Designation: E2885 – 13

Standard Specification for Handheld Point Chemical Vapor Detectors (HPCVD) for Homeland Security Applications[1]

This standard is issued under the fixed designation E2885; 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 *General:*

1.1.1 This document presents baseline performance requirements and additional optional capabilities for handheld point chemical vapor detectors (HPCVD) for homeland security applications. This document is one of several that describe chemical vapor detectors (for example, handheld, and stationary) and chemical detection capabilities including: chemical vapor hazard detection, identification, and quantification. An HPCVD is capable of detecting and alarming when exposed to chemical vapors that pose a risk as defined by the Acute Exposure Guideline Levels for Selected Airborne Chemicals (AEGL).

1.1.2 This document provides the HPCVD baseline requirements, including performance, system, environmental, and documentation requirements. This document provides HPCVD designers, manufacturers, integrators, procurement personnel, end users/practitioners, and responsible authorities a common set of parameters to match capabilities and user needs.

1.1.3 This document is not meant to provide for all uses. Manufacturers, purchasers, and end users will need to determine specific requirements including, but not limited to, use by HAZMAT teams, use in explosive atmospheres, use with personal protective equipment (PPE), use by firefighters and law enforcement officers, special electromagnetic compatibility needs, extended storage periods, and extended mission time. These specific requirements may or may not be generally applicable to all HPCVDs.

1.2 *Operational Concepts*—HPCVDs are used to detect, identify, and/or quantify chemical vapor hazards that pose 30-min Acute Exposure Guideline Level-2 (AEGL-2) dangers. The HPCVD should not alarm to environmental background chemical vapors and should provide low false positive alarm rates and no false negatives. Uses of an HPCVD include search and rescue, survey, surveillance, sampling, and temporary fixed-site monitoring. An HPCVD should withstand the rigors associated with uses including, but not limited to, high- and low-temperature use and storage conditions; shock and vibration; radio frequency interference; and rapid changes in operating temperature, pressure, and humidity.

1.3 *HPCVD Chemical Detection Capabilities*—Manufacturers document and verify, through testing, the chemical detection capabilities of the HPCVD. Test methods for assessing chemical detection capabilities are available from the Department of Homeland Security and the Department of Defense and are listed in Appendix X3.

1.4 *HPCVD System and Environmental Properties*—Manufacturers document and verify, through testing, the system and environmental properties of the HPCVD. Example test methods for assessing the system and environmental properties are listed in Appendix X4.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. Vapor concentrations of the hazardous materials are presented in parts per million (ppm) as used in *Acute Exposure Guideline Levels for Selected Airborne Chemicals*, Vols 1-9 (see 2.1) and in mg/m^3.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *Acute Exposure Guideline Levels:*

Acute Exposure Guideline Levels for Selected Airborne Chemicals, Vols 1-9[2]

2.2 *Code of Federal Regulations:*[3]

CFR Title 40 Protection of the Environment, Part 72.2 Permits Regulation, Definitions

[1] This specification is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.01 on CBRNE Sensors and Detectors.

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[2] Committee on Acute Exposure Guideline Levels, Committee on Toxicology, Board on Environmental Studies and Toxicology, Division on Earth and Life Studies, National Research Council of the National Academies; 2000-2010, http://www.epa.gov/oppt/aegl/index.htm, updated August 2010.

[3] 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.

CFR Title 10 Gas and Aerosol Detectors Containing Byproduct Material, Part 30.20, Energy

3. Terminology

3.1 *Definitions:*

3.1.1 *30-minute Acute Exposure Guideline Levels for Selected Airborne Chemicals, (30-min AEGL value), n*—represent exposure limits for the general public and are applicable to emergency exposure periods for 30 minutes.

3.1.2 *AEGL-1, n*—airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience transient health effects.

3.1.3 *AEGL-2, n*—airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

3.1.4 *AEGL-3, n*—airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

3.1.5 *alarm, n*—sound, light, vibration, and/or data communication signal to the operator(s) indicating that the handheld point chemical vapor detector (HPCVD) has detected the presence of a chemical vapor of interest at or above the alarm threshold value.

3.1.6 *alarm threshold value, n*—vapor concentration corresponding to an AEGL value (AEGL-1, AEGL-2, or AEGL-3) that activates an HPCVD alarm.

3.1.7 *background chemical vapors, n*—incidental chemical vapors present in the environment at vapor concentrations lower than the 30-minute AEGL-1 values.

3.1.8 *consumables, n*—HPCVD components that require periodic replacement.

3.1.9 *false negative, n*—the HPCVD fails to alarm in the presence of a chemical of interest when the vapor concentration is at or above the indicated alarm threshold value.

3.1.10 *false positive alarm, n*—the HPCVD indicates the presence of a chemical of interest when none is present or if the chemical is present at vapor concentrations less than 50 % of the indicated alarm threshold value.

3.1.11 *indicator, n*—information other than an alarm provided to the operator by the HPCVD.

3.1.12 *laboratory challenge stream, n*—a synthesized chemical vapor mixture used to verify in the laboratory the chemical detection capabilities of an HPCVD.

3.1.13 *mean time between failures, n*—estimate of the elapsed time between inherent failures of a system during operation, one measure of system reliability.

3.1.14 *probability of detection, n*—under specific conditions, the probability that the HPCVD will activate an alarm when a chemical of interest is present at or above the alarm threshold values.

3.1.15 *response time, n*—time for the HPCVD to detect and activate an alarm when exposed to a chemical of interest at vapor concentrations at or above the alarm threshold value.

3.1.16 *saturation, n*—a condition in which the detector response no longer increases with increased vapor concentration.

3.1.17 *selectivity, n*—ability of an HPCVD to distinguish one or more chemicals of interest in the presence of background chemical vapors.

3.1.18 *sensitivity, n*—ability to detect one or more chemicals of interest at the alarm threshold values within the specified response time.

3.1.19 *vapor, n*—in the context of this document, vapor refers to either gases or gas phase chemicals where the same substance also exists in either a liquid or solid state.

4. Chemical Detection Performance Requirements

4.1 The manufacturer shall document the capabilities of the HPCVD to detect, identify, and quantify chemical vapor hazards.

4.2 *Detection and Hazard Identification:*

4.2.1 The baseline capability of the HPCVD is to detect and alarm to at least four hazardous chemical vapors listed in the Acute Exposure Guideline Levels for Selected Airborne Chemicals. The Tables in Appendix X1 provide a representative list of chemical vapor hazards.

4.2.2 The HPCVD shall detect the manufacturer-documented chemical vapors without user intervention.

4.2.3 The HPCVD:

4.2.3.1 Shall alarm in the presence of manufacturer-documented chemical vapors at the vapor concentrations given in 4.3 with response times given in 4.4;

4.2.3.2 Shall indicate each 30-min AEGL value that the detected chemical vapor(s) is at or above; and

4.2.3.3 Should indicate the chemical class or specific chemical(s) that is detected.

4.3 *Sensitivity:*

4.3.1 For each manufacturer-documented chemical vapor, the manufacturer:

4.3.1.1 Shall declare and document the HPCVD capability to alarm at the 30-min AEGL-2 value;

4.3.1.2 May declare and document the HPCVD capability to alarm at the 30-min AEGL-1 value; and

4.3.1.3 May declare and document the HPCVD capability to alarm at the 30-min AEGL-3 value.

4.3.2 The HPCVD alarm signal shall automatically cease within 2 minutes after the concentration drops below half of the alarm threshold values.

4.3.3 At vapor concentrations greater than the 30-min AEGL-3 values:

4.3.3.1 The HPCVD shall continue to alarm;

4.3.3.2 If the detector is saturated, the HPCVD shall indicate it is saturated; and

4.3.3.3 The HPCVD should be designed to avoid detector saturation at vapor concentrations below twice the AEGL-3 vapor concentration values.

4.3.4 The HPCVD should indicate relative concentrations, for example, low, medium, and high levels based on 30-min AEGL-2 vapor concentrations.

4.3.5 The HPCVD may optionally indicate the vapor concentration of the chemical(s) present in absolute quantities (for example, ppm or mg/m^3).

4.4 *Response Time*—The HPCVD shall detect and alarm within times indicated in Table 1 for 30-min AEGL-2 values and may optionally detect and alarm within the times for 30-min AEGL-1 values and 30-min AEGL-3 values.

4.5 *Chemical Detection Climate*—For each of the manufacturer-documented chemical detection capabilities:

4.5.1 The HPCVD shall perform within the temperate climate range listed in Table 2;

4.5.2 The HPCVD may perform within the low- or high-temperature climate ranges or both listed in Table 2;

4.5.3 The chemical detection capabilities within each climate range shall be demonstrated by tests at the temperatures and relative humidities (non-condensing) listed in Table 3;

4.5.4 The HPCVD shall perform in atmospheric pressures from 101 kPa (sea level) to 68 kPa; and

4.5.5 The manufacturer may extend the range of operation.

4.6 *Probability of Detection*—For each of the manufacturer-documented chemical vapors, an HPCVD shall achieve a probability of detection of at least 85 % under any condition within each of the manufacturer-documented climate range(s) as specified by an 80 % lower confidence bound (see Appendix X2). The probability of detection shall be verified by:

4.6.1 Testing a single HPCVD, representative of all the HPCVDs with the same model designation, which shall detect and alarm:

4.6.1.1 For nine of nine replicate tests or

4.6.1.2 For 17 of 18 replicate tests.

4.6.2 The replicate tests shall be performed:

4.6.2.1 Using laboratory challenge streams that shall consist of the chemical of interest diluted in zero air (see CFR Title 40, Part 72.2).

4.6.2.2 With the laboratory challenge streams at the temperatures and relative humidities listed in Table 3.

4.6.3 The vapor concentration of the chemical of interest shall:

4.6.3.1 Be measured by an independent method, and

4.6.3.2 Have a measured value at the documented AEGL value plus the expanded uncertainty of the measured vapor concentration at the 95 % confidence level. Therefore, the vapor concentration of the laboratory challenge stream shall be set above the AEGL value by an amount equal to the expanded measurement uncertainty.

4.7 *False Positive Alarm Characterization:*

TABLE 1 HPCVD Response Time

30-min AEGL Values	Maximum Response Time	Requirement
AEGL-2	120 s	Required
AEGL-1	15 min	Optional
AEGL-3	30 s	Optional

TABLE 2 HPCVD Chemical Detection Climate Ranges

Climate Ranges	Temperature (°C)	% Relative Humidity	Water Vapor Content (g/m^3)
Low temperature	-10 to 5	5 to 100	0.1 to 6.8
Temperate	5 to 35	5 to 100	0.3 to 32
High temperature	35 to 50	5 to 77	2.0 to 32

TABLE 3 HPCVD Testing Conditions

Manufacturer Documented Climate Ranges	Temperature (°C)	% Relative Humidity	Water Vapor Content (g/m^3)
Temperate	7 ± 2	77 ± 25	6 ± 2
	33 ± 2	17 ± 6	6 ± 2
	33 ± 2	78 ± 6	29 ± 2
Low Temperature	-5 ± 2		0
High Temperature	45 ± 2	43 ± 3	29 ± 2

4.7.1 The HPCVD shall not alarm when exposed for 5 minutes to:

4.7.1.1 Each of the following four background chemical vapors representing:

(1) Exhaust from low-sulfur diesel fuel,

(2) Gasoline exhaust,

(3) Tobacco smoke, and

(4) Aqueous film-forming foam.

4.7.1.2 Each laboratory challenge stream shall:

(1) Consist of one of the specific background chemical vapors of interest at 1 % of the saturation vapor pressure at 23°C diluted in zero air;

(2) Be at a temperature between 20°C and 25°C and a relative humidity between 45 % and 55 %; and

(3) Not contain any chemical on the AEGL list at concentrations greater than the 30-min AEGL-1 vapor concentration value;

4.7.2 The manufacturer shall test the HPCVD under common ambient conditions to characterize the false positive alarm rate. This test should include three different ambient conditions with each test having a minimum duration of 150 hours. The manufacturer shall document:

4.7.2.1 The test conditions including a description of the test location and potential background chemical vapors or sources of background chemical vapors or both that could cause a false positive alarm;

4.7.2.2 The number of hours operated in the environment;

4.7.2.3 The ranges of temperatures, pressures, and relative humidity values; and

4.7.2.4 The indicated chemical, indicated alarm level, number of events, times, and duration of each alarm, if any.

4.7.3 The manufacturer may document any additional capability of the HPCVD to reject common background chemical vapors by documenting the chemical vapors and concentrations used in testing for false positive alarms.

4.8 *Chemical Detector Robustness:*

4.8.1 The HPCVD shall detect and alarm according to the manufacturer-documented capabilities after exposure to synthesized chemical vapor mixtures as described in section 4.7.

4.8.2 If after exposure to the synthesized chemical vapor mixtures, as described in section 4.7, the HPCVD no longer detects and alarms according to the manufacturer-documented capabilities, the HPCVD shall indicate a malfunction.

4.9 *Limitations of Testing*—The complex nature of chemistry, the environment, and the interaction of chemicals with the environment may impact a manufacturer's ability to demonstrate through testing that an HPCVD meets all of the requirements for all hazardous chemical vapors under all environmental conditions. Testing under extreme cases is not required, for example:

4.9.1 The HPCVD is not required to meet requirement 4.3.2 with persistent chemical vapors (for example, VX). The manufacturer shall note the chemicals for which the HPCVD does not meet the requirement.

4.9.2 Generation of laboratory challenge streams may be difficult at elevated relative humidities (greater than 90 %); therefore, tests at relative humidities greater than 90 % are not required.

4.9.3 Laboratory tests with a large number of mixtures of background chemical vapors of interest and chemicals of interest are informative. This standard specification requires a minimum number of test mixtures; therefore, it provides only a limited amount of information on how an HPCVD will perform in the field.

4.10 *Detection Capabilities for Chemicals Not on the AEGL List*—The manufacturer may document chemical detection capabilities for chemicals not on the AEGL list.

4.10.1 The manufacturer shall document the vapor concentrations at which the alarms are triggered.

4.10.2 The manufacturer shall correlate the alarms with published studies on health effects.

4.10.3 The HPCVD shall indicate the specific chemical that is detected; and

4.10.4 The HPCVD should indicate the vapor concentration of the chemical present in absolute quantities (for example, ppm or mg/m^3).

5. System Requirements

5.1 *System Properties*—The HPCVD:

5.1.1 Should weigh no more than 2.5 kg including the battery and in all of its mission configurations; and

5.1.2 If the HPCVD contains radioactive materials, then it shall contain radioactive materials only in quantities that qualify for an exempt materials license per the Nuclear Regulatory Commission CFR Title 10, Part 30.20.

5.2 *Alarms and Indicators:*

5.2.1 The HPCVD shall provide alarms in the presence of hazardous chemical vapors at the vapor concentrations given in 4.3 with response times given in 4.4.

5.2.2 The HPCVD should provide indicators relaying other information such as battery status, malfunction, or maintenance requirement.

5.2.3 The HPCVD alarms and indicators shall:

5.2.3.1 Display in English,

5.2.3.2 Have dimmable display(s) readable from low-light levels (< 50 lux) to direct sunlight (>100 000 lux),

5.2.3.3 Have an audible alarm, and

5.2.3.4 Have a muting option for each audible alarm and audible indicator.

5.2.4 The HPCVD alarms and indicators may optionally provide:

5.2.4.1 A vibrating alarm,

5.2.4.2 Remote alarm(s), and

5.2.4.3 Additional languages.

5.3 *Power*—The HPCVD shall:

5.3.1 Have a minimum operating time of 6 h on fully charged batteries;

5.3.2 Use single-use, or rechargeable batteries or both;

5.3.3 Automatically reset upon power restoration after power interruption; and

5.3.4 Automatically change between external and internal power without interruption, false alarm, loss of data, or degradation if external power source is supported.

5.4 *Reliability and Maintainability:*

5.4.1 *Reliability*—The HPCVD shall:

5.4.1.1 Have a mean time between failures of at least 720 h;

5.4.1.2 Provide a means to verify that the HPCVD is functional to include alarms and indicators; and

5.4.1.3 Have a ten-year shelf life, except batteries and consumables, when stored according to manufacturer guidelines.

5.4.2 *Maintainability*—The HPCVD shall:

5.4.2.1 Provide a mean time to maintain of 30 min or less for operator maintenance actions,

5.4.2.2 Require minimal periodic maintenance while in storage, and

5.4.2.3 Be capable of software upgrades during the expected service life.

5.5 *Data, Data Interfaces, and Communications:*

5.5.1 The HPCVD shall be capable of:

5.5.1.1 Storing data in nonvolatile memory, including time and type of alarm,

5.5.1.2 Transferring data to a data collection or monitoring system or both, and

5.5.1.3 Software updates.

5.5.2 The HPCVD data communications interface may be any combination of wired and wireless technologies.

6. Environmental Requirements

6.1 The HPCVD shall be tested and the results documented for resistance to degradation caused by environmental factors such as: storage environments, solar radiation, shock, vibration, ingress of moisture and dust, salt environments, altitude, and electromagnetic interference.

6.2 These tests shall be conducted using consensus standards, government standards, and other international standards; see Appendix X4.

7. Manuals and Documentation

7.1 The accompanying manuals may be provided in print or electronic media or both in any appropriate format.

7.2 The HPCVD manuals shall include:

7.2.1 User manuals shall describe the capabilities and uses for the HPCVD:

7.2.1.1 Manufacturer-documented capabilities;

7.2.1.2 Chemical detection capabilities (Section 4);

7.2.1.3 Specific chemical vapors and the threshold 30-min AEGL values;

7.2.1.4 Mission and transport weight and dimensions;

7.2.1.5 Climate range(s) (Table 2);

7.2.1.6 Hardware;

7.2.1.7 Software;

7.2.1.8 Accessories;

7.2.1.9 Instructions for normal operations, special operations, and restrictions;

7.2.1.10 Consumables and the replacement frequency per number of operating hours, replacement frequency per number of non-operating hours, and packaged shelf life;

7.2.1.11 Calibration frequency and associated consumables required for calibration;

7.2.1.12 Description of all alarms and indicators;

7.2.1.13 Recommended decontamination procedures;

7.2.1.14 HPCVD operating time while the HPCVD is powered by batteries, when not in alarm mode, and when in continuous alarm mode at ambient temperatures of 0, 20, and 50°C and battery type used (for example alkaline and lithium ion);

7.2.1.15 Recommended hazardous waste disposal procedures to include consumables, accessories, and the HPCVD;

7.2.1.16 Explanation of the controls and connectors;

7.2.1.17 Description and protocols for communication methods for transmitting and receiving data;

7.2.1.18 Description of data, data interfaces, and communications;

7.2.1.19 Warning statements; and

7.2.1.20 Recommended storage practices.

7.2.2 Data and communications manuals shall describe all elements of the data and communications systems in 5.5.

7.2.3 Maintenance manuals shall describe:

7.2.3.1 Field maintenance;

7.2.3.2 User maintenance, including troubleshooting guide;

7.2.3.3 Service and repair; and

7.2.3.4 Calibration.

7.2.4 Field manual(s) shall include:

7.2.4.1 Chemical detection capabilities (Section 4);

7.2.4.2 Specific chemical vapors and the threshold 30-min AEGL values;

7.2.4.3 Basic use instructions;

7.2.4.4 Battery and charging instructions;

7.2.4.5 External power requirements (voltage and frequency), if applicable; and

7.2.4.6 Consumable replacement procedures.

7.2.5 Operator training manuals.

7.2.6 Shipping and transport manuals shall describe:

7.2.6.1 Instructions for packaging and shipping, and

7.2.6.2 Transport configuration when not in shipping container.

7.2.7 Licenses and certificates required for ownership and operation.

8. Product Marking

8.1 The HPCVD shall be appropriately marked, including:

8.1.1 Manufacturer's name;

8.1.2 Model number;

8.1.3 Unique serial number;

8.1.4 Each control and connection for its intended use;

8.1.5 Battery type;

8.1.6 Battery charging capability and accessories;

8.1.7 External power, if applicable;

8.1.8 Certified for use in explosive atmospheres, if applicable; and

8.1.9 Hazard labels.

8.2 The HPCVD accessories or the packaging shall be appropriately marked, including:

8.2.1 Manufacturer's name;

8.2.2 Model number;

8.2.3 The HPCVD model number with which this accessory is associated; and

8.2.4 Hazard labels.

9. Packaging

9.1 The manufacturer shall provide a container for storage and transport for the HPCVD.

10. Keywords

10.1 chemical vapor detector; handheld point chemical vapor detector; HPCVD; homeland security

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE CHEMICAL VAPORS OF INTEREST FOR HOMELAND SECURITY APPLICATIONS

X1.1 Each manufacturer documents the chemicals that its instrument can verifiably detect and provide an alarm. Chemicals of interest are listed in the Acute Exposure Guideline Levels (AEGL). Table X1.1 is an excerpt from the AEGL. It is neither prioritized nor comprehensive. The specific chemicals of interest vary by user depending upon their specific needs. The values in Table X1.1 are the 30-min AEGL values in parts per million (ppm) at each of the hazard levels: AEGL-3, AEGL-2, and AEGL-1.

X1.2 Table X1.2 provides the 30-min AEGL values in mg/m^3 at each of the hazard levels: AEGL-3, AEGL-2, and AEGL-1. The equation below was used to convert the AEGL vapor concentration values, where $AEGL_{ppm}$ and $AEGL_{mg/m^3}$ represent the AEGL values in ppm and mg/m^3, respectively and MW represents the molecular weight (molar mass) in atomic mass units. This conversion is based on the molar volume of an ideal gas at 298 K.

$$AEGL_{mg/m^3} = AEGL_{ppm} \times (MW / 24.45) \quad (X1.1)$$

TABLE X1.1 30-min AEGLs in ppm at AEGL-1, AEGL-2, and AEGL-3[A]

CHEMICAL	Chemical Abstract Service Registry Number	AEGL-3 (30 min)	AEGL-2 (30 min)	AEGL-1 (30 min)
		parts-per-million (ppm)		
Acrolein	107-02-8	2.5	0.18	0.030
Acrylonitrile[B]	107-13-1	180	110	4.6
Ammonia	7664-41-7	1600	220	30
Arsine	7784-42-1	0.63	0.21	NR[C]
Chlorine (gas)	7782-50-5	28	2.8	0.5
Cyanogen chloride (CK)[D]	506-77-4	21	10	2.5
Cyclosarin (GF)	329-99-7	0.027	0.0035	0.000 28
Ethylene oxide	75-21-8	360	80	NR[C]
Formaldehyde[B]	50-00-0	70	14	0.90
Hydrogen chloride	7647-01-0	210	43	1.8
Hydrogen cyanide (AC)	74-90-8	21	10	2.5
Lewisite (L)[B]	541-25-3	0.17	0.027	NR[C]
Mustard (HD)	505-60-2	0.41	0.030	0.020
Nitrogen mustard (HN3)[B]	555-77-1	0.088	0.0053	NR[C]
Phosgene	75-44-5	1.5	0.60	NR[C]
Sarin (GB)	107-44-8	0.032	0.0085	0.000 68
Soman (GD)	96-64-0	0.025	0.0033	0.000 26
Sulfur dioxide	7446-09-5	30	0.75	0.20
Tabun (GA)	77-81-6	0.057	0.0075	0.0006
VX	50782-69-9	0.0014	0.000 38	0.000 03

[A] http://www.epa.gov/oppt/aegl/index.htm, updated August 2010.
[B] Interim values.
[C] None recommended (NR).
[D] Cyanogen chloride (CK) values are based upon hydrogen cyanide (HCN) values.

TABLE X1.2 30-min AEGLs in mg/m³ at AEGL-1, AEGL-2, and AEGL-3[A]

CHEMICAL	Chemical Abstract Service Registry Number	AEGL-3 (30 min)	AEGL-2 (30 min)	AEGL-1 (30 min)
			mg/m³	
Acrolein	107-02-8	5.7	0.41	0.070
Acrylonitrile[B]	107-13-1	390	240	10
Ammonia	7664-41-7	1119	154	21
Arsine	7784-42-1	2.0	0.7	NR[C]
Chlorine (gas)	7782-50-5	81	8.1	1.5
Cyanogen chloride (CK)[D]	506-77-4	23	11	2.8
Cyclosarin (GF)	329-99-7	0.19	0.025	0.0020
Ethylene oxide	75-21-8	648	144	NR[C]
Formaldehyde[B]	50-00-0	86	17	1.1
Hydrogen chloride	7647-01-0	313	65	2.7
Hydrogen cyanide (AC)	74-90-8	23	11	2.8
Lewisite (L)[B]	541-25-3	1.4	0.23	NR[C]
Mustard (HD)	505-60-2	2.7	0.20	0.13
Nitrogen mustard (HN3)[B]	555-77-1	0.74	0.044	NR[C]
Phosgene	75-44-5	6.2	2.5	NR[C]
Sarin (GB)	107-44-8	0.19	0.050	0.0040
Soman (GD)	96-64-0	0.19	0.025	0.0020
Sulfur dioxide	7446-09-5	78	1.95	0.52
Tabun (GA)	77-81-6	0.38	0.050	0.0040
VX	50782-69-9	0.015	0.0042	0.00033

[A] http://www.epa.gov/oppt/aegl/index.htm, updated August 2010.
[B] Interim values.
[C] None recommended (NR).
[D] Cyanogen chloride (CK) values are based upon hydrogen cyanide (HCN) values.

X2. STATISTICAL METHODS FOR DETERMINING PROBABILITY OF DETECTION AND TEST PEFORMANCE

X2.1 As stated in 4.6, to conform to this specification, an HPCVD shall achieve a probability of detection and alarm of at least 85 % under any condition within the stated climate type. Because the determination of the probability of detection and alarm is unavoidably subject to random measurement error during testing, conforming values of the HPCVD's probability of detection and alarm are specified by an 80 % lower confidence bound on its value. The statistical model and methods used to determine the lower bound, the number of tests required, and the performance of the lower bound when used as a conformance test are discussed in this appendix. In Fig. X2.1, the operational aspects of the test procedure from a statistical perspective and the results required for an HPCVD to comply with this specification are summarized. As indicated in 4.6 and Fig. X2.1, conformance requires either 9 alarms in 9 tests, or 17 alarms in 18 tests (see Table X2.1).

X2.2 *Statistical Model and Number of Tests Required*:

X2.2.1 The statistical model to be used for the determination of a lower bound for the probability of detection and alarm, π_{DA},[4] assumes that each test of the HPCVD independently follows a Bernoulli probability distribution with a probability of detection equal to π_{DA}. In statistical notation, this is expressed as:

$$T_i|\pi_{DA} \sim \text{Bernoulli}(\pi_{DA}) \quad (X2.1)$$

where:

T_i = any one of the $i = 1,...,n$ tests of the HPCVD given the value of π_{DA}.

X2.2.2 A further assumption included in the statistical model is that, before any testing, the test analyst's knowledge of the value of π_{DA}indicates that it is equally likely to lie anywhere in the range from $\pi_{DA} = 0$ to $\pi_{DA} = 1$. The corresponding statistical notation for this is:

$$\pi_{DA} \sim \text{Uniform}(0\ ,\ 1) \quad (X2.2)$$

X2.2.3 This assumption expresses the test analyst's knowledge about the probability of detection and alarm in terms of a probability distribution and represents a neutral initial condition for any set of tests made under fixed conditions. This initial condition is illustrated graphically by the solid black probability density function shown in Fig. X2.2.

X2.2.4 For each test, the value of T_i is defined to be:

$$\begin{aligned} T_i &= 0 \text{ if detector does not alarm within allowed response time} \\ T_i &= 1 \text{ if detector does alarm within allowed response time} \end{aligned} \quad (X2.3)$$

X2.2.5 Based on this model for the test data, the sum of the individual test results follows the binomial probability distribution with parameters n and π_{DA}:

$$S_T \sim \text{Binomial}(n\ ,\ \pi_{DA}) \quad \text{where } S_T = \sum_{i=1}^{n} T_i \quad (X2.4)$$

[4] The symbol π used here denotes the unknown value of a probability and is unrelated to the other common use for this symbol to refer to the ratio of the perimeter of a circle to its diameter ($\pi \approx 3.14$).

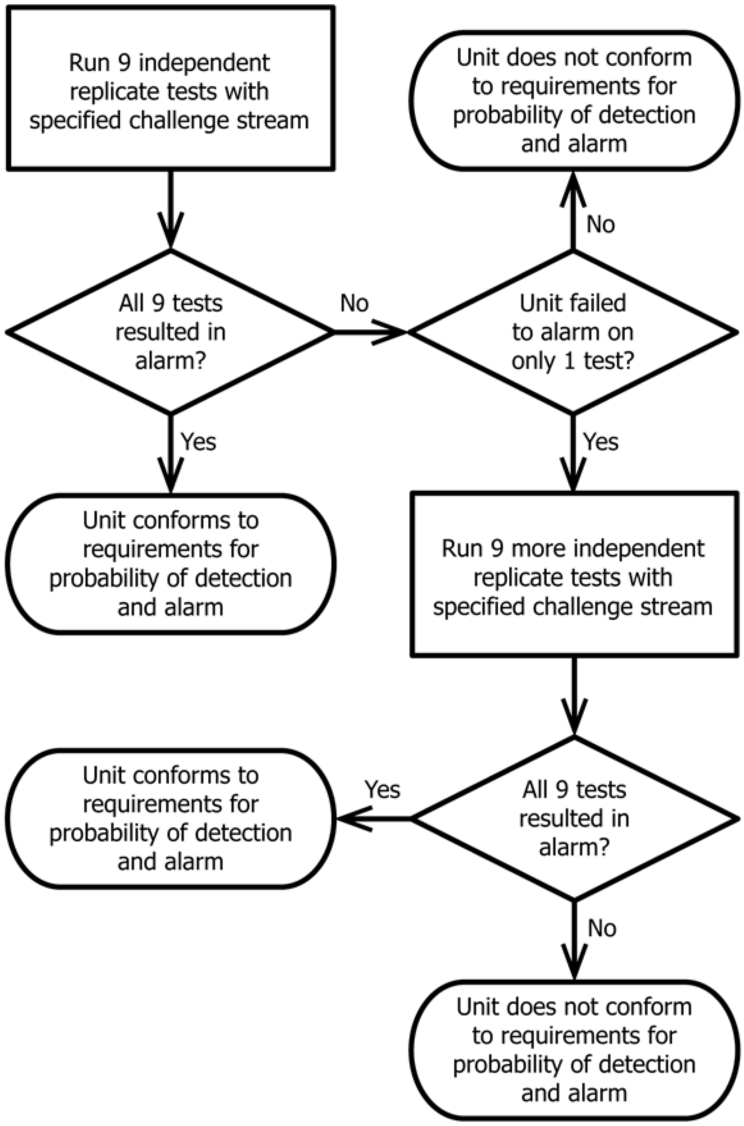

FIG. X2.1 Summary of Conformance Test Procedures

TABLE X2.1 Minimum Numbers of Tests Required to Obtain a Lower Bound for the Specified Probability of Detection and Alarm with the Specified Confidence Level

NOTE 1—The first number in each interior cell of the table assumes all tests result in an alarm. The second number in each cell assumes all tests but one result in an alarm.

		Confidence Level							
		0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
Probability of Detection and Alarm	0.60	1 / 4	2 / 4	2 / 5	2 / 5	3 / 6	3 / 7	4 / 8	5 / 9
	0.65	2 / 5	2 / 5	2 / 6	3 / 6	3 / 7	4 / 8	5 / 9	6 / 11
	0.70	2 / 6	2 / 6	3 / 7	3 / 8	4 / 8	5 / 9	6 / 11	8 / 13
	0.75	3 / 7	3 / 8	4 / 9	4 / 9	5 / 10	6 / 12	8 / 14	10 / 17
	0.80	4 / 9	4 / 10	5 / 11	6 / 12	7 / 13	8 / 15	10 / 17	13 / 21
	0.85	5 / 12	6 / 14	7 / 15	8 / 17	9 / 18	11 / 21	14 / 24	18 / 29
	0.90	8 / 19	9 / 21	11 / 23	13 / 26	15 / 28	18 / 32	21 / 37	28 / 45
	0.95	17 / 39	20 / 43	23 / 48	27 / 52	31 / 58	36 / 66	44 / 76	58 / 92

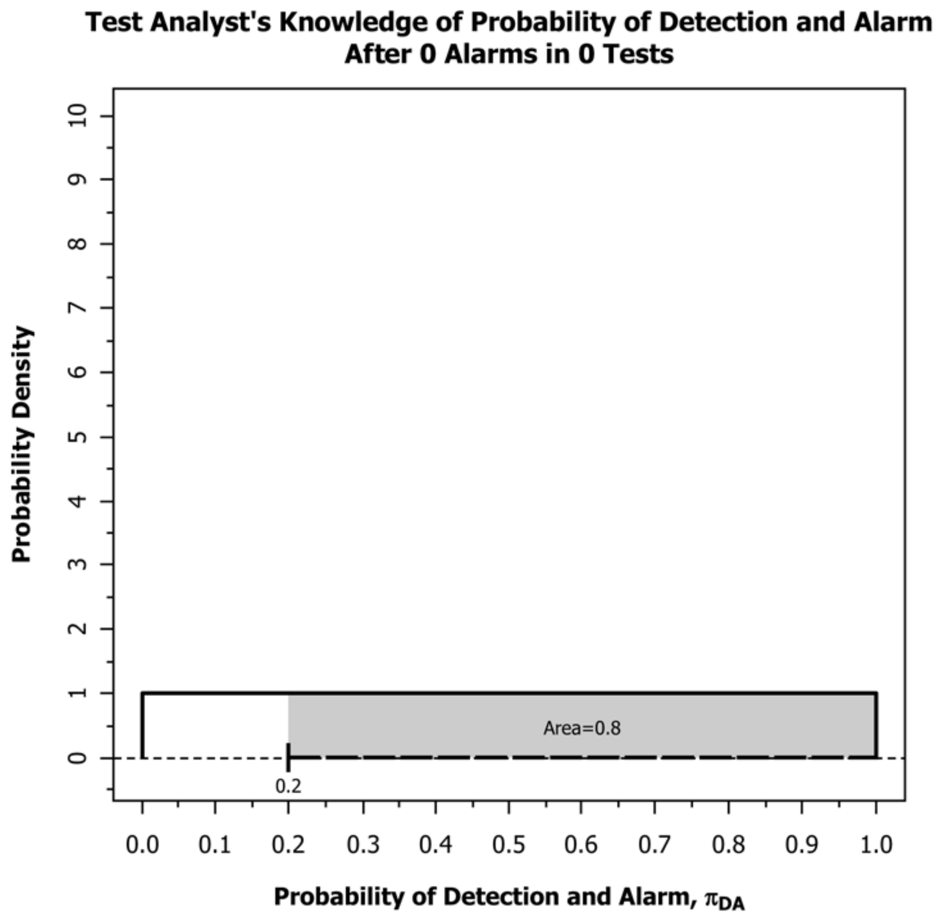

FIG. X2.2 Initial Conditions Assumed by the Test Analyst before Running Any Tests

X2.2.6 Based on the full statistical model, application of Bayes' Theorem[5] then indicates that the test analyst's updated knowledge of the value of π_{DA} given the test results S_T is:

$$\pi_{DA} | S_T \sim \mathrm{Beta}(S_T + 1 , n - S_T + 1) \qquad (X2.5)$$

X2.2.7 Using this probability distribution for the test analyst's knowledge of π_{DA}, a lower 80 % confidence bound[6] on its value is found by solving Eq X2.6 for the value of B_L, where $\Gamma(z)$ is the gamma function.[7]

$$\int_{B_L}^{1} \frac{\Gamma(n + 2)}{\Gamma(S_T + 1)\,\Gamma(n - S_T + 1)}\, x^{S_T}(1 - x)^{n - S_T}\, dx = 0.8 \qquad (X2.6)$$

X2.2.8 High-level functions to solve this equation are available in most statistical software packages, such as R[8] (qbeta), and in some spreadsheets, such as Microsoft Excel (beta.inv). The heavy dashed line along the horizontal axis in Fig. X2.2 shows the range of potential values that π_{DA} can take on based on the 80 % lower confidence bound (indicated by the short vertical black line at the end of the heavy dashed line) that the analyst assumes before collecting any test data (that is, $S_T = 0$ and $n = 0$). This indicates that before testing the analyst can only conclude $\pi_{DA} \geq 0.2$ with 80 % probability.

X2.2.9 Starting from the initial conditions assumed in this statistical model, the minimum number of tests required to determine that the value of $\pi_{DA} \geq 0.85$ based on its 80 % lower confidence bound is $n = 9$ tests. This assumes the HPCVD detects the chemical vapor within the allowed response time in every test. Fig. X2.3 shows the probability distribution the test analyst would obtain after carrying out nine tests in which every test resulted in an alarm. Based on the evidence obtained from the testing, the analyst can now conclude that $\pi_{DA} \geq 0.85$ with 80 % probability; thus, the HPCVD has been shown to have a probability of detection in compliance with this specification.

X2.2.10 In Fig. X2.4, the knowledge that the analyst would have if the HPCVD had alarmed in only eight of the nine tests is shown. In this case, the test analyst can only conclude that $\pi_{DA} \geq 0.73$ with 80 % probability. Thus, the HPCVD has not yet been shown to be in compliance with the standard. However, if an additional nine tests were carried out under

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[5] Lee, P. M., Bayesian Statistics: *An Introduction*, 2nd ed., Arnold Publishing, London, 1997, 344 p.

[6] Strictly speaking, the term confidence only applies to lower bounds determined using the frequentist approach to statistical inference, while the Bayesian approach is being used here. Nevertheless, we use the term confidence because it is more familiar and conveys the desired concept concisely.

[7] Arfken, G. W. and Weber, H. J., *Mathematical Methods for Physicists*, 6th ed., Elsevier Academic Press, Burlington, MA, 2005, 1200 p.

[8] R Development Core Team, *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, 2011, http://www.R-project.org/.

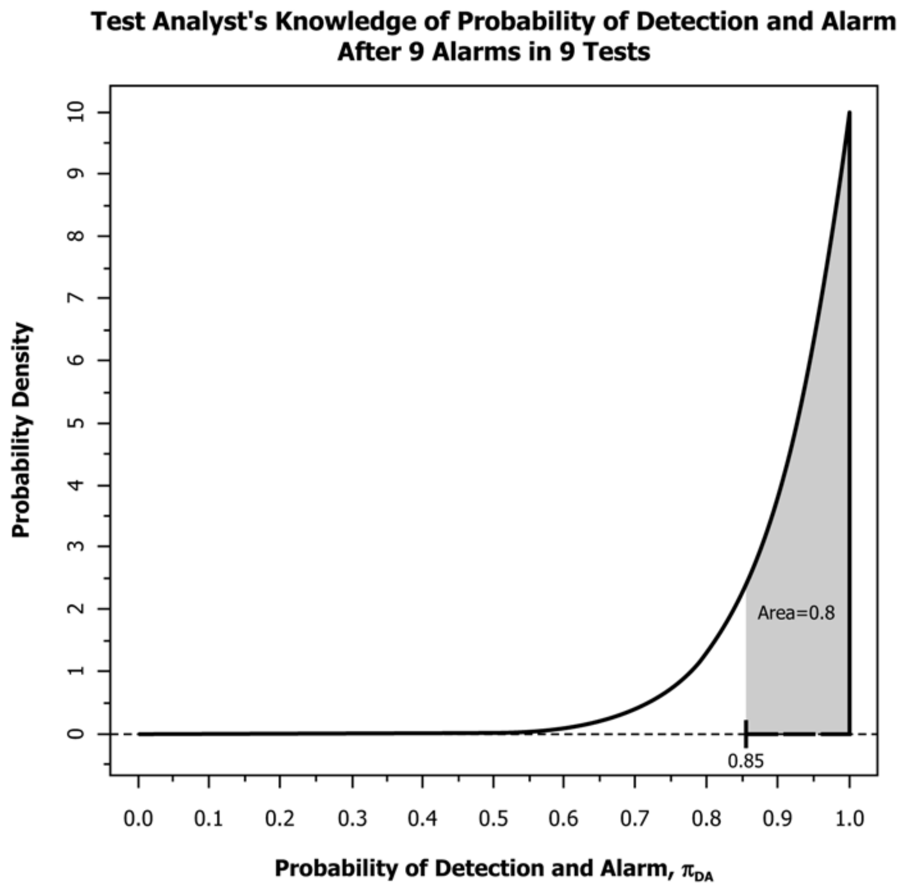

FIG. X2.3 Statistical Results after Observing Nine Tests in which Each Test Resulted in Detection and Alarm

identical conditions and the HPCVD alarmed in each of those tests, then the tester's knowledge about the value of π_{DA} would be given by the probability distribution shown in Fig. X2.5.

X2.2.11 Based on the probability distribution shown in Fig. X2.5, the analyst would again be able to conclude that the HPCVD had been shown to have a probability of detection and alarm in compliance with this specification since $\pi_{DA} \geq 0.85$ with 80 % probability. This knowledge is based on the full series of 18 tests, including the 1 test in which the HPCVD did not alarm within the allowed response time.

X2.2.12 In Table X2.1, the sample sizes for determining lower bounds like the ones described here for different specifications of the probability of detection and alarm and confidence level are given. These values illustrate how the testing effort required varies with the desired specifications. The first number in each interior cell of Table X2.1 is the number of tests required assuming the HPCVD alarms in all tests. The second number in each cell is the number of tests required if the HPCVD alarms in all tests but one.

X2.3 *Performance of the Lower Bound on* π_{DA} *as a Conformance Test*:

X2.3.1 In addition to the statistical information needed to determine the probability of detection and alarm as given in this specification, determination of the performance of the lower bound as a conformance test is also important to ensure that it has adequate ability, or operating characteristics, to distinguish correctly between HPCVDs with different true values of π_{DA}. The operating characteristics of a conformance test based on this type of sequentially determined lower bound depend on the value of π_{DA} that shall be met, the confidence level used to determine the lower bound, the number of tests for which the HPCVD is allowed to fail to alarm, and the number of tests to be carried out in each phase of the sequential estimation of the lower bound.

X2.3.2 In Fig. X2.6, the operating characteristic curve of the test outlined in Fig. X2.1 as a function of the true, unknown values of π_{DA} that an HPCVD could have is displayed. The plot shows the different true values of π_{DA} that an HPCVD might have on the horizontal axis and the proportion of HPCVDs that would be determined to have probabilities of detection and alarm in compliance with the standard on the vertical axis. The ideal performance of the conformance test is shown on the plot as a dashed line. What can be seen from Fig. X2.6 is that some HPCVDs that actually do meet the criteria given in this specification in terms of probability of detection and alarm will not be found to be in compliance, while others that do not meet the criteria may sometimes be determined to be in compliance.

X2.3.3 For example, looking at the value $\pi_{DA} = 0.99$ on the horizontal axis in Fig. X2.6, one can see that approximately 99 % of HPCVDs with a probability of detection at this level would be found to be in compliance. For HPCVDs with a true

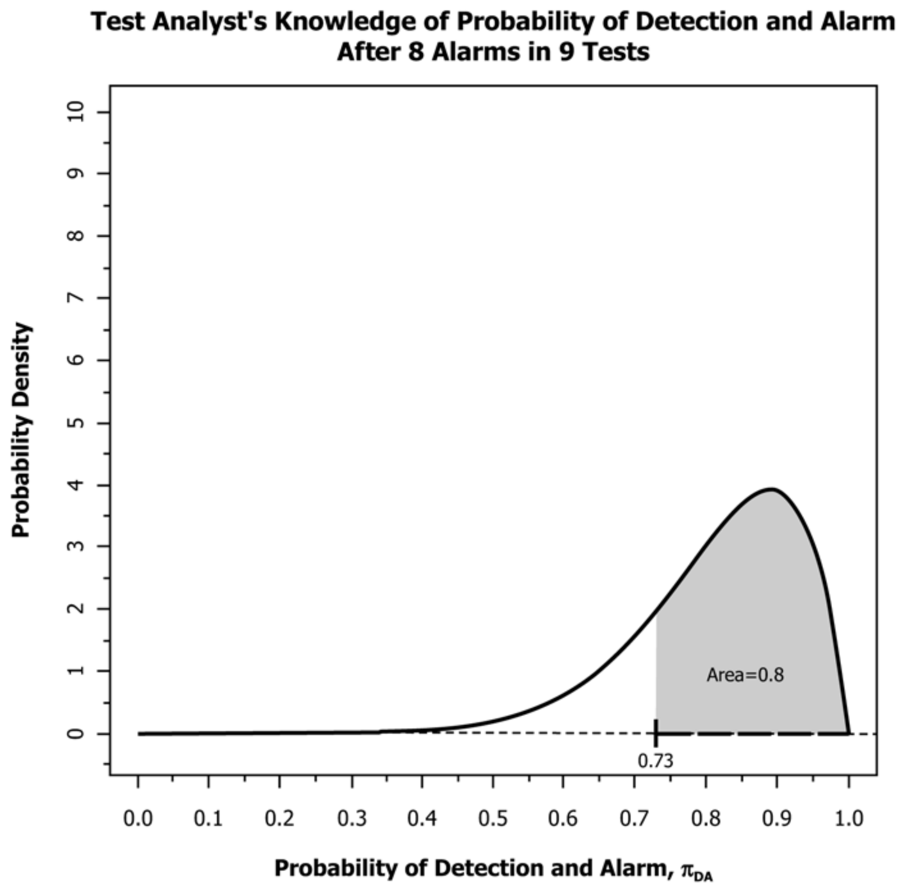

FIG. X2.4 Statistical Results after Observing Nine Tests in which Only Eight Tests Resulted in Detection and Alarm

probability of detection equal to π_{DA} = 0.95, the corresponding proportion of HPCVDs that would be found in compliance is about 82 %.

X2.3.4 The trade-offs for using a conformance test that does not find all HPCVDs with values of $\pi_{DA} \geq 0.85$ in compliance with this specification are reductions in the amount of testing required and in the proportion of HPCVDs with values of $\pi_{DA} < 0.85$ that would incorrectly be found to be in compliance with this specification. For example, just under 5 % of any HPCVDs with values of π_{DA} = 0.7 would be determined to be in compliance using the test described here. Note that values of $\pi_{DA} < 0.5$ are not shown in Fig. X2.6 since HPCVDs with those probabilities of detection and alarm would be determined to be in compliance with this specification in only a negligible proportion of test sequences of n = 9 or n = 18 tests.

X2.3.5 Three sets of potential requirements from Table X2.1 are plotted in Fig. X2.7 to illustrate how the performance of tests based on lower bounds like those used in this standard depends on the specification of the requirements. The operating characteristic curve for the conformance test when conformance is specified to require the value of $\pi_{DA} \geq 0.60$ with 60 % confidence is indicated by the solid black curve in the upper left of Fig. X2.7. Under this requirement only 1 test resulting in alarm, or 4 tests with 3 alarms, would be needed to declare conformance with the standard. However, a relatively large proportion of HPCVDs that are not in compliance will be determined to be in compliance under this requirement. For example, approximately 55 % of HPCVDs with π_{DA} = 0.50 would be found to be in conformance with the standard.

X2.3.6 The operating characteristics for $\pi_{DA} \geq 0.85$ with 80 % confidence, the requirement actually specified in this standard, are indicated by the solid black curve in the middle of Fig. X2.7. As discussed above, 9 tests with 9 alarms, or 18 tests with 17 alarms, are needed to show conformance with this requirement. In this case, however, the test is somewhat more stringent than the case discussed above and relatively few HPCVDs that have values of π_{DA} below the specified value will be determined to be in conformance with the standard. For example, only about 10 % of the HPCVDs with a value of π_{DA} = 0.75 would be found to be in compliance with the standard in this case. The cost for this increase in stringency is that proportion of HPCVDs with values of π_{DA} = 0.85 found to be in conformance drops to about 30 % from a value of about 95 % associated with the requirements that $\pi_{DA} \geq 0.60$ with 60 % confidence.

X2.3.7 Finally, the operating characteristic curve for $\pi_{DA} \geq 0.95$ with 95 % confidence is indicated by the dashed black curve with long and short dashes in the lower right of Fig. X2.7. In this case 58 tests with 58 alarms or 92 tests with 91 alarms are required to demonstrate conformance, a substantial increase in testing effort relative to the specifications discussed above. However, this is the most stringent test of the

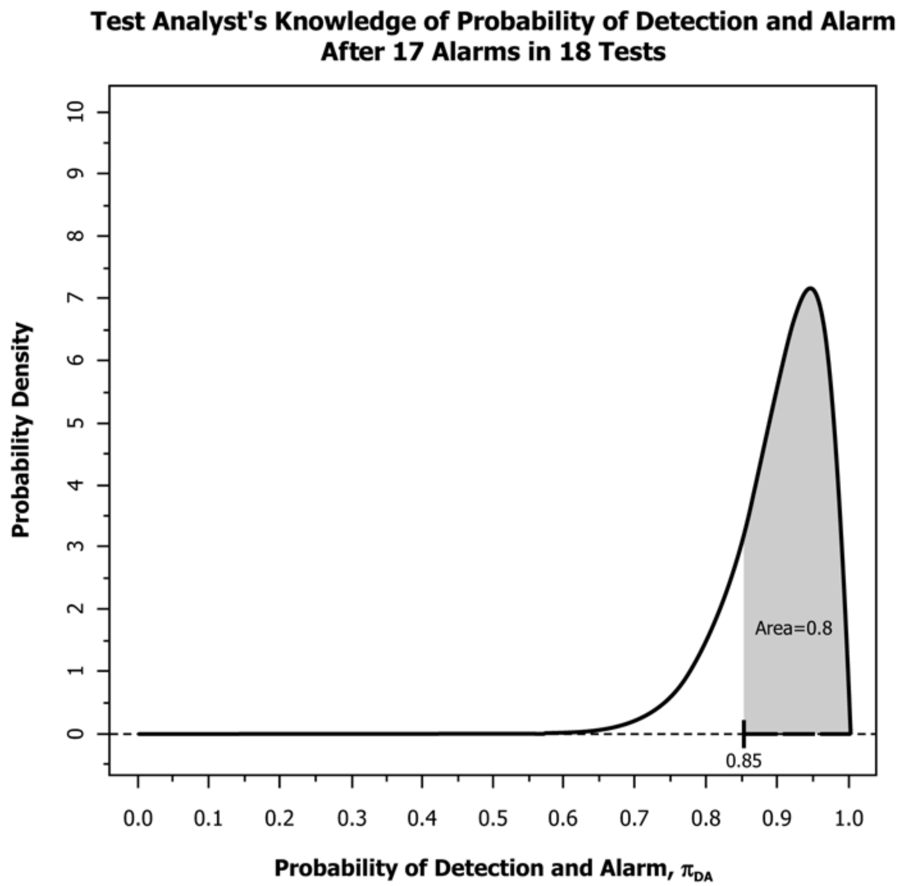

FIG. X2.5 Statistical Results after Observing 18 Tests in which Only 17 Tests Resulted in Detection and Alarm

three considered with fewer than 10 % of HPCVDs that are not in compliance with the standard being found to be in compliance.

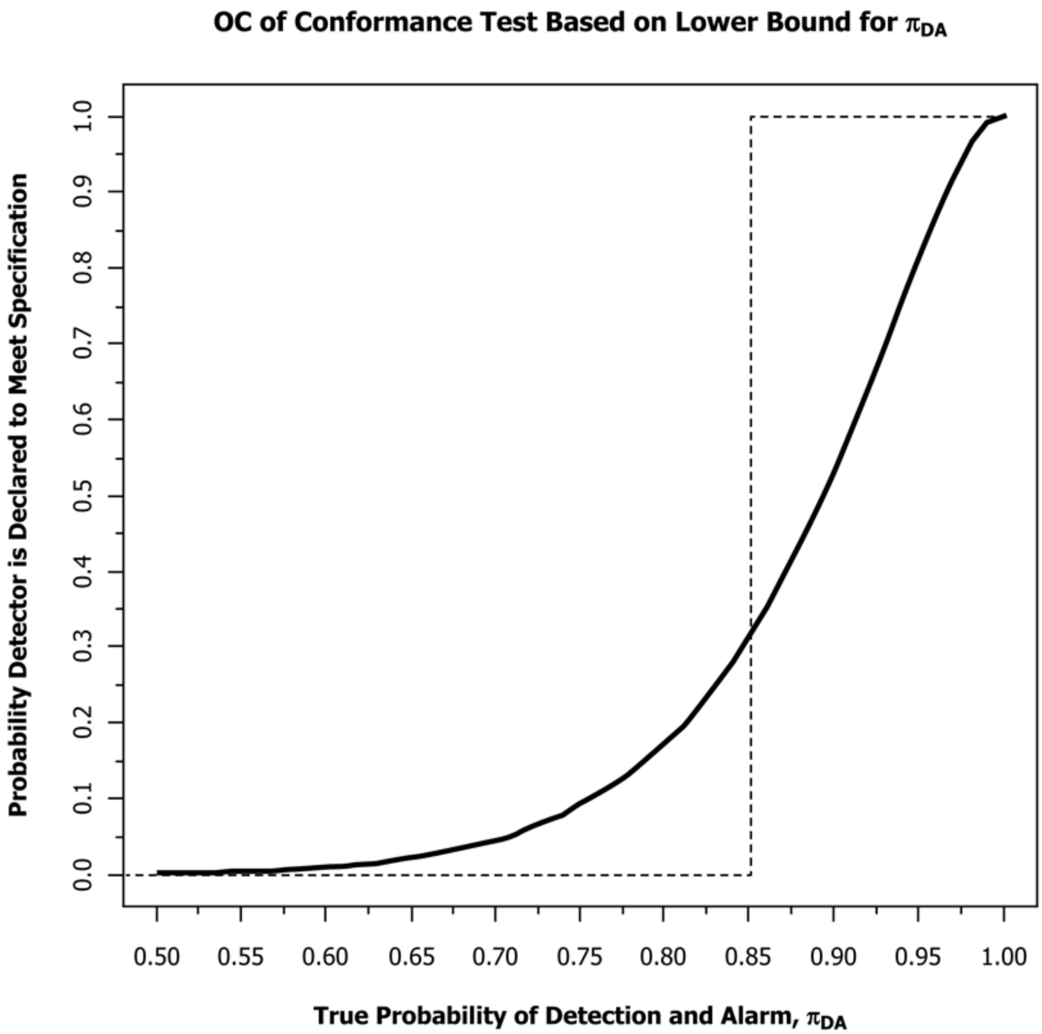

FIG. X2.6 Operating Characteristics (OC) of the Conformance Test Based on the Lower Bound for π_{DA} as a Function of Possible True Values of π_{DA} that an HPCVD Might Have

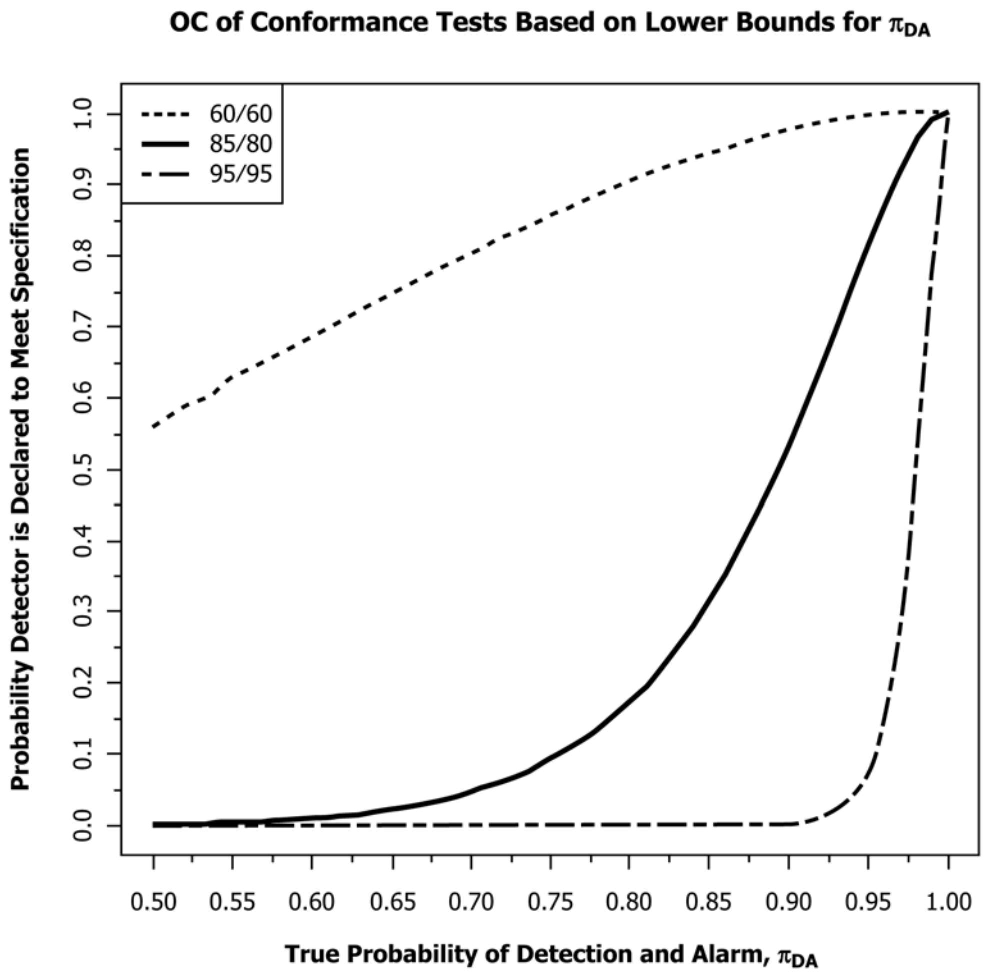

FIG. X2.7 Comparison of Operating Characteristics (OC) for Conformance Tests Based on Lower Bounds for π_{DA} with $\pi_{DA} \geq 0.60$ with 60 % Confidence (Short Dashed Curve), $\pi_{DA} \geq 0.85$ with 80 % Confidence (Solid Curve), and $\pi_{DA} \geq 0.95$ with 95 % Confidence (Long and Short Dashed Curve)

X3. EXAMPLE TEST PLANS FOR VERIFYING CHEMICAL DETECTION CAPABILITIES

X3.1 Manufacturers shall document and verify through testing the chemical detection capabilities of the HPCVD. The test methods and test plans used for conformance testing shall be cited in the test reports.

X3.2 Below is a list of test methods. This list is not meant to be comprehensive. For further information contact the Office of Standards, Acquisition Support and Operations Analysis, Science & Technology Directorate, Department of Homeland Security.

Sample Test Execution Plan for Testing Commercial Off-the-Shelf (COTS) Stationary, Autonomous Chemical Detectors used in a Subway Transit Environment, K.J. Dame, N.B. Au, J.K. Williams, and D.J. Minor, Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD 21010, February 2012.

Method Number ADT-178, Rev 4, Method for Evaluating Detectors, Report Number 2012-ADT-038, T. L. Longworth and K.Y. Ong, Engineering Directorate, Applied Detection Technology, Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD, October 2012.

Use of Sniffer to Develop a Detailed Test Plan for Commercial Off-the-Shelf (COTS) Stationary, Autonomous Chemical Detectors Used in a Subway Transit Environment, Engineering Directorate, Detection Engineering Branch Protection Factor and Toxic Chambers Branch, Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD, July 2011.

Detailed Test Plan for the Joint Chemical Agent Detector (JCAD) Toxic Industrial Chemical (TIC) Testing, K. Siddoway, T. Derringer, Battelle, Columbus, OH, September 2007.

X4. TEST METHODS FOR VERIFYING COMPLIANCE WITH SYSTEM AND ENVIRONMENTAL REQUIREMENTS

X4.1 Manufacturers shall document and verify through testing the system and environmental properties of the HP-CVD. The test methods and test plans used for conformance testing shall be cited in the test reports. Below is a list of test methods. This list is not meant to be comprehensive.

47 CFR Telecommunications Chapter 1, Rule 15, Unintentional Radiators

ANSI N42.32, "American National Standard Performance Criteria for Alarming Personal Radiation Detectors for Homeland Security"

ANSI N42.33, "American National Standard for Portable Radiation Detection Instrument for Homeland Security"

ANSI N42.34, "American National Standard Performance Criteria for Hand-Held Instruments for the Detection and Identification of Radionuclides"

ANSI N42.35, "American National Standard for Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security"

IEC 60068-1, Environmental Testing—Part 1: General and Guidance.

IEC 60068-2-18, Environmental Testing—Part 2-18: Tests—Test R and Guidance: Water.

IEC 60068-2-75, Environmental Testing—Part 2-75: Tests—Test Eh: Hammer Tests.

IEC 60529, Degrees of Protection Provided by Enclosures (International Protection Rating or IP Code).

IEC 61000-4-1, Electromagnetic Compatibility (EMC)—Part 4-1: Testing and Measurement Techniques—Overview of IEC 61000-4 Series.

IEC 61000-4-2, Electromagnetic Compatibility (EMC)—Part 4-2: Testing and Measurement Techniques—Electrostatic Discharge Immunity Test.

IEC 61000-4-3, Electromagnetic Compatibility (EMC)—Part 4-3: Testing and Measurement Techniques— Radiated, Radio-Frequency, Electromagnetic Field Immunity Test.

MIL-Standard 461 Department of Defense Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

MIL-Standard 810, "Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests."

UL 2075, "Gas and Vapor Detectors and Sensors."