In-Situ Smoke Generation for Testing Very Early Warning Fire Detection (VEWFD)

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Abstract

In-situ smoke sensitivity testing in an operational facility can be challenging when installing a Very Early Warning Fire Detection (VEWFD) system. In-situ testing is needed to verify if smoke generated within the protected space can reach the detector quickly during a fire event. It can also be instructive to quantify pre-alarm and alarm thresholds required to protect against specific performance based fire events. Several standardized test methods are available to conduct this type of in-situ testing but are all limited in application by the volume and surface area of space needed and by the specified use of chlorinated polyvinyl chloride wire jacket as a smoke source.

Alternative in-situ smoke production methods have been developed and evaluated for VEWFD sensitivity testing in confined spaces or areas that may not allow the use of chlorinated wire jackets, such as electrical and computer cabinets. The smoke production from these sources has been quantified in a controlled smoke box environment and in mock electrical cabinet applications. It has been demonstrated that controlled amounts of smoke can be generated by overheating wire jackets using a thermal controller and replaceable cartridges. The amount and character of the smoke is highly dependent on the control temperature and the chemical makeup of the wire jacket material.

Keywords: VEWFD; Smoke detection; Smoke production; In-situ testing.

Introduction

Very Early Warning Fire Detection (VEWFD) systems are used in facilities where the earliest possible response to developing fire hazards is critical. This includes telecommunications, computer data centers and servers, and mission critical control equipment, such as may be used in nuclear power generation stations. By definition in *NFPA 76, Standard for the Fire Protection of Telecommunications Facilities,* VEWFD shall provide a minimum Alert condition response at spot/sampling ports of 0.65 %/m (0.2 %/ft) obscuration and an Alarm condition at 3.2 %/m (1.0 %.ft) [1]. These systems may be installed to measure return air collection from the protected space, to provide distributed ceiling, plenum, or subfloor protection, or to provide isolated protection of a small space, such as electrical or computer cabinets.

VEWFD may include very sensitive spot type ionization or photoelectric detection or aspirated air sampling ports utilizing centralized light scattering or cloud chamber type detection. When installing a VEWFD system, the system must be tested for detection response and network integrity per the requirements of *NFPA 72, National Fire Alarm and Signaling Code* [2]. This requires a functional verification of alarm response of all spot detectors or a pipe integrity transport test conducted in accordance with manufacturer's requirements.

Existing methods for in-situ testing are summarized in NFPA 76, Annex B [1]. Existing methods apply current through a polyvinyl chloride (PVC) jacketed wire sample of a given length for a specified duration. Four tests are specified including 2 m and 1 m wire tested per BS 6266 [3], a modified BS 6266 test with parallel wires, and a North American wire test (stiffer wire than BS 6266). All tests produce a small amount of smoke by conducting a high current through a small gauge wire, resulting in elevated conductor core temperatures and smoke generation from the wire jacket. A small puff of low thermal energy smoke is generated and moved by prevailing air flow patterns. By placing the source in various locations, an installer can verifier that smoke is effectively transported to the installed detector location.

The existing methods of testing can be difficult to conduct in all environments. The NFPA 76 Annex B tests all require laying out a piece of wire 1-2 m in length and conducting up to 15 A (28 A for North American wire tests) through the wire to produce excessive heating and smoke generation. It is important that the wire does not overlap or touch itself as it may short circuit when the jacket is thermally degraded during testing. It is also important that the wire be placed on a non-combustible and disposable surface as the heated wire will deposit soot and char on the supporting surface. The amount of space necessary and the surface protection can make these tests difficult to conduct within a confined space, such as an electrical cabinet.

In addition to the physical space required to conduct the wire tests of NFPA 76 Annex B, all four provided test methods call for a wire with a PVC jacket. Although the tests are short and the temperatures minimized, overheating of chlorinated wire will produce some amount of hydrochloric acid (HCL) vapor. This is a concern for some facilities wishing to conduct an in-situ sensitivity test.

In addition to the potential acidic vapor, the characteristics of smoke particles produced from wire jackets of various materials can vary greatly in size, shape, number, albedo, and other features critical to the effectiveness of certain types of detection (e.g., light scattering, ionization, cloud chamber, etc.). If the smoke test is intended to provide more information beyond the physical transport of smoke within the protected space (e.g., sensitivity response, alarm threshold), it is important to test smoke from a realistic hazard within the protected space. This will allow for the selection of the most effective detection technology and identification of the alarm thresholds necessary to provide desired levels of protection.

Alternative Smoke Generation Apparatus

A series of development tests have been conducted to provide alternative smoke sources for in-situ testing of VEWFD systems. A wire cradle capable of supporting a 2m wire without overlapping wires and within contact of protected surfaces can be used when the existing tests must be conducted within a confined space. When other wire or more control is needed, an alternative test has been developed utilizing disposable cartridges of tightly wrapped wire externally heated by a controlled electric heater. This device has been named the Compact Incipient Smoke Detector Test Apparatus (CISTA). The wire cradle and CISTA are shown in Figure 1 below.

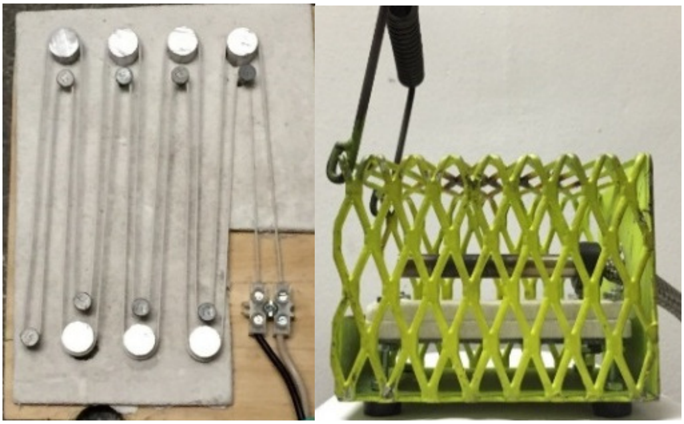

Fig. 1. BS 6266 Wire cradle (left) and Compact Incipient Smoke Detector Test Apparatus (CISTA) (right).

The wire cradle supports the wire on a series of insulated pegs and allows the 2m BS 6266 test to be conducted within a 10x12x1 cm profile. The CISTA design includes a 200 W temperature controlled cartridge heater mounted on an insulated ring collar within a 7.5x7.5x10 cm wire cage. The heater is mounted on an isolated post and the bottom of the wire cage is insulated with two layers of 6.35 mm thick insulation board.

The heater is operated with a programmable proportional-integral-derivative (PID) controller allowing the user to specify a fixed temperature set-point or ramp to produce pre-determined levels of smoke output. Disposable wire cartridges of copper tube with tightly wrapped wire shown in Figure 2 are placed on the heater cartridge.

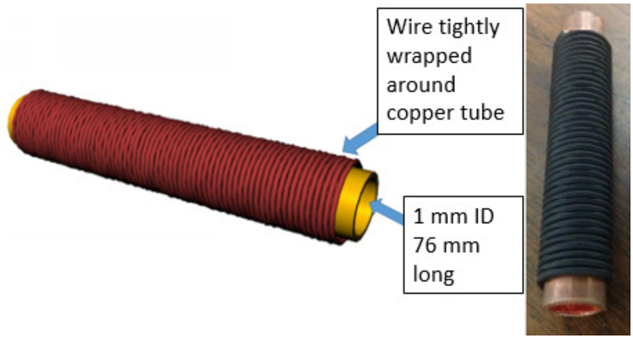

Fig. 2. Disposable wire cartridge used for CISTA smoke production.

Smoke Box Characterization

Testing was conducted using several different wire samples in a smoke box constructed in general accordance with the requirements of *Underwriters' Laboratories Standard for Safety 268: Smoke Detectors for Fire Alarm Systems* [4]. The box recirculates generated smoke at an air velocity at the detector of 9.75 m/min. Smoke production rates from the BS6266 wire cradle and several CISTA tested wires were measured by a white, incandescent spotlight bulb optical density meter (ODM), measuring ionization chamber (MIC), and a light scattering based aspirated smoke detector.

Tested wire cartridges included: 2m of polyvinyl chloride (PVC) with 10 strands of 0.1 mm tinned copper wire in the BS6266 cradle with 3 minutes of current; 3.2 m of the same PVC wire wrapped on a CISTA cartridge heated to 275 °C or 350 °C; 1.8 m of cross-linked polyethylene (XLPE) 22 AWG TXL wire heated to 410 °C; and 2.2 m of 22 AWG fluorinated ethylenepropylene (FEP) wire heated to 650 °C. The XLPE wire contains ethane (C_2H_4), but no fluorine, chlorine, or other halogenated compounds. The FEP wire contains a copolymer of hexafluoropropylene and tetrafluoroethylene (C_5F_{10}). These wires were selected to represent a range of realistic compounds. The exposure temperatures for each wire were determined experimentally to provide comparable amounts of smoke production. The comparative ODM obscuration and MIC ionization signals are shown in Figure 3.

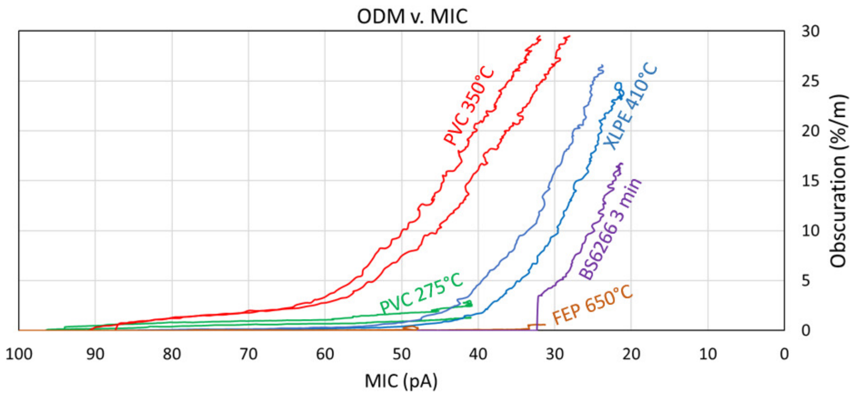

Fig. 3. Obscuration v. Ionization for wire sources in the smoke box.

Each wire source produced smoke with distinctly different characteristics at different exposure temperatures. All sources produced large numbers of particles, and MIC responses were all less than 48 pA. MIC response is generally proportional to the number of particles present [5]. Temperatures required for smoke production varied greatly among the sources tested. PVC wire at 275 °C produced high MIC response but low obscuration and light scattering response. PVC and XLPE wires created high MIC and obscuration responses comparable to the BS6266 test method at exposure temperatures of 350 °C and 410 °C, respectively.

The FEP wire produced almost no obscuration or light scattering VEWFD response even at 650°C exposure. Low ODM response with high MIC response indicates that many particles produced were too small to be visible. Peak MIC, ODM, and VEWFD responses are shown in Table 1 for each source.

Table 1. Peak response of sensors in the smoke box.

Wire Source	MIC (pA)	ODM (%/m)	VEWFD (%/m)	VEWFD Response
PVC Wire - 275°C	41	1.3	0.27	None
	41	2.9	0.52	None
PVC Wire - 350°C	32	29.5	5.93	Alarm
	28	29.5	5.55	Alarm
XLPE Wire - 410°C	23	27.9	5.70	Alarm
	21	24.8	4.40	Alarm
FEP Wire - 650°C	48	0.4	0.03	None
	31	0.6	0.05	None
BS62366 3 min overheat	21	16.7	2.85	Alert

The differences in particulate produced by various overheating materials should be considered when selecting a VEWFD system. If the bulk of electrical wiring is of high temperature FEP wire or detection of low temperature overheat conditions is necessary, an optical detector may not be the most appropriate sensor type. Ionization or cloud chamber type devices may provide better detection. In fact, slow ramping thermal exposure testing of electrical wiring and circuitry conducted by the National Institute of Standards and Technology (NIST) for the Nuclear Regulatory Commission (NRC) confirmed higher production of small invisible particles at lower temperatures than visible particle production [6].

Mock Electrical Cabinet Testing

A series of tests were conducted to evaluate the smoke production sources in a mock electrical control or data center. A series of electrical cabinets were installed in a test room with a variable, controllable air flow. Cabinets tested included empty cabinets, cabinets full of electrical equipment, and a set of cabinets interconnected with open sides as shown in Figure 5.

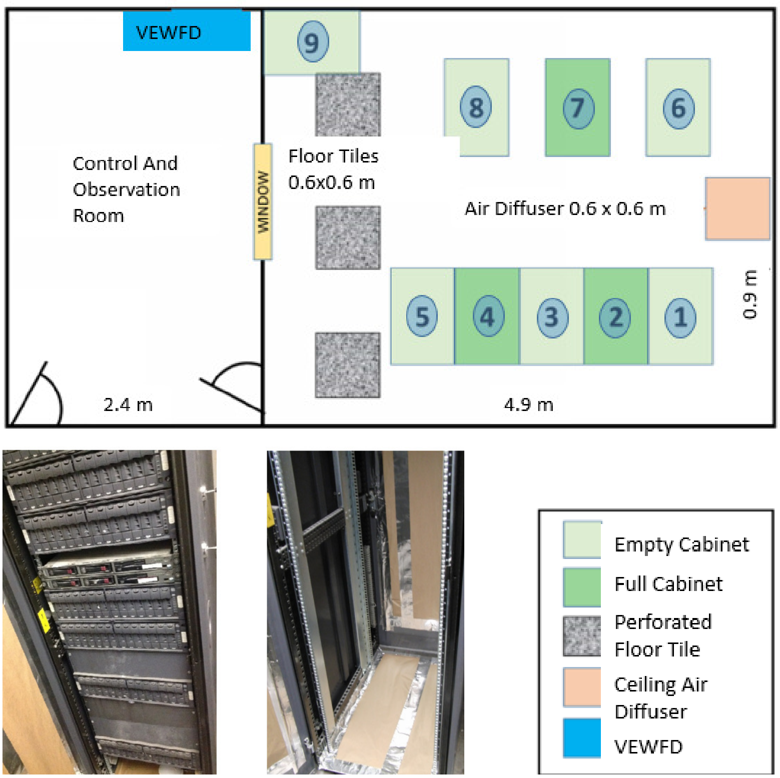

Fig. 5. Mock electrical cabinet test space and full (left) and empty (right) cabinets.

Smoke concentrations were measured in the cabinets by a light scattering aspirated smoke detector, a condensation particle counter (CPC), and a mass concentration monitor (MCM) sampling from the top of the cabinet under test. The CPC detector used a split sample dilution filter to increase the measurable range of particle densities. The detector had a function range of 100,000 particles per cm^3. Dilution factors ranging from 10/1 to 30/1 were applied to increase the range to over 3 million particles per cm^3.

These tests evaluated the temperatures needed to produce alert (0.65 %/m) and alarm (3.2 %/m) responses in the light scattering VEWFD tested for various wire sources and to evaluate test repeatability. The temperature limits tested in the smoke box generally were found to produce alert responses for the VEWFD system tested for in-cabinet applications. Except for the FEP wire, which produced no VEWFD response up to 650 °C. In general, the PVC tests using the BS6266 method and the CISTA produced the lowest numbers of particles but provided high mass concentration and light scattering detector response. The FEP wire provided no obscuration or light scattering response but produced particle densities greater than 1.78 million per cm^3 for current and thermal overheat conditions. A summary of the peak particle densities, masses, and VEWFD responses measured in a range of test conditions are shown in Table 2.

The BS6266 wire test method using PVC wire produced low particle density concentrations (less than 100,000 per cm^3) and mass concentrations between 20-50 mg/m^3. The particle densities measured for the PVC wire heated on the CISTA and using the BS6266 apparatus were an order of magnitude below the densities measured for XLPE and FEP wire sources. The XLPE wire tested on the BS6266 cradle produced over 2.3 million particles per cm^3 but mass concentrations below 30.5 mg/m^3. When heated on the CISTA, the XLPE wire produced high particle densities above 1.1 million per cm^3 and mass concentrations over 100 mg/m^3. These high concentrations resulted in light scattering VEWFD response over the 3.2 %/m alarm threshold. The PVC wire tests produced only alert level responses and the FEP wire produced no measurable response in the VEWFD system.

Table 2. Summary of In-cabinet Smoke Production Peak Measurements

Wire	Method	Configuration	Test	Particle Density ($\#x10^6/cm^3$)	Mass Range (mg/m^3)	VEWFD Obs (%/m)
PVC Wire	BS6266	Loose	1 min	0.089 - 0.090	43.9 - 48.9	1.5 - 1.6
			3 min	0.09 - 0.13	47.7 - 64.9	1.5 - 1.9
		Cradle	1 min	0.03 - 0.05	20.9 - 22.7	0.6 - 0.7
			3 min	0.08 - 0.09	42.2 - 49.8	1.8 - 1.9
	CISTA 275-400°C			0.6 - 0.9	53.2 - 163.0	1.7 - 2.7
XLPE Wire	BS6266 Wire Cradle 3 minutes			2.3 - 3.0	19.2 - 30.5	1.0 - 1.7
	CISTA		400°C	1.1 - 1.6	105.0 - 130.0	2.1 - 3.0
			410°C	1.7 - 4.1	71.5 - 159.0	1.7 - 3.6
			475°C	1.6 - 3.0	202.0 - 400.0	5.9 - 11.5
			500°C	1.8 - 2.3	146.0 - 226.0	3.7 - 5.3
FEP Wire	BS6266	Loose	1 min	1.90	3.4	0.0
	CISTA		650°C	1.78	2.4	0.0

Conclusions and Recommendations

Alternative methods for producing controlled amounts of smoke for commissioning the installation of a VEWFD have been developed. Existing test methods may require too much space to be conducted in a small or secure environment or use chlorinated wire that may not be acceptable for in-situ testing. A thermally controlled wire cartridge can produce smoke in a compact and thermally isolated environment. The wire type used determines the temperature necessary to produce test smoke and the particle characteristics of the smoke produced. The temperature and wire should be selected to evaluate the sensitivity of an installed detector, or to select the sensitivity of a detector necessary to provide desired alarm response.

Although the alternative XLPE or FEP wire sources tested do not contain chlorine, the smoke produced will still contain carbonaceous soot that may deposit on exposed surfaces. It is recommended that additional testing be conducted to verify that exposure to this smoke has no impact on operating electrical equipment. A surface insulation resistance test could be conducted to determine if deposition could negatively impact operating electrical equipment by creating unwanted conduction paths. Additional work could be conducted to explore the production and response of detectors in open areas, in smaller confined areas, or under high air flow conditions.

Additional VEWFD systems, including ionization and aspirating cloud chamber type devices could also be explored. If exposure testing is undesirable for some applications, the wire heater could also be modified to connect to a y-connection in an aspirated sample line and produce smoke in a fixed, external chamber for repeated sensitivity testing.

References

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