



Standard Guide for Testing Systems for Measuring Dynamic Responses of Carbon Monoxide Detectors to Gases and Vapors¹

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1. Scope

1.1 This guide describes testing systems used for measuring responses of carbon monoxide (CO) alarms or detectors subjected to gases, vapors, and their mixtures.

1.2 The systems are used to evaluate responses of CO detectors to various CO concentrations, to verify that the detectors alarm at certain specified CO concentrations, and to verify that CO detectors do not alarm at certain other specified CO concentrations.

1.3 The systems are used for evaluating CO detector responses to gases and vapors that may interfere with the ability of detectors to respond to CO.

1.4 Major components of such a testing system include a chamber, clean air supply module, humidification module, gas and vapor delivery module, and verification and control instrumentation.

1.5 For each component, this guide provides a comparison of different approaches and discusses their advantages and disadvantages.

1.6 The guide also presents recommendations for a minimum configuration of a testing system.

1.7 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This guide 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 and health practices and determine the applicability of regulatory limitations prior to use.* For more specific safety precautionary information, see 6.2.

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2. Referenced Documents

2.1 *ASTM Standards*:²

D1193 Specification for Reagent Water

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D1945 Test Method for Analysis of Natural Gas by Gas Chromatography

D3162 Test Method for Carbon Monoxide in the Atmosphere (Continuous Measurement by Nondispersive Infrared Spectrometry)

D3195 Practice for Rotameter Calibration

D3249 Practice for General Ambient Air Analyzer Procedures

D3687 Practice for Analysis of Organic Compound Vapors Collected by the Activated Charcoal Tube Adsorption Method

2.2 *Other Standards*:

UL 2034 Single and Multiple Station Carbon Monoxide Alarms³

CFR 1910.1450 Occupational Exposure to Hazardous Chemicals in Laboratories⁴

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology D1356.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *air change rate*—the volume of clean, humidified air plus contaminants that enters the chamber in 1 h, divided by the internal volume of the chamber, expressed as air changes per hour (h^{-1}).

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 Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, <http://www.ul.com>.

⁴ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

3.2.2 *chamber*—an enclosed test volume composed of chemically inert materials supplied with a mixture of air, gases, or vapors, or combination thereof, having known compositions.

3.2.3 *CO alarm/detector*—an alarm device consisting of an assembly of electrical and mechanical components with chemical, electrochemical, solid-state electronic, or other types of sensors to detect the presence of CO gas in specified ranges of concentrations.

3.2.4 *sensor*—the component included in the CO alarm/detector that senses CO gas.

4. Summary of Guide

4.1 This guide describes components of systems for testing CO detectors with mixtures of air and CO at different concentrations of CO. The systems are also used for evaluating the responses of CO detectors to mixtures of air and various gases or vapors, or both. Such systems require clean air with a preselected level of relative humidity supplied to an environmental chamber. Gases and vapors are introduced in the clean air supply or placed directly in the chamber to achieve desired chamber concentration. The components of such systems include devices or modules for supplying pure air, humidifying air, supplying gases or vapors, or both, to be tested, reference instruments for verifying concentrations of gases and vapors, and a chamber for placing and exposing CO detectors. The guide describes various options for each component: chamber (Section 6), clean air supply module (Section 7), humidification module (Section 8), gas/vapor delivery module (Section 9), and verification and control module (Section 10). The guide further provides recommendations on a minimum configuration for the testing system (Section 11) and reporting results (Section 12).

5. Significance and Use

5.1 This guide provides information on testing systems and their components used for measuring responses of CO alarms or detectors subjected to gases, vapors, and their mixtures. Components of a testing system include a chamber, clean air supply module, humidification module, gas and vapor delivery module, and verification and control instrumentation.

5.2 The CO detector is tested by sequential exposure to CO and interference gases at the specified challenge concentrations. A properly functioning alarm/detector will sound upon sufficient exposure to CO but will not sound upon any exposure to interference gases consistent with applicable standards (for example, IAS 6-96 (1)⁵, UL 2034).

6. Chamber

6.1 *Types of Chamber*—There are two types of chambers—static and dynamic. In a static chamber, air and known quantities of gases are introduced and then the chamber is sealed. In a dynamic chamber, a characterized air-gas mixture is continually introduced at a rate sufficient to maintain target concentrations.

6.2 *Hazards*—In a dynamic chamber, the air exiting chamber will contain CO and interference gases or vapors that may be toxic. To avoid undue exposures of toxic gases and vapors to occupants of the laboratory (where the chamber is located), the chamber should be properly vented to outside with an appropriate stack. For a static chamber, exposures to test gases should be avoided in operating (for example, opening) the chamber.

6.3 *Size of the Chamber*—The chamber size can be large (that is, room-size) or small and depends on the number of detectors to be tested. Detectors should be placed on a wire rack or similar supporting structure. Detectors should be placed at least 0.10-m away from the chamber walls. If multiple detectors are undergoing simultaneous testing, they should be spaced at least 0.051 m from each other. The chamber size required by UL 2034 is a 0.91 by 0.91 by 0.91-m box, which has been found to be practical for testing several detectors at a time.

6.4 *Material of Construction*—The chamber should be made of relatively inert materials, such as glass, stainless steel, or certain types of polymers/plastics. Materials, such as wood or gypsum board, may not be appropriate because of their absorption, adsorption, and leakage characteristics. Joints should be well-sealed using inert caulking/sealing materials. Gaskets should be used around doors and other closable openings to achieve a good seal when closed.

6.5 *Air Change Rate*—The air change rate of a dynamic chamber should be sufficient (for example, 1 h⁻¹ or higher) to overcome loss of chamber air through leakage and the depletion of test gases and vapors due to factors, such as consumption through a chemical reaction or deposition.

6.6 *Mixing*—To provide a uniform concentration for testing, the chamber air should be well mixed. With an adequate air change rate (for example, 1 h⁻¹ or higher), mixing can be achieved through proper placement and design of inlet and outlet ports. The design and placement should be such that any short-circuiting of flow from inlet to outlet ports is avoided. A better alternative to promote mixing is to use a fan that is appropriately sized for the chamber volume. For example, mixing within a large chamber having 23-m³ volume can be achieved by an 0.38-m³/s fan. Ideally, the fan should be mounted on a shaft through the chamber wall, and the fan motor should be external to the chamber to prevent contamination and heat load in the chamber. If a fan is used, the sensor ports should be shielded from direct air impingement. In addition to providing a uniform air concentration, the combination of air change rate and mixing should be such that it provides sufficient face velocity (for example, over 1 m/s) at sensor head(s) through the detector housing.

6.7 The chamber should be able to provide accurate control of temperature and relative humidity at ambient pressure as indicated in Table 1. The chamber should be airtight to minimize any leakage of ambient air into or chamber air out of the system. The environmental conditions cited in Table 1 cover ranges specified in standards listed in 2.2 and in the literature (1). Also, UL 2034 prescribes certain time period(s)

⁵ The boldface numbers in parentheses refer to references at the end of this standard.

TABLE 1 General Specifications for Test Chamber

Specification	Control Range	Control Precision
Temperature	-10 to 52°C	± 0.5°C
Relative humidity	15 % to 95 % (noncondensing)	± 5.0 %

to achieve target concentrations that should be adhered to so that undue exposures are avoided.

6.8 *Discussion*—The advantage of the static chamber is that the setup is simple, basically requiring only a sealable box. The major disadvantage of the static chamber is that the gases may be consumed or generated in the chamber, resulting in an environment that is different than originally specified. For this reason, the composition of the atmosphere should be monitored continuously for CO concentrations and other related parameters. The dynamic chamber requires a continuous and controlled supply and exhaust of air and gases to be tested but provides an environment that does not undergo changes as an artifact of testing.

7. Clean Air Supply Module

7.1 *Types*—There are two approaches for obtaining a clean air supply: (1) to use a prepackaged supply of clean air; and (2) to generate clean air by processing ambient air to remove impurities and moisture. This second approach requires equipment for removing particle and gas contaminants and moisture from the ambient air. Clean air can be generated to meet specifications for different requirements of stringency. Preassembled equipment for processing ambient air is also available from commercial gas supply vendors. Some details on the two approaches are given below.

7.2 *Packaged Clean Air*—Use of packaged air involves purchase of pressurized cylinders of clean air or zero air with certain specifications. Recommended specifications are: less than 0.5 ppm(v) (0.33 mg/m³ of methane equivalent) of total hydrocarbons, water vapor less than 3.5 ppm(v) (2.6 mg/m³), and CO less than 1 ppm(v) (1.1 mg/m³). Such gases are available from commercial vendors of pure gases and gas mixtures.

7.3 *Clean Air Generation Module*—A basic clean air generation module has the following components: oil-less compressor, desiccant to remove moisture, particle filter to remove suspended particles, and activated charcoal filter or catalyst bed, or both, to remove gaseous impurities. In addition to these components, a storage tank, high pressure lines, and regulator are necessary. A radiative cooler may be necessary to cool compressed air. An example flow diagram for a clean air generation module is shown in Fig. 1. Room air is compressed and then cooled by passing the air through a radiative cooler. Liquid water generated by the compressing and cooling is removed with a coalescer filter and may be stored in a storage tank. The compressed air is purified by passing the air through a desiccant, activated charcoal filter, and catalyst bed. Catalytic beds or a catalytic system is used to remove organic compounds (such as alkanes) as well as inorganic gases (such as CO). However, if a verification and control module (described in Section 10) is used to monitor CO concentrations, a catalyst

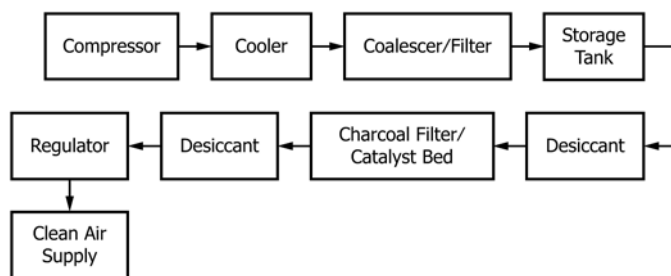


FIG. 1 Example Components of a Clean Air Generation Module

bed to remove CO may not be necessary. If a catalyst bed is used, use a desiccant and a downstream activated charcoal filter to remove water vapor and oxides of nitrogen, respectively, that are generated from the catalyst bed.

7.4 *Alternate Clean Air Module*—Air from outdoors or from the laboratory can be conditioned and cleaned by passing it through particulate filters to remove suspended solid particles, preheat coil and a chilled water dehumidifying coil to remove excess moisture, a desiccant dehumidifier to further dehumidify air, a catalytic bed to remove background CO, and an activated carbon adsorbent bed to remove volatile organic compounds in the air.

7.5 *Discussion*—The use of prepackaged clean air requires a minimal initial investment. The laboratory shall provide for safe storage of pressurized cylinders. Pressurized cylinders of clean air that meet or exceed specifications can be purchased through commercial gas supply vendors. However, this can become costly depending on the level of use of clean air. The use of a clean air module, on the other hand, requires an initial investment in a compressor and filtration/dehumidification equipment. The completed module supplies clean air at lower cost if the clean air supply is used regularly. Further, proper selection of specifications will provide adequate repeatability in testing results without undue high cost. There are various levels of clean air that can be achieved. For testing CO detectors, ultra-pure air (total hydrocarbon content < 0.1 ppm(v) or 0.06 mg/m³) is generally unnecessary. A total hydrocarbon content of less than 0.5 ppm(v) (0.33 mg/m³) is considered to be adequate.

8. Humidification Module

8.1 Air from the clean air module is fed to a humidification module. This module controls the relative humidity of the air-gas mixture delivered to the chamber. Depending on the range of specifications for humidification, the humidification module can be achieved in one of at least two ways:

8.1.1 The simple module will contain chilled water cooling coils, a reheat coil, and steam humidifier to obtain desired temperature and relative humidity. Such conditioning can be achieved as part of the generation of clean air (instead of the desiccant) described above. The degree of humidity control may be limited to ± 5 %.

8.1.2 For a more precise control of humidity (±1 %), mass flow controllers, a water vaporization chamber, and a coalescing filter to remove droplets are used. The water vaporization chamber can consist of a chamber containing deionized water

(see Specification **D1193**) or HPLC grade distilled water. Alternatively, a steam humidifier with deionized or HPLC grade distilled water can be used to generate saturated air flow. A broad range of relative humidity can be generated with acceptable control at a given humidity level by precisely controlling the ratio of dry air that bypasses the water vaporization chamber to wet, or saturated, air flow from the water vaporization chamber.

8.2 Discussion—Control of humidity by one of the above approaches or an equivalent approach (for example, use of a syringe pump to inject a measured amount of water, followed by heating to vaporize the water) is acceptable. The use of mass-flow controllers to control the ratio of dry and wet air streams may be more expensive, but it can achieve a narrower range of humidities in a reliable manner over long periods of time.

9. Gas/Vapor Delivery Module

9.1 The required concentrations of CO and interference gases/vapors in the chamber can be achieved by way of direct injection, supply from a pressurized cylinder, permeation tube, or use of a gas/solvent delivery module.

9.2 Direct Injection—This test method can be used only for static chambers. A precalculated amount of gas or solvent is introduced into a closed chamber through a gas-tight valve or septum using a suitable syringe.

9.3 Gas Cylinder—A pressurized gas cylinder with the specified gas mixture is connected to the chamber. The supply cylinder may be specified to provide the desired concentration directly. Alternatively, the supply cylinder may contain gas at a higher concentration than ultimately desired in the chamber if dilution is incorporated into the design. The flow from the gas cylinder(s) is controlled by mass flow controllers to give the desired chamber concentration.

9.4 Permeation Tube—Permeation tubes are commercially available to generate gas-phase concentrations of most compounds. A separate permeation tube is generally required for each compound selected. Clean air is passed through a temperature-controlled housing that contains the permeation tube(s) and is mixed with clean air that bypasses the permeation tubes. By controlling the flow rates of the two streams, desired concentration(s) can be achieved.

9.5 Solvent Delivery Module—A specially made solvent delivery module (**2, 3**) consists of a regulated flow of clean air passing through a bubbler that is immersed in liquid solvent contained in a jar. A parallel but lower rate of flow of clean air passes through the head-space in the jar to pick up solvent vapor-laden air. A spun-glass coalescing filter is mounted on the inner face of the glass jar lid to remove entrained droplets. A valve/restrictor assembly is mounted onto the outside of the solvent jar to control air flows through the jar. At the outlet of the jar, the solvent-laden air is immediately mixed with additional dry air to reduce or prevent downstream condensation of the solvent. To obtain mixtures of solvents, several jars, each containing a different solvent, are arranged parallel to each other and the output flows of the solvent jars are

manifolded together and combined with the humidified carrier air entering the calibration chamber.

9.6 Challenge Concentrations of CO and Interference Gases—Testing for alarm/detector response to CO and interference gases is done sequentially for each substance. **Table 2** lists relevant challenge concentrations for each test gas.

9.7 Discussion—Use of a pressurized gas cylinder is a convenient way of achieving a desired gas concentration. To achieve a greater control of gas concentration over a wide range, such as 1 to 10,000 ppm(v) (1.1 mg/m³ to 11.4 g/m³) of CO, a gas delivery module containing multiple restrictor tubes can be used (**2**). Such a wide range may not be necessary if the required concentration of interference gases is already established. In such cases, gas as well as solvent delivery modules can be designed to serve the needed range rather than a wide range needed for research purposes.

10. Verification and Control Module

10.1 Measurement and control are required for air flow, temperature, and humidity. Air flow can be automatically monitored and controlled by electronic mass flow controllers or manual flow control (for example, needle valve, orifice plate), and measurement (for example, bubbler meter, rotameter; see Practice **D3195**) can be used. Temperature control can be achieved by placing the test chambers in incubator cabinets or other controllable, constant-temperature environments. Temperature of the inlet air can be controlled by using conditioning coils. Temperature can be measured using thermocouples or platinum RTD thermistors; manual dial or stem thermometers can also be used. Control of humidity depends on the humidification module employed. If liquid injection is used, water flow is controlled by the pump setting. Control of humidity by saturated air requires temperature control of the water and flow control of the saturated air stream. Humidity measurements can be done by several types of sensors, including dew point detectors and thin-film capacitors. Temperature and humidity sensors should be located inside the chamber at least 5 cm from the inside wall and near the midpoint between air inlet and outlet ports.

10.2 Microcomputer-based measurement and control changes can be used to monitor and record air flow rates, temperature, relative humidity, and concentrations during the course of tests. Analog signals from transducers are digitized for storage and then processed to engineering units using

TABLE 2 Challenge Concentrations

Test Gas	Challenge Concentration, ppm(v)
Carbon monoxide	100 ± 1 (115 ± 1.1 mg/m ³)
Butane	300 ± 3 (712 ± 7.1 mg/m ³)
Ethanol	600 ± 6 (1129 ± 11.3 mg/m ³)
Methane	500 ± 5 (327 ± 3.3 mg/m ³)
Heptane	500 ± 5 (2045 ± 20.4 mg/m ³)
Ethyl acetate	200 ± 2 (720 ± 7.2 mg/m ³)
Isopropyl alcohol	200 ± 2 (491 ± 4.9 mg/m ³)
Carbon dioxide	5000 ± 100 (9 ± 0.18 g/m ³)

appropriate calibration factors. In this way, chamber environmental data can be continuously monitored, then compiled and reduced for archival storage or display with minimal operator effort.

10.3 Digitized signals also can be processed for automated control of temperature, humidity, and airflows.

10.4 The reference instrument for verifying CO concentrations in the chamber should be compatible with performance characteristics cited in Test Method D3162. Selected performance specifications are listed in Table 3. The reference instrument should sample air from multiple points in the chamber or from the outlet stream in case of dynamic chamber.

10.5 The reference instrument or sampling/analytical technique for verifying the target concentrations CO and concentrations of interference compounds in the chamber should be compatible with ASTM standards listed in Table 4. Further information is available in other publications (2-6).

11. Recommended Minimum Configuration

11.1 Dynamic chambers can be controlled to a narrower range of target concentrations than static chambers. This is because in a static chamber, gases may be consumed or generated, resulting in an environment that is different than the initial concentrations of test gases/vapors. The continuous supply of air and gases/vapors along with the verification and control system of a dynamic chamber provide a stable test environment that does not undergo changes as an artifact of testing. Thus, use of a dynamic chamber is recommended for evaluating detector responses to desired concentrations of CO and interference gases and vapors.

11.2 The chamber and air supply should not generate and should minimally adsorb any constituent of interest. This

TABLE 3 Performance Specifications for Carbon Monoxide Analyzer^A

Parameter	Specification
Range	0 to 500 ppm(v) (0 to 570 mg/m ³)
Limit of Detection	0.5 ppm(v) (0.6 mg/m ³)
Zero drift	±1 % per day
Span drift	±1 % per day
Precision	±4 % (maximum)
Temperature range	5 to 40°C
Linearity	2 % full scale

^ASee Test Method D3162.

TABLE 4 Performance Specifications for Measurements of Interference Gases

Interference Gas	Measurement Guidance
Butane	D1945
Ethanol	D3687
Methane	D1945
Heptane	D1945
Ethyl acetate	D3687
Isopropyl alcohol	D3687
Carbon dioxide	D3249

requires a supply of clean air. Inert materials should be used for all surfaces contacting the test atmosphere.

11.3 The system should be airtight to minimize air leakage into or out of the chamber or the supply air system.

11.4 The system should be equipped to provide continuous monitoring of test conditions including airflow(s), temperature, humidity, and CO and interference gas/vapor concentrations.

11.5 The system should be configured for ease of cleaning and maintenance.

12. Reporting Test Results

12.1 The report of test results should typically contain the following sections:

12.2 *Test Objectives*—Provide a clear description of the purpose of the test.

12.3 *Facilities and Equipment*—Give a description of the test chamber, modules supporting the chamber (for example, clean air supply, humidification, gas/vapor delivery, and verification and control), and all calibration standards.

12.4 *Test Design*—Describes the test conditions, including temperature, humidity, air change, and design and actual exposure levels to CO and interference gases/vapors.

12.5 *Test Procedures*—Describe all procedures used during the test, including details of analytical procedures.

12.6 *Quality Assurance/Quality Control*—Describe the data quality objectives and discuss adherence to acceptance criteria for all measurement parameters.

13. Keywords

13.1 alarm; carbon monoxide; chamber; clean air supply; control; detector; humidification; interference; testing system; verification

REFERENCES

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