EXTINGUISHMENT TESTS OF CONTINUOUSLY ENERGIZED CLASS C FIRES

Lawrence A. McKenna, Jr., Daniel T. Gottuk, and Philip J. DiNenno
Hughes Associates, Inc.
Baltimore, MD 21227 USA

ABSTRACT

A practical approach based on actual fire incidents in telecommunications and similar occupancies has been developed for the investigation of extinguishing agent performance on continuously electrically energized fires. From the study of telecommunication fire incidents, test fires were developed that replicate the physical phenomena present in the fires studied. These test fires were then used to study the necessary concentration of HFC-227ea to achieve fire control. It is believed that the results of this study apply to a wide range of electrical applications. The testing described in this paper demonstrates that fires initiated by, and involving, energized electrical circuits can be controlled by HFC-227ea (FM-200) at concentrations below 7%.

USING FIRE INCIDENT DATA TO DEVELOP TEST FIRES

This study is based on a thorough understanding of the fire incidents in the targeted occupancies (telecommunications and data processing) as well as a similar understanding of the equipment and materials used in these occupancies that may become either the source of ignition energy, or first fuels for a fire.

The most comprehensive study on fires in **U.S.** telecommunications facilities was collected by the Federal Communications Commission (FCC) Network Reliability Council study in 1993[1]. Analysis of the data submitted for the FCC report shows that electrical fires can be grouped into four general classes based on ignition scenario and fuel ignited overheated wire and cables, overheated terminals or connections, printed wiring board (PWB) failures, and arc strikes. Each of these scenarios has unique characteristics that can be replicated in **a** standardized test method. Since there is already an existing test to evaluate clean agent response to arc strikes, it was decided that there is no need to pursue this scenario, especially since most of these events occur during maintenance activities, and personnel are present to manually suppress the event.

To reflect actual field conditions as closely as possible, it **was** important to select materials as test fuels that are in widespread use. **A** survey of telecommunications providers was conducted to assist in this effort. The survey results reflect the wide diversity of practices in the industry. The survey showed a distinct difference in use of fire resistant materials between traditional Central Office (CO) type facilities and more modem facilities such as Cell Sites and Controlled Environment Vaults (CEV). This was as expected since there are significantly fewer assets at risk in the smaller facilities than in the COs.

Test fires were developed to replicate the physical phenomena found during the overheated cables, overheated connections, and PWB failure scenarios. **A** brief description of each test method and the results of extinguishment experiments using these tests follow.

OVERHEATED WIRES AND CABLES - THE OHMIC HEATING TEST

Background

Electrically overheated wire and cable are a well documented phenomena. Electrically overheated wire or cable has been implicated as the cause of the most serious telecommunications fire in the last 25 years [1]. It has also been a contributing factor to other, more recent telecommunications fires [2]. An electrical fault or failure of the overload protective device can result in overcurrent in a wire or cable. Given a large enough current flow through the conductor, it will overheat due to resistance in the conductor (i.e., ohmic heating). Since heating is proportional to current, higher current flows result in higher temperatures. **A** "dead" short in a circuit can result in nearly instantaneous overheat of an entire cable, rapid ignition of the cable insulation, and subsequent spread to other nearby combustible materials. While the materials burning are typical of a Class A fire, the continuing presence of the very hot (glowing) conductor is thought to make suppression more difficult.

In the development of a test method to model this scenario, a number of variables were found to impact the performance, including cable geometry (i.e., type and mass of conductor [cable diameter, length, and stranding]), insulation material, and current flow through the cable.

This scenario was modeled by creating a controlled over-current condition in a sample of wire or cable. Tests consisted of connecting the sample between two copper buss bars connected to the output leads of a 600-amp arc welder. Following a preheat period, a butane pilot flame was applied at the midpoint of the underside of the sample.

In general, it was difficult to cause a cable fire to autoignite via ohmic heating. Most wires tended to either smolder, melt, or char, or the wires would fuse due to thermal stress of the current overload. The piloted fire scenarios were such that the current load in the wires was as high as possible without causing the wires to fuse, thus breaking the circuit.

Test Setup

The fire extinguishment tests were conducted using a 1.2 m^3 enclosure constructed from 1.2 cm (0.5 in.) thick polycarbonate sheet reinforced with an angle iron frame. Figure 1 shows a schematic of the test compartment. **Air** flow through the enclosure was accomplished by means of a 280 L/min (10 cfm) blower and controlled by two 3.8 cm (1.5 in.) normally open solenoid valves.

Inside the test compartment, the test sample was located inside an open baffle structure designed to prevent the flame from being blown out during agent discharge. Figure 2 shows the baffle system, which consisted of a solid square noncombustible board on the bottom, two 34 x 34 x 20 cm high square polycarbonate boxes (with open top and bottom), and a solid 34 x 34 cm square noncombustible board on top. The polycarbonate boxes and the top board were positioned 90 deg with respect to one another such that all the comers were open. Additionally, there were open ventilation paths at the bottom of the loaffled enclosure.

The HFC-227ea (FM-200, C_3HF_7) was discharged from a stainless steel cylinder with an internal volume of 1.0 L. The agent discharged horizontally into the side of the enclosure through a Bete 0 deg NF2000 nozzle mounted 0.45 m (1.5 ft) from the top. As can be seen in Figure **1,** the cylinder was mounted above the nozzle to assure complete agent discharge from the cylinder. The cylinder was pressurized with nitrogen to 689.5 kPa (100 psig).

HFC 227-ea concentrations in the compartment were based on the mass **of** agent filled into the steel cylinder. Given the desired concentration, C, to be tested, the mass, m, of the agent was calculated based on the following formula:

$$m = \rho V\left(\frac{C}{100 - C}\right)$$

where p is the vapor density (for HFC-227ea, p = 7.26 kg/m^3 at 21.1 C) and V is the open volume of the test compartment (1.16 m^3 (40.8 ft^3)).

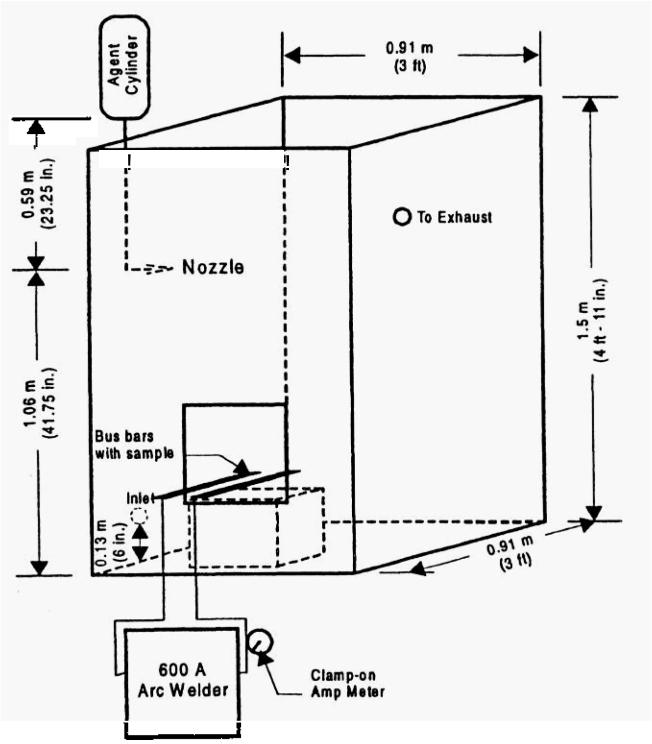

Figure 1. Test Enclosure Showing Ohmic Heating Test Apparatus and HFC-227ea Cylinder and Nozzle.

In several tests, agent concentrations in the compartment were measured using a FTIR analyzer. These measurements confirmed the agent concentrations derived from the agent mass measurements.

General instrumentation consisted of supplied current and voltage drop across the sample, nozzle pressure of the HFC-227ea agent discharge system, and video photography. Selected measurements were also made of the oxygen concentration below the base of the fire within the loaffle system. Oxygen concentrations were measured via continuous gas sampling to a paramagnetic oxygen analyzer.

The wire bundle sample was positioned in the center of the test enclosure in either a horizontal or vertical orientation. The horizontal position, 38 cm (15 in.) above the floor, is shown in Figure **1.** The wire(s) were mounted between 2 copper busses, which extended through the enclosure wall and were connected to a 600A arc welder. The supply current to the wire sample was measured using a clamp on ammeter and confirmed via an ammeter on the welder.

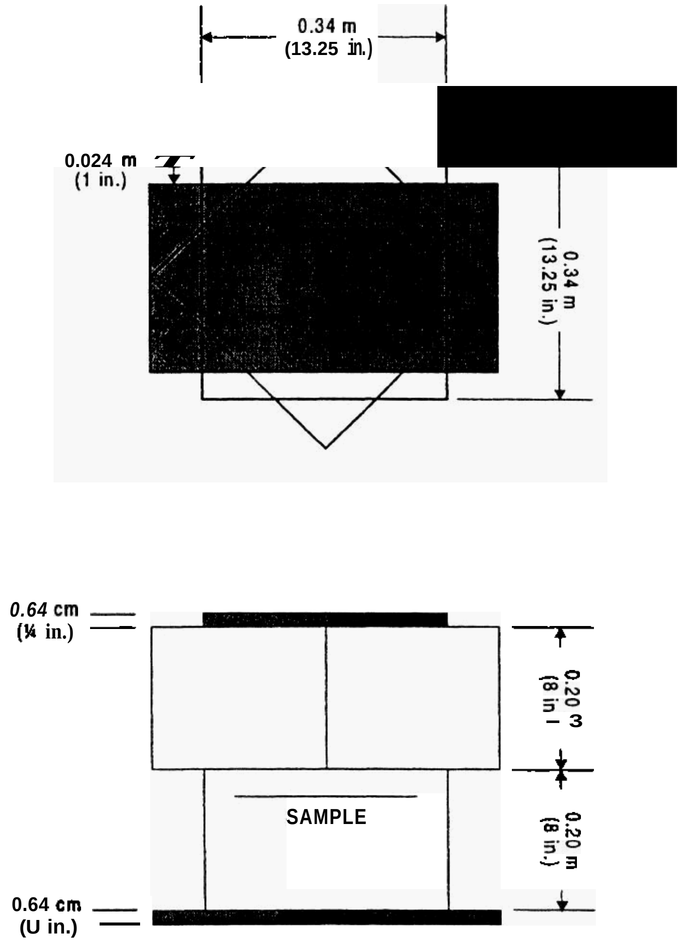

Figure 2. Baffle System Around Test Fires in Test Enclosure.

Test Results

Five different cable samples were selected to provide a representative cross-section of the types of materials found in the telecommunications industry. The five wire types selected consisted of the following materials: Cross-linked polyethylene (XLPE), SJTW-A (Thermoplastic jacket over thermoplastic insulation), Polyvinylchloride (PVC), Chrome PVC jacket over polyethylene, and Neoprene jacket over rubber insulation.

Besides these representative cables, a bounding fire scenario was evaluated using the pure polyethylene (PE) insulation from the center core of a coax cable with its outer jacket and braided conductor removed. This test scenario was deemed to be bounding because it involved untreated PE, which readily melts and bums and is not representative of the fire resistant jacket and insulation materials used in power and signal cables found in common practice. The test setup for the coax PE tire was quite contrived to facilitate burning and therefore does not represent a realistic scenario.

Most of the wire samples remained intact during the fire. That is, the insulation did not drip or fall away from the energized conductors, rather, the shape and form of the material remained the same. The notable exception was the PE insulated wire from the coax cable. The PE insulation on the coax cable wire melted and flowed away from the conductors. If it were not for a noncombustible board directly underneath the wires, the PE would have dripped away from the conductor and never burned. With the wires resting on top of the board, the melted PE formed a liquid pool, which eventually ignited via the hot energized conductor laying in the pool.

The results of the HFC-227ea discharge tests are summarized in Table 1. The table presents a description of the sample and test conditions, the agent concentration, and the time to extinguish. The results have been presented per sample type and in descending order of agent concentration. Except for the samples of chrome PVC over PE and the PE from the coax cable, all test samples were effectively extinguished at agent concentrations of 5.8%. Several test fires with XLPE and SJTW wires were also extinguished at lower concentrations of 5.5 and 5.0%.

Table 1. Summary of Ohmic Heating Tests with HFC-227ea.

TEST	SAMPLE	CURRENT (A)	ORIENTATION	IGNITION SOURCE	% C_3HF_7, (FM 200)	TIME TO EXTINGUISH (sec)[a]
EEE035	3 AWG XLPE, 5 wire bundle center wire energized	350	horizontal	pilot	5.8	9
EEE036		350	horizontal	pilot	5.8	9
EEE046		350	horizontal	pilot	5.8	10
EEE049		350	horizontal	pilot	5.8	13
EEE037		350	horizontal	pilot	5.8	13
EEE038		350	vertical	pilot	5.8	8
EEE039		350	vertical	pilot	5.8	8
EEE054		350	vertical	pilot	5.8	10
EEE055		350	vertical	pilot	5.8	10
EEE040		350	vertical	pilot	5.0	11
EEE047	12 AWGSJTW-A, 5 cable bundle 4 of 18 conductors energized	600	horizontal	pilot	5.8	11
EEE050		600	horizontal	pilot	5.8	11
EEE053		600	horizontal	pilot	5.8	9
EEE041		600	horizontal	pilot	5.5	9
EEE043		600	horizontal	pilot	5.5	8
EEE044		600	horizontal	pilot	5.0	11
EEE056	8 AWG PVC, 7 cable bundle center wire Energized	325	horizontal	pilot	5.8	12
EEE059		325	horizontal	pilot	5.8	10
EEE062		325	horizontal	pilot	5.8	13
EEE068	18 AWG Chrome PVC, over PE 4 cable bundle 12 conductors energized	350	horizontal	pilot	6.8	12
EEE069		350	horizontal	pilot	6.8	13
EEE071		350	horizontal	pilot	6.5	15
EEE075		350	horizontal	pilot	6.5	11
EEE079		350	horizontal	pilot	6.5	16
EEE076		350	horizontal	pilot	6.2	did not extinguish
EEE077		350	horizontal	pilot	6.2	15
EEE078		350	horizontal	pilot	6.2	did not extinguish
EEE058		350	horizontal	pilot	5.8	12
EEE061		350	horizontal	pilot	5.8	did not extinguish
EEE065		350	horizontal	pilot	5.8	10
EEE066		350	horizontal	pilot	5.8	11
EEE067		350	horizontal	pilot	5.8	did not extinguish
EEE057	16 AWG Neoprene Over rubber, 9 of 12 conductors energized	500	horizontal	pilot	5.8	3
EEE060		500	horizontal	pilot	5.8	6
EEE064		500	horizontal	pilot	5.8	6
EEE031	18 AWG PE. 4 parallel wire m y , all wires energized	475	horizontal	self-ignited	6.8	14
EEE033		475	horizontal	self-ignited	6.8	14
EEE048		475	horizontal	self-ignited	6.8	14
EEE029		475	horizontal	self-ignited	6.5	did not extinguish
EEE030		475	horizontal	self-ignited	6.5	did not extinguish
EEE028		475	horizontal	self-ignited	5.8	did not extinguish
EEE026		475	horizontal	self-ignited	5.7	did not extinguish

[a] Ti to extinguish is taken fro he beginning ischarge.

In the case of the chrome PVC over PE samples, **3** of *5* tests extinguished at an agent concentration of 5.8%. Agent concentrations had to be increased above 6.2% to obtain consistent fire extinguishment. Fires were successfully extinguished (i.e., **3** of **3** tests) at concentrations of 6.5 and 6.8%. Similar results were obtained for the PE insulated coax cable wire tests, except that slightly higher concentrations were required for fire extinguishment. As can be seen in Table 1, extinguishment was not obtained for any PE test at agent concentrations of 6.5% or less. For the pure PE insulation, agent concentrations of 6.8 and 7.2% yielded consistent fire extinguishment for all tests (i.e., 6 of ***6).***

The majority of fires were extinguished in 9 to 12 sec and in no case did re-ignition occur during the
5-min hold time with the sample continuously energized. It was evident from observation that the fires were being extinguished by the agent and were not being blown out during discharge.

Oxygen concentrations were measured for a select number of tests using HFC-227ea for each sample type to verify that depletion of oxygen within the enclosure (prior to discharge) was not a factor in the fire extinguishment. In all cases, the oxygen concentration within the enclosure (directly below the sample) was above 20.5% by volume. Once the HFC-227ea was discharged, the oxygen concentration within the enclosure decreased rapidly and was within the range of 18 to 19.5% by volume. The results indicate that, at the time of agent discharge, the oxygen concentration was nearly at ambient levels and therefore did not effect the agent extinguishment process.

The results demonstrated that HFC-227ea was effective at extinguishing energized electrical cable fires at the minimum design concentration of 7.0% by volume used for Class A and Class B fuels. For all material types tested, fire extinguishment was achieved at concentrations of 6.8% or less. For XLPE, SJTW-A, and Neoprene over rubber electrical cables, fire extinguishment was achieved at concentrations of 5.8% to as low as 5.0% by volume.

In the PE coax wire tests the electrical conductor was the initial ignition source and remained powered throughout the agent hold time of 5 min. Even for this bounding fuel scenario, in which the conductors were above 500 °C (cherry red), reignition of the fuel did not occur. Although these PE tests are conducted with energized cables, they are not very realistic with respect to energized power cable fire scenarios. First, the polyethylene fuel is not fire retardant; while the insulation and jacket materials on typical power and signal cables is fire retardant. Additionally, by the time a fire did occur the fuel represented a pool fire rather than an electrical cable bundle fire. Therefore, the ohmic heating tests of this study indicate that energized electrical cable fires can be suppressed and controlled with HFC-227ea concentrations below the minimum design concentration of 7.0%.

OVERHEATED CONNECTIONS - CONDUCTIVE HEATING **TEST**

Background

Overheated electrical connections are well-documented phenomena. In this scenario, a connection at the end of a wire or cable becomes loose by one or more of several mechanisms. Once sufficiently loose, a resistance to electrical flow develops in the connection, and it begins to heat. Cyclic electrical loads result in cyclic thermal stressing of the connection, and over time, it loosens more. Eventually, the conditions of looseness and current flow combine to form an arc, which results in an area of localized intense heat. The arc vaporizes the metal of the connection parts, making the connection more loose. The process continues until the power is removed deliberately, or by arc damage. As the connection heats, the copper (or aluminum) conductor of the cable acts as a heat sink, and conducts heat away from the connection. At some time the insulation of the cable reaches its ignition temperature, and a fire ensues.

In the development of the test method, a number of variables were found to impact the performance, including the following: cable geometry (i.e., type and mass of conductor [cable diameter and length]), insulation material, cable orientation (horizontal or vertical), and the type and temperature of the heater.

Test Setup

This scenario was modeled by clamping one end of a 350-mcm copper cable inside a 1,000 Watt "Ring" heater. The sample cable was prepared, weighed, mounted in the heater, and placed in the same test enclosure described earlier in this paper, and shown in Figure 1. The sample was placed inside the Ioaffles shown in Figure 2 in the enclosure, the heater was set to 900 °C, and the cable was allowed to heat until the top of the cable sample reached 310 °C (400 "C for the PVC sample). At that point, a small pilot flame was applied. After ignition, the test enclosure was sealed, and the agent was discharged 1 min later. The heater remained energized until 5 min after agent discharge to permit observation of any re-ignition that may occur.

The survey of the telecommunications industry revealed that in traditional Central Offices, hypalon (chlorosulfonated polyethylene) formulations dominate for large diameter power cables. PVC formulations are available, but not widely used in these large diameter cables. Based on the survey, three different 350-mcm cable samples were selected to provide a representative cross-section of the types of materials found in the telecommunications industry. These included Lucent Technologies type KS5482L, with Hypalon (chlorosulfonated polyethylene) insulation covered by cotton braid sheathing and saturant, Lucent Technologies type KS-20921, with unsheathed Hypalon insulation, and Lucent Technologies type KS-20747, with PVC insulation.

Test Results

Extinguishment tests using HFC-227ea (FM200) were conducted for the test samples described. The results are summarized in Table 2. The table presents a description of the sample and test conditions, the agent concentration, and the time to extinguish. The results have been presented per sample type and in descending order of agent Concentration. All test samples were effectively extinguished at HFC-227ea concentrations of **5.8%.** One test fire was extinguished at the lower concentration of 5.2%.

Fires where the concentration of HFC-227ea was 5.8% or greater were extinguished in 7 to 12 sec. In one test at 5.2% concentration, extinguishment was accomplished in 20 sec. In no case did reignition occur during the 5-min hold period during which the heater remained energized.

Table 2. Summary of Conductive Heating Tests with HFC-227ea.

TEST	SAMPLE	ORIENTATION	IGNITION SOURCE	% C_3HF_7	TIME TO EXTINGUISH (sec)[a]
CONDOM	KS5482 Hypalon	vertical	pilot	6.0	9
CONDO06		vertical	pilot	6.0	12
CONDO07		vertical	pilot	5.9	7
CONDO13		vertical	pilot	5.8	10
CONDO18		vertical	pilot	5.8	11
COND003		vertical	pilot	5.2	20
COND010	KS20921 Hypalon	vertical	pilot	6	10
COND009		vertical	pilot	5.9	11
COND012		vertical	pilot	5.8	10
COND019		vertical	pilot	5.8	9
COND020		vertical	pilot	5.8	9
COND033	KS20747 PVC	vertical	pilot	5.8	10
CONDO34		vertical	pilot	5.8	10
CONDO35		vertical	pilot	5.8	10

[a] Time to extinguish is taken from the beginning of discharge.

The results presented here for the conductive heating tests demonstrate that HFC-227ea was effective at extinguishing cable fires at the minimum design concentration of 7.0% by volume used for Class **A** and Class B fuels. For all material types tested, fire extinguishment was achieved at concentrations of 6.0% or less.

PWB FAILURES

Background

Internal PWB failures are also a fairly common event in electronics equipment. These are generally caused by contaminates within the PWB, a byproduct of the manufacturing process, but can also be induced by some component failures. (If an overheating component is located above power tracks on a PWB, pyrolization of the insulating material between the tracks can lead to development of an arc between them.)

In this scenario, an electrical fault allows excess current to flow through power tracks on the board, overheating the tracks. The overheated power tracks, typically aligned parallel to one another, pyrolyze or carbonize the substrate material between them. After a time, the insulating properties of the material are sufficiently degraded that an arc develops between the two tracks, igniting the gaseous pyrolosis products. The process is self-sustaining as long as power is applied to the circuit. The arc travels along the tracks starting at the point of ignition and moving closer to the power supply.

In the development of this test method, the variables that were found to impact performance included selection of PWB substrate material, the solder mask material used, track width, track spacing, voltage, amperage, and orientation.

This scenario was modeled with a specially designed PWB that can be overloaded to create an arcing short between two tracks. The test board is fabricated with two parallel 50-mil wide tracks, spaced 50 mil apart. The tracks extend to one end of the 41-cm long board where solder coated pads are provided to connect the circuit to the power supply. At the opposite end of the 38-cm long tracks, they are connected by a 10 or 20-mil track, which completes the circuit and provides a short length of higher resistance track where localized heating can develop and in time lead to the formation of an arc. The test board was fabricated of FR-4 substrate material, and the board was coated with dry film solder mask, with the exception of the pads at the end, which are exposed solder coated, to facilitate connection of the board to the power supply. Optimal results were obtained with this configuration when it was powered by a regulated DC power supply, set to deliver a constant current of 8.5 amps, at voltages from 7-9 VDC.

Test Setup

The experimental setup developed for the PWB Failure test was placed in the test enclosure described previously (Figure 1). The prepared PWB setup was placed within loaffles similar to those shown in Figure 2, the only difference being their larger size to accommodate the large test PWB. The test enclosure was then sealed and the power supply was set to provide a constant 8.5 amps, with voltage limited to 8.75 VDC. After the arc and flame had traveled 130 mm (5 in.) from the ignition end of the PWB, the fire was judged to be established, and the agent was discharged into the enclosure. Agent concentrations and power to the PWB were maintained for a 5-min hold time after discharge.

Test Results

Extinguishment tests using HFC-227ea (FM200) were conducted using the PWB test samples. The results of each agent discharge test are summarized in Table **3.** The table presents a description of the sample and test conditions, the agent concentration, and the time to extinguish. The flaming fire was extinguished in under 10 sec in all HFC-227ea tests. It was evident from observation that the flames were being extinguished by the agent and were not being blown out during discharge.

Table 3. **Summary** of PWB Tests with HFC-227ea.

TEST[a]	SAMPLE	ORIENTATION	IGNITION SOURCE	% C_3HF_7	TIME TO EXTINGUISH (sec)[b]
CKTB018	II	horizontal	self-ignited	5.8	6
CKTB019	II	horizontal	self-ignited	5.8	3
CKTB022	II	horizontal	self-ignited	5.8	3
CKTB026	II	horizontal	self-ignited	5.8	3
CKTB020	II	horizontal	self-ignited	7.0	2
CKTB021	II	horizontal	self-ignited	7.0	4
CKTB023	II	horizontal	self-ignited	7.0	4
CKTB027	II	horizontal	self-ignited	7.0	4
CKTB028	II	horizontal	self-ignited	7.0	3
CKTB024	II	horizontal	self-ignited	9.0	3
CKTB025	II	horizontal	self-ignited	9.0	9

[a] **All** tests run at 8.5 amps and 8.75 volts.

[b] Time to extinguish is taken from the beginning of discharge.

While the flames were extinguished in each test, the arc between the circuit paths was not extinguished. The arc continued to propagate along the PWB, moving towards the power supply connection, albeit at a slower rate. Following initial suppression, occasional intermittent flickering would occur at the arc site when the vapors produced by the arc would ignite and instantaneously extinguish.

The results presented here for the PWB Failure tests demonstrate that HFC-227ea was effective at extinguishing the flaming fires at concentrations of 5.8% by volume. It is clear that the fires were controlled by the suppression agent. The flames were extinguished, and the arc propagation rate was decreased. The remaining arc was confined to the immediate area between the tracks on the test PWB.

To assess the impact of the continuing arc in a field situation, a number of tests were conducted with three test PWBs mounted parallel to one another, ranging from 6 to12 mm apart. In these tests, the circuit on the center PWB was energized in an attempt to propagate the fire to the adjacent PWBs before agent discharge. In only one case, at a 6-mm spacing, did the fire spread to the adjacent PWBs. In this case, the fire attached to the adjacent PWBs was an ordinary Class **A** fire that was easily extinguished.

SUMMARY

The testing described in this paper demonstrates that fires initiated by, and involving, energized electrical circuits can be controlled by HFC-227ea (FM-200) at concentrations below 7%. Most of the test fires were completely extinguished within 15 sec of agent discharge. In all tests, the circuits were energized for 5 min after agent discharge, and no re-ignition was observed. In the PWB tests, the initiating arc continued to propagate after agent discharge, and intermittent flickering flames were observed attached to the arc. These intermittent flames were immediately extinguished.

The small-scale tests developed in this study replicate the physical phenomena found in the ignition scenarios in actual fire incidents. They do not model wire-to-wire interactions or the effects of wires or cables in large bundles or trays. In developing the test methods, it was difficult to produce consistent results in the ohmic heating test and the conductive heating test while relying on autoignition of the sample. The application of **a** small pilot flame to the sample allowed testing of a wider range of materials under a consistent set of conditions. The difficulties in creating an autoignited fire in the materials tested indicates the rather safe nature of the energized systems studied.

Overall, this study does not indicate a need for concentrations above the minimum Class **A** design concentration of 7% of HFC-227ea in applications where energized electrical circuits may initiate or propagate a fire. In fact, extinguishment was achieved in many cases at concentrations of 5.8%.

ACKNOWLEDGMENTS

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