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RESPONSE BIAS OF ELECTRICAL CABLE COATINGS AT FIRE CONDITIONS

Volume 1
Fire-Retardant Electrical Cable Coatings and History of use in Nuclear Facilities

Final Report

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ABSTRACT

This report contains the results of an experimental research program on the performance of fire-retardant cable coatings. The program is sponsored by the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research, and the experiments were performed at Sandia National Laboratories and the National Institute of Standards and Technology. The goal of the experiments was to assess the effects of commercially available fire-retardant cable coating materials on the thermal and electrical responses of cables exposed to fire conditions.

This research is being conducted in several phases. Phase 1 consists of developing a fundamental understanding of the use and performance of fire-retardant cable coatings and is documented in Volumes 1–3 of this research information letter. Volume 1 traces the history and use of fire-retardant electrical cable coatings. Volumes 2 and 3 provide empirical data on the performance of selected cable coatings, with Volume 2 discussing fire resistance properties and Volume 3 covering electrical cable functionality.

The experiments performed in Phase 1 ranged from bench scale to full scale. Different types of thermal exposures were used to evaluate cable coating performance, including radiant heat, vertical and horizontal flame impingement, horizontal fire plume, and hot gas layer exposures. Experiments included both uncoated cables (as a control) and cables with a fire-retardant cable coating material applied. The variables evaluated included coating material, coating thickness, cable system mass, cable type, exposure conditions, cable orientation, and cable construction. Recommendations and conclusions based on these results have been compiled but are being withheld until Phase 2 of the project is complete, to ensure that guidance is not issued prematurely.

The goal of Phase 2 is to evaluate the effects of aging on the performance of fire-retardant cable coatings. Phase 2 has already started and is expected to be completed by the end of fiscal year 2027. In Phase 3, the final phase of the project, the NRC will work with the Electric Power Research Institute to develop updated guidance and recommendations for performance-based applications. The Phase 3 work is planned to be performed concurrently with the completion of Phase 2.

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EXECUTIVE SUMMARY

PRIMARY AUDIENCE: Fire protection engineers and fire probabilistic risk assessment (PRA) analysts conducting or reviewing fire modeling that supports analysis related to fire characteristics and fire-induced circuit damage associated with fire-retardant cable coatings.

SECONDARY AUDIENCE: Engineers, reviewers, utility managers, and other stakeholders who conduct, review, or manage fire protection programs and need to understand the underlying technical basis for the performance of fire-retardant cable coatings.

KEY RESEARCH QUESTIONS

What are the origins of the fire-retardant cable coatings used in U.S. nuclear power plants, how well do various types of coatings perform, what are some issues related to their performance, and how does aging affect their performance?

RESEARCH OVERVIEW

The goal of this experimental research program is to better understand how the use of fire-retardant cable coatings affects flame spread, heat release rate, ignition, and loss of function. This research is needed because some of the guidance in NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," issued September 2005, is unclear or uncertain, primarily because empirical data to support it are lacking.

Previous research programs have provided considerable information on the fire characteristics and electrical response of electrical cables damaged by fire conditions. How the use of fire-retardant cable coatings changes these characteristics is less well understood. This research program focuses on developing an empirically based dataset to support fire modeling and fire PRA assumptions about the performance of fire-retardant cable coatings.

The research was performed in several stages at multiple fire testing laboratories, using both standardized and non-standardized experimental techniques. Initial screening experiments at Sandia National Laboratories provided insight into the ignition and circuit functionality of electrical cables covered with fire-retardant coatings. Subsequent experiments at the National Institute of Standards and Technology focused on flame spread, heat release rate, ignition, and circuit functionality, through both bench-scale and large-scale tests.

Another important question is how aging affects the performance of fire-retardant cable coatings. In several instances, U.S. Nuclear Regulatory Commission (NRC) regional inspection personnel have identified changes in the appearance of cable coating materials. Currently, little to no information is available about how age-related degradation may affect the performance of cable coatings. Further research to investigate this question is being planned.

KEY FINDINGS

This research program has yielded significant data on the fire characteristics of electrical cables with fire-retardant coatings, as well as the impact of such coatings on circuit functionality. The results significantly advance scientific understanding of cable coating performance and will be used to update the guidance in NUREG/CR-6850. The guidance updates will be incorporated into Phase 2 of the project and issued during Phase 3.

WHY THIS MATTERS

This report provides empirical evidence to assist the NRC staff and nuclear power plant engineers performing and reviewing fire modeling analyses and fire PRAs.

HOW TO APPLY RESULTS

Engineers performing and reviewing fire modeling analyses and fire PRAs should focus on the results in Volumes 2 and 3 of this report. The results should be applied with caution, however, as the NRC anticipates updating the fire PRA methodology in Phase 3 of the project. Conclusions are intentionally omitted from Volumes 1–3, as additional testing is forthcoming. Volume 4 will document the conclusions when all testing is complete.

LEARNING AND ENGAGEMENT OPPORTUNITIES

On July 14, 2025, NRC staff conducted a public meeting with members of the public and interested stakeholders. This was a comment-gathering meeting, with allotted time to allow for members of the public and interested stakeholders to ask questions and comment on Volumes 1–3 of the draft cable coating RIL and the aged cable coating project plan.

The meeting summary and presentation slides from the public meeting can be found in the NRC Agencywide Documents Access and Management System (ADAMS) under accession numbers ML25210A426 and ML25191A208, respectively.

The attendees asked questions, made comments, and participated in the topics covered by the NRC staff. Even though the NRC will not make any regulatory decisions from this meeting, this meeting was a way to facilitate feedback on the cable coating research and the aged cable coating project plan. NRC Staff considered all stakeholder comments and after review, no changes were made to the draft reports. However, stakeholder feedback provided valuable information and will be considered when completing the next phases of this project.

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ABBREVIATIONS AND ACRONYMS

°C	degrees Celsius
°F	degrees Fahrenheit
1/C	single conductor
3/C	three conductor
AEC	Atomic Energy Commission
APCSB	Auxiliary and Power Conversion Systems Branch
ASTM	American Society for Testing and Materials
AWG	American Wire Gauge
BFN	Browns Ferry Nuclear Plant
BTP	branch technical position
Btu	British thermal unit(s)
CFR	*Code of Federal Regulations*
CLPC	Connecticut Light and Power Company
cm	centimeter(s)
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FAQ	frequently asked questions
FPP	fire protection program
FHA	fire hazard analysis
ft	foot/feet
GDC	general design criterion/criteria
GL	generic letter
h	hour
HRR	heat release rate
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
in.	inch(es)
JCAE	Joint Committee on Atomic Energy
kg	kilogram(s)
km	kilometer(s)
kW	kilowatt(s)
L	liter(s)
lb	pound(s)
m	meter(s)
MCC	microcombustion calorimetry
mi	mile(s)
min	minute(s)
MJ	megajoule(s)
NASA	National Aeronautics and Space Administration

NELPIA	Nuclear Energy Liability Property Insurance Association
NFPA	National Fire Protection Association
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
PCB	polychlorinated biphenyl
PE	polyethylene
PRA	probabilistic risk assessment
PVC	polyvinyl chloride
RES	NRC Office of Nuclear Regulatory Research
RG	regulatory guide
s	second(s)
SCDU	surrogate circuit diagnostic unit
SFPE	Society of Fire Protection Engineers
SNL	Sandia National Laboratories
TGA	thermogravimetric analysis
TVA	Tennessee Valley Authority
UL	Underwriters Laboratories Inc.
V	volt
XLPE	cross-linked polyethylene

1. INTRODUCTION

Electrical cables perform numerous functions in nuclear power plants (NPPs). Power cables supply electricity to motors, transformers, heaters, light fixtures, fire suppression equipment, and reactor cooling equipment. Control cables connect plant equipment such as motor-operated valves and motor starters to remote initiating devices (e.g., switches, relays, and contacts). Instrumentation cables transmit low-voltage signals between input devices and display panels. NPPs typically contain hundreds of miles of electrical cables. A typical boiling-water reactor requires approximately 100 kilometers (km) (60 miles (mi)) of power cable, 80 km (50 mi) of control cable, and 400 km (250 mi) of instrument cable. A pressurized-water reactor may require even more cables. The containment building of Waterford Steam Electric Generating Station, Unit 3, contains nearly 1,600 km (1,000 mi) of cable (Lofaro, et al. 1996)

Electrical cable insulating materials dominate the in situ fire fuel load in most areas of an NPP. These materials are found both in the cable routing raceways throughout the plant and in the electrical control cabinets. In a postulated fire scenario, they may be an ignition source or an intervening combustible, and they may also themselves lose functionality. Electrical cables are made up of a variety of thermoplastic and thermoset materials. The primary characteristics that distinguish one cable type from another with respect to fire behavior include cable jacket formulation, conductor insulator formulation, number of conductors, conductor size, and combustible mass ratio.

Electrical cables have been involved in several fires in NPPs over the years. In March 1975, a serious fire involving electrical cables occurred at the Browns Ferry Nuclear Plant (BFN), operated by the Tennessee Valley Authority (TVA) (Collins, et al. 1976). The fire damaged more than 1,600 cables, resulting in loss of all emergency core cooling system equipment in Unit 1 and much of it in Unit 2. The damage was extensive because of the flammability of the cables, including their ease of ignition, flame spread, and heat release rate (HRR).

After the 1975 BFN fire, NPP operators and the U.S. Nuclear Regulatory Commission (NRC) staff sought ways to improve fire safety. One option they considered was the use of fire-retardant[1] cable coatings. In the late 1970s, the NRC-sponsored Fire Protection Research Program investigated seven fire-retardant coating materials approved by Factory Mutual (Nowlen 1989). These early efforts focused on flammability effects, including whether the coatings could prevent or delay flame spread along the length of a cable, delay cable ignition, and prevent or delay tray-to-tray fire spread. The tests also explored cable electrical failure behaviors using low-voltage (28-volt (V) alternating current (ac)) power sources. However, experiments using low-voltage sources are now considered suspect, because they are not representative of in-plant performance and generally understate cable damageability.

Although these early experiments produced some unique insights on flame propagation and fire spread behavior of coated and uncoated cables, they provided only limited information about the electrical performance of cables. They showed some differences in behavior between coated and uncoated cables, as well as between coating types, but the results are not considered reliable by current standards. Also, while temperature measurements were made

1 The terms “fire-retardant” and “flame-retardant” are used interchangeably in the fire protection community. This report will use “fire-retardant.” Appendix D Appendix D provides definitions of these and related terms, taken from the National Fire Protection Association’s (NFPA’s) glossary (NFPA 2019). It also indicates the fire protection codes that use each term.

during the tests, the measurements could not be correlated to the actual cable conditions—in particular, to electrical failure behaviors.

Overall, these early tests resulted in important insights but do not provide the type of information of most interest to current applications. Current methods, used for fire modeling tools, are able to predict both temperature response and failure time for cables exposed to fire. Understanding the impact of fire-retardant cable coatings on cable performance and combustion characteristics could support more realistic quantification of their performance in fire safety assessments.

1.1 Background

Fire-retardant cable coatings have been used in U.S. NPPs since the late 1970s. The BFN fire of 1975 served as the catalyst for the nuclear industry to start using fire-retardant materials to minimize flame spread within cable raceways. In licensing, the NRC requires licensees to meet the fire protection requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.48, “Fire protection”; General Design Criterion (GDC) 3, “Fire protection,” in Appendix A, “General Design Criteria for Nuclear Power Plants,” to 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities”; and Appendix R, “Fire Protection Program for Nuclear Power Facilitates Operating Prior to January 1, 1979,” to 10 CFR Part 50.

On May 1, 1976, the NRC’s Auxiliary and Power Conversion Systems Branch (APCSB) issued Branch Technical Position (BTP) APCSB 9.5-1, “Guidelines for Fire Protection for Nuclear Power Plants” (NRC 1976). BTP APCSB 9.5-1 provided guidelines for meeting fire protection requirements and directed licensees to establish fire protection programs (FPPs) and conduct fire hazard analyses (FHAs). As part of the FPP and FHA, licensees were to perform bounding deterministic evaluations to estimate fire fuel loads; see Appendix C for examples of fire load calculations. These fuel loads included contributions from cables (e.g., polymers) as well as transient combustibles. The fuel load calculations were used to establish the adequacy of passive fire barriers and fire protection systems. During plant operation, the fuel load rating and limits served as the basis for allowing the addition of transient combustibles.

As part of the FHA and the design process for fire barriers and fire protection systems, fuel loads were converted to fire durations using the standard time-temperature exposure curves given in the American Society for Testing and Materials (ASTM) standard ASTM E119, “Standard Test Methods for Fire Tests of Building Construction and Materials” (ASTM 1976). Section 1.3 of NUREG-1547, “Methodology for Developing and Implementing Alternative Temperature-Time Curves for Testing the Fire Resistance of Barriers for Nuclear Power Plant Applications,” issued August 1996, discusses the history of ASTM E119 (Cooper and Steckler 1996). For example, for a fire area containing a fuel load that would burn for 2.5 hours, the designer would need to provide a firewall rated for at least 3 hours. Moreover, a plant modification introducing transient combustibles would not be allowed to add more than 0.5 hour of fuel load.

As part of this research program, the Office of Nuclear Regulatory Research (RES) reviewed the cable tray fire load calculations used in licensing-basis documents. In these calculations, even today, licensees estimate the mass of each type of material available for combustion and multiply this mass by the heat of combustion of the material. The following are three examples of typical assumptions made for these calculations:

(1) Cable trays are assumed to be loaded to their maximum allowed capacity.

(2) The cable type with the highest possible fire load for its corresponding cable tray is assumed to be used for all trays of that type.

(3) Cable jackets are assumed to be made of the same type of material as cable insulation.

These assumptions usually result in conservative case analyses with the highest fire load values theoretically possible for the cable trays analyzed. The conservatism of the assumptions permits the licensee to install new cables on a tray without having to update the fire load calculations if the tray is loaded to its maximum allowed capacity or less.

After the BFN fire, the NRC started extensive research on fire protection (Salley and Woods 2009). In the first revision of BTP APCSB 9.5-1, the NRC stated that electrical cable construction should, at minimum, pass the flame test in the Institute of Electrical and Electronics Engineers (IEEE) standard IEEE 383-1974, "IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations" (IEEE 1974), although cables passing this test could require other forms of fire protection. It was in this document that the NRC recommended that NPPs add fire breaks along vertical and horizontal cable routings. Many licensees applied fire-retardant cable coatings to satisfy the latter requirement.

In the early 1980s, the NRC revised 10 CFR 50.48 and Appendix R to 10 CFR Part 50. The new regulations required physical separation of redundant trains (specifically, either by a horizontal distance of 20 feet or more with no intervening combustibles, or by fire barriers). Plants that had installed fire-retardant coatings had to update their FHAs to consider the coatings as intervening combustibles.

On April 24, 1986, the NRC published Generic Letter (GL) 86-10, "Implementation of Fire Protection Requirements" (NRC 1986), which discusses the implementation of fire protection requirements and provides a list of questions and answers, including a definition of combustibility. The letter references BTP Chemical Engineering Branch 9.5-1 (NRC 1981), which defines noncombustible material as one of the following:

(1) material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat

(2) material having a structural base of noncombustible material, as defined in (1) above, with a surfacing not over 1/8 inch (in.) thick that has a flame spread rating not higher than 50 when measured using ASTM E84, "Standard Test Method for Surface Burning Characteristics of Building Materials (ASTM 1976)"

GL 86-10 also references GL 83-33, "NRC Positions on Certain Requirements of Appendix R to 10 CFR 50," dated October 19, 1983 (NRC 1983), which states, "Section III.G.2.b requires 'separation...with no intervening combustibles...' To meet this requirement, plastic jackets and insulation of grouped electrical cables, including those which are coated, should be considered as intervening combustibles." For the purposes of fire protection, "no intervening combustibles" means that there are no significant quantities of in situ combustible materials that could ignite and burn located between redundant shutdown systems. The amount of such materials considered significant is a matter of judgment. As with other issues, if the licensee's fire protection engineer is concerned that an independent reviewer might not consider the quantity of combustibles located between shutdown divisions insignificant, the licensee could request an exemption or consult the NRC staff. Transient combustible materials are not considered intervening combustibles; however, they must be considered as part of the overall fire hazard within a fire area. Cables in cable trays that are either open or fully enclosed should also be considered intervening combustibles, as should cables coated with a fire-retardant material. However, cables coated with a fire-retardant material and cables in cable trays having solid sheet metal bottom, sides, and top, if protected by automatic fire detection and suppression systems and if the design is supported by a FHA, have been found acceptable under the license exemption process.

In the late 1990s, the NRC staff revisited the strategy described in SECY-98-058, “Development of a Risk-Informed, Performance-Based Regulation for Fire Protection at Nuclear Power Plants,” dated March 26, 1998, and initiated work on an alternative fire protection regulation (NRC 1998). In the early 2000s, the NRC reviewed the 2001 edition of National Fire Protection Association (NFPA) 805, “Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants,” and approved it as an alternative regulation, incorporating it by reference in 10 CFR 50.48(c). In 2005, the Electric Power Research Institute (EPRI) and the NRC published the joint report NUREG/CR-6850, “EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities,” issued September 2005 (NRC, EPRI 2005).

The alternative risk-informed, performance-based regulation at 10 CFR 50.48(c) permits operating plant licensees to use fire modeling or probabilistic risk assessment (PRA) methods to transition their deterministic FPPs to risk-informed, performance-based FPPs. However, such methods require inputs for the model (e.g., HRR values). Past NRC fire research, such as that described in NUREG/CR-7010, “Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE),” issued July 2012, confirmed that thermoset cables used in the nuclear industry burn at a lower rate than those manufactured with thermoplastic materials (McGrattan, et al. 2012). This three-volume report explores the properties of these cables when fire-retardant coatings are applied.

1.2 <u>Objective of Fire-Retardant Cable Coating Research Program</u>

In 2011, during the triennial fire protection inspection at Brunswick Steam Electric Plant (NRC 2011), NRC inspectors identified discoloration (i.e., change of color) in fire-retardant cable coating materials. Since the licensee was not currently taking credit for these materials as a fire protection barrier, the discovery of the discoloration did not result in a finding. However, it raised questions about the performance of the material and about the adequacy of the test data on which Appendix Q, “Passive Fire Protection Features,” to NUREG/CR-6850 was based. RES was tasked to develop a test program to address outstanding questions, confirm past performance data, and develop more data that could be used for performance-based applications.

RES performed a literature search to collect data available related to fire-retardant coatings. Volume 1 of this report series presents the results of the literature search, as well as an account of the history of the use of fire-retardant coatings, past tests, and related standards. To quantify the performance of fire-retardant coatings, the NRC sponsored a variety of experiments at Sandia National Laboratories (SNL) and the National Institute of Standards and Technology. These experiments shed light on burning behavior (and the resulting temporal effects on circuit functionality) for a variety of fire-retardant coatings and cable materials typically used in NPPs. The experiments ranged from bench-scale to full-scale, and they used both standardized and non-standardized testing techniques. Volumes 2 and 3 of this report series describe and discuss the tests and their results in detail. Together, Volumes 1–3 of the series represent Phase 1 of the program.

A second phase of the program is planned to evaluate the effects of aging on fire-retardant cable coatings. For this effort, coatings will be procured new, applied to an assembly, subjected to an accelerated aging process, and then tested for fire characteristics and circuit functional response. Volume 4 of this report series will document this effort.

In the last phase of the program, the NRC will work with EPRI to develop updated guidance for use in performance-based applications. The last phase is expected to take place concurrently with the second phase, and its results will be documented in a joint research report issued at the same time as the Phase 2 results.

2. ORIGINS OF FIRE-RETARDANT CABLE COATINGS

2.1 Early Fire Protection Methods

The main motivation for the development of cable insulation was the invention of the commercial electric telegraph in 1837. To establish telegraph communications between countries (and later continents), the British needed to run submarine cable under major waterways. Thus, the primary goal of early cable insulation was waterproofing, and this was achieved using natural resins. The secondary goal was durability against abrasion. For underwater applications, flammability was of no concern (Haigh 1968).

As technology evolved, cable was adapted for use in other industries. Advances in power generation and the development of alternating current created a need for long-distance land-based power distribution systems. However, such systems were prone to fire. In several incidents, cable insulation made of natural resin was completely consumed by fire. The first attempts to fireproof electrical cable for land-based applications involved using asbestos fibers as a layer of the insulation material. The material properties of asbestos made it well suited for strengthening items that would be exposed to heat (Selikoff and Lee 1978). In 1897, a prominent cable manufacturing company developed a high-conductivity copper wire that used asbestos and was marketed as being nonignitable (Edmunds and Samuelson 1897). At around the same time, a patent was issued for a fireproof paint product composed of pulverized ceramics and asbestos (Merrell 1891). This product was primarily meant to coat the structural members of buildings, but it was also used to coat electrical cables. Asbestos use remained immensely popular until the U.S. Environmental Protection Agency (EPA) passed laws to limit its use in 1973.

In the 1930s, polyvinyl chloride (PVC) was invented and began to replace natural resins as a synthetic alternative for insulating cables (Semon 1933). PVC was cheaper to produce and more abrasion resistant than rubber, and it did not require vulcanizing with curatives or accelerators. PVC is a thermoplastic material, meaning that it melts when heated and resolidifies when cooled. While PVC inherently resists ignition, it will burn when exposed to an adequate ignition source. In the early years of its use, to make PVC more resistant to heat and flame, manufacturers added liquid coatings of a chemical called polychlorinated biphenyl (PCB) to flexible PVC and electrical components (Kaley, et al. 2006, 6-7). The use of PCB coatings continued until 1979, when EPA studies showed that PCB was carcinogenic to humans, and consequently the EPA banned the production of PCB (EPA 1979). Appendix E gives more details about the history of fire-retardant cable coatings.

2.2 Early Fire Protection Regulations

The development of commercial nuclear reactors for peaceful use began in the 1950s and 1960s. During this period, the Atomic Energy Commission (AEC) funded a great deal of research to advance nuclear technology as an efficient and cost-effective means of generating electricity. However, minimal attention was given to fire protection at the time. Fire was not considered a high-priority threat to NPPs, relative to other failure mechanisms.

One of the first major fire incidents at an operating commercial NPP occurred at the San Onofre Nuclear Generating Station in 1968. Between that event and the BFN incident in 1975, 39 fire-related incidents were reported at U.S. NPPs (Lindeman and Melly 2015, A62-A65). These incidents, summarized in Table in Appendix E.2, brought the AEC's attention to the need for fire prevention to preserve nuclear safety. The AEC's first fire prevention regulation, adopted in February 1971, was GDC 3, which states the following:

> Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

Also starting in the 1970s, the IEEE developed a series of electrical standards that included sections pertaining to fire protection in NPPs. The first of these standards were the following:

- IEEE 279-1971, "IEEE Standard: Criteria for Protection Systems for Nuclear Power Generating Stations" (IEEE 1971)

- IEEE 383-1974, "IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations" (IEEE 2003)

- IEEE 384-1977, "IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits" (IEEE 1977)

In February 1974, the AEC issued Regulatory Guide (RG) 1.75, "Physical Independence of Electric Systems," which endorsed parts of the preliminary version of IEEE 384 (Zar 1995).

In 1975, the newly created NRC contracted with SNL to initiate a research program to support the development of a comprehensive system of fire protection regulations. This program was relatively limited in scope at the time of its inception; its goal was to identify areas of weakness in the existing regulations and then to develop new guidelines (Nowlen 1989). However, only 3 months later, the BFN fire took place. BFN was the first major fire incident at an NPP that threatened the safe shutdown of the reactor. Although some fire protection research was already in progress within the nuclear power industry, BFN served as a major catalyst for increasing funding and widening the scope of research (Dube 1983, 1).

2.3 The Browns Ferry Nuclear Plant Fire of 1975

On March 22, 1975, around 12:00 p.m., a fire was accidentally started at a temporary polyurethane penetration seal between the cable spreading room and the equipment room of the secondary containment building at BFN. A plant worker was using a candle to check whether the cable spreading room seal was hermetic, which was a common procedure in the industry at the time. During the test, air flowed from the cable spreading room through the penetration seal, causing the candle flame to ignite the polyurethane. The fire spread to the cable insulation and burned in the cable trays for approximately 7 hours. The damage to the cables disabled several plant systems, including the emergency core cooling system. Fortunately, the Unit 1 and Unit 2 reactors were both manually shut down without any damage to the nuclear fuel or primary containment structures.

The fire at BFN was one of the most severe incidents in the history of nuclear power generation in the United States (U.S. Congress 1975), and it was a major turning point for fire protection practices in the commercial nuclear power industry. The near-miss nature of the incident catalyzed much research on fire protection methods and practices at NPPs.

As part of this research, the NRC and the nuclear industry started exploring the use of fire-retardant cable coatings and penetration seals. For example, in BTP APCSB 9.5-1, the NRC recommended that licensees add fire breaks along vertical and horizontal cable routings (NRC 1976, 29). To satisfy this requirement, many licensees applied fire-retardant cable coatings to grouped electrical cables. At the time, this modification was adequate to satisfy the NRC's guidance. On August 29, 1977, the NRC issued GL 77-02, "Fire Protection Functional Responsibilities (Davis-Besse Nuclear Power Station, Unit 1)," which outlined the responsibilities of an onsite inspector at each plant who was responsible for ensuring quality control in the installation of cable coatings and the continued maintenance of the coating material (NRC 1977, 2). By 1981, the NRC had published new regulations on fire safety—most significantly, those in 10 CFR 50.48 and Appendix R to 10 CFR Part 50.

2.4 Fire Protection Regulations of 10 CFR 50.48 and Appendix R to 10 CFR Part 50

The new fire protection regulations in 10 CFR 50.48 and Appendix R to 10 CFR Part 50 laid out deterministic design criteria that would apply to NPPs licensed after January 1, 1979. Licensees could commit to complying with Appendix R as one way of satisfying the NRC's fire protection requirements. The affected NPPs were required to backfit their existing equipment to comply with Sections III.G, III.J, and III.O of Appendix R. In particular, Section III.G.2 states that certain sets of equipment must be protected by one of the following means:

> b. "Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance more than 20 feet with no intervening combustibles or fire hazards [emphasis added]. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area; or
>
> c. Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour rating. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area;" (U.S. CFR 1981).

After the release of BTP APCSB 9.5-1 in 1976, tests done at SNL suggested that fire-retardant cable coatings reduce the probability of ignition in electrical cables and inhibit flame spread both vertically and horizontally (Klamerus 1978). However, further research showed performance variations across coating manufacturers and several other test parameters. As a result, fire-retardant cable coatings came to be regarded not as a comprehensive solution to cable fires, but rather as a layer of resistance in a problem that required additional intervention (1982).

The proposed regulations in the new 10 CFR 50.48 and Appendix R to 10 CFR Part 50 were announced in GL 80-45, "Fire Protection Rule," dated May 19, 1980 (NRC 1980b). GL 80-45 states that "fire-retardant coatings retard fire propagation but do not prevent organic cable insulation and jacket materials from burning" (NRC 1980, 23). This position caused disagreement between the industry and the NRC, because for plants constructed before 1979, it would have been prohibitively expensive to move cables to comply with the 20-foot separation requirement of Appendix R, Section III.G.2. Furthermore, the utilities that had invested in fire-retardant cable coatings in the late 1970s had not expected the NRC to categorize coated cables as intervening combustibles. The NRC found that different licensees had significantly varying interpretations of certain requirements in Appendix R. To clarify the requirements, the NRC released GL 83-33, which states, "Section III.G.2.b requires 'separation…with no intervening combustibles…' To meet this requirement, plastic jackets and insulation of grouped electrical cables, including those which are coated, should be considered as intervening combustibles" (Dube 1983). Fire-retardant coatings thus transitioned from being recognized as fire protection measures to being seen as intervening combustibles. That meant that utilities would have to make further modifications to comply with Section G of Appendix R.

2.5 NFPA 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants," 2001 Edition

The NFPA Standards Council approved NFPA 805 in 2001 as a risk-informed, performance-based standard for fire protection in existing light-water NPPs. NFPA 805 describes a methodology for establishing the fire protection procedures, systems, and features required for all modes of reactor operation, as well as for NPPs that are decommissioning and permanently shut down.

The Commission approved the final rule incorporating NFPA 805, with exceptions, into 10 CFR 50.48(c) through a staff requirements memorandum dated May 11, 2004 (NRC 2004). The rule was published on June 16, 2004, and became effective July 16, 2004. The Commission provided enforcement discretion as an incentive for licensees to voluntarily transition to NFPA 805.

The new rule at 10 CFR 50.48(c) allowed licensees to use performance-based approaches to meet fire protection requirements (NRC 2004). The deterministic approach of Appendix R to 10 CFR Part 50 was still considered valid, but 10 CFR 50.48(c) offered more flexible options for meeting the license requirements for fire protection. The use of PRAs in performance-based approaches motivated new efforts to classify cables by their construction type (e.g., type of cable insulation and jacket) and coating materials so that they could be credited appropriately in fire PRA analyses.

Section 3.3.5.3 of NFPA 805 states the following regarding cable construction:

> Electric cable construction shall comply with a flame propagation test as acceptable to the AHJ. *Exception: Existing cable in place prior to the adoption of this standard shall be permitted to remain as is.*[2]

The regulation at 10 CFR 50.48(c)(2)(v) states the following regarding existing electrical cables:

> In lieu of installing cables meeting flame propagation tests as required by Section 3.3.5.3, a flame-retardant cable coating may be applied to the electric cables, or an automatic fixed fire suppression system may be installed to provide an equivalent level of protection. In addition, the italicized exception to Section 3.3.5.3 is not endorsed.

After the NRC's endorsement of NFPA 805, some stakeholders were confused about what the NRC considered an acceptable flame propagation test, and they sought clarification on this

[2] This exception was not endorsed by 10 CFR 50.48(c).

issue through the NRC's NFPA 805 Frequently Asked Questions (FAQ) process. The NRC responded to this inquiry with FAQ 06-0022, which is discussed in greater detail in Appendix E.3.

2.6 NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities"

In September 2005, RES collaborated with EPRI to publish NUREG/CR-6850. This document provides the state-of-the-art methodology for performing a fire PRA. Appendix Q, "Passive Fire Protection Features," to NUREG/CR-6850 provides guidance on crediting fire-retardant cable coatings. However, this guidance was developed using a limited set of purely empirical results.

The focus of the research documented in this report series is to provide data and updated guidance to enable a more realistic treatment of fire-retardant cable coatings as credited in fire PRAs today.

3. CONGRESSIONAL HEARING ON THE BROWNS FERRY NUCLEAR PLANT FIRE AND LEGAL ACTIONS CONCERNING CABLE COATINGS

The fire at BFN was the most severe fire incident ever to have taken place at an NPP in the United States. It had three major attributes that distinguished it from previous incidents:

(1) The fire brigade stood by and did not extinguish the fire because they were concerned about the electrical safety hazard of applying water to electrically charged conductors.

(2) The operators could have lost their ability to safely shut down the reactor if the fire had damaged certain safety-related cables.

(3) The fire was ignited by workers because of a procedural error. Workers were allowed to use a candle to check for penetration seal leakage. However, a fire-protective coating was supposed to have been applied over the polyurethane foam before this test was performed.

Several organizations, including the NRC, Nuclear Energy Liability Property Insurance Association (NELPIA), the TVA, and the State of Alabama, conducted independent investigations of the event. The results of the investigations were presented before the U.S. Congress Joint Committee on Atomic Energy (JCAE) in a series of hearings that began on September 16, 1975. The JCAE pressured the NRC to implement regulations to correct the problems seen at BFN. The NRC therefore initiated test programs to research the fire and make recommendations for corrective regulation. Many of these programs were completed by SNL between 1975 and 1980. One focus of the programs was to study the effectiveness of fire-retardant cable coatings.

On November 19, 1980, the NRC published revised versions of 10 CFR 50.48 and Appendix R to 10 CFR Part 50 with new regulations on fire protection features at NPPs (NRC 1980). One of the most significant implications of the new regulations was that fire-retardant cable coatings were no longer recognized as a solution for protecting cables from fire. (The regulations pertaining to cable coatings and cable separation are quoted in Section 2.5 of this report.) The industry believed that the new regulations were rushed and had been implemented without adequate technical backing. The regulations would have considerable monetary implications for utilities, which had invested heavily in cable coatings in the years before the implementation of Appendix R to 10 CFR Part 50. The Connecticut Light and Power Company (CLPC), on behalf of the nuclear industry, sued the NRC over the Appendix R regulations. The U.S. court of appeals hearing the case reluctantly ruled in favor of the NRC. This section discusses the history of the legal proceedings surrounding fire-retardant cable coatings and how that history has shaped current regulation.

3.1 Congressional Hearing on Browns Ferry Nuclear Plant Fire, Part 1

During the congressional hearing on the BFN fire, the JCAE raised questions about how the incident developed, how the TVA responded to the incident, whether the current regulations were adequate, and how the incident would affect the future of the U.S. nuclear power program. Appendix E.3 contains a detailed summary of the incident and of the NRC's testimony during the hearing.

3.1.1 Nuclear Energy Liability Property Insurance Association Investigation Report

NELPIA conducted an independent investigation of the incident and issued a report that made numerous recommendations for preventing and controlling the impact of cable fires in the future. In his testimony, NRC Chairman William Anders said that of the 35–40 recommendations in the NELPIA report, 20 or more clearly deserved adoption.

The JCAE expressed concern over the fact that there had been 209 plant inspections at BFN before the 1975 fire. Senator Joseph Montoya asked why the deficiencies that contributed to the incident had not been noted and corrected during these inspections. The response was that the NRC's inspection procedures involved taking representative samples of certain conditions and applying the observations made of the samples to the entire plant; not every area of the plant had to be explicitly inspected. The NRC largely relied on utilities to self-assess and maintain safe practices themselves (U.S. Congress 1975, 9-12).

3.1.2 Flammability of Polyurethane

The JCAE asked why NPPs used polyurethane foam when several AEC bulletins had documented that the foam was highly flammable and had suggested that further testing was needed to understand its hazards (U.S. Congress 1975, 892-900). Such testing would have the following objectives:

- Explain the fire risks of polyurethane foam.
- Explain the need for smoke ejectors and self-contained breathing apparatus.
- Explain the importance of notifying the fire department quickly of even a seemingly small fire.
- Explore the possibility of applying foam in a more temporary way so that it could be removed quickly in the event of a fire.

The JCAE expressed surprise that the foam was still being used and asked the NRC representatives why they knowingly permitted its use. Chairman Anders replied that he agreed that polyurethane foam was a fire hazard, but it was also a very effective penetration seal, as it had the ability to expand into small spaces (U.S. Congress 1975, 15). As the foam was required to be completely covered with a fire-retardant coating, Chairman Anders explained that he did not feel that the flammability hazard grossly outweighed the merits of its sealing properties. There was no provision in the regulations allowing partial coverage of foam or the use of rags as temporary penetration seals. (U.S. Congress 1975, 14-18)

The JCAE expressed concern over the lack of regulatory attention given to cable insulation fires. The committee felt that procedural and installation issues at BFN should have been identified by both the NRC and the TVA in their prior inspections. Appendix E.3 gives a summary of the NRC's testimony.

3.1.3 Cable Coating Tests at NASA's Marshall Space Flight Center

After the BFN incident, the NRC sponsored research at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center to study the combustibility of fire-retardant cable coatings (Riehl 1975). The findings of this research are outlined below.

Figure 3-1 illustrates the penetrations involved in the BFN incident (Riehl 1975). The cables and cable trays covered the bottom of the penetration. Foam rubber polyurethane insulation had been stuffed, poured, or sprayed into the void space above the cables. Three types of polyurethane foam were used at BFN: (1) Aire Lite, a stuffing product that was hand applied, (2) Selectrofoam, a pourable product manufactured by Pittsburgh Plate Glass Company, and (3) Instafoam, a spray-applied product. Instafoam was rated as self-extinguishing according to ASTM-1692-59T, “Flammability of Plastic Sheeting and Cellular Plastics” (Riehl 1975).

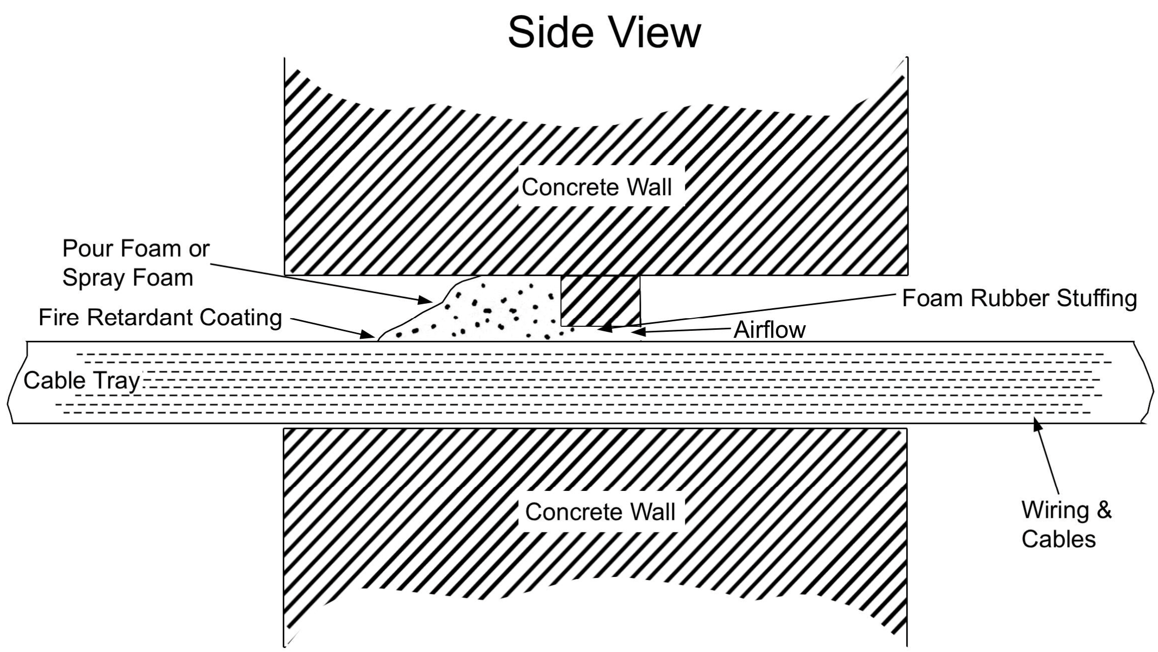

Figure 3-1 Cable tray materials and usages similar to BFN configuration (side view) (Riehl 1975)

To better understand the penetration that was involved in the fire, the inspection team analyzed other nearby penetrations. The void spaces above the cables were large, as shown in Figure 3-2 (Riehl 1975). In some cases, the void space was filled with foam rubber material, with a fire-retardant layer applied to each end of the penetration (Riehl 1975). In other cases, penetrations had been stuffed with cotton rags, with only a light covering of foam rubber partially coated with fire-retardant material. Later tests showed that the configurations with cotton rags, while seemingly primitive, were in fact less hazardous than any of the other configurations in the immediate area.

Front View

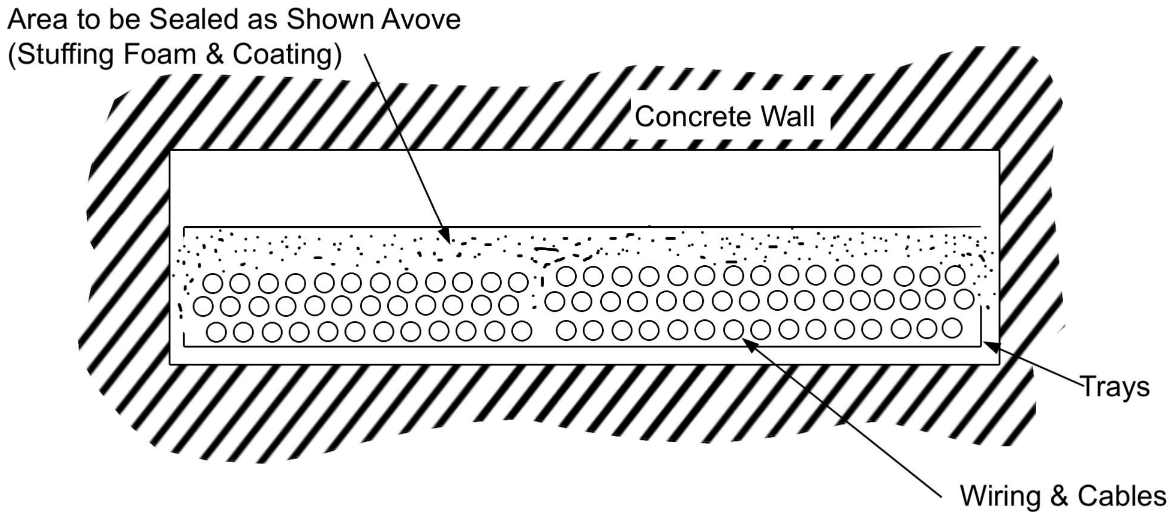

Figure 3-2 Cable tray materials and usages (front view) (Riehl 1975)

Flame tests were conducted on the foam rubber using the vertical flame test outlined in ASTM D3014, "Standard Test Method for Flame Height, Time of Burning, and Loss of Mass of Rigid Thermoset Cellular Plastics in a Vertical Position," and the horizontal flame test outlined in ASTM D1692-59T, "Tentative Method of Test for Flammability of Plastics and Sheeting" (Riehl 1975). The testing showed that the foam rubber was readily ignited even by an open flame as far as 2.5 centimeters (cm) (1 in.) away. As it burned, it melted and dripped burning droplets which propagated the fire. The same tests showed that the cotton rags did not ignite as easily, did not produce flaming droplets, and burned at a much lower HRR. The results of this testing are shown in Table 3-1. Ultimately, all materials except the Flamemastic 71 fire coating and Firewall board were flammable and needed to be protected.

Table 3-1 Cursory Materials Burning Tests

MATERIAL			BURNING TESTS	
USAGE	SOURCE	DESCRIPTION	SAMPLE SIZE	RESULTS
Stuffing	Worker in Cable Spreader Room	Polyurethane Foam Rubber	1" x ¼" x 1"	Very rapid flash burning with dripping fiery droplets
Pour Foam	Adjacent Cable Tray	Pittsburgh Selectro foam	¼" x ¾" x 1"	Rapid complete burn with heavy soot, no droplets
Fire-Retardant Coating	Cable Spreader Room	Flame mastic	¼" x $^{1}/_{16}$" x 1"	No ignition or burning
Caulking	Adjacent Cable Tray	RTV-102 Silicone	¼" x ½" x ¼"	Very slow but intense burning, self-extinguished

MATERIAL			BURNING TESTS	
USAGE	**SOURCE**	**DESCRIPTION**	**SAMPLE SIZE**	**RESULTS**
Cable Ties	Cable Spreader Room	Nylon	$^1/_8$" x $^1/_{32}$" x 2"	No upward propagation but drips burning droplets
Cotton Rag	Stuffing in Adjacent Cable Tray	Red Denim	½" x 1"	Ready burning, no droplets
Pillow	Home Residence	Polyurethane Foam Rubber	½"x 1" x 2"	Flash burning, burning droplets
Firewall	Wall Penetration in Stairway	Inorganic Board	$^1/_8$" x ½" x 1"	No ignition or burning

The tests verified that the BFN fire was started when an open candle flame ignited foam rubber material, which burned rapidly and released flaming droplets onto other flammable materials. The air draft through the penetration contributed to the rapid spread of the fire.

As part of the experiments, all three of the polyurethane foam materials in use at BFN were coated in Flamemastic 71 cable coating and were retested using the ASTM D3014 standard. The fire-retardant coating was found to be extremely effective in preventing ignition of the otherwise highly flammable materials.

3.1.4 Atomic Energy Commission Bulletins on Polyurethane Use

The following AEC Bulletins were included in the Congressional Report on BFN Part 1 (1975) to provide background information on previous fire incidents involving polyurethane foam rubber products.

3.1.4.1 Issue No. 170, "Foamed Polyurethane Fire Proves Difficult to Control"

The incident described in this issue occurred in a sphere that was heavily coated with polyurethane insulation, in the form of solid polyurethane pyramids, to achieve a high degree of sound absorption. Employees had been drilling holes in steel angle iron when they noticed small amounts of smoke coming from the polyurethane foam. From that point the fire grew quickly and produced dense black smoke with extreme heat. The workers were not able to extinguish the fire, and the fire department required extensive resources to control it. At the time, there was no known method for controlling deep-seated fires within large pieces of foamed polyurethane (AEC 1963). This incident indicated a need to better understand the hazards of polyurethane foam.

3.1.4.2 Issue No. 254, "Recent Foamed Polyurethane Fires on Non-AEC Facilities"

This incident occurred in a test facility where workers were cutting bolts with an acetylene torch on the outer wall of the facility (AEC 1967). Molten metal from the cutting operation fell and came in contact with polyurethane foam insulation that was spray-applied to the inside surface of the aluminum wall. The molten metal ignited the insulation, causing a rapidly growing fire inside the test facility. Fire watch personnel acted quickly and tried to extinguish the fire using an extinguisher. However, the fire grew so quickly and produced such high heat and dense smoke that neither fire watch personnel nor firefighters wearing self-contained breathing apparatus could enter the facility to extinguish the fire.

Subsequent tests showed that polyurethane would ignite when lit with an acetylene torch but would extinguish when the torch was removed. Other tests showed that placing a red-hot bolt on insulation resulted in charring and smoking but no flaming ignition. These tests created a false assumption that the polyurethane had fire-retardant properties. Later tests showed that polyurethane could support and sustain combustion in an environment where a limited air supply was available. All instances of polyurethane combustion studied by this facility involved areas where oxygen supply was limited. In each instance, the combustion produced dense smoke, which is typical of combustion in an oxygen-limited environment.

These findings indicated that polyurethane insulation should only be used on the exterior of a building. Extra attention would be needed to ensure that polyurethane foam would not enter void spaces. Firebreaks should be used to compartmentalize the areas of insulation, and a fire-retardant coating should be applied on all externally exposed portions of the insulation.

3.1.4.3 Issue No. 336, "Two Fires Involving Urethane Foam"

This incident occurred at a large laboratory with a 131 meter (m) (430 foot (ft)) corrugated steel tunnel where workers were cutting a bolt hole with an acetylene torch. The steel was coated with 3.8 cm (1.5 in.) thick spray-applied polyurethane foam. The tunnel was intended to meet the standards for flame spread and smoke development set forth in Underwriters Laboratories (UL) 723, "Standard for Test for Surface Burning Characteristics of Building Materials". The design plan was to coat the foam in intumescent paint and to install a firebreak and sprinkler water curtain at each end of the tunnel. The fire occurred while the tunnel was still under construction. The firebreaks had been installed, the water curtain had been installed but was turned off, and the foam had only been coated for 45.7 m (150 ft) of the 131 m (430 ft) tunnel. The coating used was a non-intumescent fire-retardant paint. The fire spread rapidly along the entire length of the tunnel. Witnesses reported dense black smoke and high heat during the fire.

Issue No. 336 also included some background information on polyurethane foams. Several bench-scale laboratory test methods, such as ASTM D635, "Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position," (ASTM n.d.) and ASTM D1692, "Method of Test for Rate of Burning of Extent and Time Burning of Cellular Plastics Using a Specimen Horizontal," (ASTM n.d.) had been used to show that polyurethane foams are self-extinguishing or slow burning. In October 1962, Factory Mutual published a study in the NFPA's quarterly report that shed light on the inadequacies of ASTM D635 and ASTM D1692 in describing the flammability characteristics of polyurethane foams in full-scale settings. The study found that, out of four wood samples tested using ASTM D635, all except balsa wood were categorized as self-extinguishing according to the standard. In the *Modern Plastics Encyclopedia*, between 1971 and 1972, as many as 149 plastics were listed as self-extinguishing or slow-burning on the basis of ASTM D635. These classifications directly contradicted observations in several full-scale fire events, where, given the correct ventilation conditions and an adequate ignition source, many of these materials proved to be highly flammable and fast-burning (AEC 1974).

3.2 Connecticut Light and Power Company vs. U.S. Nuclear Regulatory Commission

In 1982, CLPC filed suit against the NRC with the U.S. Court of Appeals for the District of Columbia Circuit (1982). The suit cited the financial burden that the new regulations of Appendix R to 10 CFR Part 50 imposed on the nuclear industry. The industry felt that the NRC had done a poor job of communicating while developing the new regulation. The lawsuit cited four grievances:

(1) Most seriously, the NRC had not explained the technical basis of the new regulation. CLPC challenged the NRC's methodology for protecting alternative shutdown capability. It said that the requirements for the design of alternative shutdown mechanisms were not supported by any technical evidence (1982). The initial notice of public comment period cited BTP APCSB 9.5-1 and the BFN Report (1975), and stated that "the position of staff and the licensees regarding the provisions of this rule is documented and well known." The Appendix R regulation was heavily influenced by the results of the tests documented in SAND78-0518, "Preliminary Report on Fire Protection Research Program Fire Retardant Coatings Tests," issued March 1978 (Klamerus 1978). However, those test results varied widely and did not decisively support the use of fire-retardant cable coatings for protecting safety-related cables (1982). The industry felt that the limited testing at SNL did not justify the change in the rule. The tests were not referenced in the notice of proposed rulemaking that was disseminated for public comment. The industry claimed that the NRC's reply to its request for additional documentation of the technical basis was unhelpful and overly general.

(2) On this complaint, the court ruled that while the NRC had done a "less than exemplary" job at disclosing the technical basis of its decisions, the research on cable coatings had been ongoing for the past 5 years, was available in the public domain, and had been subject to adversarial comments. The court also noted that the technical material provided was insufficient in proving that a protective system, including fire-retardant cable coatings, could never be as effective as the three methods of Section III.G.2 of Appendix R to 10 CFR Part 50.

(3) The rules adopted were significantly different from the rules proposed during the public comment period. After the BFN fire and before the implementation of the Appendix R regulation, the NRC had accepted the use of fire-retardant cable coatings. The new regulation phased out the postulated hazards method and replaced it with a prescriptive method called the stipulated hazards approach. The new method outlined three ways for licensees to comply with the NRC's duplicate shutdown capacity standards. In this framework, fire-retardant cable coatings were considered beneficial in protecting redundant shutdown systems. At the NRC's suggestion, several licensees had invested heavily in such coatings (1982). The change in the rule, which no longer considered cable coatings as a fire protection measures, was a significant imposition for licensees' FPPs. It afforded no credit for the use of fire-retardant cable coatings and did not consider the relative risk of fire in a particular area.

The new rule included one caveat that offered some flexibility to licensees. Under 10 CFR 50.48(c)(6), a licensee could apply for an exemption from any aspect of the FPP within 30 days of the rule's effective date. However, even licensees whose plans had previously been approved by the NRC (but were not compliant with the new regulation) would have to apply for exemptions. The court found that because the NRC had offered an avenue for requesting an exemption to the stipulated hazards approach, the method was acceptable and did not need to be put out for re-notice or a second public comment period.

(4) The NRC had given the industry 30 days to review the proposed regulation. The statutory minimum requires the NRC to provide at least 30 days for public comment. CLPC felt that, given the complex nature of the regulation, 30 days was not enough time to review it and provide comprehensive comments.

(5) The NRC had failed to comply with its own regulations governing the imposition of new requirements for nuclear plants already in service.

The court ruled against CLPC to uphold the NRC’s regulations but did so reluctantly, acknowledging that the NRC had not done a good job of working with licensees to implement the new regulation. The court concluded that under the exemption procedure already in place, licensees could make a case to the NRC that their coated cables did contribute to their FPP. If licensees could not successfully make such a case, then the NRC’s regulation was in fact in the best interest of public safety.

3.3 Petition for Writ of Certiorari and Resolution by the Supreme Court (SECY-82-342)

In fall 1982, CLPC petitioned for a writ of certiorari to the United States Supreme Court to have the ruling of the Court of Appeals reexamined (1982). CLPC felt that the decision by the Court of Appeals had improperly relied on the provision permitting exceptions to regulations. The Solicitor General reviewed the petition and made the following conclusions: The fire protection tests conducted at SNL showed that the previous separation requirements for redundant cables did not provide adequate protection for redundant cable trains. The results of these tests were made publicly available and were discussed in two public proceedings in 1977 and 1978. The Solicitor found that the petitioners were incorrect in their assertion that the final regulation only allowed for three explicit options to achieve safe-shutdown capability. The fourth option, the exemption rule, was included in Appendix R as a natural transition from the old regulation. Instead of explicitly permitting the use of fire-retardant cable coatings or other alternative methods, the Commission had shifted the onus onto the licensee to prove that its method achieved an acceptable level of safety. With this onus came a degree of flexibility. No fire protection method, including but not limited to fire-retardant cable coatings, was explicitly prohibited. The old postulated hazards approach was still valid as a way to comply with the exception portion of the regulation. The Solicitor found that the Court of Appeals ruling was justified and denied the writ of certiorari. The case was never heard by the Supreme Court.

4. CABLE COATINGS RESEARCH PROGRAM OF THE 1970S

The authors of this report undertook a literature review to better understand previous research on fire-retardant cable coatings and cable tray covers—in particular, with regard to the time to ignition and time to electrical failure of cables enclosed by these systems. This section summarizes the results of the literature review, supplementing the information in NUREG/CR-6850, and identifies areas for future research. Of the documents reviewed, the following are of particular interest and discuss fire-retardant coatings for electrical cables in some detail:

- RG 1.75, "Physical Independence of Electric Systems," issued February 1974 (NRC 1974)
- NUREG/CR-2607, "Fire Protection Research Program for the U.S. Nuclear Regulatory Commission 1975–1981," April 1983 (a summary of SNL/NRC fire research programs between 1975 and 1981) (Dube 1983)
- SAND78-0518, "A Preliminary Report on Fire Protection Research Program Fire Retardant Coatings Tests," March 1978 (Klamerus 1978)
- NUREG/CR-0381, "A Preliminary Report on Fire Protection Research Program Fire Barriers and Fire Retardant Coatings Tests," September 1978 (continuation of SAND78-0518) (Klamerus 1978)
- NUREG/CR-0366, "Fire Protection Research Quarterly Progress Report, October–December 1977," August 1978
- NUREG/CR-5384, "A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories, 1975–1987," December 1989 (Nowlen 1989)
- SAND77-1424, "A Preliminary Report on Fire Protection Research Program (July 6, 1977, Test)," October 1977 (covers IEEE 383 qualified cables without cable coatings) (Klamerus 1978)
- Research Information Letter 46, "Effectiveness of Cable Tray Coating Materials and Barriers in Retarding the Combustion of Cable Trays Subjected to Exposure Fires and in Preventing Propagation Between Cable Trays (Horizontal Open Space Configuration)," February 1979 (NRC 1979)

Appendix A contains a list of all documents reviewed. This section summarizes the scope, methods, and results of past cable coating tests.

4.1 Cable Tray Fire Propagation

In the late-1970s, SNL performed fire spread tests to evaluate the adequacy of the guidance on circuit separation in RG 1.75, Revision 2, issued September 1978 (NRC 1978). SNL researchers used the IEEE 383 test standard to analyze flame spread in cable trays. The testing showed deficiencies in the guidance, which prompted additional testing. The researchers explored alternative methods for reducing the severity of cable tray fires and the likelihood of fire-induced damage. One of these methods involved applying fire-retardant coatings or cable tray covers, or both.

Initial testing was performed to evaluate the spacing requirements in RG 1.75, Revision 2, under severe fire conditions. The experimental setup featured an array of cable trays filled with

IEEE 383 qualified electrical cables. The cable trays were arranged in an open-space horizontal configuration, with trays representing redundant safety divisions separated by the distances specified in RG 1.75. Propane burners were used to produce a fully developed cable fire in one tray, which then was allowed to spread to the other trays. Figure 4-1 shows the full-scale test apparatus.

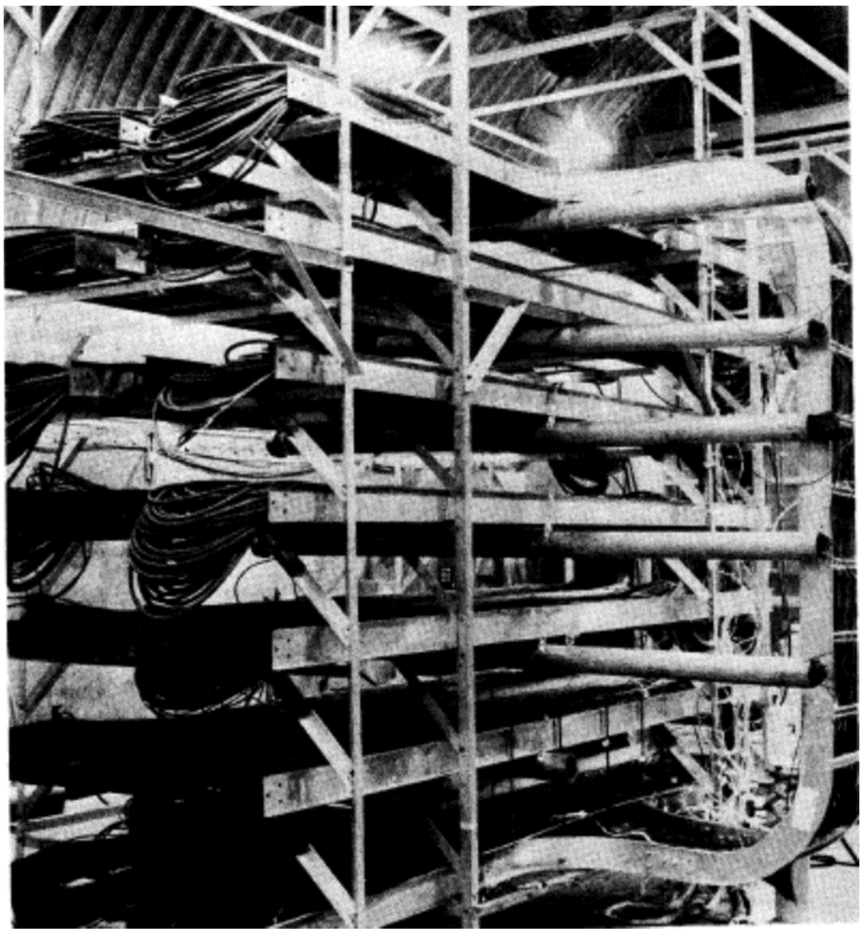

Figure 4-1 Full-scale test apparatus (Dube, 1983, 14)

One redundant safety division was represented as two vertical stacks of seven cable trays each, arranged with vertical separations of 27 cm (10.5 in.) and horizontal separations of 20 cm (8 in.). The second division was represented by two trays 1.52 m (5 ft) above and one tray 0.91 m (3 ft) to the side, at the same elevation as the highest tray in the seven-by-two array. All horizontal trays were 3.7 m (12 ft) long.

The cable trays were filled with IEEE 383 qualified cable to the top of the 10 cm (4 in.) side rails. Cables were placed into the trays in figure-eight configurations to allow for ample air space. Two types of cables were used:

(1) three conductor (3/C), 12AWG, XLPE/XLPE (Supplier A)
(2) single conductor (1/C), 12AWG, XLPE/No Jacket (Supplier B)

The fire was ignited by two IEEE 383 burners located below one of the lowest cable trays in the seven-by-two array. In addition, an insulation board was placed above the lowest cable tray (donor tray) until the donor tray ignited and sustained burning.

The SNL report on this experiment (NRC 1978) does not provide complete details on circuit integrity, but it does mention that for the circuits monitored in the conduits, continuity measurements were normal (i.e., there were no open circuits), and insulation resistance showed short circuits in all conduits above level three.

The report documents fire propagation upward (vertically) based on the peak temperature of each cable tray. This method of documenting flame spread is not as accurate as a time-stamped video recording, as the cable tray is likely to ignite before reaching its maximum temperature. Therefore, the reader should exercise caution when interpreting the data in Table 4-1.

Table 4-1 Cable Failure Progression (Based on Peak Tray Temperature)

Circuit Failure Approximation			Fire Propagation[a]	
Tray	Time (minutes)		Tray	Time (minutes)
1N	N/A - Donor Tray		1N	5
2N	10		2N	14
3N	10		3N	13
4N	14		4N	23
5N	23		5N	45
6N	21		6N	38
7N	26		7N	75[b]
8N	24		8N	35

(a) Fire propagation is based on maximum tray temperature and not on observations.
(b) Temperature rose steadily for 75 minutes.

This test demonstrated that upward fire propagation between cable trays with a vertical separation distance as specified in RG 1.75 (1.5 m (5 ft)) was creditable, if a fully developed cable tray fire could occur at lower elevations. The test results prompted the NRC to sponsor additional fire research at SNL to evaluate the effectiveness of alternative cable fire protection measures (namely, fire-retardant cable coatings and metal cable tray covers).

4.2 Fire-Retardant Cable Coatings

The test described in Section 4.1 showed that fire propagation with fire-retardant (IEEE 383 qualified) cable is possible if a fully developed cable fire is assumed (Klamerus 1978). The testing validated the NRC’s position in requiring cable coatings for fire protection of essential safety systems. The following tests were done to explore the effectiveness of fire-retardant cable coatings in more depth.

4.2.1 Small-Scale Testing

Smithers Scientific Services of Akron, Ohio, performed small-scale tests on six types of fire-retardant cable coatings applied to two types of cables supplied from independent manufacturers. The cables used were of the same types as those in the full-scale fire propagation test described above, namely a 3/C, 12AWG, XLPE/XLPE (Supplier A) and a 1/C, 12AWG, XLPE/No Jacket (Supplier B). The cable coatings were identified as A, C, D, E, F, and G.

Each cable type was cut into 15 cm (6 in.) lengths and placed in wood forms lined with plastic to create a 15 cm by 15 cm (6 in. by 6 in.) sample. The fire-retardant coatings were troweled onto the cable samples (with each coating applied to a 1/C cable sample and a 3/C sample) to the manufacturer's specified wet thickness and allowed to dry for 30 days. The cured samples were then mounted vertically into a holding fixture and tested for ignition characteristics by placing a small pilot flame to impinge on the center of the lower edge of the sample. The sample was then exposed to a radiant heat flux of 10, 20, 30, or 40 kilowatts (kW)/m^2 and a constant air flow rate of 0.04 m^3/second (s) (1.4 ft^3/s) to allow for smoke and heat release measurements. Table 4-2 presents the results of the testing. The test report focuses on the 40 kW/m^2 heat exposure, because the researchers found that it showed the strongest discrimination between coatings and provided results consistent with full-scale tests. Although the analytical method of correlation between small-scale and full-scale testing is vague, the time to ignition in small-scale testing tends to correlate well with the time to ignition in full-scale testing, as will be described later.

Table 4-2 Results for Small-Scale Tests of Coatings

Coating	Heat Flux = 40 kW/m^2		Lowest Heat Flux for Ignition (kW/m^2)
	Time to Ignition (minutes)	Time to Maximum Heat Release (minutes)	
Flamemastic #71A (Item A)	8	16	4
Vimasco #1A (Item C)	8	17	2
Albi-Clad (Item D)	14	28	–[a]
Carboline Intumastic 285 (Item E)	24	34	2
Intumescent Paint (Item F)	5	12	3
Quelcor 703B (Item G)	13	22	2
383 Cable—No Coating	0.8	6	–

(a) Coating D did not ignite but showed signs of an intumescent reaction at 2 kW/m^2.

The report notes that coating F (intumescent paint) fell off during one of the tests, and post-test examination showed that the coating exhibited low adhesion characteristics.

4.2.2 Full-Scale Testing

SNL also conducted the full-scale testing. Three horizontal test configurations were used: (1) a single-tray propane burner, (2) a two-tray propane burner, and (3) a two-tray diesel pool fire configuration. A variety of cable coatings and tray covers were tested in all three configurations.

4.2.3 Single-Tray Tests

Figure 4-2 shows the test setup with a single horizontal tray. The lower ignition tray was the only location used and was loaded with coated cables. The ignition source was two IEEE 383 burners, which were adjusted to provide a combined 140,000 British thermal units (Btu) (41 kW-h) and ignited in cycles of 5 minutes' burn followed by a 5-minute delay, until a sustained fire was observed in the cable tray. For each coating type (A, B, C, D, E, and G), two tests were run: one with the 1/C cable (25 percent cable tray fill) and one with the 3/C cable (15 percent cable tray fill). In addition, tests were performed with two uncoated IEEE 383 qualified cables (one with 1/C and one 3/C) and one uncoated non-IEEE 383 qualified cable (PE/PVC). Table 4-3 presents the results of the tests.

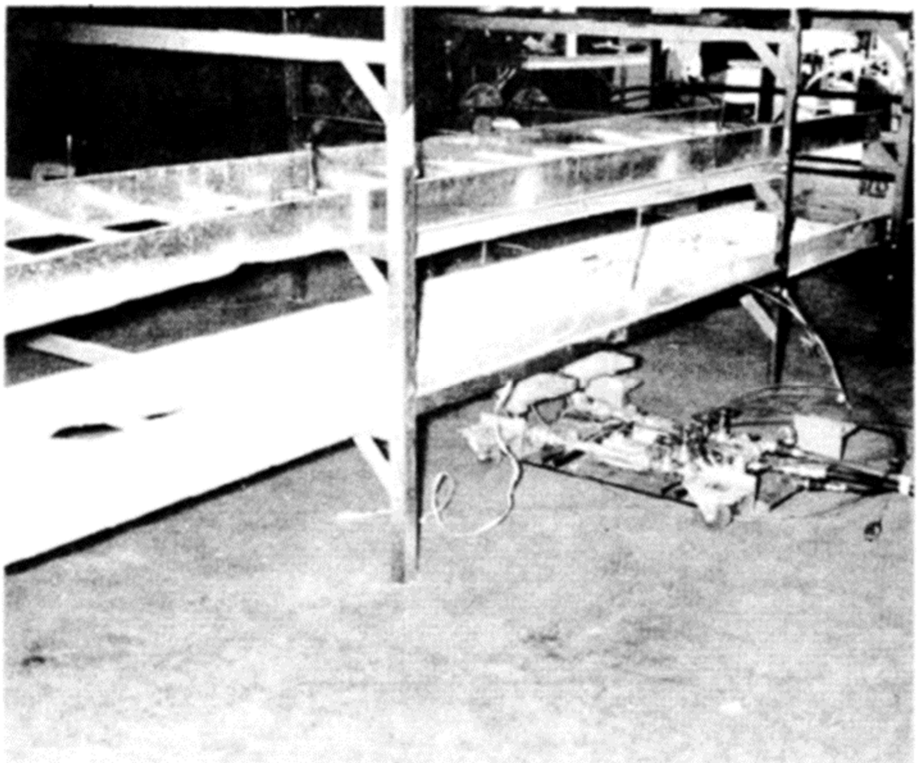

Figure 4-2 Full-scale single-tray test apparatus

Table 4-3 Results of Full-Scale Single-Tray Tests

Coating	# Cycles to Ignite	Time to Electrical Damage (minutes)	Fire Duration (minutes)	Flame Height Above Cables (in.)	Affected Area (in.^{2})
A (1/C)	2	-	6	5–7	595
A (3/C)	2	26	15	7	450
B (1/C)	4	-	7	7–9	774
B (3/C)	3	-	7	5–8	680
C (1C)	2	24	15	9.5+	1,044
C (3/C)	1	5	40	9.5+	774
D (1/C)	>6	-	N/A	N/A	648*
D (3/C)	>6	-	N/A	N/A	648*
E (1/C)	>6	-	N/A	N/A	N/A
E (3/C)	>6	-	N/A	N/A	N/A
G(1/C)	6	40	10	No data	540
G(3/C)	4	-	4	No data	792
None (1/C) Qualified	1	5	10	9.5+	612
None (3/C) Qualified	1	9	13	9.5+	486
None (3/C) Nonqualified	1	6	36	9.5+	1260

Coating Key
Coating A: Flamemastic #71A
Coating B: Flamemastic #77
Coating C: Vimasco #1A
Coating D: Albi-Clad
Coating E: Carboline Intumastic 285
Coating G: Quelcor 703B

4.2.4 Two-Tray Tests

The two-tray horizontal test apparatus was identical to the single-tray apparatus, with the addition of a cable tray 26.7 cm (10.5 in.) above the ignition cable tray, as shown in Figure 4-3. The lower tray was filled with 3/C IEEE 383 qualified cables, while the upper tray was filled with 1/C IEEE 383 qualified cables. A removable fire barrier board was placed between the two cable trays. This barrier was removed once the fire in the lower tray developed. The results of this testing are summarized in Table 4-3 and Table 4-4 later in this section. Table B-1 presents a table containing the complete results.

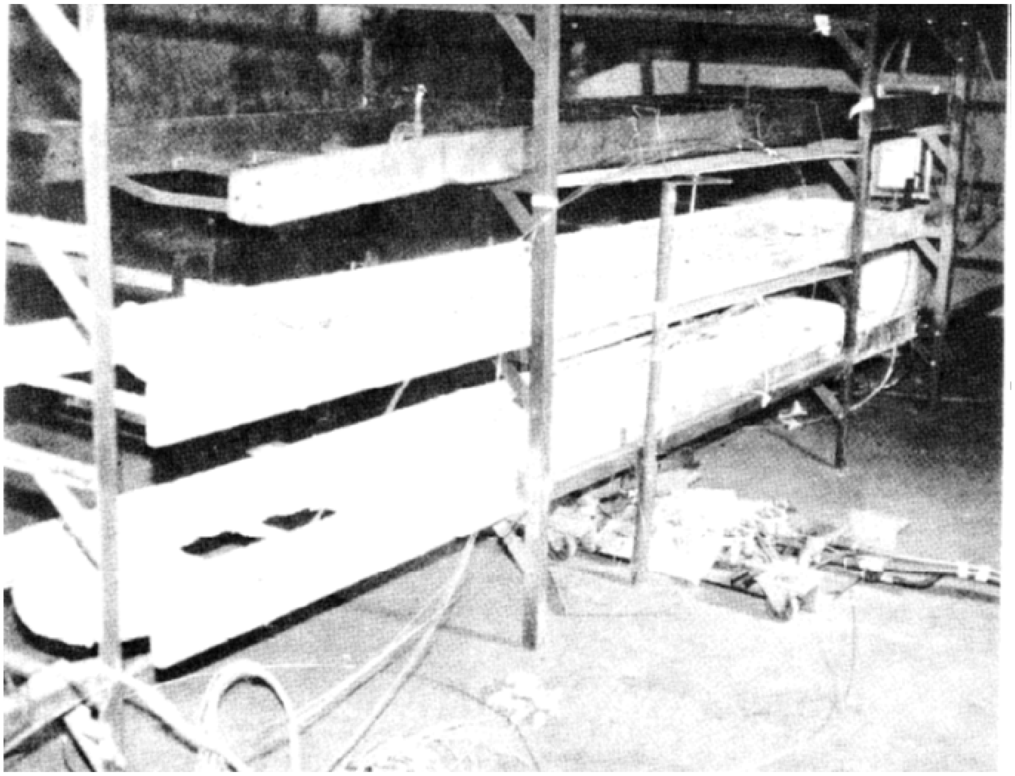

Figure 4-3 Full-scale two-tray test apparatus

4.2.5 Two-Tray Diesel Fuel Pool Fire Tests

The two-tray diesel fuel pool fire test apparatus was identical to that of the two-tray propane fire apparatus, except with the propane burners replaced by a fuel pan measuring 0.91 m x 0.46 m (3 ft x 1.5 ft), located at the same height as the propane burners (12 cm (4.75 in.) below the bottom cable tray). Before each test, 7.6×10^{-3} m^3 (2 gallons) of diesel #2 was poured into the pan and ignited with the aid of approximately 1.5×10^{-4} m^3 (5 ounces) of mineral spirits. The diesel fuel burned for approximately 11–13 minutes.

Unlike in the two-tray propane fire tests, no insulation board was placed between the two cable trays in the diesel fuel tests. The diesel fuel tests were performed only on non-IEEE 383 qualified cables. The researchers found that only cable coating C (Vimasco #1A) resulted in fire propagation to the second cable tray. The test results are presented in Table 4-3 and Table 4-4 below.

Previous research indicates that all seven of the cable coatings tested provide some fire protection relative to unprotected cable. However, they vary widely in effectiveness. The ranking of the coating types in terms of resistance to ignition and cable damage is as follows:

Highest Protection	Albi-Clad
	Carboline Intumastic 285
	Flamemastic #77A
	Quelcor 703B
	Flamemastic #71A
	Vimasco #1A
	Intumescent Paint
	Uncoated 383 Cable
Lowest Protection	Uncoated Non-383 Cable

In these early tests, the reported cable failure results should be viewed with considerable skepticism. As noted earlier, the test reports do not specify the nature of the apparatus for testing electrical failure. Cable functionality testing has evolved substantially in the last several decades, and many practices commonly applied in the 1970s are no longer considered appropriate.

The authors discussed this aspect of the tests with a current SNL staff member, Mr. Steven Nowlen, who was not with SNL when the tests took place but who had reviewed this work in some detail in 1988 and 1989 (see, for example, NUREG/CR-5384). Mr. Nowlen had access to many of the original test records and to one of the SNL technicians who had supported the testing. He could not fully identify the details of the cable monitoring systems, but he determined that the insulation resistance measurements were based on a low-voltage (likely 28 V ac) short-circuit monitoring system. His conclusion was that the tests had likely used a 28 V ac power source and panel-mounted indicator lights (of unknown resistance) that would be illuminated in the event of a conductor-to-conductor short circuit. The use of a low-voltage source for cable insulation resistance monitoring is no longer considered acceptable practice, because it does not place a representative stress (in terms of either voltage or available fault current) on the cable insulation (unlike, for example, a 120 V ac or 125 V direct current power source). Mr. Nowlen therefore recommends that these early results not be taken as accurate indications of actual cable condition during the tests. In particular, it is not appropriate to conclude that coatings that proved effective in the tests would have prevented cable failures given more realistic voltage levels. However, while the circuit integrity results are not definitive, Mr. Nowlen’s opinion is that they do qualitatively indicate the relative performance of the coating materials. That is, coatings that prevented low-voltage cable integrity failures may indeed be considered to perform better than coatings that did not prevent failures under the same conditions.

Of the seven coating types, Albi-Clad and Carboline Intumastic 285 performed the best, in that they did not ignite during any of the full-scale testing, nor was electrical failure observed in the IEEE 383 qualified cable specimens coated with them. Cable damage did occur in non-IEEE 383 qualified cables coated with Carboline. Albi-Clad was not tested in that configuration.

The lowest performing cable coating was Vimasco #1A, which provided marginal to no protection in terms of time to ignition and time to cable damage. In one case, a Vimasco-coated cable experienced cable damage earlier than an uncoated cable.

Flamemastic #71A was also a low performer; it showed improvements in time to damage and ignition and fell in the middle range in terms of protection. The performance of Quelcor 703B was mid-range.

Table 4-4 Summary of Results—Time to Ignition

Coating		Small-Scale Radiant (minutes)	Full-Scale (minutes)			
			Single-Tray	Two-Tray		Diesel Pool Non-383
				383	Non-383	
	Uncoated 383	0.8	5	4–5		Not tested
	Uncoated pre-383	Not tested	5		3–5	Not tested
A	Flamemastic #71A	8	10	10	10	13
B	Flamemastic #77	Not tested	15–20	10	15	13
C	Vimasco #1A	8	5–10	5	15	12
D	Albi-Clad	14	- - -	- - -	Not tested	Not tested
E	Carboline Intumastic 285	24	- - -	- - -	Not tested	- - -
F	Intumescent Paint	5	Not tested	Not tested		Not tested
G	Quelcor 703B	13	30	15	10	12

- - - Indicates no failure

Table 4-5 Summary of Results—Time to Cable Damage (Electrical Failure)

Coating		Single-Tray	Two-Tray		Diesel Pool Non-383
			383	Non-383	
	Uncoated 383	5–9	9		
	Uncoated pre-383	6		2	
A	Flamemastic #71A	26	20	6	10–11
B	Flamemastic #77	- - -	23	14	6–11
C	Vimasco #1A	5–24[(a)]	8–20	6	3–7
D	Albi-Clad	- - -	- - -	Not tested	Not tested
E	Carboline Intumastic 285	- - -	- - -	32	10–19
G	Quelcor 703B	40		7	11

(a) NUREG/CR-2607 and SAND78-0518 provide different values for electrical failure, 5 and 15 minutes, respectively (the most conservative value was chosen for this table).

- - - Indicates no failure

4.2.6 General Conclusions

All fire-retardant cable coatings offer some fire protection (although products like Vimasco #1A and intumescent paint provide only minimal protection). However, the coatings vary widely in both their ability to retard combustion when exposed to a fire and in their ability to prevent fire propagation from one tray to another. No propagation to the second tray was observed in any of the two-tray tests using IEEE 383 qualified cables; in the three tests in which propagation to the second tray was observed, non-IEEE 383 qualified cable was used.

As would be expected, non-IEEE 383 qualified cables failed earlier than IEEE 383 qualified cables when tested in identical configurations and with the same cable coating.

The diesel fuel tests provided a more realistic fire exposure scenario than the propane burner tests, in which a fire barrier separated the lower tray from the upper tray until the lower-tray fire had developed. As the tables above indicate, all test setups (both small scale and full scale) resulted in failures (ignition and cable damage) within roughly the same relative timeframe. Thus, the radiant, single-tray propane, two-tray propane, and two-tray diesel fuel test results are consistent and could be used in fire hazard analysis or fire PRA for exposure conditions equal to or less severe than the test exposures.

Although some cable coatings did not fail under the test conditions, they would likely fail under more severe conditions. Therefore, analysts should *not* consider these coatings to provide infinite resistance to ignition or to electrical damage. Because the current data are so limited, future research is needed to understand the failure points of the more robust cable coatings.

As different coating types exhibit widely varying levels of resistance to fire damage and ignition, analysts should use the data available for the specific coating type under consideration, rather than using generalized values.

5. FIRE STANDARDS RELATED TO FLAME-RETARDANT CABLE COATINGS

This section outlines several technical reports and test standards pertaining to the use of fire-retardant cable coatings in the commercial nuclear power industry. Facilities such as marine, nuclear, and fossil fuel generating stations all use fire-retardant cable coatings. Coating materials are sold in several forms, including tapes, blankets, liquids, and mastics, which can be applied to either individual cables or groups of cables. The cable coating standards that the NRC endorses are IEEE 383 and IEEE 1202, "IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies" (IEEE 1991). Regulatory Position 4.1.3.1 in RG 1.189, "Fire Protection for Nuclear Power Plants," outlines guidance for the use of fire-retardant cable coatings to protect safety-related cable in NPPs (NRC 2001). In this guidance, the effects of applied cable coatings are not recognized as an ultimate fire protection solution.

Section III.G.2 of Appendix R to 10 CFR Part 50 states that fire-retardant cable coating material is considered an intervening combustible. Although cable coatings increase the time to ignition, they are still combustible; therefore they may not be used as an equivalent to a 1- or 3-hour fire barrier. The NRC credits the application of fire-retardant cable coatings to nonqualified cables as an improvement in fire resistance. The credit that is given is not the same as that given to thermoset cables that are IEEE 383 qualified without the use of a fire-retardant coating.

The industry requested additional guidance on the use of fire-retardant cable coatings and how to credit them in the probabilistic approach of NFPA 805, particularly in section 3.3.5.3. This section states that newly installed electrical cable construction must pass a flame propagation test acceptable to the authority having jurisdiction. The industry requested clarification as to what specific tests are acceptable to the NRC. In response to this inquiry the NRC published FAQ 06-0022, dated March 16, 2009 (NRC 2009). The FAQ cited three previous NRC publications that offered guidance on the intent of NFPA 805:

(1) NUREG-0800, section C.7.1.4, Revision 4, issued October 2003 (NRC 2003), which states the following:

> Electrical cables should meet flame test criteria of IEEE 383 or 1202 or be provided with alternative protection as allowed by the specific plant licensing and/or design basis (See Regulatory Guide 1.189).

(2) Appendix A to BTP APCSB 9.5-1 states, "Electric cable construction should, as a minimum, pass the flame test in IEEE Std. 383." It also states, "For cable installation in operating plants and plants under construction that do not meet the IEEE No. 383 flame test requirements, all cables must be covered with an approved flame retardant coating and properly derated."

(3) RG 1.189, Revision 1, issued March 2007 (NRC 2007), states the following:

> Electric cable construction should pass the flame test in [IEEE 383 or IEEE 1202]. (This does not imply that cables passing either test will not require additional fire protection). For cable installations in operating plants and plants under construction before July 1, 1976, that do not meet the IEEE Standard 383 flame test requirements, all cables should be

covered with an approved flame-retardant coating and properly derated or be protected by automatic suppression.

The standards identified in this section are part of a much larger number reviewed; they are limited to relevant standards and test methods that could be used or have been used to characterize fire-retardant cable coatings. Appendix A gives a more complete list of the reports, standards and tests reviewed.

5.1 IEEE 383, "Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations"

IEEE originally created the IEEE 383 standard in 1974 (IEEE 1974). The purpose of the standard was to qualify cables and field splices to demonstrate satisfactory performance under a specific set of service conditions. The standard outlined certain methods for aging cable through vibration, electrical load cycle testing, thermal exposure, and radiation exposure. It included a flame propagation test, which was conducted by igniting cables from the bottom of a vertically oriented test apparatus. Flame spread along the cable was measured after 20 minutes. If the flames had spread the entire height of the test apparatus in 20 minutes or less, the cable failed the test and was considered nonqualified; if not, the cable passed and was considered IEEE 383 qualified (with respect to the flame test requirements of the standard). The NRC has used IEEE 383 to investigate cable test parameters, as discussed in NUREG/CR-4112, "Investigation of Cable and Cable System Fire Test Parameters," issued January 1985 (Underwriters Laboratories Inc. (UL) 1985). In 1991, IEEE removed the vertical flame test from the IEEE 383 standard and published it as an independent test protocol, IEEE 1202 (see section 5.2).

5.2 IEEE 1202, "IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies"

IEEE 1202 is a test protocol and performance criterion measuring the flame propagation properties of cables in a vertical cable tray (IEEE 1991). It applies to single insulated and multiconductor cables. The test consists of exposing cable samples to a flaming ignition source for 20 minutes. At the end of the 20-minute period the burner is turned off. If the fire continues to burn independent of the burner, it is allowed to burn until it self-extinguishes, and the time at which it does so is recorded in the test data. The protocol explains the test facility, sample requirements, procedure, and evaluation of results.

The test incorporates an enclosure structure that surrounds the burning cables and allows control of the ventilation and heat transfer conditions during the test. This enclosure was not included in the original vertical flame spread test of IEEE 383. Also, the height criterion of IEEE 383 was lowered in IEEE 1202. In the IEEE 1202 protocol, the cables being tested are arranged in a single layer within the cable tray. The protocol specifies the separation distance between the cables, which depends on their diameter and geometry. After the test is concluded, the cables are cleaned of smoke deposits. The area of the cables that has charred is considered to be the affected area. On cable insulation materials that do not char, the affected area is considered to be the area in which the overall cable diameter has either increased (e.g., for intumescent materials) or decreased (e.g., because of melting of thermoplastic material).

5.3 IEEE 817, "IEEE Standard Test Procedure for Flame-Retardant Coatings Applied to Insulated Cables in Cable Trays"

IEEE 817 "IEEE Standard Test Procedure for Flame-Retardant Coatings Applied to Insulated Cables in Cable Trays," published in 1993 (IEEE 1993), was intended for testing of flame propagation in cables with fire-retardant coatings applied. IEEE 817 resembles IEEE 1202; however, the scope of IEEE 1202 did not include fire-retardant coatings. The intent was that if a cable was found to be nonqualified in an IEEE 1202 test, one could follow up by applying a fire-retardant cable coating and running an IEEE 817 test. The IEEE 817 test applies to both retrofitted existing applications and new installations. Cables are arranged in three layers in a vertically oriented cable tray. (The procedure specifies the arrangement of the various cables within the tray.) The tray is to be loaded with a mixture of coated and uncoated cables. The burner configuration and overall test structure are based on IEEE 1202. IEEE 817 is no longer an active standard, is no longer endorsed by the IEEE, and was withdrawn by the IEEE in 2000.

5.4 International Electrotechnical Commission Standard 60331, "Tests for Electric Cables Under Fire Conditions—Circuit Integrity"

International Electrotechnical Commission (IEC) 60331, "Tests for Electric Cables Under Fire Conditions—Circuit Integrity," was originally published in five parts in 1970 as a standard for testing the circuit integrity of electrical cables exposed to fire conditions (IEC 1970). By 1999, the standard had been expanded to incorporate electrical data cables (Part 23) and fiber-optic cables (Part 25). Part 1 (for cables of diameter over 20 millimeters), Part 2 (for cables of diameter under 20 millimeters), and Part 3 (for cables inside a metal enclosure) outline the basic method for testing circuit integrity. The test involves exposing an energized cable to fire of at least a minimum specified temperature. The scope of the test is limited to cables of rated voltage up to 0.6 kilovolts and including 1.0 kilovolts. There is an exception in the test procedure that allows cables rated up to 3.3 kilovolts to be tested, with approval from the manufacturer and if fuses are installed into the circuit. The standard describes a test enclosure and specifies its volume and temperature. The enclosure is to be equipped with a ventilation system that monitors the mass flow of inlet and outlet air. The test apparatus uses a propane burner for which the flow rate is specified and is monitored during the test. The cables are installed on a metal test ladder and wired into a circuit with a power source on one end and an incandescent lamp on the other. The test apparatus incorporates a shock-producing device. A steel rod mounted to a hinge mechanism is dropped onto the test ladder at specified time intervals throughout the test. The cable is exposed to direct flame impingement for one of four specified time intervals. During the time that the cable is exposed to the fire, it is energized at its rated voltage. The acceptance criteria for the test are that the voltage through the cable is maintained and that the conductor does not rupture (the lamp remains illuminated).

Note that some coating manufacturers reference IEC 60331 and the time to circuit failure in their product documentation. Reviewing several instances of such product documentation and the IEC 60331 laboratory reports used by the manufacturers, RES observed that the reports contained no details on the type of cable used in the testing sample; furthermore, the time to circuit failure is given as an absolute value, rather than a value relative to the time for an uncoated cable. The research in this program shows that the time to circuit failure depends on the base cable used in the sample; in some tests performed for this program following the IEC 60331 test procedure, an uncoated cable did not fail in circuit functionality for the full 90-minute test period. This raises questions as to the applicability of the IEC 60331 test method in evaluating the benefits of fire-retardant cable coatings. The time to circuit failure for a coated cable is uninformative and may be misleading unless one knows the base cable material and the time to circuit failure of the uncoated cable.

5.5 UL 1581, "Reference Standard for Electrical Wires, Cables, and Flexible Cords"

UL 1581, "Reference Standard for Electrical Wires, Cables, and Flexible Cords" (UL 2001), contains specific information about a variety of electrical conductors, insulation, jackets, and other coverings. It also outlines different methods of sample selection, preparation, conditioning, measurement, and calculation that are relevant to wire and cable standards. UL 1581 references two flame tests, the FT1 and FV-1/Vertical Flame tests, which both appear in UL 2556, "Wire and Cable Test Methods" (UL 2021). In both test methods, a burner is applied to cable sample for a specified amount of time. The burner is removed and reapplied repeatedly until a specified number of exposures is reached. If cable insulation maintains independent flaming combustion for a specified period after the burner applications have stopped, it is considered capable of conveying flame.

5.6 UL 2556, "Wire and Cable Test Methods"

The FT1 test establishes a method for determining the resistance of a wire, cable, or cord to the vertical propagation of flame. The cable is to be allowed to straighten and acclimate to room temperature for a specified amount of time before the test. Cable specimens are then secured to a vertical test apparatus. Kraft paper of a specified nominal thickness is affixed to the back of the cables and wrapped so as to encase them above the point of contact with the burner flame. The excess paper is glued to make a flag strip that protrudes from the center of the broad face of the specimen. The test is conducted inside an enclosure in which the ventilation characteristics can be regulated and measured. The burner is applied, and the results are measured against the acceptance criteria described in UL 1581 (UL 2001). In the FT1 test, the amount of flame propagation is measured by the distance to which the flag is burned away or charred; burning of the kraft paper that is in direct contact with the specimen is not considered, and neither is scorching or soot deposition on the flag section without charring or burning.

The FV-1/Vertical Flame test is identical in structure to the FT1 test. However, there are procedural differences between the two tests—for example, in how the burner is applied and how the flame spread is measured. In the FT1 test, if the specimen begins to flame while the burner is removed, the burner is not to be reapplied until immediately after the specimen self-extinguishes. The FT1 test documents the time needed for the specimen to self-extinguish once the burner is removed. If the specimen burns for a specified time independent of the burner, the test may be concluded before all iterations of burner application have been completed. In the FV-1 test, all iterations of burner applications must be completed, irrespective of the flame spread characteristics of the specimen.

5.7 UL 1807, "Outline for Investigation for Fire-Resistant Cable Coating Materials"

UL 1807, "Outline of Investigation for Fire-Resistant Cable Coating Materials", gives a test method for determining the effect of fire-retardant cable coating materials on flame propagation. The purpose of the test is to determine whether applying a fire-retardant coating to a nonqualified cable will enable it to pass the vertical flame spread test. UL 1807 uses the FT1 test from UL 2556 (UL 2021), which is also referenced in UL 1581. The reduction in the cable's ampacity rating due to the application of a coating may also be investigated. The relationship between UL 1807, UL 2556, and UL 1581 is similar to the relationship between IEEE 817, IEEE 383, and IEEE 1202, in that the primary standard draws from the others.

5.8 ASTM Standards for Material Combustibility

The ASTM has developed several standards for testing material properties that address burning characteristics and combustibility. The methods of ASTM E119 along with a hose stream test have been used in the nuclear industry as an acceptance criterion to evaluate the performance of fire barrier systems (NRC 1994). Other related standards include ASTM E84; ASTM E136, "Standard Test Method for Assessing Combustibility of Materials Using a Vertical Tube Furnace at 750 °C" (ASTM 2011); ASTM E162, "Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source" (ASTM 2022); and ASTM E1354, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter" (ASTM 2022). These standards apply to any material, including fire-retardant coating materials.

6. RESEARCH PROGRAM

6.1 Details of the Current Research Program

The research program documented in this series of reports evaluated the properties of several types of cables and fire-retardant coating materials typically used at NPPs. Ignition temperatures were measured using a well-controlled convection oven. To evaluate the burning behavior of coated cables, researchers used a cone calorimeter to determine burning rate, heat of combustion, and other properties. Full-scale horizontal and vertical flame spread experiments were conducted, and fire-retardant coatings were evaluated for effectiveness in preserving circuit integrity during fire exposure. The results of these experiments will support updates to existing fire PRA methods and input parameters for fire modeling.

Two main cable types were tested: a thermoset cable with good fire-retardant properties (e.g., passing the flame spread test of IEEE 383 or IEEE 1202) and a thermoplastic cable with poor fire-retardant properties (e.g., failing the flame spread test of IEEE 383 or IEEE 1202). Various combinations of cables and fire-retardant coatings were tested; Table 6-1 and Table 6-2 detail the cables and coatings used, respectively. The cables listed in Table 6-1 are called “qualified” if they meet the requirements of IEEE 1202 and “unqualified” otherwise.

Table 6-1 Primary Test Cable Descriptions

Test Cable ID No.	Insulation Material	Jacket Material	Year Manufactured	Description
802	XLPE	CSPE	2006	Qualified, thermoset, 7-conductor cable
807	PE	PVC	2006	Unqualified, thermoplastic, 7-conductor control cable
813	XLPE	CSPE	2006	Qualified, thermoset, 12-conductor cable
900	PE	PVC	2015	Unqualified, thermoplastic, 7-conductor control cable
902	PE	PVC	1975	Unqualified, thermoplastic, 3-conductor cable

Note: Other cables have been evaluated in past NRC research programs.

Table 6-2 Fire-Retardant Coating Materials Used in Testing

Flame-Retardant Material	Description
Carboline Intumastic 285	Product of the Carboline Company. A water-based mastic that can be applied to impede fire propagation along the length of coated electrical cables.
Flamemastic F-77	Product of the Flamemaster Corporation. Consists of water-based thermoplastic resins, fire-retardant chemicals, and inorganic, incombustible fibers. Described as a non-intumescent, thixotropic compound with no asbestos. Available in spray or mastic form; the latter was used in the experiments.
Vimasco 3i	Product of the Vimasco Corporation. Described by the manufacturer as "a heavy-bodied, water-based intumescent coating that is designed to prevent flame spread along the jacketing of electrical (or other) cables and to provide a thermal barrier for protection against heat damage."
Fire Security FS15	Product of Fire Security Systems. A water-based ablative coating; its primary mode of protection is ablation as opposed to thermal insulation. Not used in U.S. NPPs.

To study the fire properties of these materials and their electrical response (i.e., circuit failure times) under fire conditions, several bench-scale and full-scale tests were performed. Bench-scale tests provided data on material properties, while full-scale tests provided data on configurations more representative of those in NPPs.

The bench-scale tests included thermogravimetric analysis (TGA), micro combustion calorimetry (MCC), cone calorimeter, and furnace ignition tests. They measured material properties including density, heat capacity, thermal conductivity, mass loss as a function of temperature, heat of combustion, HRR, and ignition temperature. The bench-scale tests indicated that coatings did not systematically increase the effective ignition temperature of the cables. In fact, the bench-scale TGA and MCC and the cone calorimeter measurements show that the coatings pyrolyze at about 350 degrees Celsius (°C) (662 degrees Fahrenheit (°F)) and contribute (albeit weakly) to the volatized fuel vapors. The coatings are not designed to prevent pyrolysis and ignition but rather to delay it by slowing the penetration of heat into the cable.

The circuit integrity test of IEC 60331-11, "Apparatus—Fire alone at a flame temperature of at least 750 °C," (IEC 2011) was used, with some modifications, to measure the effect of cable coating thickness on the cables' electrical response to fire conditions. The main deviation from the IEC 60331-11 standard was that the burner had a nominal face length of 25 cm (10 in.) rather than 50 cm (20 in.). The nominal width of the burner was 1 cm. The propane and air flow rates into the premixed burner were half of what the standard calls for—2.5 liters (L) per minute (min) of propane and 40 L/min of air at 1 bar and 20°C (32°F) producing a 3.6 kW flame. In addition, the electrical response was characterized using a surrogate circuit diagnostic unit (SCDU) rather than a light bulb as specified in the standard.

In each iteration of this experiment, a single cable, either coated or uncoated, was immersed in a premixed propane-air flame generated by a line burner. In accordance with IEC 60331-11, each test evaluated a single cable; consequently, temperature and circuit integrity could not be measured within the same cable because of electrical “cross-talk” between the instruments. Thus, separate experiments were conducted for each test sample: one for circuit integrity and one for temperature. Experiments involving coated cables were performed three times (i.e., three circuit integrity experiments and three temperature measurements were performed). For the circuit integrity experiments, three circuit pairs were energized with 120 V ac, and the cable was heated until a 3-amp fast-acting fuse cleared, indicating circuit failure. The average time to circuit failure (across the three repeated experiments) and the average interior temperature of the cable at the time of failure were calculated. The results exhibit variation across cable and coating types, but in general the presence of a coating delayed the failure time for the unqualified cable.

The full-scale tests performed included a radiant heat test, the IEEE 1202-1991 vertical flame spread test, and multitray horizontal fire tests intended to represent typical tray configurations at NPPs. For full-scale tests, cable electrical response (i.e., circuit integrity) and temperature were monitored. Two systems were used to monitor electrical response: (1) an insulation resistance measurement system, which measured actual insulation resistance between the conductors of a multiconductor cable and between the conductors and ground (this system was used only during the SNL radiant experiments), and (2) an SCDU that simulated a 120 V ac control circuit for a motor-operated valve (which was used in both the SNL and the National Institute of Standards and Technology experiments). Cable temperature response was measured beneath the cable’s outer jacket (subjacket).

The radiant heat test featured a heating apparatus called the Penlight, which uses computer-controlled, water-cooled quartz lamps to heat a thin, intermediate Inconel steel shroud. The shroud is painted flat black and acts as a gray-body radiant heating source, reradiating heat to a test sample (cables in these experiments) located within the shroud. The exposure temperature is monitored and computer-controlled based on readings from thermocouples mounted inside the shroud. The Penlight creates a radiant heating environment analogous to that of an object enveloped in a fire-induced hot gas layer or a fire plume outside the flame zone. The cable trays tested were loaded with two cables or bundles mirroring each other, with one monitored for temperature and the other for electrical response.

Cables 802 and 807 were used for these tests. The samples tested were in either single-cable, 7-cable bundle, or 10-cable bundle configurations and were either uncoated or coated with a fire-retardant coating (FS15 was not tested in this experiment, as it was added later in the research program). A total of 35 tests were performed. For single-cable configurations, the tests showed that coated samples (at the manufacturer-recommended coating thickness of 1/16 in. (1.6 millimeters) had little to no delay in electrical failure time relative to uncoated samples. However, the bundle configurations showed at least 5 minutes of delay relative to uncoated samples.

The vertical flame spread test was based on the one in IEEE 1202-1991, with some modifications. These included the removal of a wall to allow for video recording, increased burner times (testing until electrical failure or 90 minutes, whichever came first), and the use of an SCDU to monitor electrical response. Two sets of tests were performed—one with non-energized cables and the other with cables energized and thermally monitored. Cables 813, 900, and 902 were tested in uncoated and coated configurations. The purpose of the tests was to confirm that coatings prevent upward flame spread and to quantify the delay in electrical failure afforded by the coatings. A total of 41 tests were performed. Electrical response was monitored only in 20 of these tests.

The purpose of the multitray horizontal test was to determine the extent to which coatings delay electrical cable failure and to obtain data for input parameters to be used in fire modeling. A test compartment was constructed that permitted various cable tray configurations to be tested at the same time, either exposed to direct flame impingement or in the hot gas layer. A total of eight tests were conducted, with four cable trays in each test; in one, the cables in the uppermost two trays dropped down from one tray to the other. The main data obtained from these tests were HRR values, cable failure times, and corresponding temperatures.

Volume 2 and 3 of this report series discuss in more detail each of these test procedures, the test configurations, and the results and data obtained.

6.2 Coating Discoloration at Brunswick Steam Electric Plant, Unit 1

During a triennial fire protection inspection at Brunswick Steam Electric Plant (NRC 2011), inspectors identified discoloration (i.e., change of color; see figure 5-1) in some fire-retardant cable coating materials. This observation did not result in a finding, as the material was not credited as a fire protection barrier and the licensee had implemented derating factors on the cable. However, the questions it sparked were one of the main motivations for creating the testing program documented in this report. RES wanted to investigate whether the discoloration was associated with any changes in the fire-retardant properties of the material.

Figure 6-1 Cable coatings showing change from their original white color

RES attempted to obtain samples of the Brunswick discolored material. A very small sample of the material (just a few grams) could have been tested using TGA and MCC to measure its properties; such testing would have provided insight on the material's fire-retardant characteristics. However, because the licensee is not taking credit for the material as part of the plant's safety systems, and because the material was manufactured with asbestos, Brunswick and the NRC Office of Nuclear Reactor Regulation decided against providing samples. However, Brunswick provided its adverse condition report from 1992, which is when the discoloration was first observed.

The Brunswick report notes that the licensee contacted the manufacturer of the coating material by telephone to discuss the discoloration.[3] The report evaluates the discoloration and concludes that it does not affect material's fire resistance. Furthermore, the report states that cable derating is necessary to mitigate the heat loading caused by normal current loading and by the additional insulation provided by the coating material. The report mentions that the discoloration suggests weathering effects or cable overheating, potentially due to incorrect use of derating factors. Brunswick stated that it had at some point obtained a cross-section of a sample of the coated cable with the discolored material, and this sample showed that discoloration was located only in the internal and external surfaces of the material.

In 2015, the resident inspectors at Brunswick measured the temperature on the surface of the coatings. No significant temperature difference was found between material that seemed intact (i.e., white or without discoloration) and material that showed discoloration.

6.3 Evaluation of Effects of Aging on Cable Coatings

Coating discoloration has been identified in a few other U.S. NPPs. To ensure that coatings provide consistent levels of performance throughout the license renewal and subsequent license renewal periods, and to make sure the updated guidance being developed from this research is applicable during those periods, the NRC is conducting research to evaluate how aging affects cable coating performance. In this research, fire-retardant coatings will be subjected to an accelerated aging process and then tested for performance. The results of these experiments will be compared to the results in Volumes 2 and 3 of this report series. It is expected that the aging research will be published as Volume 4, and a final Volume 5 will be published concurrently to provide updated guidance on crediting fire-retardant cable coatings in a risk-informed manner. It is anticipated that the Volume 5 work will be performed jointly with EPRI under the NRC-RES/EPRI memorandum of understanding on collaborative research.

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3 RES communications with the coating manufacturer in 2016 seemed to indicate that the manufacturer was unaware of issues with the coating.

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Appendix A
Literature Review

The authors conducted a literature search of U.S. Nuclear Regulatory Commission (NRC) documents to identify any past guidance pertaining to fire-retardant cable coatings. Appendix A is a compilation of publicly available NUREG-series publications that mention fire-retardant cable coatings. Many of the documents reference at least one of the seven test standards outlined in Section 5 of this report.

Document Number	NUREG-0050		
Coating Type	Flamemastic 71A	Publish Date	February 1976
Title	Recommendations Related to Browns Ferry Fire		
Summary	The review group suggested that more attention be paid to fire protection in nuclear power plants (NPPs). It recommended that natural combustibles be limited and encouraged the application of fire-retardant coatings where appropriate. The group said that guidance in the form of standards or regulatory guides should be developed to enforce fire protection standards in NPPs.		
Conclusion	The application of Flamemastic coating would have reduced the hazard associated with the highly flammable flexible foam. For new plants, the use of cable with fire-resistant insulation material should be considered.		

Document Number	NUREG-0061		
Coating Type	Flamemastic 71A	Publish Date	March 1976
Title	Safety Evaluation Report Related to Operation of Browns Ferry, Units 1 and 2, Following the March 22, 1975, Fire		
Summary	The Tennessee Valley Authority (TVA) proposed to use Flamemastic 71A coating to coat all cable types to a wet thickness of ¼ inch, which would dry to a cured thickness of at least 1/8 inch. The manufacturer recommends 1/8 inch wet thickness application. Tests showed a reduction of 1–10 percent derating in coated cables. The cables were still adequately rated with a safety factor after the derating was accounted for.		
Conclusion	Coating cables in fire-retardant coating works to ensure that cable insulation is not a source of fire propagation. TVA will begin to coat all its cables in Flamemastic in all vital safety areas.		

Document Number	NUREG-0061, Supplement 1		
Coating Type	Flamemastic 71A	Publish Date	June 1976
Title	Supplement No. 1 to the Safety Evaluation by the Division of Operating Reactors Supporting the Operation After the Restoration and Modification of the Browns Ferry Nuclear Plant, Units 1 and 2 Following the March 22, 1975 Fire		
Summary	The Flamemastic coating provides a barrier that restricts the transport of chloride residue and protects the piping of the primary coolant system. A surveillance program would be developed to periodically remove part of the cable coating and inspect the cables inside to verify that there was no degradation. The place where the coating had been disturbed would then be recoated. Testing on Flamemastic 71A showed that while it would flame when burned, it would not support combustion independently after the heat source was removed.		
Conclusion	Applying Flamemastic 71A to cables prevents the cable insulation from contributing to fire propagation and greatly reduces the production of hydrochloric acid gas.		

Document Number	NUREG-0298		
Coating Type	N/A	Publish Date	February 1978
Title	Fire Protection Action Plan: Status Summary Report		
Summary	A survey of coating materials will be initiated to determine which materials will be studied and what is already known of the characteristics. Research and testing will be conducted to determine performance variations due to application method variations and environmental differences, as well as consistency of performance with age.		
Conclusion	Many U.S. plant licensees have taken steps to apply cable coatings and suppression systems to vital areas of the plants.		

Document Number	NUREG-0847, Supplement 6		
Coating Type	None specified	Publish Date	April 1991
Title	Safety Evaluation Report Related to the Operation of Watts Bar Nuclear Plant, Units 1 and 2		
Summary	This publication discusses how coating cable trays and support structures in fire-retardant coatings decreases the dampening ratio.		
Conclusion	The minimum observed damping ratio was 7.5 percent for coated cables and 20 percent for uncoated cables for 100 percent loaded trays that were found to be acceptable.		

Document Number	NUREG-1521		
Coating Type	None	Publish Date	July 1998
Title	Technical Review of Risk-Informed Performance-Based Methods for Nuclear Power Plant Fire Protection Analyses		
Summary	This technical review discusses the massive combustible loads that are located throughout NPPs in the form of cable insulation. Insulation accounts for roughly 30 pounds per foot of combustibles. NPPs are at a high fire severity risk because of these combustibles.		
Conclusion	Passive fire-retardant coatings on cable trays and conduits are not assumed for this study.		

Document Number	NUREG-1552		
Coating Type	None	Publish Date	July 1996
Title	Fire Barrier Penetration Seals in Nuclear Power Plants		
Summary	Certain cable jacket types can prevent silicone seal materials from curing in the immediate vicinity of the cable jacket. The silicone seal is affected, but the cable jacket is not. Seal installers can prevent this condition by coating the cable jackets with a releasing agent before installing the penetration seal materials.		
Conclusion	The staff concluded that industry personnel, including material manufacturers, penetration seal installers, and licensees, are aware of the potential causes and problems associated with cure inhibition.		

Document Number	NUREG-1552, Supplement 1		
Coating Type	Flamemastic	Publish Date	January 1999
Title	Fire Barrier Penetration Seals in Nuclear Power Plants		
Summary	The fire at Browns Ferry Nuclear Plant (BFN) on March 22, 1975, is widely represented as an incident in which a fire spread after overcoming a fire-rated penetration seal. The author expresses disagreement with this characterization, because the penetration seals at BFN were not compliant with the accepted design criteria; therefore, in their state at the time of the fire, they could not have been reasonably considered fire rated.		
Conclusion	The seal did not have the fire-retardant coating specified in the design criteria.		
Document Number	NUREG-1718		
Coating Type	None	Publish Date	August 2000
Title	Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility		
Summary	As part of the fire protection safety plan for mixed oxide facilities, there will be periodic inspections to minimize the amount of combustibles in areas with items relied on for safety; determine the effectiveness of housekeeping practices; ensure the availability and acceptable condition of all fire protection systems and equipment, fire stops, penetration seals, and fire-retardant coatings (if any); and ensure that prompt and effective actions are taken to correct conditions adverse to fire protection and preclude their recurrence.		
Conclusion	The staff concluded that the applicant’s proposed equipment, facilities, and commitments provide reasonable assurance that the applicant's design bases will provide adequate fire protection to meet the safety performance requirements and the baseline design criteria for construction approval in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 70, “Domestic Licensing of Special Nuclear Material.” (U.S. CFR 1956, U.S. CFR 1956)		

Document Number	NUREG-1934		
Coating Type	None	Publish Date	November 2012
Title	Nuclear Power Plant Fire Modeling Analysis Guidelines (NPP FIRE MAG)		
Summary	The FLASH-CAT model makes use of the following information: The cable trays are horizontal and stacked vertically, there are no barriers separating the trays, and the tray tops are open. The cables are not protected with coatings, shielding, or thermal blankets. There is fire beneath the lowest tray. Each tray has at least a single row of cables.		
Conclusion	First ignition of the cables in the lowest tray occurred at 400 degrees Fahrenheit (°F). The burn rate in the lowest tray was 250 kilowatts per square meter (kW/m^2).		

	Fire in the first tray spread at 3.2 m per hour. The fire in the second tray ignited 4 minutes after the first with a burning area of 1.3 m. The third ignited 3 minutes after the second with a burning area of 2 m.

Document Number	NUREG/CR-7010		
Coating Type	None	Publish Date	July 2012
Title	Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE)		
Summary	Research was conducted to better understand and quantify the burning characteristics of grouped electrical cables commonly found in nuclear power plants.		
Conclusion	Heat release rate per unit area was 100–200 kW/m^2 for thermoset cables and 200–300 kW/m^2 for thermoplastic cables. Effective heat of combustion for cable insulation is 16 megajoules per kilogram.		

Document Number	NUREG/CR-0152		
Coating Type	None	Publish Date	June 1978
Title	Development and Verification of Fire Tests for Cable Systems and System Components		
Summary	Experiments were performed to define the effects of several test parameters on the results of vertical flame tests of tray-mounted cables in a configuration like that specified by Institute of Electrical Electronics Engineers (IEEE) 383. The parameters considered were fuel input rate, fuel-to-air ratio, burner location, and test cell configuration.		
Conclusion	See report for test data.		

Document Number	NUREG/CR-0366		
Coating Type	Not explicitly named; referred to as coatings A–F.	Publish Date	August 1978
Title	Fire Protection Research Quarterly Progress Report, October–December 1977		
Summary	This report describes a testing program undertaken to assess the adequacy of fire-retardant coatings as applied on electrical cables. The preliminary results show a remarkable consistency between small-scale tests and a full-scale single-tray testing program.		
Conclusion	Preliminary results showed that all coatings offer a measure of additional protection, but they vary widely in relative effectiveness.		

Document Number	NUREG/CR-0381		
Coating Type	Not explicitly named; referred to as coatings A–F.	Publish Date	September 1978
Title	A Preliminary Report on Fire Protection Research Program Fire Barriers and Fire-Retardant Cable Coatings Tests		
Summary	An exposure fire test at Sandia National Laboratories (SNL) showed that the Regulatory Guide 1.75 separation guidelines and IEEE 383 fire retardancy standards for safety cables are not sufficient, in themselves, to protect essential safety systems against the effects of fires. Two of the measures studied are fire barriers and fire-retardant cable coatings.		
Conclusion	Preliminary results showed that all coatings offer a measure of additional protection. No propagation of fire to the second tray was observed in any of the two-tray tests where IEEE 383 qualified cable was used. In the three tests where		

	propagation to the second tray was observed, nonqualified cable was used. (See table VIII of the report.)

Document Number	NUREG/CR-0833		
Coating Type	None	Publish Date	December 1979
Title	Fire Protection Research Program Corner Effects Tests		
Summary	The tests showed that additional measures were required to protect essential safety systems against the effects of fire and confirmed the NRC's position requiring that protection.		
Conclusion	All fire-retardant cable coatings offered some protection, but the results varied depending on the coating type and test method. Tests were based on SAND78-1456 and SAND78-0518; section II.3 of the report for details.		

Document Number	NUREG/CR-2258		
Coating Type	None	Publish Date	September 1981
Title	Fire Risk Analysis for Nuclear Power Plants		
Summary	The report refers to the testing done at SNL and does not add anything new.		
Conclusion	None		

Document Number	NUREG/CR-2431		
Coating Type	None	Publish Date	February 1982
Title	Burn Mode Analysis of Horizontal Cable Tray Fires		
Summary	Test results indicate that all cable tray burns include at least two different combustion reactions, which are triggered at different auto-ignition temperatures. The differences between the first auto-ignition temperatures for the different cable types may be statistically significant and indicate that low-temperature combustion reactions are affected by fire-retardant components of the cable surface. The effect of the IEEE qualification is counterintuitive: it lowers the auto-ignition temperature. The high-temperature combustion reactions on pre-383 and 383 qualified cables are ignited at very similar temperatures that exceed most flammable gas flash points. Coating an IEEE 383 qualified cable raises both auto-ignition temperatures but lowers the char oxidation temperature threshold.		
Conclusion	The results suggest that flammable gas evolution of pre-383 cables is associated with decomposition of the polyvinyl chloride (PVC) jacket. Flammable gas evolution of IEEE qualified cables probably reflects volatilization of a plasticizer or fire retardant. First-stage auto-ignition of both 383 and pre-383 cables probably indicates the combustion of polyethylene decomposition products. The second auto-ignition threshold is characteristic of spontaneous ignition of surface-heated cellulose materials (930–1,200°F) and plastics (12,00°F).		

Document Number	NUREG/CR-2431		
Coating Type	None	Publish Date	February 1982
Title	Burn Mode Analysis of Horizontal Cable Tray Fires		
Summary	The use of fire-retardant materials (IEEE 383 qualified cables, cable tray coatings) tend to increase the duration of deep-seated cable fires. A reasonable doubt thus exists that industrial experience with IEEE cable qualification and fire-retardant coatings applies fully to arrangements with multiple cable trays.		
Conclusion	The use of fire-retardant materials does significantly reduce the probability of self-sustained surface fires, but associated longer lasting deep-seated fires might increase the probability that surface fires, once started, will propagate.		

Document Number	NUREG/CR-2607		
Coating Type	None	Publish Date	April 1983
Title	Fire Protection Research Program for the U.S. Nuclear Regulatory Commission 1975–1981		
Summary	Small-scale and full-scale tests were conducted to evaluate the effectiveness of fire-retardant cable coatings and fire shields. The full-scale tests used both propane and diesel fuel exposure fires. For the small-scale tests the fires were electrically initiated.		
Conclusion	These tests indicate that all coatings and barriers offer a measure of additional protection against cable tray fires. No propagation of fire to the second tray was observed in any of the two-tray tests where IEEE 383 qualified cable was used. In the three tests where propagation to the second tray was observed, nonqualified cable was used. The coatings tested vary greatly in relative effectiveness.		

Document Number	NUREG/CR-3122		
Coating Type	None	Publish Date	August 1983
Title	Potentially Damaging Failure Modes of High- and Medium-Voltage Electrical Equipment		
Summary	Even when protected by coatings and/or located in covered trays, cabling rapidly becomes unusable for electrical circuitry when subjected to fire or extreme heat. There is even some evidence that coatings may increase the duration of long-lasting deep-seated fires, making it more difficult to extinguish cable tray fires quickly and completely once they are started. Therefore, extra care must be given to prevention and early detection of overheating and possible ignition in any area where cables contribute significantly to the fire loading.		
Conclusion	The report references SAND78-1465.		

Document Number	NUREG/CR-3192		
Coating Type	None	Publish Date	October 1983
Title	Investigative of Twenty-Foot Separation Distance as a Fire Protection Method as Specified in 10 CFR 50, Appendix R		
Summary	A combined experimental/analytical program was conducted to examine the adequacy of the 20-foot separation requirement set forth in Appendix R, “Fire Protection Program for Nuclear Power Facilitates Operating Prior to January 1, 1979,” to 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” for the fire protection of redundant safety systems needed to achieve hot shutdown in NPPs. Researchers conducted six full-scale fire tests of unqualified and qualified electrical cables separated by 20 feet with (1) no protection, (2) protection by a ceramic fiber blanket and sheet metal covers on the cable trays, and (3) protection by a fire-retardant coating. For the test conditions investigated, all unqualified cable electrically shorted, while qualified cable shorted only when left unprotected.		
Conclusion	More research is needed on the effectiveness of various fire-protective coating and barrier systems. In some tests, the cable jackets melted and seeped through cracks in the fire-retardant coating.		

Document Number	NUREG/CR-4230		
Coating Type	None	Publish Date	May 1985
Title	Probability-Based Evaluation of Selected Fire Protection Features in Nuclear Power Plants		
Summary	The document describes a method for probabilistically assessing the merits of the NRC's fire protection guidelines. It presents two examples incorporating a range of fire protection features identified in NRC guidance.		
Conclusion	None.		

Document Number	NUREG/CR-4310		
Coating Type	None	Publish Date	November 1985
Title	Investigation of Potential Fire Related Damage to Safety-Related Equipment in Nuclear Power Plants		
Summary	During high-sensitivity tests, to maintain the cable/connector integrity of the test set, mechanical protection must be provided. The cable connector interface should be coated with fire-retardant mastic and shrink-tube should be fitted around it. The test set cable should be enclosed with metallic steel conduit or pressure hose. If possible, sealing material should be applied at the connector/equipment interfaces.		
Conclusion	None.		

Document Number	NUREG/CR-4479		
Coating Type		Publish Date	December 1985
Title	The Use of a Field Model to Assess Fire Behavior in Complex Nuclear Power Plant Enclosures: Present Capabilities and Future Prospects		
Summary	The Office on Nuclear Reactor Regulation requested a series of tests to ascertain the adequacy of the 20-foot separation guideline. Full-scale replicas of an NPP enclosure were set up, with cable tray systems representing two redundant trains located at a horizontal distance of 20 feet apart. In some of the tests in which one train (a vertical cable tray) was set on fire, the second train suffered electrical failures at varying times from the inception of the fire. IEEE 383 qualified cables fared better than their unqualified counterparts, and fire-retardant coatings and ceramic fiber blankets on cable trays improved the chances of survival of both cable types. No fire suppression was attempted; the goal was to ascertain the level of protection afforded by spatial separation alone, without benefit of the automatic suppression system.		
Conclusion	The tests provided insight into the fire growth process in a cable tray and the nature of the consequent damage to a second cable system separated by an intervening space. They did not, however, provide a basis for extrapolation of the data to the numerous enclosure geometries and equipment layouts found in NPPs.		

Document Number	NUREG/CR-4832		
Coating Type	"Flamemastic-like material"	Publish Date	March 1993
Title	Analysis of the LaSalle Unit 2 Nuclear Power Plant: Risk Methods Integration and Evaluation Program (RMIEP)		
Summary	Researchers used the COMPBRN fire growth code to calculate fire propagation and equipment damage.		
Conclusion	Only a very large fire will cause damage to the coated cables in Fire Area E.		

Document Number	NUREG/CR-5088		
Coating Type	None	Publish Date	January 1989
Title	Fire Risk Scoping Study: Investigation of Nuclear Power Plant Fire Risk, Including Previously Unaddressed Issues		
Summary	When the BFN fire started, the seal had been applied but the fire-retardant barrier had not. Therefore, at the time of the fire the seal could not be considered a qualified fire barrier. Once the fire-retardant coating was in place, the seal would have been considered a qualified fire barrier.		
Conclusion	In discussions of the BFN incident, the seal is sometimes described as having failed. This report clarifies that the seal was incompletely installed and did not fail as described.		

Document Number	NUREG/CR-5384		
Coating Type	None	Publish Date	December 1989
Title	A Summary of Nuclear Power Plant Fire Safety Research at Sandia National Laboratories, 1975–1987		
Summary	The issues investigated include the impact of aging on the fire damageability and flammability of cables and other types of Class 1E equipment, as well as on passive fire protection features such as cable wraps and coatings and fire barrier penetration seals.		
Conclusion	While each measure studied provided some increase in protection, similar measures developed by various manufacturers varied widely in effectiveness.		

Document Number	NUREG/CR-6042, Revision 2		
Coating Type		Publish Date	March 2002
Title	Perspectives on Reactor Safety		
Summary	Diagram of the BFN fire from the NRC Reactor Safety Course (R-800).		

Document Number	NUREG/CR-6220		
Coating Type	Century Series Coil	Publish Date	March 1995
Title	An Assessment of Fire Vulnerability for Aged Electrical Relays		
Summary	The Century Series coil spool comprises high-thermal-strength glass-filled polyester for extended life at elevated temperatures. The wire insulation is a polyamide-imide wire coating (180 degrees Celsius (°C) rating) that retains insulation integrity and mechanical strength at elevated temperatures. The encapsulation is described by the manufacturer as polybutadiene, solventless, and impregnant.		
Conclusion	Accelerated life tests conducted at an elevated temperature and maximum voltage have established a projected service life of 40 years at 55°C and 110 percent of rated voltage for this coil design.		

Document Number	NUREG/CR-6384, Volume 1		
Coating Type	None	Publish Date	April 1996
Title	Literature Review of Environmental Qualifications of Safety-Related Electric Cables: Summary of Past Work		
Summary	Fire-retardant coating and fire barriers are used in NPPs to prevent fire propagation through electrical and telecommunications cables. Fire-retardant coatings may be applied either along an entire cable run or only at critical		

	locations. The adequacy of several protective coatings was tested, and their relative effectiveness was demonstrated, in two studies.
Conclusion	Although no specific study relating to aging effects on cable polymers due to the presence of coatings was found, coatings can affect the dissipation of internal heat generated in power cables, thus exposing them to temperatures beyond design conditions. Also, coatings can absorb moisture, which could keep cables wet and accelerate their degradation. These factors are often accounted for in the design of a cable and hence discredited for their impacts on lifetime.

Document Number	NUREG/CR-6384, Volume 2		
Coating Type	None	Publish Date	April 1996
Title	Literature Review of Environmental Qualifications of Safety-Related Electric Cables: Literature Analysis and Appendices		
Summary	Cables in trays are typically sprayed with fire-retardant coatings to protect them from external sources of fire or extreme heat. This can prevent cables from dissipating internal heat, thus exposing them to temperatures beyond design conditions. Also, coatings can absorb moisture, which could keep cables wet and accelerate their degradation.		
Conclusion	Research is needed to determine whether coating-induced stresses on cables are significant enough to affect cable degradation rates, and, if so, whether current qualification requirements are sufficient to ensure that such stresses do not compromise accident survivability.		

Document Number	NUREG/CR-6476		
Coating Type	Acrylic Coating	Publish Date	October 1996
Title	Circuit Bridging of Components by Smoke		
Summary	The paper describes a range of test specimens and fire scenarios selected to study the impact of smoke on digital equipment. Three types of equipment were exposed to smoke: SIR boards, individual components, and functional circuits. The tests of individual components were designed to study the impact of smoke on circuit bridging, obscuration, and short-term corrosion. In these tests, exposure conditions such as burn temperature, fuel-to-air ratio, presence of galvanic metals, humidity level, and suppression effects were varied.		
Conclusion	The likelihood of circuit bridging was tested by measuring leakage currents and converting them to resistance in ohms. Hermetically sealed ceramic packages were found to be more resistant to smoke than plastic packages. Coating the boards with an acrylic spray provided some protection against circuit bridging. The smoke generation factors that most strongly affected the resistance were humidity, fuel level, and burn temperature. The use of carbon dioxide as a fire suppressant, the presence of galvanic metal, and the presence of PVC did not significantly affect the results.		

Document Number	NUREG/CR-6738		
Coating Type	Flamemastic 71A	Publish Date	September 2001
Title	Risk Methods Insights Gained from Fire Incidents		
Summary	Only one large cable fire has occurred in a U.S. NPP (the BFN fire), and the damage from that fire was limited. U.S. plants have a total experience base of over 2,000 years. By contrast, the experience for Soviet-designed plants includes at least five large cable fires in less than 1000 years of experience. In the United States, close attention is paid to the sealing of all fire barrier penetrations and openings. In several of the Soviet fire incidents, unsealed barriers allowed fires to spread virtually unchecked from room to room. Other potential factors include electrical maintenance and design practices and compartmentalization practices.		
Conclusion	No significant cable fires for Soviet-designed plants were identified in this review since the mid-1980s. This coincides with efforts in these plants to apply fire-retardant coatings on their cables and to upgrade the status and quality of their fire barriers.		

Document Number	NUREG/CR-6834		
Coating Type	None	Publish Date	September 2003
Title	Circuit Analysis: Failure Mode and Likelihood Analysis		
Summary	Most NRC-sponsored test programs have focused on cable flammability and the benefits of fire protection features such as barriers, coatings, low-flame-spread cables, spatial separation, and suppression. However, many of the test series did include substantial efforts to measure cable electrical performance during fire exposure. The tests were predominantly large-scale fire tests, but several small-scale investigations were also undertaken.		
Conclusion	A protective coating is generally a mastic material sprayed directly onto the cables in a cable tray or air. While coatings will delay cable heating during a fire, they are not designed to prevent thermal damage; rather, they are primarily intended to reduce cable flammability and minimize fire growth potential. They may have some impact on a cable’s failure mode, because the delay in thermal heating may result in a “slow cook” rather than a “fast burn” exposure. However, because coatings are applied only after cable installation, there is no impact on raceway contact. It may be appropriate to account for the impact of a coating by adjusting the nominal fire intensity influence factor to reflect a less severe but longer fire exposure (e.g., the slow cook versus the fast burn).		

Document Number	NUREG/CR-6850, Supplement 1		
Coating Type	None	Publish Date	September 2010
Title	Fire Probabilistic Risk Assessment Methods Enhancements		
Summary	Fire-retardant cable coatings are among the many factors that complicate the analysis of cable tray fires. Cables that are thermally stable are difficult to ignite and exhibit higher ignition temperature. A cable can ignite when its surface is hot enough to generate flammable gas, unless the level of oxygen available is insufficient for ignition. Then the gas may accumulate elsewhere and burn later.		
Conclusion	Because the analysis of cable tray fire propagation is complicated and depends on many factors, some unknown, the NRC recommends that licensees use fire propagation models from existing guidance only to analyze certain specific configurations, and that they develop plant-specific and configuration-specific models for other settings.		

Document Number	NUREG/CR-6850, Volume 2		
Coating Type	None	Publish Date	September 2005
Title	EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Volume 2: Detailed Methodology		
Summary	Cables coated by a fire-retardant coating should be considered as both thermal damage and fire spread targets. No credit may be given to the coating for delaying or preventing the onset of damage and/or ignition. However, coatings may be assumed to slow the subsequent spread of fire.		
Conclusion	Passive fire protection features include coatings, cable tray barriers, fire stops, dampers, penetration seals, doors, and walls. State-of-the-art fire modeling tools offer limited capabilities for modeling the effectiveness of these features, particularly if the equipment is degraded. For example, the effectiveness of an intact firewall can be evaluated, but the effectiveness of the same firewall with cracks or unsealed penetrations cannot.		

Document Number	NUREG/CR-7150, Volume 1		
Coating Type	None	Publish Date	October 2012
Title	Joint Assessment of Cable Damage and Quantification of Effects from Fire, Volume 1: Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure		
Summary	Because there are only limited data from tests on cable coatings, the PIRT panel concluded that it would be appropriate for test data analyses to consider combinations of jacket and insulation type, rather than jacket polymer alone.		
Conclusion	Cable coatings and electrical raceway fire barrier systems were expected to have no effect on intra-cable shorting and at most a small effect on inter-cable shorting. Coatings are applied to the outside of a cable or group of cables, so the impact on the cable itself is minimal. The most significant effect that might occur is a delay of the onset of damage. In addition, coatings may alter the effective exposure mode or the time/temperature relationship.		

Appendix B
Supplemental Information on Testing of Cable Coatings

B.1 Complete Full-Scale Two-Tray Propane Burner Test Results

Table B-1 provides a consolidated summary of the results of testing performed at Sandia National Laboratories in the late 1970s.

Table B-1. Results from Two-Tray Propane Burner Tests

Coating	Time to Electrical Short	Time to Ignition (minutes)	Fire Duration (minutes)	Affected Area (in.^{2})	IR to Ground (ohms)
					Post
IEEE 383 Qualified					
A (3/C)	20	10	18	442	132k
A (1/C)	+++	- - -		442	23.7
B (3/C)	23	10	9	510	2.4k
B (1/C)	+++	- - -		None	720k
C (3/C)	8	5	26	810	120k
C (1/C)	20	- - -		1170	0.41
D (3/C)	+++	- - -	N/A	N/A	>20M
D (1/C)	+++	- - -		N/A	>20M
E (3/C)	+++	- - -	N/A	N/A	4M
E (1/C)	+++	- - -		N/A	>20M
G (3/C)	+++	15	14	684	>20M
G (1/C)	+++	- - -	N/A	N/A	>20M
Uncoated Bottom	+++	5	9	432	26k
Uncoated Top	9	- - -	16	972	0.375
Nonqualified (3/C)					
E (Bottom)	32	- - -	N/A	N/A	5M
E (Top)	+++	- - -	N/A	N/A	>20M
G (Bottom)		10	15		0.74
G (Top)		No Propagation			
Uncoated Nonqualified Bottom	2	5	39	1206	1.1
Uncoated Nonqualified Top	6	N/A	59	1512	0.46

<u>Coating Key</u>

Coating A: Flamemastic #71A
Coating B: Flamemastic #77
Coating C: Vimasco #1A
Coating D: Albi-Clad
Coating E: Carboline Intumastic 285
Coating G: Quelcor 703B

B.2 Fire-Retardant Cable Coatings Not Tested in the NRC Fire Protection Research Program

The U.S. Nuclear Regulatory Commission's (NRC's) research program on fire-retardant cable coatings was not intended to evaluate all products in use or available on the market. Listed below are several coating products that were not evaluated. This is not an exhaustive list but illustrates the plentiful availability of such products.

FSS Thermalastic 83C™ is a Factory Mutual approved fire-retardant cable coating. The product website identifies the following fire-retardant mechanisms. During fire conditions, a chemical reaction produces cooling vapors from metallic hydrates in the coating. Inorganic components in the coating form a surface of high emissivity that results in the radiation of significant amounts of heat away from the protected cables. Fire retardants in the material form products that inhibit combustion in the immediate vicinity of the cables (Fire-Stop Systems USA 2015).

KBS Cable Coating is a Factory Mutual approved water-based ablative fireproofing material developed for the protection of grouped or bundled electrical cables and penetration seals. It consumes thermal energy through an endothermic process in which the coating ablates through chemical and physical reactions, creating gases that displace oxygen and dilute flammable gases. This coating has been tested in accordance with BS 476 Part 7, "Surface Spread of Flame Test," and IEC 60331-11, "Apparatus—Fire Alone at a Flame Temperature of at Least 750 °C" (Antec Engineering Pty Ltd 2015).

Firefree® Cable is a Factory Mutual approved (FM3971) ablative fire-retardant coating material (Firefree Coatings Inc. 2015)

Other Factory Mutual approved products include the following:

- Flammadur A77 (Germany), AIK GmbH
- Thermo-Lag 270 (United States), Carboline Co.
- Nelson FSC (United States), EGS Nelson Firestop Products
- FIRESEC FS 5 (Norway), Fire Security A/S
- Thermalastic 83C (United States/Canada), Fire-Stop Systems
- Hilti CP 678 Cable Coating and Hilti CP679A Ablative Cable Coating (Liechtenstein), Hilti Aktiengesellschaft
- Intertherm 677WB (Australia), International Paint
- Intumex AC (Austria), BiP GmbH
- CAFCO T.P.S., Type CT (United States), Isolatek International
- PROMASTOP CIS (Malaysia), Promat International (Asia Pacific) Ltd.
- Metacaulk BioFireshield, Industrial Cable Coating (United States), ReactorSeal Corp.
- Hemsomastik 5 KS (Germany), Rudolf Hensel GmbH
- SpecSeal Cable Spray CS105 (United States), Specified Technologies Inc.
- PYRO-SAFE Flammoplast KS1 and PYRO-SAFE Flammotect-A (Germany), svt BRANDSCHUTZ Vertriebsgesellschaft GmbH International
- Vimasco Cable Coatings No. 2-B and No. 3i (United States), Vimasco Corp.

Appendix C
Supplemental Cable Coating Testing Information

C.1 Example of Fire Load Calculations for Electrical Cables

The fuel loading of a tray is estimated in units of energy per foot (ft) (e.g., British thermal units (Btu)/ft) of tray. This result is then used to calculate the total fuel loading of a fire area. The fuel loading for a tray is calculated as follows:

$$Fuel\ Loading = N * H_c * (A_{ins} * \rho_{ins}) = \mathrm{N} * H_c * (ml_{cable} * f_{ins}),$$

where

- N = number of cables in tray
- H_c = heat of combustion of cable insulation
- A_{ins} = cross-sectional area of cable insulation
- ρ_{ins} = density of cable insulation,
- ml_{cable} = mass per length of cable
- f_{ins} = mass fraction of insulation

For example, consider the following conditions:

- cable tray dimensions: 2.44 meters (m) (8 ft) long, 304.8 millimeters (12 inches) wide, and 95.25 millimeters (3.75 inches) of inside rail height
- cable properties:
  - three-conductor cable with a diameter of 10 millimeters, mass per length of 0.13 kilograms per meter (kg/m), and copper mass fraction of 0.42
  - polyethylene (PE) insulation, insulation thickness of 1.09 millimeters, insulation mass fraction of 0.10
  - polyvinyl chloride (PVC) jacket, jacket thickness of 1.32 millimeters, jacket mass fraction of 0.36
  - filler mass fraction of 0.12

Table C-1. Polymer Heat of Combustion* and Density*

Polymer	**Heat of Combustion***		**Density***	
	MJ/kg	**Btu/lb**	**kg/m^3**	**lb/ft^3**
PE	43.28	18,607	920	57.44
PVC	16.43	7,064	1,305	81.48

**SFPE Handbook of Fire Protection Engineering*, Third Edition

It is important to note that the values for heat of combustion in table C-1 were measured using combustion bomb calorimetry. This is performed in ideal conditions, with precise amounts of fuel, pure oxygen inside a pressure vessel whose temperature is strictly monitored, and an apparatus designed to minimize heat loss (The SFPE Handbook of Fire Protection Engineering 2002). Furthermore, combustion is assumed to be complete, which may not be the case in in-plant environments. Nonetheless, the values given yield the maximum theoretical heat release.

The tray described above could fit a maximum of 270 cables if perfectly laid (with 30 cables horizontally and 9 cables vertically). For this tray and cable arrangement, the maximum theoretical fuel loading is estimated as follows:

$$Fuel\ Loading = \mathrm{N} * H_c * (ml_{cable} * f_{ins}) = 270 * 0.13\frac{\mathrm{kg}}{\mathrm{m}} * (1 - 0.42) * 43.28\ \mathrm{MJ/kg}$$

= 881 MJ/m (254,516 Btu/ft)

A configuration with these cable and tray dimensions was tested as part of this research program, as documented in Section 6.2.6 of Volume 2 of this Research Information Letter (RIL). The test tray contained 24 cables, representing 9 percent tray fill, and readily burned when uncoated. Given the assumptions and equation above, the theoretical heat release from the tray is 193.45 megajoules (MJ) (183,251 Btu).

For the latter test tray, the mass fraction of the insulation, jacket, and filler are known in detail and were used in the conditions above. These values can be used to estimate the theoretical total heat release more precisely. Since the properties of the filler are not known, it is assumed that its mass fraction is the same as that of the insulation. The fuel loading and total heat release are then calculated as follows:

$$Fuel\ Loading = N * ml_{cable} * ([f_{ins} + f_{filler}] * H_{c,ins} + f_{jacket} * H_{c,jacket}$$

= 24 x 0.13 kg/m ([0.1 + 0.12] x 43.28 MJ/kg + 0.36 x 16.43 MJ/kg)
= 48.16 MJ/m

Total Heat Release = 48.16 MJ/m x 2.44 m = 117.51 MJ

Table C-2. Comparison of Theoretical and Measured Total Heat Release

Example	Tray Fill	Total Heat Release, MJ (Btu)
Theoretical, assuming insulation properties	100%* (270 cables)	2149.64 MJ (2,036,128 Btu)
	9% (24 cables)	193.45 MJ (183,251 Btu)
Theoretical, assuming insulation and jacket properties	100% (270 cables)	1305.67 MJ (1,237,536 Btu)
	9% (24 cables)	117.51 MJ (111,378 Btu)
Test (measured)	9% (24 cables)	~65 MJ (61,646 Btu)

*Value typically reported in the fire hazard analysis.

In Table C-2. Comparison of Theoretical and Measured Total Heat Release, the calculations assuming 100 percent tray fill reflect the highest heat situation and the material with the highest heat of combustion (which in this case is the insulation). These assumptions yield a potential total heat release that is not realistic or representative of an operating plant. However, as stated previously, the use of these highly conservative assumptions means that there will be no need to revise the calculations when cables are added (assuming the cables added have a lower heat of combustion than those used for the original calculations). It also results in a fire protection system that is designed to account for the maximum possible heat release.

For the tray with 9 percent fill, the actual measured heat release during the test was 65 MJ, while the theoretical value was 193 MJ or 118 MJ (depending on whether all combustible material was assumed to be insulation or a combination of insulation and jacket material). Thus, the theoretical value was double or triple the measured value.

Cable trays in nuclear power plants typically contain a mixture of cable types. Most installations segregate the cables by electrical function (e.g., power versus instrumentation and control), but not by construction or material type. When licensees perform fire load calculations, it may be cost-prohibitive if not impossible for them to determine exactly what combustible materials are in a given tray. The assumptions described above, although they are very conservative, reduce the costs of calculating fire loads.

C.2 Example of Fire Load Calculations for Electrical Cables with Fire-Retardant Coatings

Similarly to the example above, to calculate the fuel load of a cable tray with fire-retardant coating applied, a licensee needs to estimate the mass per length of the relevant material and multiply this by its heat of combustion. Fire-retardant coatings contribute substantially to the total fuel load of a fire area; however, as documented in Volumes 2 and 3 of this report, they also greatly limit the heat release rate of a coated cable tray. This insight could be used in performance-based calculations using fire modeling techniques. However, for plants governed by deterministic calculations, fire protection systems must be designed based on the total heat load, regardless of heat release rate.

The example in this section considers a cable tray with the same parameters as assumed in Section C.1, only coated with Fire Security FS15 fire-retardant coating. (The same calculations could be performed for other coatings.) For the purposes of this example, the cables are assumed to be covered to the manufacturer-recommended thickness of 1.6 millimeters (1/16 inch). It is important to note that in practice, installed fire-retardant coatings vary substantially in thickness depending on how they were applied (e.g., by hand or sprayed), as well as on the underlying cable placement. These variations affect the accuracy of theoretical calculations and may lead to further conservatism.

The density of the coating material was estimated in two ways (see Volume 2, section 3.2.5). First, the “bulk” density was determined by weighing samples that had been prepared for cone calorimeter testing. Second, the “true” density (which excludes air gaps within the sample) was determined using a technique based on gas displacement. Only the “true” density will be used in this example.

Table C-3 Properties of Fire Security FS15

Fire-Retardant Material	Heat of Combustion*		“True” Density**		Approximate Volume of Fire-Retardant Material Assuming 1.6 mm Thickness			
					100% Fill***		9% Fill****	
	MJ/kg	Btu/lb	kg/m^3	lb/ft^3	m^3	ft^3	m^3	ft^3
FS15	17.6	7567	1660	104	0.003	0.11	0.001	0.035

*See Volume 2, table 3-6.
**See Volume 2, section 3.2.5.
***Calculated using a block with the internal dimensions of the tray covered in 1.6 mm thickness of coating.
****Calculated using a block of one row of cables covered in 1.6 mm thickness of coating.

Using the equations in Section C.1 and the properties of FS15 in Table C-3, the total heat release of a sample of 0.003 m^3 of FS15 is estimated to be 88 MJ; that of a sample of 0.001 m^3 of FS15 is estimated to be 29 MJ.

Table C-4 presents the calculated total heat release values for coated and uncoated trays under different tray fill assumptions (9 percent and 100 percent), as well as the measured values documented in Volumes 2 and 3 of this report. The table shows that in theoretical calculations, the use of a coating increases the total heat release. However, in experimental measurements, the use of a coating significantly reduces the total heat release, because it reduces the heat release rate.

Table C-4. Theoretical and Measured Total Heat Release for Uncoated and Coated Trays

Example	Tray Fill	Total Heat Release, Uncoated Tray, MJ (Btu)	Total Heat Release, FS15 Coated Tray, MJ (Btu)
Theoretical, assuming insulation properties	100%* (270 cables)	2150 MJ (2,036,128 Btu)	2238 MJ (2,121,214 Btu)
	9% (24 cables)	193 MJ (183,251 Btu)	222 MJ (210,415 Btu)
Theoretical, assuming insulation and jacket properties	100% (270 cables)	1306 MJ (1,237,536 Btu)	1394 MJ (1,321,257 Btu)
	9% (24 cables)	118 MJ (111,378 Btu)	147 MJ (139,329 Btu)
Test (measured)	9% (24 cables)	~65 MJ** (61,646 Btu)	~3.6 MJ** (34,121 Btu)

*Value typically reported in the fire hazard analysis.
**Values estimated from Volume 2 test data.

Appendix D
NFPA Definitions of "Fire-Retardant," "Flame-Retardant," "Fireproof," and Other Terms

This section presents several definitions found in the National Fire Protection Association's (NFPA's) glossary of terms, together with a short list of codes using each term. Many of these terms are used interchangeably within the fire protection community and convey the same meaning.

Fire-retardant

A liquid, solid, or gas that tends to inhibit combustion when applied on, mixed in, or combined with combustible materials.

NFPA 1, "Fire Code"

NPFA 909, "Code for the Protection of Cultural Resource Properties—Museums, Libraries, and Places of Worship"

NFPA 914, "Code for the Protection of Historic Structures"

Flame-retardant

So constructed or treated that it will not support flame.

NFPA 79, "Electrical Standard for Industrial Machinery"

Fire-Resistant

Construction designed to provide reasonable protection against fire.

NFPA 495, "Explosive Materials Code"

Fire-Resistive

Refers to properties or designs to resist the effects of any fire to which a material or structure can be expected to be subjected.

NFPA 1144, "Standard for Reducing Structure Ignition Hazards from Wildland Fire"

NFPA 914, "Code for the Protection of Historic Structures"

NFPA 1123, "Code for Fireworks Display"

Flame Resistance

The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or nonflaming source of ignition, with or without subsequent removal of the ignition source.

NFPA 1975, “Standard on Emergency Services Work Apparel”

NFPA 1951, “Standard on Protective Ensembles for Technical Rescue Incidents”

NFPA 2113, “Standard on Selection, Care, Use, and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire”

NFPA 1855, “Standard on Selection, Care, and Maintenance of Protective Ensembles for Technical Rescue Incidents”

NFPA 1971, “Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting”

NFPA 2112, “Standard on Flame-Resistant Clothing for Protection of Industrial Personnel Against Short-Duration Thermal Exposures from Fire”

Appendix E
History of Fire-Retardant Cable Coatings

This appendix contains a detailed description of the history of cable coatings, the fire events that took place during the tenure of the Atomic Energy Commission (AEC), the congressional hearing on the Browns Ferry Nuclear Plant (BFN) fire event, and the resulting regulations. Sections 2 and 3 of the report summarize the history and events following BFN.

E.1 Early Fire-Retardant Cable Coatings

The main motivation for the development of cable insulation was the invention of the commercial electric telegraph in 1837. Soon after telegraph technology became operational, there was a demand to increase its effective range. To establish telegraph communications between countries (and later continents), the British needed to run submarine cable under major waterways; thus, the primary goal of early cable insulation was waterproofing. This was initially accomplished using natural resins such as gutta-percha; later, rubber and then asphalt (bitumen) were also used. The secondary goal of insulation was durability against abrasion. For underwater applications, flammability was of no concern (Haigh 1968).

As technology evolved, cable was adapted for use in other industries. Advances in power generation and the development of alternating current created a need for long-distance land-based power distribution. The first high-voltage alternating current power station was developed in Great Britain in 1887 and opened in 1891 (Edison Tech Center 2014). The mining industry began using cables, run in wooden troughs, to transmit electrical power for operating machinery. These applications prompted further development of cable insulation technology. In particular, the amperage of electricity used for power applications—which is generally several orders of magnitude greater than that used for telecommunications—necessitated measures for fire protection.

The first attempts to fireproof electrical cable involved using asbestos fibers as a layer of the insulation material. Asbestos is a naturally occurring silicate mineral that has been mined for thousands of years. It was originally used by the Ancient Greeks for its ability to withstand fire damage, as documented by Herodotus in 456 B.C.[1,2] The material properties of asbestos made it well suited for strengthening items that would be exposed to heat (Selikoff and Lee 1978). Asbestos mining became commercialized in the late 1800s. One of its early uses was for insulating pipes.

At this time, natural resins were still the preferred material for cable insulation, and many common resins (including gutta-persha, rubber, and bitumen) are flammable. The use of natural resins gave rise to several fire incidents in which cable insulation was completely consumed by fire. In 1897, W.T. Glover and Company, a prominent cable manufacturer in London, developed a cable consisting of a high-conductivity copper wire encased in rubber insulation that was braided over with pure asbestos yarn and then with an abrasion-resistant layer. This cable was marketed as being nonignitable (Edmunds and Samuelson 1897), and it proved its effectiveness

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1 The word *asbestos* means “unquenchable” or “inextinguishable” in Ancient Greek.

2 Upon death, the wealthy would be embalmed in asbestos linen to prepare them for cremation and isolate their ashes from the ashes of the burning wood.

in a fire at The Liverpool Telephonic Exchange of the Lancashire and Cheshire Telephone Company.

In 1891, Isaac Merrell patented a fireproof paint product composed of pulverized ceramics and asbestos (Merrell 1891). Soon after, H.W. Johns Manufacturing Company began distributing a fireproof liquid asbestos paint product that was primarily meant to coat the structural members of buildings but was also used to coat electrical cables.

The mining industry was one of the first industries to express concern about the flammability of cable insulation. A typical mine contains long spans of cable that run down the mine shaft and along tunnel ceilings. The insulation of such cable could easily be abraded, causing an electrical arc which would ignite the insulation. This exact scenario occurred in 1917 at the Granite Mountain Copper Mine in Butte, Montana, where 168 men died because of a cable insulation fire. The incident began when crews were lowering a heavy cable down the mine shaft. The cable slipped from its clamps and fell to the bottom of the shaft, 2400 feet below. The cable was insulated with bitumen, an oiled paraffin paper, and an outer coating of lead. The outer coating was abraded during the fall, exposing the paper middle layer. When the men went to inspect the damage, they accidentally ignited the paraffin paper with a lamp. The fire spread along the cable insulation and eventually ignited the shaft timbers (Minememorial 2010).

In 1931, Turner and Newall, a prominent London-based company with a large market share in asbestos products, patented a machine that could spray a cement, water, and asbestos slurry called Limpet onto building structural elements for soundproofing, fireproofing, and condensation control. Limpet sales expanded rapidly during World War II, when the product was heavily used for fire protection in war ships (Tweedale n.d.). The workers at Turner and Newall were exposed to high concentrations of asbestos dust, and many developed asbestos-related diseases. Documented evidence exists that the company’s management knew about the health hazards of asbestos exposure but allowed hazardous conditions to persist.

Although health concerns due to asbestos exposure were documented as early as 1906, asbestos use remained immensely popular until the U.S. Environmental Protection Agency (EPA) passed laws to limit its use in 1973. At this point, companies like Turner and Newall were overwhelmed by lawsuits from workers and their families seeking compensation for illness and death attributed to asbestos exposure. Turner and Newall filed for bankruptcy in 2001 and now exists only in the form of a trust to fund future settlements related to asbestos liabilities (Mesothelioma Cancer Alliance 2015). However, to this day, asbestos use is not entirely banned.

Meanwhile, in the 1930s, polyvinyl chloride (PVC) was invented and began to replace natural resins as a synthetic alternative for insulating cables (Semon 1933). PVC was cheaper to produce and more abrasion-resistant than rubber, and it did not require vulcanizing with curatives or accelerators. PVC is electrically insulating but is sensitive to heat and ultraviolet radiation. It is a thermoplastic material, meaning that it melts when heated and resolidifies when cooled. While PVC inherently resists ignition, it will burn when exposed to an adequate ignition source. In the early years of its use, to make PVC more resistant to heat and flame, manufacturers added liquid coatings of a chemical called polychlorinated biphenyl (PCB) to flexible PVC and electrical components (Kaley, et al. 2006). The use of PCB coatings on PVC cable insulation continued until 1979, when EPA studies showed that PCB was carcinogenic to humans, and consequently the EPA banned the production of PCB (EPA 1979).

E.2 Fire Events Under the Atomic Energy Commission

In 1954, construction began on the Shippingport Atomic Power Station, which was the first full-scale nuclear power plant (NPP) in the United States. In this and other early NPPs, fire-retardant materials such as PCB and asbestos were used to prevent fire damage in electrical cables. One of the first major fire incidents at an operating commercial NPP occurred at the San Onofre Nuclear Generating Station in 1968. Between that event and the BFN incident on March 22, 1975, there were 39 fire-related incidents reported in U.S. NPPs, some of which directly involved cable fires in raceways and through penetration seals (Lindeman and Melly 2015, A62–A65). Table E-1 provides information about several particularly significant fire incidents during this period. These incidents brought the AEC's attention to the need for fire prevention to preserve nuclear safety. As a result, the AEC began to promote test programs to explore solutions to the problem.

Table E-1 Summary of Recorded Fire Events in U.S. NPPs

Plant	Incident Date	Description of Event
San Onofre, Unit 1	February 7, 1968	The fire occurred after "45 No. 6 AWG[3] conductors supplying the pressurizer heaters had each been loaded at approximately 46 amperes for 96 hours." Thermal overload accelerated the aging of the insulation and ultimately caused it to fail. It was reported that the cables were grouped in bundles, which prevented adequate ventilation from dissipating the heat (Southern California Edison Company / San Diego Gas & Electric Company 1968, 5-1).
San Onofre, Unit 1	March 12, 1968	This incident occurred when feeder cable in a raceway ignited and caused significant damage to several other cables. Two similar fire events had happened earlier in the plant's lifetime. The raceways were overloaded with cables, which were piled up above the side rails, preventing heat dissipation and subjected the cables in the bottom of the raceways to abnormal stresses (Southern California Edison Company / San Diego Gas & Electric Company 1968, 1-7). The fire was confined to three overhead cable trays stacked one above the other. The cables in the trays were badly burned for a length of 15 feet. The trays contained 185 electrical circuits, including the leads for the pressurizer heaters. The zone of influence of the fire was relatively small. There was no overheating of the grates, the beams, or the air intake located 38 inches above the trays (Southern California Edison Company / San Diego Gas & Electric Company 1968, 1-3, 5-2). A joint task force was assembled to investigate this incident and recommend corrective actions. The task force recommended using heavier-gauge cables to prevent thermal overloading, and distributing cables between different raceways to avoid physically overloading any one raceway (Southern California Edison Company / San Diego Gas & Electric Company 1968, 5-4, 5-5). These events prompted additional research that ultimately resulted in the development of an ampacity standard.

[3] American Wire Gauge (AWG) is the standardized wire gauge system used in the United States.

Plant	Incident Date	Description of Event
Quad Cities, Unit 2	July 16, 1972	There was a fire in two electrical trays in the reactor building. The fire was confined to approximately 5 feet at the end of two cable tray sections (U.S. Congress 1975, 1191).
Oconee, Unit 2	June 27, 1975	A fire took place in the turbine building. An oil leak from the turbine oil purifier system ignited when it came in contact with the purifier heaters. Cables above the fire were charred; however, there was no loss of operational circuits (U.S. Congress 1975, 1192).

E.3 Browns Ferry Nuclear Plant Fire and Congressional Hearings

On March 22, 1975, a fire broke out at the BFN plant when a worker who was using a candle to test a polyurethane penetration seal between the cable spreading room and equipment room accidentally ignited the seal. The fire spread to the cable insulation and burned for 7 hours, damaging critical plant systems, including the emergency core cooling system. Fortunately, both reactors were manually shut down without any damage to the nuclear fuel or primary containment structures.

The incident, one of the most severe in the history of nuclear power generation in the United States, prompted significant advancements in fire protection standards for NPPs. Immediately after the incident, several organizations conducted independent investigations into it. The results of these investigations were presented before the U.S. Congress Joint Committee on Atomic Energy (JCAE) in a series of hearings which began on September 16, 1975.

During these hearings, the JCAE expressed concern over the lack of regulatory attention given to cable insulation fires. The committee felt that procedural and installation issues at BFN should have been identified by both the NRC and the Tennessee Valley Authority (TVA) in their prior inspections of the facility.

The JCAE asked how the NRC's inspection program had failed to identify the fire hazard before the incident occurred. NRC representatives responded that the NRC already had test programs in progress to analyze the flammability of cable insulation. However, these tests used single cables, whose behavior might not accurately represent that of a bundle or group of cables in a cable tray application. In addition, the room in which the BFN fire had broken out had previously been inspected multiple times; however, these inspections all focused on the criteria related to cable separation distances between redundant systems, as outlined in Regulatory Guide 1.75, "Physical Independence of Electric Systems," and Institute for Electrical and Electronics Engineers (IEEE) standard IEEE 383, "IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations" (U.S. Congress, 1975, 17–19).

When BFN Units 1 and 2 were placed in service, the penetrations seals in the cable spreading room had not been installed. The TVA was in the process of installing these seals when the fire occurred. The JCAE asked why the missing penetration seals had not already been documented and addressed in NRC and TVA inspections. The NRC explained that the inspections followed a specific plan covering only certain representative samples of the facility, which in this case had not included the penetration seals. The JCAE also asked why the TVA had not notified the NRC of its plans to make an alteration to the plant. The answer was that Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59, “Changes, tests and experiments,” allows licensees to make changes to a plant without notifying the NRC unless they believe the changes will affect something that poses a significant safety hazard. This judgment is based on the licensee’s own evaluation of the situation. In this case, the TVA had not done a self-assessment, and so the NRC assumed that this meant the TVA did not believe that the modification would pose a significant safety hazard. The technical specification requirement at the time was that airflow through a penetration be restricted to a maximum of 7,000 cubic feet per minute or a differential pressure of 0.25 inches of water (U.S. Congress, 1975, 75). The method used to achieve this condition was left to the licensee’s discretion. The TVA was in compliance with that requirement before beginning operations; the addition of the polyurethane foam penetration seal was an upgrade that did not require NRC notification (U.S. Congress, 1975, 69–72).

Bernard C. Rusche, the Director of the Office of Nuclear Reactor Regulation, provided additional testimony on the state of the reactor during the fire and on the challenges that the fire brigade faced in mitigating the incident. At no point was there immediate danger of a radioactive release from the reactor. Once the control room had been notified of the fire, the operators began to monitor the event and make decisions on how to best protect the reactor core and containment. Roughly 15 minutes after the fire started, the operators elected to manually scram the reactor, a decision saved time and enabled the operators to more effectively manage the decay heat from the fuel rods. If they had not made this decision, however, the scram would subsequently have been initiated as an automatic function of the reactor protection system, in response to damage to protection circuitry. Mr. Rusche emphasized that the failsafe functions of the reactor protection system had worked as designed. The operators used the safety relief valves to depressurize the reactor so that low-pressure pumps could be used for cooling. The reactor needed to be scrammed as a protective measure, but there was never a deficiency of cooling water from multiple low-pressure sources.

The JCAE asked what implications the BFN event might have on other operating reactors in the United States. Mr. Rusche explained that while there were procedural and regulatory improvements to be made, he did not feel that it was necessary to suspend the operation of other plants. One improvement he identified was related to the prevention of and response to cable insulation fires. The JCAE had mentioned nine cases of cable insulation fires involving cables trays. One major issue during the BFN event was that firefighters could not confirm that the cables had been deenergized, so they did not feel that it was safe to use water to extinguish the flames. In addition, carbon dioxide extinguishers were available in the cable spreading room, but they were not readily available on the other side of the penetration in the reactor room. (Carbon dioxide is an acceptable agent for extinguishing Class C electrical fires, whereas water is not.) Mr. Rusche promised the committee that the NRC would give greater attention to the question of preventing and responding to cable insulation fires (U.S. Congress, 1975, 73–85).

E.4 Fire Protection Regulations After the Browns Ferry Nuclear Plant Incident

After the BFN fire, the NRC implemented new fire protection regulations in 10 CFR 50.48, “Fire protection,” and Appendix R, “Fire Protection Program for Nuclear Power Facilitates Operating Prior to January 1, 1979,” to 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities.” These regulations laid out deterministic design criteria that would apply to NPPs licensed after January 1, 1979. Plants could commit to complying with Appendix R as one way of satisfying the NRC's fire protection requirements. Three sections of Appendix R applied to plants licensed before 1979: Section III.G, "Fire Protection of Safe Shutdown Capacity"; Section III.J, "Emergency Lighting"; and Section III.O, "Oil Collection System for Reactor Coolant Pump." The affected NPPs were required to backfit their existing equipment to comply with these sections. The implications of section III.G were a source of contention between the industry and the NRC. Section III.G.2 states in part the following:

> b. Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance more than 20 feet with no intervening combustibles or fire hazards [emphasis added]. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area; or
>
> c. Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having 1-hour rating. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area;
>
> Inside non-inerted containments one of the fire means specified above or one of the following fire protection means shall be provided…" (U.S. CFR 1981, 1039).

Tests done at Sandia National Laboratories between 1977 and 1978 had suggested that fire-retardant cable coatings reduce the probability of ignition in electrical cables and inhibit flame spread both vertically and horizontally (Klamerus 1978). In the wake of the BFN fire, based on the recommendation of the NRC's Auxiliary and Power Conversion Systems Branch (APCSB) Branch Technical Position APCSB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants," dated May 1, 1976 (Collins, et al. 1976), plants installed or planned to install fire-retardant cable coatings. However, further research showed performance variations across coating manufacturers and several other test parameters. As a result, fire-retardant cable coatings came to be regarded not as a comprehensive solution to cable fires, but rather as a layer of resistance in a problem that required additional intervention (1982).

The proposed new regulations in 10 CFR 50.48 and Appendix R to 10 CFR Part 50 were announced in Generic Letter 80-45, "Fire Protection Rule," dated May 19, 1980 (NRC 1980). This letter contained a controversial statement about fire-retardant cable coatings that the industry felt was inconsistent with the NRC's previous position. The letter stated that "fire-retardant coatings retard fire propagation but do not prevent organic cable insulation and jacket materials from burning" (NRC 1980, 23). This position caused disagreement between the industry and the NRC, because for plants constructed before 1979, it would have been prohibitively expensive to move cables to comply with the 20-foot separation requirement of Appendix R, Section III.G.2. Furthermore, the utilities that had invested in fire-retardant cable coatings in the late 1970s had not expected the NRC to categorize coated cables as intervening combustibles. The NRC found that different licenses had significantly varying interpretations of certain requirements in Appendix R to 10 CFR Part 50. To clarify the requirements, the NRC released Generic Letter 83-33, "NRC Positions on Certain Requirements of Appendix R to 10 CFR 50," dated October 19, 1983 (NRC 1983), in which the agency took the position that "Section III.G.2.b requires 'separation...with no intervening combustibles...' To meet this requirement, plastic jackets and insulation of grouped electrical cables, including those which are coated, should be considered as intervening combustibles" (NRC 1983, 4). With this change, fire-retardant coatings transitioned from being recognized as fire protection measures to being seen as intervening combustibles. That meant that utilities would have to make further modifications to comply with Section G of Appendix R.