SUMMARY OF ONGOING CLASS C FIRE RESEARCH FOR THE PURPOSE OF IDENTIFYING AND EVALUATING CLASS C FIRE RISKS AND SUPPRESSION NEEDS IN MODERN DATA CENTERS, INTERNET SERVICE PROVIDERS AND TELECOMMUNICATIONS FACILITIES

Mark L. Robin, Ph.D.
DuPont Fluoroproducts
Ph: 302-999-5002; mark.l.robin@usa.dupont.com

Bon Shaw and Brad Stilwell
Fike Corporation

ABSTRACT

This paper identifies typical Class C hazards found in modern data processing and telecommunication facilities and proposes new test methodologies for comparing the Class A minimum extinguishing concentrations (MECs) of clean agents with Class C hazards requirements. Industry specific Class C hazards, configurations and environmental conditions are utilized to develop test procedures and to evaluate the performance of clean agents on Class C fires. Laboratory Class C test results, using the clean agents at their design and minimum extinguishing concentration levels with this methodology are presented and discussed.

TELECOMMUNICATION FACILITIES

The Telecommunications Industry [1]

The telecommunications industry is one of the fastest growing industries on the planet. Globally, telecommunications industry revenues totaled $3.32 trillion in 2006 and worldwide telecommunications industry revenues are estimated to reach $4.26 trillion by 2010 [2]. 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.

Central Offices [1]

Central offices house the primary control equipment for telecommunication networks. Many central offices are highly automated and are either unstaffed or have limited staff present only during standard working hours. A central office typically consists of a variety of equipment and spaces [1, 3]:

- Cable vaults
- Battery rooms
- Generator rooms
- Distributing frames
- Switching equipment
- Computer rooms
- Conventional offices, building systems, mechanical rooms

Cables typically enter and leave the central office through a *cable vault* where they are spliced to smaller cables for distribution throughout the facility. US codes require that cables inside a building comply with stringent criteria for flame spread; the cables used outside a building are exempt from such regulations. The cables then rise through the building to a *main distributing frame* (MDF) where they separate into individual pairs of wire for each circuit and connect to cables leading to the *switching systems*. After switching, signals pass to *transmission systems* which multiplex and boost the signals. Finally, the signal travels back out the facility through the cable vault over other cables. In addition, the central office contains standby generators, battery systems and associated power and distribution equipment. In remote areas, all of these components may be housed in a single room, whereas large facilities may involve one or more rooms or floors of a building.

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, that is, 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.

The financial impact of a service disruption can be significant [4]. The downtime impact for a typical computing infrastructure is estimated at $42,000 per hour; downtime impacts for companies relying entirely on telecommunications technology, such as online brokerages or e-commerce sites can reach $1 million per hour or more.

Fire History of Telecommunication Facilities

In 1993, the Federal Communications Commission (FCC) conducted a study on the fire history of the telecommunications industry, which covered the years 1988 to 1992 [5]. The report identified seven fundamental root fire causes of fires in the telecommunications industry; these are listed below in decreasing order of occurrence:

- Fires initiating within telco equipment and peripheral equipment
- Fires involving power equipment (e.g., cable shorts/arcs, batteries)
- Vendor/Contractor initiated fires (e.g., lack of bus bar protection, welding, cable mining)
- Telco personnel (e.g., lounge or kitchen area appliances, smoking)
- Natural causes (e.g., storms)
- Causes external to the building, (e.g., garbage, landscape fires)
- Building system fires (e.g., elevator, HVAC system)

Fire record data for the telecommunication industry for the years 1980 to 1998, based on both NFPA and NFIRS data, has been reported by Transue [6] and is summarized in Table 1.

A study by Hall in 2004 concluded that properties wholly dedicated to computer or telecommunication activities are a comparatively small part of the U.S. fire problem [7]. In this study, electronic equipment areas included computer areas, data processing centers, control

Table 1. U.S. Structure Fires in Telephone Exchanges or Central Offices [6]

Year	Total Fires	Fires with Electronic Equipment Involved in Ignition
1980	132	5
1981	138	0
1982	117	4
1983	138	11
1984	79	5
1985	88	0
1986	86	3
1987	41	2
1988	73	7
1989	50	0
1990	58	5
1991	56	2
1992	75	9
1993	55	4
1994	44	0
1995	52	6
1996	37	4
1997	58	6
1998	37	0

centers, radar rooms, telephone equipment rooms and telephone booths. The main conclusions of this survey included the following:

- A large number of fires in electronic equipment rooms do not begin with the electronic equipment or even with any equipment
- The leading cause of fires in electronic equipment areas involves electrical distribution equipment (e.g., wiring, cables, cord, plugs, outlets, overcurrent protection devices), but not electronic equipment
- In most cases fire damage is limited to the object of origin

As indicated by the above surveys, the occurrence of fires in telecommunication facilities, especially fires originating in electronic equipment, are relatively rare. In fact, there have only been eight major central office fires in North America from 1975 to 2000, as detailed in Table 2.

Characterization of Telecommunication Facility Fires and Fire Risk

Transue has categorized telecommunications facilities areas into one or more of eight types of areas, each with its own fire hazard characteristics, as shown in Table 3 [6].

Numerous sources indicate that fires characteristic of those occurring in telecommunication facilities, especially those involving electronic equipment, are small in size [1,8,9]. 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,

Table 2. Major Central Office Fires in North America, 1975 to 2000

Incident	Service Interruption	Fire Origin
New York City 1975	170,000 customers, several weeks	Cable vault
Brooklyn, NY 1987	41,000 customers, 16 days	Main distribution frame
Hinsdale, IL 1988	38,000 customers, 12 days	Cable tray
Los Angeles, CA 1994	911 for 12 hours	Battery plant undergoing reconfiguration
Orangeburg, NY 1994	14,000, 1 day	Obsolete transmission equipment
Idabel, OK 1995	5,000 lines, 13 hours	DC power cable
Portland, OR 1996	88,900 lines, 15 hours	Cables
Toronto, Ontario 1999	113,000 lines, 1 day	AC switchgear under going reconfiguration

Table 3. 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

insulating materials, and plastic housings [8,9]. The majority of these fires are characterized by Meacham 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

Detection systems employed in telecommunication facilities are designed to detect fires in their incipient stages, and there is an industry wide desire and trend to detect fires at as small a size as possible. For example, telecommunication industry leaders have indicated their desire for detection of typical equipment fires in telecommunications facilities at a fire size of 1 kW, whereas for highly sensitive equipment, detection at a fire size of 0.1 kW is desirable [10]. As discussed by Meacham, detector selection for the telecommunications industry can be based upon an evaluation of the level of damage which is tolerable; employing the tolerable damage limits proposed by Meacham, the detector selections shown in Table 4 can be made [1].

Table 4. Detection Device Selection Based On Potential Loss Characterization [1]

Potential Loss Characterization	Fire Size	Suitable Detection Device
Major	100 kW or greater	Standard or fast response sprinkler
	50 - 100 kW	Spot type heat detection device
Large	5 - 50 kW	Spot or linear beam detector at “listed” spacing or Line type heat detector at reduced spacing
Moderate	2 - 5 kW	Incipient (air sampling) detection system at "listed" coverage. Spot or linear smoke detectors installed with reduced spacing
Small	less than 2 kW	Incipient (air sampling) detection system installed with reduced coverage area. Smoke detectors installed within equipment cabinets

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 [6].

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 911 communications. De-powering of telecommunications equipment in telecommunication facilities is also difficult due to the several levels of power redundancy present. Selective de-powering has been proposed as an optimized approach, i.e., the removal of power from the smallest segment of the power distribution system necessary to de-energize the equipment or cable involved in the fire.

DATA PROCESSING FACILITIES

Comparison of Data Processing and Telecommunications Facilities [6]

Although similar equipment is involved in the two types of facilities, differences exist between the two. The most significant difference involves the type of information processing performed. As discussed above, telecommunication systems are on-line information exchange systems, that is, 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, and the ability of the system to transmit data ceases. As long as the disruption continues, data and programs cannot be reloaded. 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 into permanent memory is lost. Finally, because service interruption is not as critical in data processing facilities as it is for telecommunication facilities, equipment shutdown is more likely to be practiced in the event of a fire in a data processing facility.

Fire History of Data Processing Facilities

As for the case of telecommunication facilities, fires in data processing facilities are rare, and involve relatively small fires. In 1988, Taylor reported that an estimated average of 80 structure fires involving computer and data processing centers occurred annually in the United States from 1981 to 1985 [11]. Of these fires, approximately 30 percent started in electrical distribution systems. The analysis by Hall, discussed above, concluded that for data processing centers the leading cause of fires in electronic equipment areas is related to electrical distribution equipment (e.g., wiring, cables, cord, plugs, outlets, overcurrent protection devices etc.), not electronic equipment, and that in most cases fire damage is limited to the object of origin

Characterization of Data Processing Facility Fires

Fire hazards occurring in data processing facilities have been discussed by several authors [6, 11]. As is the case for telecommunication facilities, fires in data processing facilities are relatively rare and 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 technology (IT) equipment.

CLASS C FIRES [12-16]

ROC Comment 2001-61a

At a recent meeting of the NFPA 2001 Technical Committee, Comment ROC 2001-61a (log #CC7) was proposed and, after much debate, accepted by the Committee. The comment was subsequently subject to a floor vote which overwhelmingly rejected the comment and the current edition of NFPA 2001 retains the requirement that Class C minimum design concentrations should be at least equal to the minimum Class A design concentration. Comment ROC 2001-61a would have required that the minimum design concentration for a Class C hazard be increased from the current level of 1.2 times the Class A minimum extinguishing concentration to at least 1.6 times the Class A minimum extinguishing concentration.

The field experience gained with clean agent systems does not justify the drastic changes called for in Comment ROC 2001-61a. During the past 15 year period in which clean agent fire suppression agents have been employed, there is not a single documented report of the failure of any clean agent system to extinguish a fire involving energized electrical equipment.

In its acceptance of ROC 2001-61a, the NFPA 2001 Technical Committee provided the substantiation that "Laboratory testing indicates that the agent concentration required to extinguish a fire in energized electrical equipment typically increases with increased electrical power input." The laboratory testing employed as a basis for this substantiation is described in a series of reports and can be categorized as follows:

- Tests involving electrically energized metals in flames;
- Tests lacking the presence of electrically energized equipment;
- Conductive heating, ohmic heating and PC board failure (arcing) tests;
- Modified conductive heating; and
- Tests involving nichrome wire as a conductor and polymethylmethacrylate.

Robin, et. al. [13] have reviewed these tests in detail and it has been found that they suffer from a number of serious shortcomings including the use of nonrepresentartive materials and test conditions, as well as poor reproducibility.

Temperature Behavior of Copper Wire: DuPont/Fike Studies

One of the major shortcomings of previous studies on clean agent suppression of Class C fires was the use of nichrome wire as the electrical conductor. Copper is employed as the electrical conductor in almost all electrical applications - nichrome wire is never employed. In order to better understand the characteristics of copper wire, DuPont Fluoroproducts and Fike Corporation carried out a series of simple laboratory scale tests involving electrically energized copper wires [13].

The behavior of copper wire subjected to elevated temperatures was examined by connecting the ends of a ten inch length of 24 AWG bare copper wire to Electronics Measurements, Inc. Model TCR power supplies rated up to 40 volts @ 100 amps. The current was then adjusted to a constant level and the temperature of the wire monitored using unsheathed, bare, thermocouple wires and Fluke thermocouple meters. The results of these tests are shown in Table 5, where it can be seen that for wire temperatures below approximately 950 ^{o}F, the copper wire remained intact for a time period of at least 10 minutes. Wire temperatures above approximately 1000 ^{o}F could not be maintained for 10 minutes as the wire would break; higher wire temperatures could be tolerated for shorter time periods before the wire was observed to break

Table 6 shows the results of the same test, but conducted with jacketed copper wire. In this case the wire was observed to fail at average temperatures in excess of approximately 725 ^{o}F. Compared to bare wire, less heat is dissipated away from the copper wire when it is surrounded

Table 5. Overloaded Copper Wire; 24 AWG Bare Copper Wire

Current (A)	Temperature (^oF)	Duration (time to wire failure)
21	700	> 10 min
23	800-825	> 10 min
25	925-950	> 10 min
26	1000	8 min
27	1050	3:23 ; 5:13 ; 6:02

Table 6. Overloaded Copper Wire; 24 AWG Jacketed Copper Wire

Current (A)	Temperature (^oF)	Duration (time to wire failure)
20.5	700	> 10 min
21.5	725	24 s
23.5	850	28 s
27	1050	10 s

by the insulator, leading to an increased corrosion rate due the higher localized wire temperatures.

Additional tests were conducted to examine the temperature limitations of braided copper wire compared to stranded wire, and no significant differences were observed.

A number of important conclusions can be drawn from these tests:

- Bare copper wire can withstand a 10 minute overcurrent only when the wire temperature is limited to 1000 ^oF
- Insulated copper wire can withstand a 10 minute overcurrent only when the wire temperature is limited to 700 ^oF
- Larger gauge wires require more current to attain a given temperature but behave similarly to smaller gauge wires at similar temperatures
- Wire gauge makes little difference in the ability of copper wire to withstand high temperatures: - the maximum temperature which can be tolerated for 10 minutes is approximately 900 to 1000 ^oF
- Stranded cables and single conductor cables behave similarly
- Copper wire heated to 750-1000 ^oF is sustainable for 10 minutes only if these temperatures are not exceeded anywhere along the length of the wire
- When copper wire is heated to above 700 ^oF, corrosion is accelerated and this corrosion is the primary reason for failure at these temperatures

A large number of the studies used as the basis for increasing the Class C design concentration employed nichrome wire at current levels corresponding to wire temperatures in excess of 1800 ^oF. At this temperature, bare copper wire is sustainable for less than 10 seconds, and at 1800 ^oF insulated copper wire is sustainable for even lesser periods of time. Hence, these tests involving a nichrome wire would be impossible to conduct if one were to employ, instead of nichrome, the conductor used in essentially all power transmission cables. The conditions employed in these tests are clearly not representative of the real world hazard.

DuPont/Fike Cable Bundle Tests [15,16]

The plastic slab tests described above demonstrate the ability of the clean agents 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.

An example of a typical, representative Class C hazard is an electrically energized cable bundle. In order to evaluate the performance of the clean agents on cable fires a cable bundle test was devised which employed the test enclosure described above for the plastic slab tests and consisted of a bundle of seven PVC cables through which a central 18 gauge nichrome wire was inserted. The nichrome wire was electrically energized to a wire temperature of 1800 ^{o}F and maintained at this temperature throughout the entire test. Following ignition, the cable bundle was allowed to burn for 60 seconds (i.e., a 60 s preburn was employed) and the suppression agent was then released, and the test configuration observed for extinguishment and reignition over a soak period. The cable bundle configuration is shown in Figure 1. Test were conducted at minimum design concentration and as low as minimum design concentration minus 30 percent - in all cases the PVC bundle fire was extinguished by the clean agents. Results of the testing at minimum design concentration are shown in Table 7. Figure 2 shows typical results, those for HFC-227ea at minimum design and at minimum design minus 30 percent.

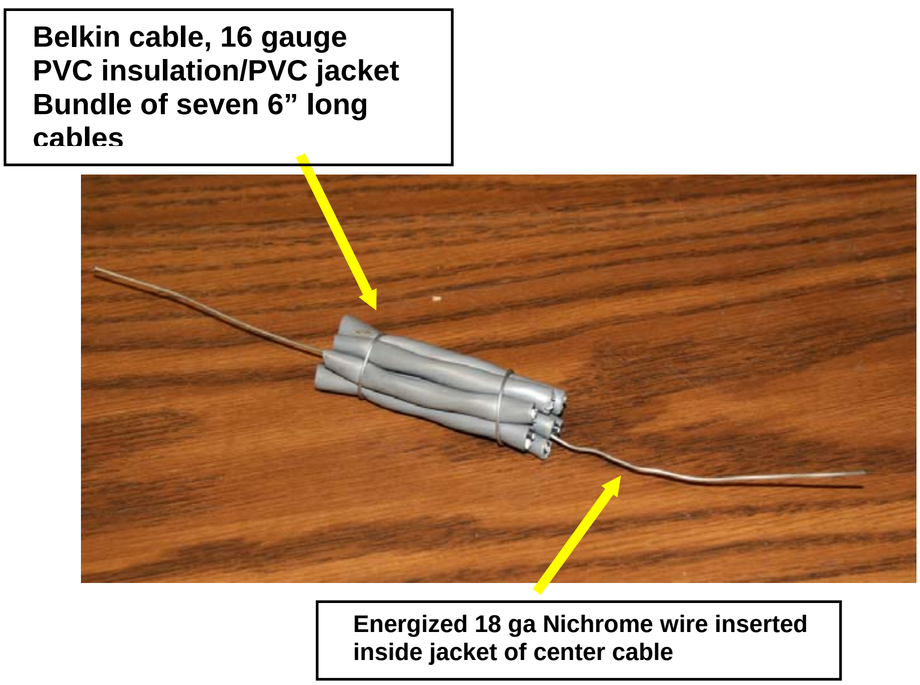

Figure 1. Cable Bundle

Table 7. 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

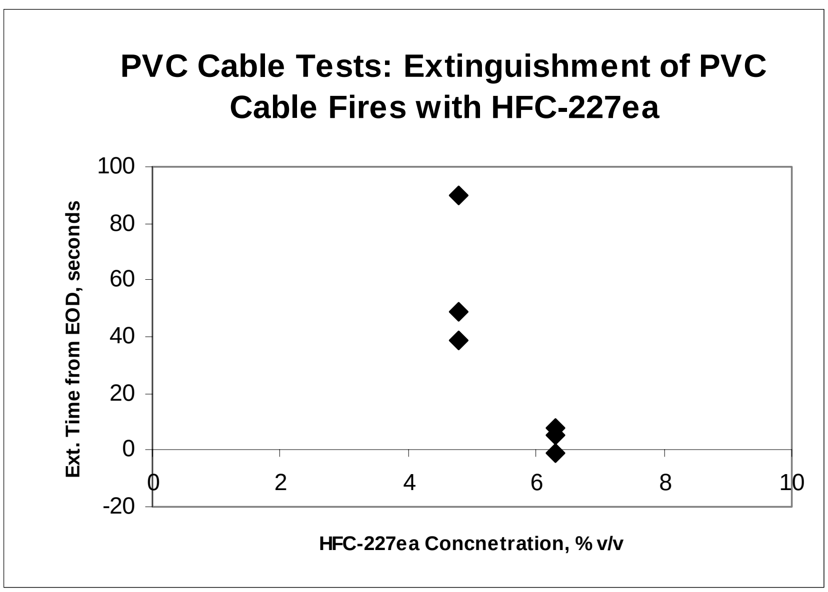

Figure 7. Extinguishment of PVC Cable Bundles with HFC-227ea

Justification of ROC Comment 2001-61a

A detailed analysis of 15 years of field experience, past testing and the results of the recent DuPont/Fike studies result in the following conclusions with respect to Comment ROC 2001-61a:

- Field experience does not justify ROC 2001-61a
- The earlier studies reviewed by NFPA do not justify ROC 2001-61a
- The results of the DuPont/Fike study do not justify ROC 2001-61a.

Field experience does not justify the changes that would have been required following acceptance of Comment ROC 2001-61a. Clean agent systems have been installed in hundreds of thousands of facilities over the past 15 years, and there is *not a single* documented piece of evidence indicating the failure of these systems in fire scenarios involving electrically energized equipment.

The studies cited as justification for ROC Comment 2001-61a are characterized by serious flaws with regard to the materials and test conditions employed, and in several cases are also plagued by a lack of reproducibility. As a result, they do not justify the far-reaching changes that acceptance of ROC 2001-61a would have required.

CONCLUSIONS

In this paper we have reviewed the nature of fires involving electrically energized equipment in telecommunications and data processing facilities. This review has included an investigation of the nature of telecommunication and data processing facilities and their fire history, 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 DuPont/Fike:

- The fire history of telecommunications and data processing facilities shows that, while relatively rare, fires in these facilities can lead to substantial damage and revenue loss
- Fires in telecommunications and data processing facilities are characterized by low fuel loads, primarily involving wire insulation, printed circuit boards, electronic components, transformers, insulating materials, and plastic housings
- Fires in telecommunications and data processing 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
- The vast majority of tests involving powered equipment have been conducted on the recently developed clean agents. Many of these tests employ unusual test configurations which are difficult to relate to real world Class C fire scenarios
- Neither field experience, nor past testing justify the increase in minimum Class C design concentrations proposed by ROC Comment 2001-61a
- 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 at least some Class C fires, e.g., cable bundle fires

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