FIRE PROTECTION FOR ELECTRONIC EQUIPMENT

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INTRODUCTION

In recent years the dependence on computers and other electronic equipment has increased significantly in both the business sector and in households throughout the world. Along with this increased reliance on computers and electronic equipment, the importance of providing fire protection for these critical assets has also increased. Throughout numerous industries there are countless processes and systems which are controlled by computers. Computers control semiconductor fabrication, steel-making processes, petrochemical production facilities, and local and global telecommunication systems. In many instances it is critical that the operation of these computer and electronic systems is not interrupted. For example, the financial impact of service disruptions can be significant in the energy and telecommunication industries, exceeding one million US dollars per hour. The estimated downtime impact per minute for various industries is shown in Table 1.

Table 1: Downtime Impact for Various Industries

Industry	**Hourly Cost of Downtime** Millions of Dollars (USD)
Energy	2.8
Telecommunications	2.1
Manufacturing	1.6
Information Technology	1.3
Retail	1.1
Pharmaceutical	1.1
Chemicals	0.7

Source: Constantdata

INFORMATION TECHNOLOGY FACILITIES

In recent years businesses' dependence on computers and other electronic equipment has increased exponentially. Computers now control numerous processes including petrochemical production, semiconductor fabrication and steel and paper production. Electronic equipment such as production prototypes, simulators and specialized measuring devices and test equipment are vital to continued business operation. In addition to controlling countless processes, computers and associated electronic equipment are employed for the storage of critical data and information vital to the day to day operation of numerous types of facilities. The computers and electronic equipment forming a vital part of a modern business vary widely in their end use are commonly referred to as information technology (IT) equipment, and their physical locations are typically to as IT facilities.

Business interruption can have a devastating effect in industries such as the energy and telecommunications industries; as seen from Table 1, the hourly cost of downtime in these business segments can exceed one million US dollars per hour, and computer and/or electronic equipment failure can lead to both business interruption and the loss of vital data. In IT facilities data is stored in the systems memory, and during an interruption all data which has not yet been placed into permanent memory is lost.

Fire History of IT Facilities

Reported fires in IT facilities typically involve relatively small fires; however, due to the expensive and sensitive nature of the IT equipment, and the high cost of downtime, even small fires can have devastating consequences. In the event that fires are not extinguished while of relatively small size, even further damage will result, including potential loss of the entire facility. The leading cause of fires in IT facilities has been reported to be related to electrical distribution equipment (e.g., wiring, cables, cord, plugs, outlets, overcurrent protection devices etc.), and in most cases fire damage is limited to the object of origin [1].

Characterization of IT Facility Fires

Fire hazards occurring in IT facilities have been discussed by several authors [2,3]. Fires in IT facilities typically involve small fires of low energy output. The fuel load in a typical computer room consists primarily of electronic equipment and the electrical cables employed to supply power to the various electronic components.

In order to provide a reduced fire hazard, current standards specify the construction of the electronic equipment itself, construction requirements for the building housing the computer room, and the materials and equipment permitted in areas containing computers and other information IT equipment. For example, in the United States, equipment and replacement parts for use in computer rooms must meet the requirements of UL 1950 *Standard for Safety of Information Technology Equipment, Including Electrical Business*

Equipment. With regard to materials allowed within an IT facility, NFPA 75 *Standard for the Protection of Information Technology Equipment* requires the following:

- Only computer and IT equipment and support equipment are permitted in the computer room
- Office furniture within the computer room must be of metal construction
- Only approved self-extinguishing trash receptacles are allowed
- Small offices and light hazard occupancies are allowed in the computer room only if noncombustible containers provided for combustible materials
- The amount of records within the computer room must be kept to the absolute minimum required for essential and efficient operation
- Rooms used for the storage of records are to be separated from the computer area by fire-resistive construction

TELECOMMUNICATIONS FACILITIES [4]

Over a relatively short time, telecommunications has progressed from an industry involving a single service, standard telephone service, to one which affects numerous facets of our daily life, and includes not only standard telephone service, but also automatic teller machines (ATMs), facsimile machines, teleconferencing services, video conferencing services, point of sale transaction terminals, electronic funds transfer, cable TV and Internet access. The telecommunications industry is one of the fastest growing industries on the planet. Global telecommunications revenues have been estimated at $3.85 trillion in 2008, with projections of high single-digit percentage growth over the next several years [5]. Telecommunications companies worldwide have spent billions of dollars to ensure that voice, data and video routes operate reliably, and of primary concern to these providers is the minimization of service disruptions. One of several possible causes of service disruption in telecommunication facilities is fire.

Service interruption is a major concern in telecommunication facilities due to the unique nature of the information processing performed in such facilities. Telecommunication systems are on-line information exchange systems, i.e., the system does not store or process customer data but merely transfers the data from one point to another. When a disruption occurs, all information in transit is lost. This contrasts to the case of data processing centers, where data is stored in the systems memory, and during an interruption only that data which has not yet been placed in permanent memory (disks, tapes) is lost.

Characterization of Telecommunication Facility Fires and Fire Risk

Telecommunications facilities' areas can be categorized into one or more of eight types of areas, each with its own fire hazard characteristics, as shown in Table 2 [6].

Table 2. Hazard Areas in Telecommunications Facilities [6]

Area	Contents	Fire Scenarios
Telecommunications equipment	Electronic equipment in racks or cabinets or under a raised floor	Slow developing, smoky fires with heat release rates of typically 5 to 15 kW, which do not exceed 150 kW for fully involved cabinet or rack
Cable entrance facility	Cables with no fire resistance rating entering building from outside and spliced to rated cables	High or low heat release rate fires
Power areas	Batteries on racks Switchgear Rectifiers Bus bars, cables	Low heat release rate fires
Main distribution frame	Large quantities of low voltage communications wire	Low to medium heat release rate smoky fires
Standby engine area	Generator powered by internal combustion engine Fuel day tank Starting batteries	Electrical or fuel fires
Tech support areas	Metal desks, cabinets, tools, equipment	Same as for telecommunications equipment since combustibles load is small
Administrative areas	Normal commercial office furniture and equipment	Fires typical of commercial offices
Building services and support areas	Mechanical and maintenance equipment, storage	Fires typical of well-maintained commercial office building support areas

Numerous sources indicate that fires characteristic of those occurring in telecommunication facilities, especially those involving electronic equipment, are small in size [2,4,7]. For example, Meacham indicates that fire hazards in telecommunication facilities are characterized by low fuel loads, and include wire insulation, printed circuit boards, electronic components, transformers, insulating materials, and plastic housings [2,7]. The majority of these fires are characterized as:

- Initiating from an overheating , shorting or arc condition
- Of low energy output, often less than 5 to 10 kW
- Producing varying amounts of combustion products, often corrosive and toxic

Power Disconnection in Telecommunication Facilities

One method of intervention for electrical fires or overloads is to disconnect the power to the equipment involved. However, as discussed above, service interruption is a major concern in telecommunication facilities due to the unique nature of the information processing performed in such facilities, and when a disruption occurs, all information in transit is lost. Due to the complexity of the control programs employed in some facilities, in some instances equipment shutdown could require the restoring of millions of lines of software code.

Due to this desire to avoid service disruptions, equipment shutdown is often avoided in telecommunications facilities. Depowering of telecommunications switching equipment may disrupt not only voice conversations, but also critical data and vital emergency communications. Depowering of telecommunications equipment in telecommunication facilities is also difficult due to the several levels of power redundancy present.

SUSCEPTIBILITY OF ELECTRONIC EQUIPMENT TO DAMAGE [8]

Fire damage to electronic equipment can result from three major sources. Thermal damage due to the fire itself (e.g., heat), nonthermal damage due to combustion products (e.g., smoke, soot), and nonthermal damage due to the fire suppression agent.

Fire Damage: Thermal Damage

Magnetic tapes, flexible discs and similar storage media are susceptible to thermal damage when exposed to sustained ambient temperatures above 38 ^{o}C (100 ^{o}F). Damage to hard disks can occur at sustained ambient temperatures of 66 ^{o}C (151 ^{o}F) and above. Electronic component failure can occur at temperatures as low as 79 ^{o}C (174 ^{o}F)and at temperatures in the range of 149 to 200 ^{o}C (300 to 392 ^{o}F) major component failures are common. Damage to paper products occurs at temperatures in excess of approximately 177 ^{o}C (350 ^{o}F), and microfilm is damaged at temperatures exceeding 107 ^{o}C (225 ^{o}F).

Fire Damage: Combustion Products

Combustion products formed during a fire include steam (water vapor), smoke, soot, and various additional chemical species depending upon the material involved in the combustion process, and electronic components are susceptible to damage due to exposure to these combustion products.

Hydrogen chloride (HCl) is a commonly encountered combustion product in computer facilities due to the widespread use of polyvinyl chloride (PVC) cable insulation in these facilities. Upon exposure to elevated temperatures, PVC produces gaseous HCl, which reacts with the galvanized zinc encountered in most electronic circuitry and components, resulting in the formation of a layer of zinc chloride ($ZnCl_2$) on the surface of the equipment. Zinc chloride is extremely hygroscopic, and picks up moisture from the surrounding air at as low as 10% relative humidity to form an extremely corrosive zinc chloride solution.

Additional corrosive combustion products often encountered in computer room and data processing facility fires include hydrogen fluoride (HF) from the decomposition of fluoropolymers such as FEP (fluorinated ethylene-propylene), hydrogen bromide (HBr) from the decomposition of flame retardant chemicals employed in cable and in electronic components and housings, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), acetic acid (CH_3COOH), hydrogen cyanide (HCN), and other species depending upon the exact composition of the organic materials undergoing pyrolysis.

Electronic components are also susceptible to damage from the smoke, soot and corrosive particulates produced by a fire. For example, disk drives are susceptible to damage from particulates as small as 0.5 microns in diameter.   Smoldering or slow growth fires, as are characteristic of computer room and data processing facilities, can produce non-conductive soots. These soots are large particulates (> 0.5 microns) and deposit out horizontally on equipment, forming an insulating layer on equipment, impacting contacts. In the case of more rapid growth fires, the amount of organic volatiles produced from the fire is small due to efficient combustion, and conductive soots are formed, comprised of small particulates (< 0.5 microns) which deposit on both vertical and horizontal surfaces. These conductive soots can lead to electrical shorting.

Fire Damage: Extinguishing Agent

The use of certain fire extinguishing agents on fires occurring in computer rooms or data processing facilities can result in damage caused by the suppression agent itself, and in many cases the secondary damage resulting from the suppression agent can exceed the damage from the fire itself. Water-based extinguishing systems such as sprinklers or water mist systems will leave an electrically conducting residue (water) on equipment which can lead to shorts. Dry powder agents or foam agents will leave a residue on equipment, and their use will require equipment shutdown and an extensive cleanup.

FIRE EXTINGUISHING SYSTEMS

Clean Agents

Given the high value and sensitivity of the electronic equipment involved, and the consequences of system interruptions, gaseous clean agent systems are often provided for the protection of computer rooms and electronics. The use of a clean gaseous total flooding agent is especially critical where there is the need to reduce equipment damage and to reduce or eliminate system downtime. The primary advantages of total flooding clean agents are:

- Clean extinguishment - fires are extinguished without collateral damage due to agent discharge (no corrosive residues formed, no cleanup required)
- Rapid extinguishment during the early stages of fire growth
- Ability to extinguish shielded, obstructed or three-dimensional fires in complex geometries

These characteristics render the clean agents especially suitable for the protection of electronic equipment areas. The absence of residues and subsequent lack of cleanup allow for minimum service interruptions, and extinguishment in the early stages of the fire limits fire damage to the object(s) involved in the fire. The three dimensional nature of the clean agents allows them to extinguish hidden or obstructed fires within the protected area, for example a fire inside an electrical equipment cabinet.

The two most widely employed total flooding clean agent systems for IT and telecommunication facilities are FM-200® (DuPont) and Inergen™ (Tyco) systems. FM-200® systems employ HFC-227ea (CF_3CHFCF_3) and extinguish fire primarily through the absorption of heat. Inergen™, a blend of nitrogen, argon and carbon dioxide, extinguishes fire by lowering the oxygen content to below the level required for sustained combustion. Both agents are electrically non-conductive and applicable for use in normally occupied areas.

Water Sprinkler and Water Mist Systems

The primary objective of a sprinkler system, whether wet-pipe or pre-action, is fire *control*, with the goals of containing the fire to its place of origin and controlling ceiling temperatures sufficiently to prevent structural damage and/or collapse. Actuation of sprinkler systems does not occur until the temperature at the glass bulb or fusible link of a sprinkler head exceeds its temperature rating, typically 57 ^{o}C (135 ^{o}F) or higher. As a result of these relatively high actuation temperatures, fires will be well-developed before the sprinkler system activates, with fire sizes of several hundred kW being typical. This contrasts with the case of clean agent systems, where the primary objective is not control but *extinguishment* of fire in its incipient stages where fire sizes may be as small as 0.1 to 1 kW.

Sprinkler systems employ water, which has obvious disadvantages in applications where electronic equipment is involved, require cleanup after activation, and in some cases can produce more secondary damage than the damage produced by the fire itself. Sprinkler systems are more suited to the protection of the facility itself, whereas the clean agents are more suited to the protection the assets located within the facility. Maximum levels of protection for a facility can be accomplished by employing both a clean agent system to protect the facility's assets and a sprinkler system to protect the facility itself.

Water mist systems have also been considered for the protection of computer rooms. The extinguishing action of water mist on the relatively small fires characteristic of those involving electronic equipment is due predominantly to dilution of oxygen in the zone of burning, with steam resulting from the evaporation of water droplets in the heated area surrounding the fire and causing extinguishment vi oxygen dilution. The ability of water mist systems to extinguish fires increases with the fire size: the extent of evaporation, and hence the degree of oxygen dilution at the fire, increases as the fire size increases. As a result, water mist systems perform well in the extinguishment of large fires, hence their use in marine applications, for the protection of machinery spaces. The extinguishment of small fires with water mist systems can be problematic due to the limited evaporation of water droplets and hence limited oxygen dilution at the fire location. In addition, water mist is not a total flooding agent like the gaseous clean agents, and as a result may experience difficulty in extinguishing obstructed fires, such as fires originating within an equipment cabinet.

As water mist systems will leave a residue (water), many IT managers are reluctant to install water mist systems for protection of computer rooms. Therefore, water mist systems generally are not recommended for IT facilities.

CLASS C FIRES

NFPA Standard 10 defines Class C fires as those that, "involve energized electrical equipment." A Class C fire actually involves Class A (solids, cellulosic materials) or Class B (liquids, gases) materials and energized electrical equipment. For example, a fire involving a power cable that is electrically energized (i.e., has current flowing through the cable during the fire) is considered a Class C fire. In this case, the insulation on the wire, a Class A material, is burning (the copper wire itself is noncombustible) while an electrical current flows through the wire. If the current is removed, the situation is considered a Class A fire.

Suppression of Class C Fires

Surprisingly relatively few studies have been reported for the suppression of Class C fires with any type of fire suppression agent. Suppression testing of many of the *materials* found in electronic data processing facilities has been reported, but in almost all cases no electrical current flow was involved, and hence these tests do not evaluate Class C performance.

Several studies of clean agent suppression of Class C fires have been reported recently, but as reviewed by Robin, et.al. [9,10], many of these tests were found to be flawed in both the materials and the test conditions employed, neither of which were not representative of real world hazards. Three separate studies have been reported examining the performance of the clean agents in true Class C fire scenarios, i.e., fire scenarios involving the flow of electrical current.

McKenna, et. al. [11]

McKenna, *et al.* reported the results of fire testing of FM-200® (HFC-227ea) on continuously energized Class C fires, employing configurations designed to replicate hazards encountered in power conduction applications. These studies employed materials that can be related to real world applications, *i.e.*, copper wire conductors, common insulation materials (PVC, Hypalon, polyethylene), printed circuit boards, etc. Test fires were developed to replicate the physical phenomena found during the following fire scenarios, which are typical of those occurring in IT and telecommunication facilities:

- Ohmic heating (overheated cable) tests;
- Conductive heating (overheated connection) tests; and
- Printed Wire Board (PWB) failure tests.

Ohmic Heating Tests. Electrically overheated wire and cable are a well-documented phenomenon. An electrical fault or the failure of an overload protective device can result in the development of an overcurrent in a wire or cable. When sufficient current flows through the conductor, it will overheat due to resistance in the conductor (*i.e.*, ohmic heating). Heating is proportional to the current flow and hence higher current flows result in higher temperatures. A "dead" short in an electrical circuit can result in a nearly instantaneous overheating of an entire cable and ignition of the cable insulation.

This scenario was modeled by creating a controlled overcurrent condition in a sample of wire or cable. A wire bundle sample was positioned in the center of a test enclosure and the wires were mounted between two copper busses which extended through the enclosure wall. The copper busses themselves were connected to a 600 A arc welder, which supplied current to the conductors of the wire bundle. Following a preheat period, a butane pilot flame was applied at the midpoint of the underside of the sample to ignite the cable insulation and, after a suitable preburn period, the suppression system was activated. Five commonly encountered cable types were examined: crosslinked polyethylene (XLPE), polyvinyl chloride (PVC), chrome PVC jacket over polyethylene, neoprene jacket over rubber insulation and SJTW-A (thermoplastic jacket over thermoplastic insulation). All test samples were effectively extinguished at FM-200® concentrations of 5.8% v/v (note that the minimum Class A design concentration for FM-200® is 6.25 % v/v).

Conductive Heating Tests. Overheated electrical connections are a well-documented phenomenon. In these scenarios, the connection at one end of a wire or cable becomes loose due to one or more causes (mechanical stress, vibration, *etc*.). When the connection becomes sufficiently loose, a resistance to electrical flow develops in the connection, and the connection will begin to heat. As the connection heats, the copper conductor of the cable acts as a heat sink, conducting heat away from the connection, and at some point the insulation of the cable can reach its ignition temperature.

This scenario was modeled by clamping one end of a copper cable inside a 1000 Watt ring heater. Three typical 350 MCM cables, currently in common use, were employed: Lucent Technologies type KS 5482-L28FR (Hypalon insulation covered by cotton braid sheathing), Lucent Technologies type KS 20921 (unsheathed Hypalon insulation) and Lucent Technologies type KS 20747 (PVC insulation). The sample cable was heated until the top of the cable sample reached 590 ^{o}F (750 ^{o}F for PVC cables) and a small pilot flame applied. The enclosure was then sealed, and the suppression agent discharged into the enclosure following a one minute preburn period. All test sample fires were effectively extinguished at FM-200® concentrations of 5.8% v/v.

Printed Wire Board Failures (Arcing). Internal printed wire board (PWB) failures are a common event in electronics equipment, generally caused by contaminants within the PWB. They can also be induced by component failures. If an overheating component is located above the power tracks on a PWB, pyrolysis of the insulating material between the tracks can lead to the development of an arc between the power tracks. In this scenario, an electrical fault allows excess current to flow through the power tracks on the board, overheating the tracks. The overheated power tracks pyrolyze the substrate material between them and after a time the insulating properties of the material are sufficiently degraded such that an arc develops between the two tracks, igniting the gaseous pyrolysis products. The arc travels along the tracks starting at the point of ignition and moves towards the power supply.

This scenario was modeled with a specially designed PWB failure board; when overloaded, an arcing short could be created between two tracks on an FR-4 board substrate. At the point at which the arc had traveled 130 mm, the fire was judged to be well established and the suppression agent was discharged. All test samples were effectively extinguished at FM-200® concentrations of 5.8% v/v.

Based on the results of their ohmic heating, conductive heating, and PWB failure tests, McKenna, et. al., concluded that "fires initiated by, and involving, energized electrical circuits can be controlled by FM-200® at concentrations below 7%."

Robin, et. al. [9,10]

Robin, et. al. [9] reported the results of the suppression of plastic samples involved in a Class C fire scenario. The test configuration employed is shown in Figures 1 through 3. The test frame is constructed from aluminum and contains two electrical standoffs with ceramic insulators for connection of the test frame to a power supply. The test specimen is shown in Figure 1, and Figures 2 and 3 show the plastic specimen in place within the specimen holder.

Suppression tests were conducted in a 200 ft^3 (5.7 m3) box constructed from plywood and measuring approximately 3.3 feet wide (1.0 m), 7.6 feet (2.3 m) deep and 8 feet (2.4 m) tall. A walk-in door was located on one end of the enclosure, a 12 inch (30.5 cm) square viewing window, and two ventilation ports for purging the enclosure between tests. Electronics Measurements, Inc. Model TCR power supplies were employed to heat

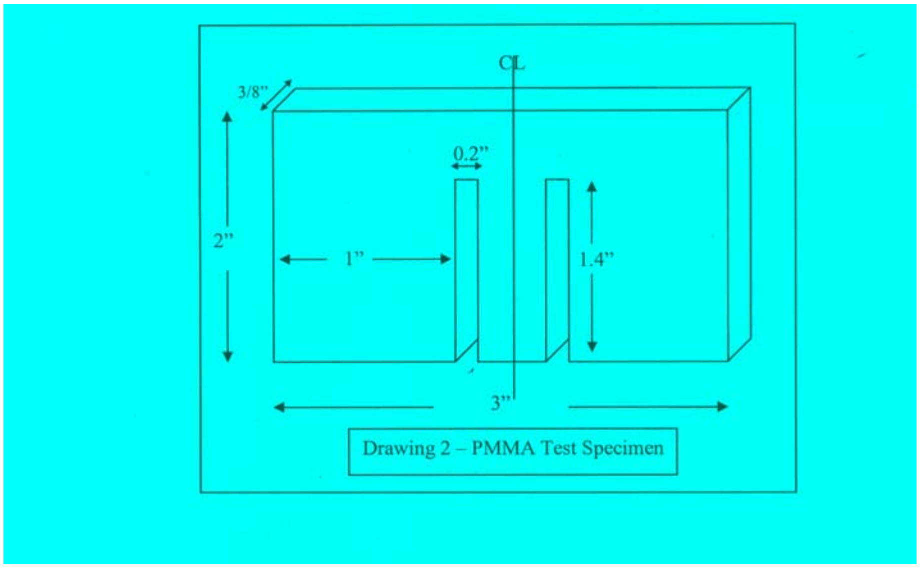

Figure 1. Test Specimen

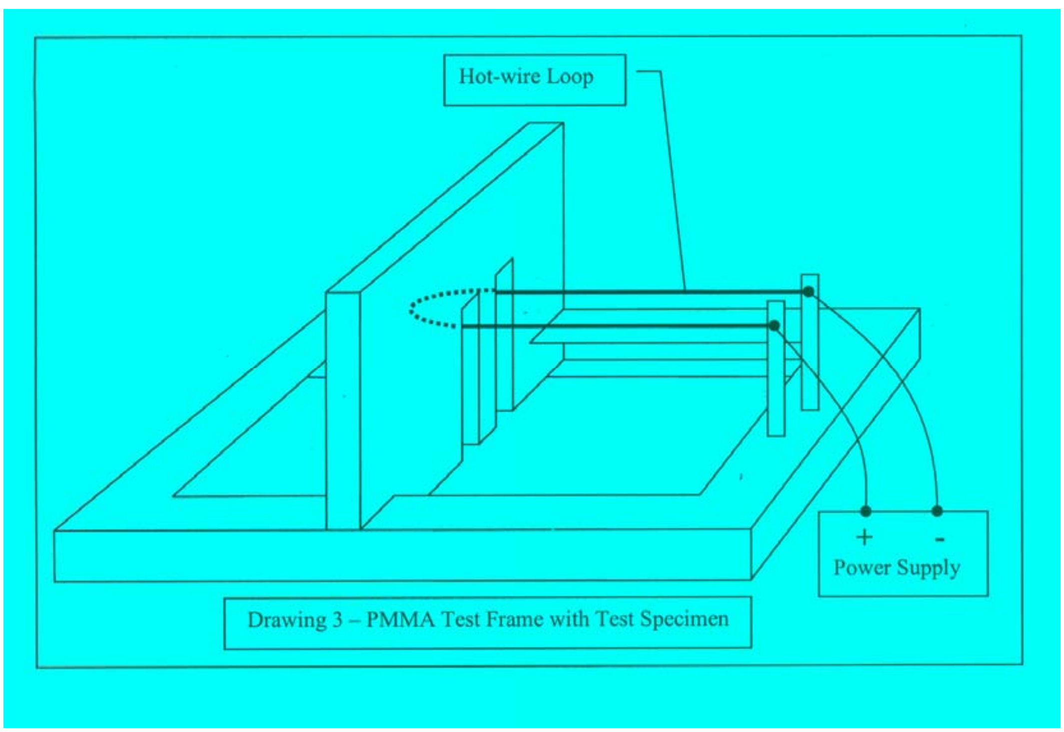

Figure 2. Test Specimen in Test Frame

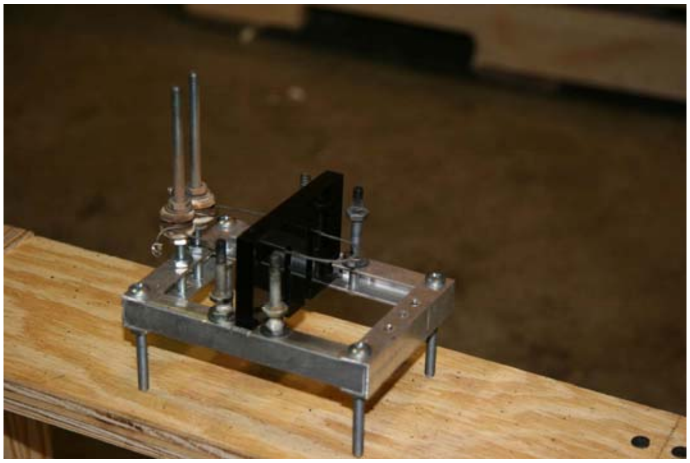

Figure 3. Plastic Slab Test Configuration

a nichrome (Ni-Cr) wire to the desired temperature. Temperatures were determined using unsheathed, bare, thermocouple wires and Fluke thermocouple meters. Agent was discharged into the test cell using an inverted container to ensure that the entire contents were discharged into the test cell. A single 360^o nozzle was installed centrally in the test cell. Samples investigated included PVC, HDPE, PMMA, ABS, and PP.

Tests were conducted with FM-200® (HFC-227ea) at its minimum Class A design concentration of 6.25% v/v. A current corresponding to a wire temperature of 1800 ^{o}F (982 ^{o}C) was applied to the nichrome wire to afford ignition of the sample. At 30 seconds after ignition, the current was reduced to a level corresponding to a wire temperature of 1200 ^{o}F (649 ^{o}C), and maintained at this level throughout the entire test; it should be noted that copper wire, employed almost exclusively for current conduction, will rapid fuse at temperatures above 1000 ^{o}F (538 ^{o}C). At 60 seconds from ignition the suppression system was activated. The system was then observed for any reignition during a 10 minute soak period. The test results are shown in Table 4. In all cases, the Class A minimum extinguishing of FM-200® (6.25% v/v) was found to be capable of extinguishing the fires and preventing reignition over a 10 minute hold period during which the nichrome wire remained energized. The tests also demonstrated the "self-extinguishing" nature of PVC. Although small intermittent flames were observed with PVC, a self-sustaining flame could not be generated under the test conditions.

The plastic slab tests described above demonstrate the ability of the FM-200® to suppress PMMA, PP, ABS and PVC fires when employed at their minimum design concentrations. The tests are not, however, representative of typical Class C hazards due to differences in the configurations and materials employed in the tests compared to real world Class C fire scenarios. For example, electrical current conduction is accomplished via copper wire in almost all cases and never via nichrome. In addition, in real world scenarios the conductor is located inside the plastic insulation, not wrapped externally around the insulator.

Table 4. Suppression Testing of 6.25% v/v FM-200®
on Energized Plastic Slab Fires

Run	Plastic	Ignition (s)	Ext Time from EOD (s)	Reignition during Soak?
A1	ABS	10	10	NO
A2	PP	25	10	NO
A3	PP	30	12	NO
A4	PMMA	5	20	NO
A5	PVC	NA	NA	NO
A6	PVC	NA	NA	NO
A7	PVC	NA	NA	NO
A8	HDPE	30	10	NO
A9	PMMA	20	40	NO
A10	ABS	3	11	NO
A11	PP	4	10	NO
A12	HDPE	30	10	NO
A13	ABS	4	12	NO
A14	PMMA	9	41	NO
A15	HDPE	9	6	NO

Robin, et. al. [10] have also reported the results of suppression testing of clean agents on energized wire bundles. Suppression tests were conducted in a 200 ft^3 (5.7 m3) box constructed from plywood and measuring approximately 3.3 feet wide (1.0 m), 7.6 feet (2.3 m) deep and 8 feet (2.4 m) tall. A walk-in door was located on one end of the enclosure, a 12 inch (30.5 cm) square viewing window, and two ventilation ports for purging the enclosure between tests. Seven individual PVC cables were bound together, and a nichrome wire inserted through the center cable, as shown in Figure 4; the ends of the nichrome wire exited the test enclosure and were attached an Electronics Measurements, Inc. Model TCR power supply to heat the nichrome wire to the desired temperature. Agent was discharged into the test cell using an inverted container to ensure that all contents were discharged into the test cell; a single 360^o nozzle was installed centrally in the test cell, and all tests employed baffling modeled after the UL 2166 polymer fire.

Ignition of the cable bundle was accomplished by increasing the current through the nichrome wire to a value corresponding to a wire temperature of 1800 ^oF (982 ^oC). Once ignition of the cable bundle occurred, the cable was allowed to burn for a period of 60 seconds, at which time the clean agent was released into the enclosure. A five minute "soak" period followed during which the cable bundle was observed for any signs of reignition. The cable bundle remained electrically energized throughout the entire test.

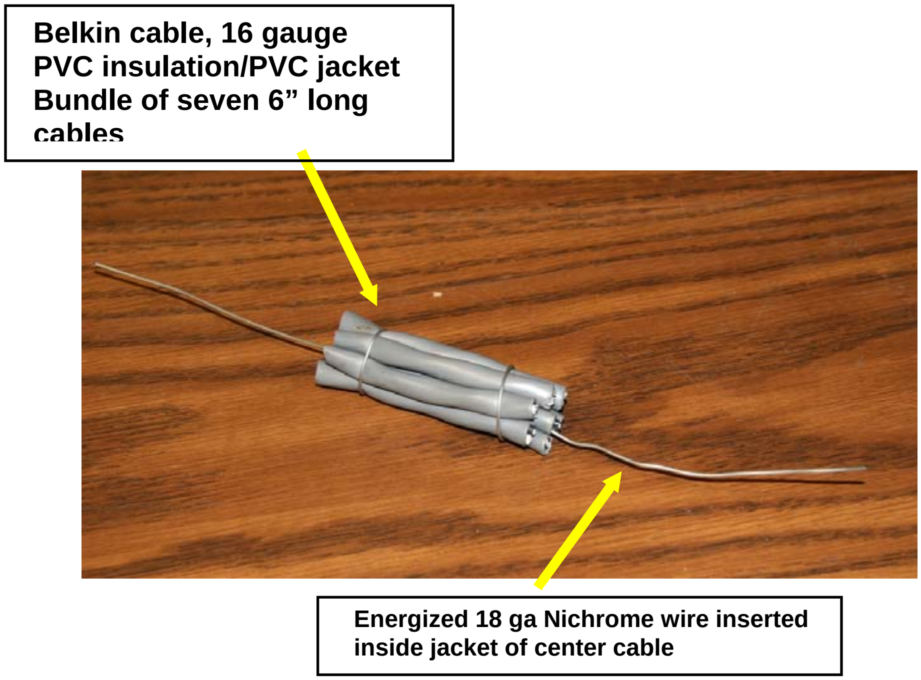

Figure 4. Cable Bundle

Tests were conducted with the clean agents FM-200® (HFC-227ea), FE-25™ (HFC-125), Argonite™ (Ar/N_2), and Novec™ 1230 (Perfluoroketone 5-1-12) at their minimum Class A design concentrations as defined in NFPA 2001 (2004 edition), i.e., at 1.2 times their Class A extinguishing concentrations, as shown in Table 5.

Table 5. Concentrations Employed in Energized Cable Bundle Tests

Agent	Minimum Class A Design Concentration, % v/v
HFC-125	8.0
HFC-227ea	6.3
IG-55	34.2
Perfluoroketone 5-1-12	4.2

For all of the clean agents tested, the energized cable bundle fire was rapidly extinguished and reignition suppressed at the Class A minimum design concentration of the clean agent. The test and test results were also found to be highly reproducible, and are summarized in Table 6.

Table 6. PVC Cable Fire Tests: Agent at Design Concentration

Run	Agent	Conc., % v/v	Ignition (s)	Ext time from EOD (s)
A1	HFC-125	8.0	0:10	0:08
A2	HFC-125	8.0	0:06	- 0:01
A3	HFC-125	8.0	0:10	0:05
A4	HFC-227ea	6.3	0:09	0:05
A5	HFC-227ea	6.3	0:08	-0:08
A6	HFC-227ea	6.3	0:11	- 0:04
A7	PFK-5-1-12	4.2	0:09	0:03
A8	PFK-5-1-12	4.2	0:10	0:00
A9	PFK-5-1-12	4.2	0:09	0:05
A10	IG-55	34.2	0:10	- 0:50
A11	IG-55	34.2	0:11	2:10
A12	IG-55	34.2	0:05	0:20

Additional testing by Robin, et. al. [10] demonstrated that the electrically energized cable fires described above could be extinguished at agent concentrations as low as 30 percent *below* the Class A minimum design concentrations allowed under NFPA 2001.

The results of the McKenna, et. al. and Robin, et. al. studies are consistent with real world experience: clean agent systems have been installed in hundreds of thousands of facilities over the past two decades, and there have been no reports indicating the failure of these systems in fire scenarios involving electrically energized equipment.

CONCLUSION

In this paper we have reviewed the nature of fires involving electrically energized equipment in IT and telecommunications facilities, the types of equipment employed in these facilities and their susceptibility to fire, and test methods employed for the evaluation of fire suppression agent performance on fires involving electrically energized equipment (Class C fires).

Several major conclusions may be drawn from a review of the fire suppression literature and the results of the recent Class C testing by McKenna and Robin:

- The fire history of IT and telecommunications facilities shows that fires in these facilities can lead to substantial damage and revenue loss

- Fires in IT and telecommunications facilities are characterized by low fuel loads, primarily involving wire insulation, printed circuit boards, electronic components, transformers, insulating materials, and plastic housings

- Fires in IT and telecommunications facilities typically initiate from an overheat, short or arc condition, are of low energy output, often less than 5 to 10 kW, and produce varying amounts of combustion products, often corrosive and toxic

- Relatively few tests have been reported in which energized electrical or electronic equipment were involved. The vast majority of tests involving electronic equipment employ unpowered equipment and a means of ignition other than electrical

- Recent evaluations of the performance of the clean agents on Class C fires indicate that current Class A minimum design concentrations of the clean agents are sufficient to suppress typical Class C fires

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