on the instrument). If the calibration period has expired, calibrate the instrument before use.
2. Zero the instrument according to the manufacturer's recommendations.
3. Check the range for gas leaks with a combustible gas detector before igniting burners.
4. Read and fully understand all instrument manufacture's instructions before using the instrument.

D. Range Top Burner Testing

1. Remove all objects from the range top.
2. Identify the gas the range uses, either natural or propane.
3. The range top burners are to be tested in order of right rear (RR), left rear (LR), right front (RF), and left front (LF).
4. Test each range top burner with the CO Hot Pot™, model 1.[7] *This protocol with its limit of as-measured CO per burner is based on the use of the CO Hot Pot™, model 1, exactly as designed. The use of any other device or a variation of the CO Hot Pot™, model 1, invalidates this range top burner test procedure.*
    a. Test range top burners before testing oven.
    b. If room air from a fan or open window or door is blowing across the range top burners, ask the client to turn off or redirect the fan, or close the window or door. The natural flow of combustion gases upward from the burner must not be disrupted during the emissions testing process.
    During chamber testing at the GARD Analytics house in Chicago, the

[6] Use of two instruments, for example, one for measuring CO and another for measuring O_2, can result in out-of-phase readings. The different hose lengths and vacuum pump flow rates from two instruments could mean that CO is read 15 seconds after collection at the probe tip and O_2 is read 30 seconds after collection at the probe tip. This out-of-phase reading can produce less accurate results than synchronized readings from one instrument.
[7] Instructions for making this device are at http://www.karg.com/makehotpot.htm.

air conditioner fan in the chamber turned on a few times during the first few tests. This difficulty was corrected and the first two tests were aborted. However, these two tests, examined later, revealed the significant impact air moving laterally across a range top burner can have. While the air conditioner fan was operating, not only did the emissions at the burner increase significantly, the ambient chamber concentrations also increased.

c. Center the CO Hot Pot™ on the burner grate.
d. Prepare the emission measurement instrument for the test.
e. Ignite the burner and turn to the highest setting.

At least one study (Tikalsky et al 1987) found that CO emissions from a range top burner are usually higher on a low setting than on a high setting: "The data sets reveal mean CO emissions on the low setting to be much larger than the values obtained when the burners were set on high or medium" (p. 28, 32-35). Our testing in the field and the laboratory was done with the range burner setting on high. The highest setting was selected for this protocol because 1) it most closely matches the Btuh rating on the range name plate; 2) it is the easiest setting for the technician to find; and 3) it is the only repeatable setting on most range top burners, allowing the technician to re-test at the same setting – Btuh firing rate – after a burner is adjusted.

f. Start timing device.
g. Insert the probe of the emission measurement device into the hole on the side of the CO Hot Pot™ and through the eyebolt. The open end of the probe should be positioned concentrically at the eyebolt.

Tests in the field with the CO Hot Pot, model 1 have demonstrated that small lateral movements of the instrument probe tip do not significantly effect the emission readings. However, larger lateral movements of two inches or more do effect the readings. More study is needed here.

h. At six minutes after ignition, watch the instrument carbon monoxide readings for two minutes. Record high and low readings for this period. Average the high and low readings to get the 2-minute average CO_{ppm} (as-measured). Use the printing function on the emissions analyzer, if available.

CO emissions measurement in the field and the chamber often – not always – that five to six minutes of burner and CO Hot Pot warm up are needed before the CO emissions stabilize. This field and chamber data are responsible for this six-minute warm up time.

i. ***The CO_{ppm} at the burner averaged over the two minutes must be 35 ppm or less, as-measured, using the CO Hot Pot™, model 1.***

A handful of the resource people disagreed with the use of "as-measured" CO for the measurement of range top burners, especially since the oven part of this protocol calls for the use of "air-free" CO. Calculating the air-free CO for range top burners with the CO Hot Pot, model 1 is subject to a significant amount of error. For example, at an oxygen percentage of 20 percent, the multiplier to convert CO as-measured to CO air-free is 23.22. At this high level of oxygen, a 0.1 error in reading oxygen can lead to a 29 CO ppm air-free error at a level of 10 CO ppm as-measured. In addition, a 1.0 CO ppm as-measured reading error can lead to a 2.6 CO ppm air-free error at a level of 10 CO ppm as-measured. [Of 78 burners tested with the CO Hot Pot, model 1 in the field, 20.024 was the average oxygen reading between 4 and 5.5 minutes, with a mode of 20.00, a median of 20.00, a maximum standard deviation of the 78 data sets of 0.069 and the mode of the standard deviation

sets being zero.] Given that typical emissions measurement field instruments are rated with ±0.3% accuracy for the measurement of O_2 (29 x 3 =87 CO air-free error) and ±10 ppm accuracy for the measurement of CO as-measured (2.6 x 10 = 26 CO air-free error), the total CO air-free error could be very high for a measurement at a level of 10 CO ppm as-measured and 20 percent oxygen. So, for the sake of expediency, and probably without any significant loss in accuracy, it was decided to use 35 ppm as-measured as the range top burner level, rather than 800 ppm air-free.

j. Determine whether the burner passes or fails the limit.
k. Test each of the four range top burners.

E. Oven Bake Burner Testing

1. Test the oven bake burner only.[8] If the oven has a separate broil burner, do not test it.
   a. If room air from a fan or open window or door is blowing across the range top burners, ask the client to turn off or redirect the fan, or close the window or door. The natural flow of combustion gases upward from the oven and out of the oven vent must not be disrupted during the emissions testing process.
   b. Clear the oven of all pots, pans, or other objects.
   c. Clear area below oven of all objects.
   d. Leave oven shelves in place.
   e. If the vent holes on the oven bottom are blocked with foil, catch pans, or anything else, ask the client to remove the blockage.
   f. Prepare the emission measurement instrument for the test.
   g. Ignite the burner, with the temperature setting at 350^{O}F. The oven burner may not ignite immediately; this is normal for some electronic ignition systems. Bake burners with standing pilots usually ignite faster.

      The oven temperature setting for the protocol is 350^{O}F, a common temperature used for baking. Tikalsky et al (1987, p. 22) used 400^{O}F for their field testing. Tsongas (1995) suggested a 350^{O}F setting for his oven field protocol.
   h. Start timing device.
   i. Insert the probe of the emission measurement instrument into the oven vent sleeve at the back of the range top. Make sure the open end of the instrument probe is fully inserted into the oven vent opening at its center. Do not allow dilution air to mix with the sampled combustion by-products. Ensure that grease or other buildup does not inadvertently block the probe tip.
   j. After beginning the oven test, do not open the oven door. If the oven door is opened after the testing period begins, wait at least five minutes or to the end of the fifteen-minute warm up time, whichever is longer, before taking emissions readings.
   k. It is not necessary to turn on the emissions measurement instrument at the beginning of the warm up; it may be turned on at a later, but must be ready to take readings after fifteen minutes of oven warm up time.
   l. After fifteen minutes of burner warm-up, watch the emission measurement instrument for the minimum and then maximum CO_{ppm}

[8] Separate broil burners are not to be tested because 1) they are not used as often as bake burners; 2) when they are used, they are not on as long as bake burners; and 3) not all ovens have separate broil burners.

values. The corresponding $CO_{air\text{-}free}$ must be calculated and averaged for these minimum and maximum CO_{ppm} readings. The step-by-step details:

Field studies demonstrated that the initial CO peak and valley had passed by fifteen minutes. The relationship of this peak and valley to the average emissions after warm up is unknown. After the fifteen-minute warm up, the emissions patterns settle into the typical "saw tooth" profile of the oven duty cycle. There is no way we know of to avoid this lengthy warm up time. Of course, there is no need for the oven to be attended or watched during this warm up, so the analyst can be performing other tasks during warm up.

i. After fifteen minutes of warm up, watch for the *minimum* CO_{ppm} value (not the minimum $CO_{air\text{-}free}$ value).
ii. Record this *minimum* CO_{ppm} value and the corresponding O_2 percentage (if your instrument automatically calculates $CO_{air\text{-}free}$, record this value at the minimum CO_{ppm} value).
iii. Continue to watch the instrument until you detect the *next maximum* CO_{ppm} value.
iv. Record this *maximum* value and the corresponding O_2 percentage (if your instrument automatically calculates $CO_{air\text{-}free}$, record this value at the maximum CO_{ppm} value).
v. Use the printing function on the emissions analyzer, if available.

m. Calculate the $CO_{air\text{-}free}$ emission rates for the minimum and maximum CO_{ppm} readings from the following equation. Some emissions measurement instruments calculate $CO_{air\text{-}free}$ automatically.[9] If this is the case, this equation need not be used.[10]

1. For natural gas and propane:

$$CO_{air-free} = \left(\frac{20.9}{20.9 - O_2}\right) x\, CO_{ppm}$$

Where: $CO_{air\text{-}free}$ = carbon monoxide, air-free
CO_{ppm} = as-measured carbon monoxide, ppm
O_2 = oxygen in combustion gas, percentage

n. Average the $CO_{air\text{-}free}$ emission rates for the minimum and maximum CO_{ppm} readings.

o. ***Averaged CO air-free must be 800 ppm or less, averaged from the CO air-free values corresponding to the CO_{ppm} minimum and maximum occurring after fifteen minutes of warm-up, with oven set to $350^{O}F$.***

The duty cycle of the oven makes it much more difficult to measure than the range top burners. After analyzing the field data of oven tests, CO as-

[9] Instruments that calculate *$CO_{air\text{-}free}$* automatically do so with an integral computer chip. The instrument reads CO and O_2 and then calculates *$CO_{air\text{-}free}$* with the use of Equation 1, above. These instruments will not calculate *$CO_{air\text{-}free}$* automatically if the O_2 percentage is high, for example, Bacharach equipment will not calculate *$CO_{air\text{-}free}$* if the O_2 percentage is above 16; Testo equipment will not calculate *$CO_{air\text{-}free}$* if the O_2 percentage is above 20.

[10] The following equations may be used for natural gas and propane if the analyst has collected carbon monoxide and carbon dioxide readings.

For natural gas: $CO_{air-free} = \left(\frac{12.2}{CO_2}\right) x\, CO_{ppm}$

For propane: $CO_{air-free} = \left(\frac{14}{CO_2}\right) x\, CO_{ppm}$

Where CO_2 = carbon dioxide in combustion gas, percentage

measured was found to be the best, and probably the easiest of the emission gases to watch (other possible values are CO air-free, O_2, CO_2, and temperature). We determined that the method of measurement called for above is, on average, within 95 percent (17% standard deviation) of the averaged air-free CO values of the field tested ovens during the second 15 minutes of the 30-minutes field test time. One of the difficulties of the oven bake burner duty-cycle is that the emissions during stand-by (no combustion) are most likely misleading. The measurement protocol calls for the measurement of CO as-measured from a minimum to a maximum, in other words, when combustion is taking place in the oven.

p. Determine whether the burner passes or fails the limit.

F. Burner or Range Failure

1. If a failed burner can be adjusted in a way that reduces the CO emissions to below those set by the levels of this protocol, then the range passes the protocol after the field analyst retests the range to ensure that the burner(s) now passes limits of the protocol.
2. ☞ If the failed burner(s) cannot be tuned or replaced to pass the protocol levels or the gas range construction does not allow for adjustment or parts replacement, the gas range should be replaced.
3. If the field analyst believes, *for reasons beyond the scope of this protocol*, that a range burner(s) or the oven bake burner are emitting unacceptable levels of carbon monoxide, the range should be repaired or replaced.
    a. ☞ If the testing leads to range replacement, use the same shutdown, safety, and replacement procedures that your organization uses in the case of a cracked furnace heat exchanger.
    b. ☞ Those funding the program must determine whether to replace the range with program funds.

G. Closure of Test Procedure

1. Pack up test equipment and remove it from house.
2. Return range to condition in which it was found, unless returning it to pre-test condition will create an unacceptable situation (for example, do not put foil back on the oven bottom).

Tools Required for Protocol

- Timing device for timing burner warm-up and test-reading periods
- Combustible gas leak detection instrument.
- CO Hot Pot™, model 1 (Instructions for making this device can be found at http://www.karg.com/makehotpot.htm.)
- Emission measurement instrument(s).
    - Must measure carbon monoxide, as-measured.
    - Must measure carbon dioxide or oxygen as a percentage.
    - Optional – instrument calculation and display of carbon monoxide, air-free, is an advantage, but not necessary.
- Optional – thermometer for measuring temperature of oven at the oven vent. (This might be part of another instrument).
- Flashlight.
- Calculator for determining carbon monoxide, air-free.

- Oven mitten to handle hot CO Hot Pot™ and instrument probe.
- Inspection mirror for inspecting bake oven spreader plate, etc.

Assumptions for Single-Zone Mass Balance Model

The predicted room concentrations of CO of 28 ppm after one hour and 45 after two hours of range operation are based on a single-zone (one-room) mass balance model. More complex multi-zone mass balance models are available, but single-zone models are suitable for protocols such as this. The CO emission standard (ANSI Z21.1) for gas ranges used by manufacturers (American Gas Association 1993 is based on a single-zone mass balance model) and most research examining the concentrations of gases in buildings use single-zone models (Hendrick and Krug 1995; Nabinger et al. 1995; Tamura 1987; Traynor et al. 1982). [ANSI Z21.1 assumes an allowable room CO concentration of 100 ppm.]

The modeled prediction of the CO room concentrations is based on the assumptions below:

1. ***The air change rate per hour (ACH) of the kitchen and surrounding rooms is 0.5. One significant study found the median ACH in 266 low-income houses in 16 US cities was 0.9 (Grot and Clark 1979). It is likely that most of the homes in this study were not weatherized. If any of them were, the air-sealing work was done before blower doors were commonly used to find leaks. Post-weatherization ACH values today are likely to be closer to 0.5. Another important factor to consider here is the variability of the annual ACH of the kitchen and the adjoining rooms. While a blower door test for the measurement of ACH is reliably repeatable, the results do not reliably predict the ACH at any one time during the year. For example, a house with an ACH of 0.5 (based on a blower door test) result might experience an actual ACH range throughout the year of 1.3 to zero. Based on the existing data and the variability of actual ACH, the assumption of 0.5 ACH is reasonable. [ANSI Z21.1 assumes an ACH of 4.0.]***
2. ***The volume of the area into which the CO emissions are allowed to flow is 3770 ft^3, or about one-half the volume of a 1000 ft^2 house. Various studies have shown that CO produced in the kitchen reaches a concentration in adjoining rooms that is very close to the concentration in the kitchen (Persily 1996, p. 8). These studies indicate that there is normally good mixing of air among rooms when adjoining doors are open. It is reasonable to assume that doors from the kitchen to other rooms in the house will be open, but that some bedroom and closet doors will be closed, leading to the 3770 ft^3 assumption. [ANSI Z21.1 assumes a 1000 ft^3 kitchen with no mixing into adjacent rooms.]***
3. ***A 50 percent oven duty-cycle is assumed, that is, once the oven reaches steady-state condition, the burner operates one-half of the time. The results of four ovens monitored at the GRI/GARD Analytics test facility in Chicago showed that the oven steady-state duty-cycle varied from 10 – 40 percent.[11]***
4. ***A two-hour burn is assumed for the oven (50% duty cycle), thirty minutes for two of the range top burners, fifteen minutes for one range top burner, and zero minutes for the other range top burner. A number of assumptions had to be made regarding the operation of the range burners. First, should it be assumed that all the burners are operating at once, as might be the case if the range is being misused as a space heater, or should a more realistic cooking/baking use be assumed? This protocol cannot cover misuse of the appliance as a heating apparatus, so a realistic use of the appliance to a gastronomic end was assumed. Thus, the second question: What should be assumed***

[11] Telephone conversation with Roger Hedrick, June 20, 2001.

for the weighted-average use of the range top burners? Technically, this is not a duty-cycle but the realistic length of time each burner will operate during a two-hour period. If the right-front range top burner operates for thirty minutes each hour, although this is controlled by the cook, it is mathematically similar to the oven automatically operating for thirty minutes each hour based on temperature – a duty-cycle of 50 percent. This weighted average/duty cycle calculation based on the table below was compiled for the determination of the room CO concentrations. The maximum input of this range is 54,000 Btuh, a realistic average for a range manufactured during the last twenty years (Reuther 1996). [ANSI Z21.1 assumes a 60,000 Btuh input value with all burners firing simultaneously at this rate (Reuther 1996).]

Combination of Burners with Different Duty Cycles

Burner	F, Btuh	Duty %
Top, RF	9000	0.5
Top, LF	9000	0.5
Top, RR	9000	0.25
Top, LR	9000	0
Oven	18000	0.5
Total Btu input/hr Weighted Ave./Duty Cycle		**20250**

5. *A two-hour burn time was assumed for the single-zone mass balance model used to determine the ambient CO room concentrations at the end of one and two hours. Tikalsky et al (1987) found "Gas stove use in the 50 Home Study averaged 6.35 hr/wk for burner use and 2.73 hr/wk for oven use. This corresponds to approximately 1.3 hr/day for cooking, which compares well with the American Gas Association estimate of 1.5 hr/day . . ." (p. 7). Although for most families baking a large turkey or ham is unusual, it might require three to five hours of oven operation. Although the assumed two-hour burn is one-third more than the presumably intermittent average daily use, it is probably less than the maximum, although infrequent, burn period experienced in most households and is a reasonable assumption for the basis of these room CO concentrations.*
6. *The 20,250 weighted-average/duty-cycle value discussed in number 4, above, is based on typical burner input rates. These nominal input rates can vary, for example, range top burner can vary from 5,000 to 12,000 Btuh and oven bake burner nominal rates can vary from 14,000 to 20,000 Btuh. Additionally, the burner input rate printed on the range nameplate for both natural gas and propane can vary significantly from the actual firing rate. The ANSI Z21.1 for manufacturers states "When operated for 5 minutes, starting with all parts of the appliance at room temperature, the burner adjustment shall be within ± 5 percent of the capacities specified [on the nameplate]" (Section 2.3.5). Metering gas consumption during laboratory testing for this study showed that the metered consumption in Btuh of five range top burners on two ranges varied from rated consumption by from + 15% to – 29%. The metered burner consumption closest to rated consumption was – 12%. These variations were significantly greater than the ± 5 percent called for by the ANSI Standard. More field research is needed to determine the typical variation between nominal nameplate ratings and actual burner Btuh. The input ratings of 9,000 Btuh for range top burners and 18,000 Btuh for oven bake burners were used to determine the room CO concentrations of 28 ppm after one hour and 45 ppm after two hours of combustion, even though the nominal input rating range of burners is broad, nominal ratings of burners appears to vary significantly from real firing rates, and each burner has a variable input-control,*

Additional Research Required

The field and laboratory research and study required for the development of this protocol has revealed the need for more research. These research ideas are under development; reviewers are welcome to refine these ideas and add others. Rick Karg, perhaps in collaboration with others, will pursue funding for this additional research. Suggestions for funding sources and contacts are welcome. Ideas for research now include:

1. ***Analyze existing CO emission field and laboratory data and publish report of data. Important information contained in this data includes:***
    a. ***Field data (ovens and range top burners):***
        i. ***The number of oven bake burner in the field that failed this protocol (approximately one-half).***
        ii. ***The number of range top burners in the field that failed this protocol (low percentage).***
        iii. ***The correlation between range age and CO emissions.***
    b. ***Laboratory data (range top burners only):***
        i. ***Develop hypothesis for reasons the five different burner measurement techniques resulted in varying levels of chamber CO concentrations.***
        ii. ***Develop hypothesis for reasons the five different burner measurement techniques resulted in varying levels of CO measured at the burner.***
        iii. ***Compare the actual burner emissions and ambient CO concentrations to predicted ambient concentrations using a singe-zone mass balance model.***
2. ***Additional field testing of gas ranges to determine:***
    a. ***Percentage of range top burners that fail this protocol.***
    b. ***Percentage of oven bake burners that fail this protocol.***
    c. ***Reasons of high CO emissions.***
        i. ***Gas pressure***
        ii. ***Excessive draft***
        iii. ***Lack of primary air***
        iv. ***Lack of secondary air***
        v. ***Impingement***
    d. ***Find significant correlation between level of CO emissions and age of range.***
    e. ***Impact that CO emissions have on ambient air.***
3. ***As others assemble CO Hot Pot, model 1 units, how repeatable will the measurements be? This can be tested 1) by having a variety of people assemble CO Hot Pots, 2) having a single tester use them on a single range, and 3) comparing the measured values. Measurement of both ambient CO levels and burner CO emission levels are needed.***
4. ***How repeatable are the measurements among different testers? This can be determined by having a number of testers make measurements using a single range top burner and CO Hot Pot, model 1. Measurement of both ambient CO levels and burner CO emission levels are needed. Instrument calibration practice comes into play here and should be addressed in the experiment plan.***
5. ***Can CO as-measured be used to reliably determine range top burner CO air-free emissions, as called for in the protocol? This can be determined by collecting both values for a large sample of burners, and checking the correlation between the two. Measurement of both ambient CO levels and burner CO emission levels are needed.***

6. ***Does the CO Hot Pot require periodic calibration to ensure that it is working properly in consort with an emissions measurement instrument? Are there characteristics of the CO Hot Pot that can cause poor measurements? Measurement of both ambient CO levels and burner CO emission levels are needed These characteristics might include:***
    a. ***Age.***
    b. ***Number of times heated and cooled.***
    c. ***Galvanic corrosion.***
    d. ***Bent or misshaped parts.***
7. ***What are effective ways to reduce the time required for the protocol without sacrificing repeatability and complexity? Some possibilities for time reduction include:***
    a. ***Testing the range top burners during oven warm up.***
    b. ***Using at least two CO Hot Pots so that one can be warming up while another range top burner is being tested.***
8. ***Is there a better CO Hot Pot design that is less expensive and easier to make and, perhaps more importantly, better reproduces the emission level from a typical pan used on a range? Laboratory testing for this protocol revealed hints of better design. This laboratory research will require:***
    a. ***Chamber measurement of CO emissions from real pans on range top burners.***
    b. ***Determination of the effect of burner draft on CO emissions.***
    c. ***Determination of the effect of impingement on CO emissions.***
    d. ***Design of new CO Hot Pot that reproduces impingement, draft, and emissions characteristics of a real pot on burner.***
9. ***Can the Billick/Williams method of firing all range burners simultaneously and measuring CO and CO_2 room concentrations (Billick and Williams 2000) work effectively in the field? This method, as a minimum, has the potential of serving as an effective and simple screening test.***
10. ***Are the technicians and services called for by this protocol readily available in all parts of the US? Example study questions include:***
    a. ***Is there an adequate number of technicians with the capability of checking and tuning gas ranges, both natural gas and propane ranges.***
    b. ***Is there an adequate number of technicians with instruments capable of measuring CO, as called for in this protocol.***
    c. ***Will the check and tune every other year specified by this protocol impose a difficult burden on the existing businesses and technicians in the field?***
    d. ***Can gas ranges that fail this protocol, especially newer gas ranges, be tuned in a way that adequately lowers CO emissions?***
    e. ***What is the best strategy for mobilizing businesses and technicians so that they can adequately respond to the possible customer demand if this protocol is adopted on a broad scale?***
        i. ***Market transformation comes to mind here.***
        ii. ***Solicit help of natural gas industry first.***
        iii. ***Etc.***
11. ***Are CO alarms a good first defense for gas ranges emitting unacceptable levels of CO? Are these alarms reliable enough for occupants and technicians to depend on in the field? Where should these alarms be located to adequately detect unacceptable levels of CO from a gas range? This research might require the following:***
    a. ***Literature review of studies regarding CO alarms.***
    b. ***Measurement of CO emissions in a laboratory.***
    c. ***Computational fluid dynamic simulation of gas range CO emissions in a typical home.***

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