NUMARC

NUCLEAR MANAGEMENT AND RESOURCES COUNCIL

1776 Eye Street, N.W. • Suite 300 • Washington, DC 20006-2496
(202) 872-1280

October 26, 1992

Mr. Conrad E. McCracken
Plant Systems Branch Chief
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. McCracken:

Enclosed is a revised version of the draft white paper discussing NUMARC's proposed test and acceptance criteria for fire endurance testing to be used for performance of the industry test program to address the Thermo-Lag fire barrier issue. An earlier version of this paper was provided to NRC on September 15, and discussed with you and your staff in a meeting held September 24. The enclosed revision has been substantially expanded to provide detailed technical rationales for the proposed acceptance criteria, and to address the issues raised by NRC in our previous meeting. We will be meeting with you on November 5 to discuss this paper further, and to address any staff questions.

In summary, the proposed criteria are as follows:

1. Testing would be conducted to the standard ASTM E 119 time-temperature curve. Appendix II provides a discussion of the conservative nature of this time-temperature curve.

2. Test protocol relative to thermocouple placement, specimen configuration, and temperature measurement would be in accordance with UL Subject 1724.

3. Fire testing will be performed without cables in the enclosures to conservatively address thermal mass considerations and alleviate the potential for cables blocking heat transfer to thermocouples.

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4. Temperatures will be measured on bare copper conductors placed in accordance with UL 1724 requirements. A maximum temperature of 250°C would provide a basis for acceptance of the tested enclosure for use with power and control cables. For instrument cables, loop inaccuracies may result at elevated cable temperatures, and a plant-specific engineering evaluation should be performed to justify use of the tested enclosure for temperatures greater than 200°C.

   [The above temperatures have been determined based on evaluation of existing equipment qualification test data for cable functionality at elevated temperatures. These test data cover cable types commonly used in nuclear plant safe shutdown applications. A sufficient base of test data exist for cable functionality at elevated temperature exists such that we do not anticipate the need for performance of additional air oven tests. The equipment qualification tests were performed to rigorous conditions and provide an appropriate basis for demonstration of cable functionality.]

5. UL 1724, Sections 9.3 and B4.5 discuss the approach of adding the cable rating temperature to the observed temperature rise from the fire test to account for the temperatures of initially energized circuits. We do not believe this approach is necessary. Appendix V provides a heat transfer calculation relative to the effect of initial temperature on the endpoint temperature for a typical power cable. This calculation shows the effect to be minimal (12°C) at one hour, and negligible at three hours. Other calculations in this Appendix demonstrate the accuracy of the #8 bare copper conductor for determination of enclosure temperature.

6. No hose stream test is proposed as there is not a clear technical basis for this requirement. Appendix III provides a discussion of hose stream testing.

7. No criterion for barrier burn through is proposed. In the case of a sacrificial material like Thermo-Lag, physical appearance of the barrier at the end of the fire exposure is immaterial if enclosure temperatures have been maintained to appropriate values. The use of empty enclosures and bare copper conductors for temperature measurement will provide assurance of detection of any burn throughs or hot spots that could result in cable damage in an actual application.

We look forward to meeting with you on November 5 to explain these proposals in more detail. In the meantime, please contact me or Alex Marion if you have any questions.

Sincerely,

Biff Bradley
Senior Project Manager

REB/cma
Enclosure

cc: Mr. Ashok C. Thadani, NRR
Mr. Ralph E. Architzel, NRR

FIRE TESTING ACCEPTANCE CRITERIA

FOR ELECTRIC CABLE SYSTEM

FIRE BARRIER ENCLOSURES

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Executive Summary

Title 10 Code of Federal Regulations (CFR) Part 50, Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," section III.G.1.a established a performance requirement for protection of plant safe shutdown capability. "One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage." Appendix R further gave prescriptive requirements of "ensuring that one of the redundant trains is free of fire damage . . ." These requirements included "Separation of cables and equipment and associated non-safety circuits of redundant trains by a fire barrier having a 3-hour rating," or "Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour rating." A variety of barrier designs which measurably improved the level of safety against fire were offered by barrier material vendors and accepted by nuclear utilities and insurers of nuclear power plants.

In subsequent regulatory documents (Generic Letter 86-10), the USNRC staff provided guidance for testing of these cable-protecting fire barrier enclosures by reference to ASTM E-119, "Standard Methods of Fire Tests of Building Construction and Materials." Cable protection systems have specific performance objectives different from those of the structural assemblies described in ASTM E-119/NFPA 251. The sample size, thermocouple location and acceptance criteria should not apply to cable system fire barrier enclosures. Therefore, cable system fire barrier enclosures can not be tested in accordance with all the specific requirements of ASTM E-119 and produce meaningful results.

After the installation of many cable system fire barrier enclosures, the USNRC has raised concerns about the adequacy of testing, design, and installation of barriers constructed of TSI's Thermo-Lag material. The first step in addressing many of these concerns is defining acceptance criteria based on performance objective defined in 10 CFR 50, Appendix R.

To resolve these issues, NUMARC offers the following proposals regarding testing and performance-based acceptance criteria.

1. Test protocol regarding sample size, temperature measurement procedures, and time-temperature exposure should be based on Underwriters Laboratories Subject 1724, Outline of Investigation for Fire Tests for Electrical Circuit Protective Systems. The methods described in ASTM E-119/NFPA 251 do not apply to cable system fire barrier enclosures, (except that the standard Time-Temperature curve used in both ASTM E-119/NFPA 251 and UL 1724, represents a conservative and severe fire exposure for testing of these enclosures).

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2. Acceptance criteria for fire damage should be based on the cables being able to perform their intended function during and after the fire exposure, as necessary. Generic Letter 86-10 defines free of fire damage as "the structure, system, or component under consideration is capable of its intended function during and after the postulated fire, as needed." This means the maximum thermal exposure that would be seen by a cable inside the fire barrier enclosure should not cause a cable failure at the service voltage and amperage necessary to perform its function.

3. Based on environmental qualifications data and fire test data, a conservative generic temperature acceptance criteria of 250°C (482°F) as measured in the UL 1724 protocol is proposed for power and control cables. If temperatures in excess of 250°C are reached during the test, specific EQ/LOCA or specific air oven tests can be used to verify the performance of the cables. For instrument cables, engineering evaluation of instrument loop inaccuracies should be performed for temperatures exceeding 200°C.

4. Fire endurance tests of cable system fire barrier enclosures need not incorporate a hose stream test as in ASTM E-119. This test has no bearing on the ability of the cable system to perform its intended function.

The technical bases for these positions are contained in this document.

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1.0 INTRODUCTION

1.1 Purpose

General Design Criterion 3 of 10 CFR Part 50, Appendix A states "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." Specific regulatory guidance on meeting criterion 3 has been provided over the past 16 years (see Appendix I). These guidance documents have evolved as the technical information and experience dictated. As technical issues regarding fire protection arise, it is important that these issues be resolved based on performance criteria consistent with the safety objective of plant systems. The purpose of this document is to define the technical issues relating to cable system fire barrier enclosures, establish the performance objectives for these enclosures and to outline a testing method and acceptance criteria to demonstrate these performance objectives are achieved.

1.2 Fire Endurance Test Standards

Fire endurance standards in the United States, both ASTM and NFPA, share a common origin. Joint meetings of various groups with interests in the fire problem throughout the United States were convened in 1915 and 1916. Representatives at these meetings included members of the American Society of Testing and Materials, National Fire Protection Association, Underwriter's Laboratories, National Bureau of Standards, National Board of Fire Underwriters, Associated Factory Mutual Insurance Companies, American Institute of Architects, American Society of Mechanical Engineers, American Society of Civil Engineers, Canadian Association of Civil Engineers, and American Concrete Institute. A consolidated standard for the testing of both walls and floors was adopted by a conference of those bodies on February 24, 1917 under the designa-

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tion ASTM C-19. This standard contained a prescribed time-temperature curve for the fire test furnace and assigned a maximum unexposed side single point temperature of 149°C (300°F) for walls. In 1926, this was changed to an average temperature rise of 139°C (282°F) and a maximum single point temperature of 181°C (358°F). The test method also included a standard hose stream test.

The NFPA adopted the test protocol as NFPA 251 at its annual meeting in 1918. The ASTM and NFPA standards have evolved separately with separate membership of the standards committees and different review, revision, and re-affirmation cycles. Both the ASTM and NFPA fire endurance test methods share the same temperature-time fire exposure curve and contain similar requirements for acceptance in response to fire exposure and hose stream.

The basic methods of tests in each of the standards are common to all types of assemblies addressed by the standards. However, different and specific criteria are applied to different types of assemblies, including bearing walls and partitions, non-bearing walls and partitions, columns, floor and roof assemblies, loaded and unloaded restrained or unrestrained beams, and protective membranes for wall, floor, and roof assemblies. The arrangement and size of test specimen, thermocouples, and acceptance criteria differ for each type of assembly. The unique fire barriers of cable system enclosure are not included and do not fit into any of these categories.

Although the standard temperature-time curve of ASTM E-119/NFPA-251 might be used for qualification testing of alternate types of fire endurance rated assemblies, the fire protection community recognized that <u>the specific requirements of these standards with regard to test specimen, measurement of critical parameters, and conditions of acceptance, cannot be directly applied to alternate constructions such as fire doors, fire dampers, through-penetration seals and cable system fire barrier enclosures</u>. The response

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was the adoption of ASTM E-152 and NFPA 252 on Fire Doors in 1941. UL 555 was subsequently developed to address the unique fire testing and acceptance criteria for fire dampers. The USNRC required 3-hour rated dampers in BTP APCSB 9.5-1 although a standard "fire damper" was tested for 1-1/2 hour rating. In 1979, UL 555 was modified to incorporate a 3-hour test.

The testing and acceptance criteria for fire doors and dampers vary significantly from those included in ASTM E-119/NFPA 251. Approved and accepted fire doors and dampers could not meet the acceptance criteria as applied by ASTM E-119/NFPA 251 for non-bearing fire walls. Because their methods of fabrication, application, and function are different, it is generally accepted that such equipment need not meet the same conditions of acceptance as the fire barrier walls in which they may be installed.

In a similar manner, the testing and acceptance criteria of ASTM E-119/NFPA 251 do not (and should not) apply directly to penetration seals and cable fire barrier enclosures. This was recognized with respect to penetration seals and responded to initially by the development of an ANI test protocol specifically addressing cable and pipe penetration fire stops. The USNRC also provided guidance to licensees (see Appendix I) on penetration seals. Later, the fire test standards organizations responded to the recognized unique fire endurance testing requirements for penetration seals. IEEE 634, Standard Cable Penetration Fire Stop Qualification Test, was adopted in 1978. ASTM E-814 on penetration fire stops was adopted in 1981 and was subsequently adopted by Underwriters Laboratories as UL 1479. While both contain fire exposure and hose stream testing in conformance with ASTM E-119, the arrangement of specimen, measurement of critical parameters, and conditions of acceptance are very different from those contained in ASTM E-119.

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Similarly, nuclear licensees, power plant designers and constructors, nuclear insurance organizations, and fire testing laboratories acknowledged that the requirements of ASTM E-119/NFPA 251 are not directly applicable to cable system fire barrier enclosures and that an alternate test method must be provided. The initial response to this need was the development of the ANI/MAERP Standard Fire Endurance Test Method to Qualify a Protective Envelope for Class 1E Electrical Circuits. This was the first such test protocol for fire endurance-rated cable system fire barrier enclosures and remains the test protocol which has been most widely applied in the testing of protective envelope systems for use in nuclear power plants in the USA. The ANI method provided the basis for the test protocol in UL 1724, which has been used by UL to list[1] electrical circuit protective systems. The ANI and UL tests contain similar requirements for specimen arrangement, fire exposure test, hose stream test, and conditions of acceptance, which differ from those contained in ASTM E-119/NFPA 251. ASTM also recognized the need for a fire endurance test for circuit protective envelope systems which would be separate and distinct from ASTM E-119.

In 1986, ASTM convened Task Group E5.11.8 to develop a fire test method for circuit protection systems. The initial draft of the proposed ASTM standard was based on the ANI test method. Membership in the ASTM E5.11.8 task group includes representatives of test laboratories, vendors, research scientists, building code organizations, consultants, architect/engineers, power plant operators, the NRC, and insurers. The proposed standard remains an internal ASTM draft.

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[1]Note - UL "lists" tested configurations against their standards and publishes these listings in their approval guide.

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2.0 PROPOSED TEST PROTOCOL

This section describes the test protocol proposed by NUMARC which is based on voluntary standards activities of UL and ASTM. The technical basis for the protocol and the comparison to ASTM E-119/NFPA 251 are included.

2.1 Fire Exposure

The proposed fire exposure is the standard time-temperature curve which is shown in Table 2.1. This fire exposure is in common with the testing of all assemblies, including doors, dampers, and penetration seals as well as those structural components addressed in ASTM E-119/NFPA 251.

TABLE 2.1

Standard Time-Temperature Exposure

Temperature	Time into Test
1000°F (538°C)	at 5 min
1300°F (704°C)	at 10 min
1550°F (843°C)	at 30 min
1700°F (927°C)	at 1 h
1850°F (1010°C)	at 2 h
2000°F (1093°C)	at 4 h
2300°F (1260°C)	at 8 h or over

This exposure is severe and conservative when compared to compartment fires in nuclear power plants (See Appendix II.) This standard curve was prescribed by the ASTM committee in 1917, without any information about what actual fire exposures would be. Large scale building burnouts were conducted from 1922 to the 1940's by the National Bureau of Standards. The actual fire test data was

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not published, but S.H. Ingberg of NBS published conclusions on fire severity based on fire load, with the standard time-temperature curve being the most severe. Minor and Berry (1) of Sandia National Laboratory concluded that although the standard time-temperature curve can not be considered as representative of a compartment fire in a nuclear power plant, the exposure should not be changed because:

- A large amount of experience has been gained usir the standard exposure,
- No "standard" exposure can be defined which will eliminate all such objections, and
- Utilities are expected to assess the types of fires to which a given barrier may be exposed and evaluate the barrier in the light of such knowledge.

2.2 Test Sample Configuration

From UL 1724 the test sample configuration is as follows:

> The raceways protected by electrical circuit protective systems are to be representative of the smallest and largest sizes for which rating is desired. The raceways are to be installed as complete systems and are to each incorporate at least one intermediate support which is representative of that for which rating is desired. The raceways are to terminate a maximum of 36 inches (914 mm) beyond the unexposed surface of the floor or wall assembly.

The smallest cross-sectional area represents the smallest thermal mass and should be the limiting case for the speed of heating up, and reaching the highest internal temperatures. The largest cross-sectional area represents the limiting case for structural stability of the barrier material.

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The test sample must be conditioned prior to the test. The test assembly moisture condition is to be considered as that which would be established in equilibrium from drying of a sample in air having a 50% relative humidity at 73°F (23°C). This is also a common requirement of ASTM E-119/NFPA 251.

It is proposed that no insulated conductors be installed inside the fire barrier enclosure test sample. Any cables introduce thermal mass in the enclosure which retard heating of the cables. Cable loading introduces a virtually infinite combination of materials and raceway loadings. Grouped cables will also shield each other, and introduce uncertainty over the "worst case" location to measure cable temperature. The proposed temperature measurement technique is a bare copper wire which represents a conservative case of low thermal mass (resulting in rapid heating). The pertinent provisions of the UL 1724 protocol is as follows:

> The electrical conductors within the electrical circuit protective system are to be simulated by No. 8 AWG (8.38 mm^2) stranded medium or hard-drawn temper bare copper conductors weighing 0.051 pound per foot (75 g/m). The bare copper conductors are to have an outside diameter of 0.146 inch (3.71 mm) and are to consist of seven 0.049 inch (1.24 mm) diameter strands. The bare copper conductors are to be installed along the entire length of the electrical circuit protective system, and are to terminate within the floor or wall firestop system. The bare copper conductor fill within the electrical circuit protective system shall be in the minimum fill which will effectively cover the supporting surface of the raceway.

2.3 Sample Temperature Measurement

As will be discussed in Section 3.0, the measurement of the temperature of the cable inside the enclosure is the most effective measure of thermal performance of the fire barrier enclosure. To measure temperature, thermocouples will be placed on the bare

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copper conductors at 12 inches on center. These thermocouples will be held in direct contact with the conductor with steel wire ties. To measure the temperature of the raceway, thermocouples will be placed on the bottom and side of the raceway at the locations shown in Figure 2.1. These thermocouples will be held in place by wire ties, screws, bolts, or other positive fasteners. The temperature of these locations will be measured at intervals of 5 minutes or less. The raceway temperatures are used for comparison purposes. Acceptance criteria will be based on the bare copper wire temperatures.

2.4 Hose Stream Test

Structural integrity of cable system fire barrier enclosures in response to the ASTM E-119 standard hose stream test is not a relevant measure of the ability of the system to achieve its goal of maintaining the function of the cable system being protected. Hose stream tests are currently required for walls, in accordance with ASTM E-119/NFPA 251. Floors, ceilings, roofs, beams, columns, and protective membranes are not required to be subjected to a hose stream test. The hose stream test, which dates back to 1917, has been eliminated in total from international standards and is not applied outside North America. The test conditions do not reflect any rational performance objective related to cable system fire barrier enclosures or their ability to function in the field. The hose stream test is also difficult to prescribe and execute for a 3 dimensional enclosure, since the requirements of ASTM E-119 are for a 2 dimensional wall, a minimum of 100 sq ft and a minimum of 9 feet on a side. (See section 4.3.) Therefore, no hose stream test requirement is proposed. Appendix III provides further technical discussion to support this position.

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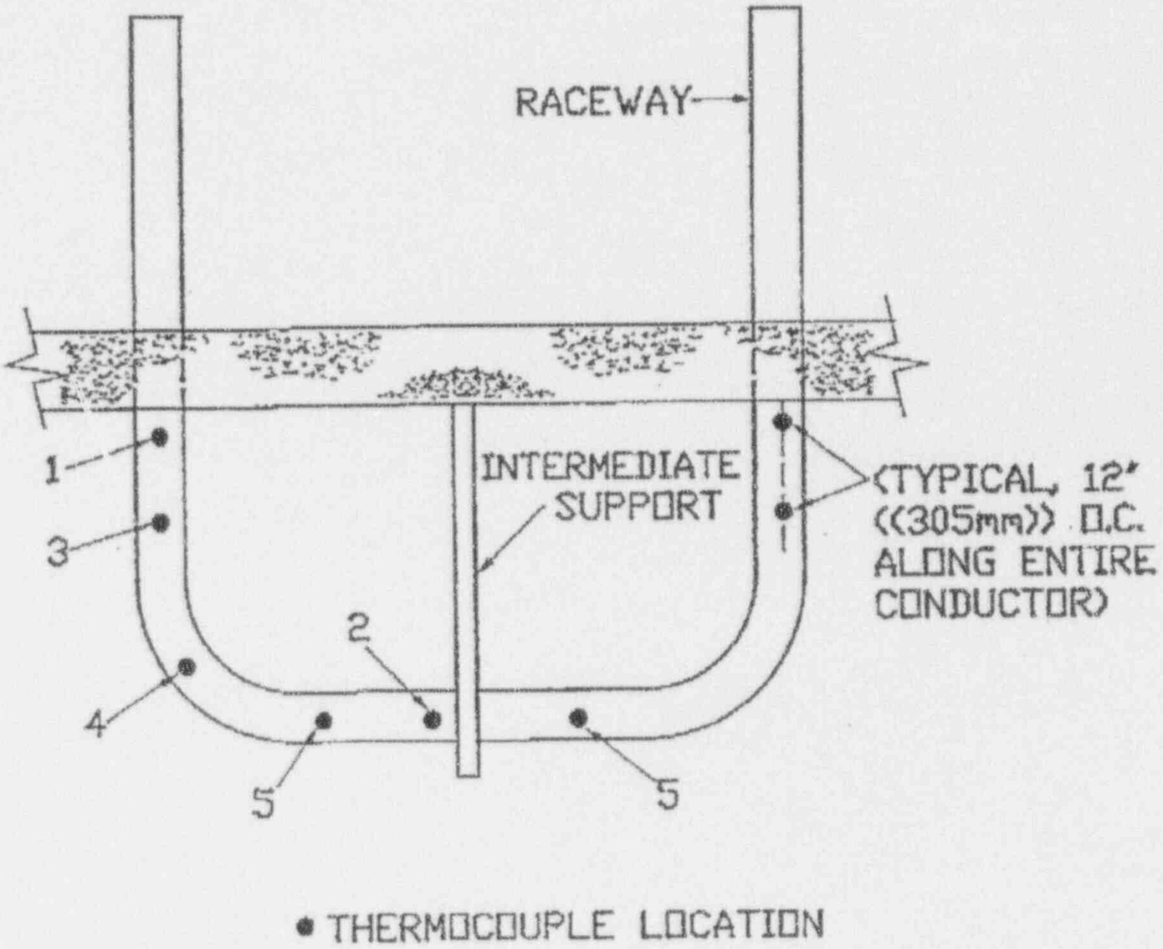
Figure 2.1

TEMPERATURE MEASUREMENT LOCATIONS



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3.0 ACCEPTANCE CRITERIA

3.1 Cable Performance Criteria

10 CFR, Part 50, Appendix R, III.G.1 states that fire protection features shall be capable of limiting fire damage so that one train of systems necessary to achieve and maintain hot shutdown conditions is free of fire damage. for an electrical cable "free of fire damage" from a safe shutdown standpoint means that the circuit can perform its intended function to achieve and maintain hot shutdown for up to 72 hours. This functionally identifies circuit performance as a key measure of damage. Loss of cable function is unacceptable. Therefore, acceptance criteria should be b: ed on the temperature performance of the cable insulation and jacket materials. Based on the test data described below, a maximum temperature of 250°C (482°F) measured on a bare copper conductor inside the fire barrier enclosure is an appropriate conservative peak temperature acceptance criteria. If the temperature measured on the bare copper wire inside the enclosure does not exceed 250°C (482°F) during the fire exposure duration, the fire barrier enclosure is acceptable for power and control cables. Instrument cables should be evaluated for loop inaccuracies when temperatures exceed 200°C (392°F).

Although another consideration for quantifying cable damageability is whether the cable has to be replaced after the fire, if the cable has performed its intended function during and after the fire, replacement becomes a restart (repair) issue but not a safe shutdown issue. Damage such as loss of elasticity, discoloration, jacket blistering, and mass loss may require a cable to be replaced however, those conditions are not relevant acceptance criteria if the cable can perform its safe shutdown function.

extensive research has been conducted on the performance of electrical cables at high temperatures. This research has included thermal accelerated aging, high temperature performance, and environmental qualification (LOCA).

The impact of temperature on cable performance is a major reason for environmental qualification testing of cables. The effect of temperatures will depend on the function of the cable. Control and power cables can perform their function properly as long as they can carry their intended current and voltage. For instrument and signal cables, however, leakage current from reduced insulation resistance (IR) may introduce errors in instruments (See Appendix III).

Environmental qualification testing can provide the temperature performance data necessary to develop acceptance criteria for cable system fire barrier enclosure. Nowlen and Jacobus (2) of Sandia National Laboratories compared fire damageability test data with high temperature steam testing and concluded the following.

> Direct comparisons were made between cable thermal vulnerability data gathered in two independent studies. The first of these studies was performed as a part of efforts specifically intended to address fire safety issues. The second study was performed as a part of the Nuclear Plant Aging Research (NPAR) program and involved the exposure of a number of common nuclear qualified cable samples to a high temperature steam environment. While these two studies involved seemingly different damaging environments, that is, a superheated steam environment versus elevated temperatures only, the damage thresholds determined for two types of cables common to both studies agreed to within ± 10°C. This correspondence between results indicates that elevated temperature was the primary damaging environmental effect in both test programs.
>
> Based on this commonality of results, the cable performance data gathered in the high temperature steam exposure test was used as the basis for estimating the lower limits of fire-induced thermal damage for scenarios involving the exposure of limited segments of cable. Estimates were developed for 13 specific nuclear qualified cable products, and for five generic classes of electrical insulation. The values reported are considered appropriate for use in the evaluation of fire risk, and represent a significant expansion of the available cable thermal vulnerability data base.

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Table 3.1 provides failure temperature criteria recommended by Nowlen and Jacobus on 13 cables. Based on these Sandia tests, estimated thermal damage thresholds for generic insulation types are shown in Table 3.2.

Nowlen (3) test aged and unaged cables of XLPE/Neoprene and EPR/Hypalon at high air temperatures to determine thermal damage thresholds. Each cable was energized using a three-phase 208 volt power source and placed in a preheated test chamber. Leakage currents between power phases were monitored continuously. The ultimate cable failure was determined by a 2 ampere fuse in any one of the three phase circuits. The damage threshold temperature range was determined with the upper limit defined by the lowest experimental exposure temperature at which electrical failure was observed following exposures of up to 80 minutes. The lower limit of the range was the highest experimental exposure temperature for which no electrical failures were observed following exposure of not less than 80 minutes.

Jacobus (2) exposed 12 different cable products to high temperature steam as hot as 400°C (750°F). The total exposure time was up to 40 hours. The exposure to 400°C was approximately 2 hours. Cables were energized at 110 Vdc. Leakage currents were monitored to measure insulation resistance. Comparing these two independent efforts resulted in the conclusions quoted above and the data shown in Tables 3.1 and 3.2.

These generic types represent most of the cable insulation used in US nuclear power plants. EPRI TR100516, Nuclear Power Plant Equipment Qualification Reference Manual (4) reports the principle cable insulating materials are cross-linked polyethylene (XLPE), ethylene propylene rubber (EPR), silicone rubber (SR), and chlorosulfonated polyethylene (CSPE or Hypalon). The principle jacket materials include neoprene, hypalon, and fiberglass braid (for SR insulated cables). Figure 3.1 shows a distribution of number of pants using these insulations.

Research was conducted for EPRI (5), concerning insulation performance of EPR, XLPE, and high molecular weight polyethylene (HMPE) which included aging tests involving two days of 190°C (374°F). The research indicated no major changes in chemical, electrical, and mechanical properties resulted from this exposure.

Thermogravimetric analysis of XLPE and EPR compounds conducted during accelerated aging testing (5) indicated initiation of volatile evolution (5-10% weight loss) from both XLPE and EPR cables tested in the range of 300°C -400°C. Refer to Figure 3.2.

Based on the tests reported above and other tests at Sandia National Laboratories (6), a peak temperature criteria of 250°C (482°F) for power and control cables is a conservative value. For the case of instrument and signal cables, Section 9 of EPRI NP-7485s (7) provides a useful dissertation on the performance of electrical circuits to assess the effects of high temperature. Potential instrument error will be a function of the length of cable exposed, the temperature of the heated cable, the circuit voltage, and the resistance and current of the loop instrument. Appendix IV contains calculations which show the potential effect of localized heating of instrument cables simulating the effects of the thermal exposure inside a fire barrier enclosure. These calculations demonstrate that 200°C (392°F) is a reasonable acceptance criteria for instrument cables.

TABLE 3.1 (2)

Physical and Electrical Characteristics of the 13 Cable Products Evaluated in the Aging Degradation of Cables Study and their Derived Thermal Damage Threshold Limits.

Supplier	Description	Failure Threshold (°C)
1. Brand Rex	Cross-linked polyethylene (XLPE) Insulation, Chlorosulfonated Polyethylene (CSPE) Jacket, 12 AWG, 3-Conductor (3/C), 600 Volt (V)	385
2. Rockbestos	Firewall III, Irradiation XLPE Insulation, Neoprene Jacket, 12 AWG, 3/C, 600 V	320-322
3. Raychem	Flamtrol, XLPE Insulation, 12 AWG, 1/C, 600 V	385-388
4. Samuel Moore	Dekoron Polyset, Cross-Linked Polyolefin (XLPO) Insulation, CSPE Jacket, 12 AWG, 3/C and Drain	299-307
5. Anaconda	Single Conductors Removed From: Anaconda Y Flame-Guard Flame Retardant (FR), Ethylene Propylene (EP), Ethylene Propylene Rubber (EPR) Insulation , Chlorinated Polyethylene (CPE) Jacket, 12 AWG, 3/C, 600 V	381
6. Anaconda	Anaconda Flame-Guard EP, EPR Insulation, Individual CSPE Jacket, Overall CSPE Jacket, 12 AWG, 3/C, 1000 V	394-DNF
7. Okonite	Okonite Okolon, EPR Insulation, CSPE Jacket, 12 AWG, 1/C, 600 V	387-DNF
8. Samuel Moore	Dekoron Dekorad Type 1952, Ethylene Propylene Diene Monomer (EPDM) Insulation, Individual CSPE Jackets, Overall CSPE Jacket, 16 AWG, 2/C Twisted-Shielded Pair (TSP), 600 V	370-372
9. Kerite	Kerite 1977, FR Insulation, FR Jacket, 12 AWG, 1/C, 600 V	372-382
10. Rockbestos	RSS-6-104/LE Coaxial Cable, 22 AWG, 1/C Shielded	278
11. Rockbestos	Firewall Silicone Rubber Insulation, Fiberglass Braided Jacket, 16 AWG, 1/C, 600 V	396-DNF
12. Champlain	Polyimide (Kapton) Insulation, Unjacketed, 23 AWG, 1/C	399
13. BIW	Bostrad 7E, EPR Insulation, Individual CSPE Jackets, Overall CSPE Jacket, 15 AWG, 2/C TSP, 600V	384-DNF

1. DNF (Did Not Fail) indicates the insulation resistance of at least one sample did not fall at this failure criteria during the high temperature steam exposure that peaked at 400°C.

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TABLE 3.2 (2)

Estimated Thermal Damage Threshold Limit Ranges for Generic Insulation Types

Insulation Type (Number of Samples Tested)	Recommended Failure Threshold Range (°C)[1]	
	≤ 1000 Ω over 100 m	≤ 100 Ω over 100 m
XLPO (13)[2]	254-378	299-388
EPR (16)	235-400	370-400
Silicone Rubber (2)	396-400	396-400
Kerite FR (2)	153-171	372-382
Polyimide or Kapton (1)	399	399

1. Failure criterion is based on the stated insulation resistance over an equivalent 100 meter length of cable.

2. Note that XLPE is a specific type of polymer of the generic class XLPO, and hence, all XLPE cables are grouped under the more generic designation XLPO.

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Figure 3.1

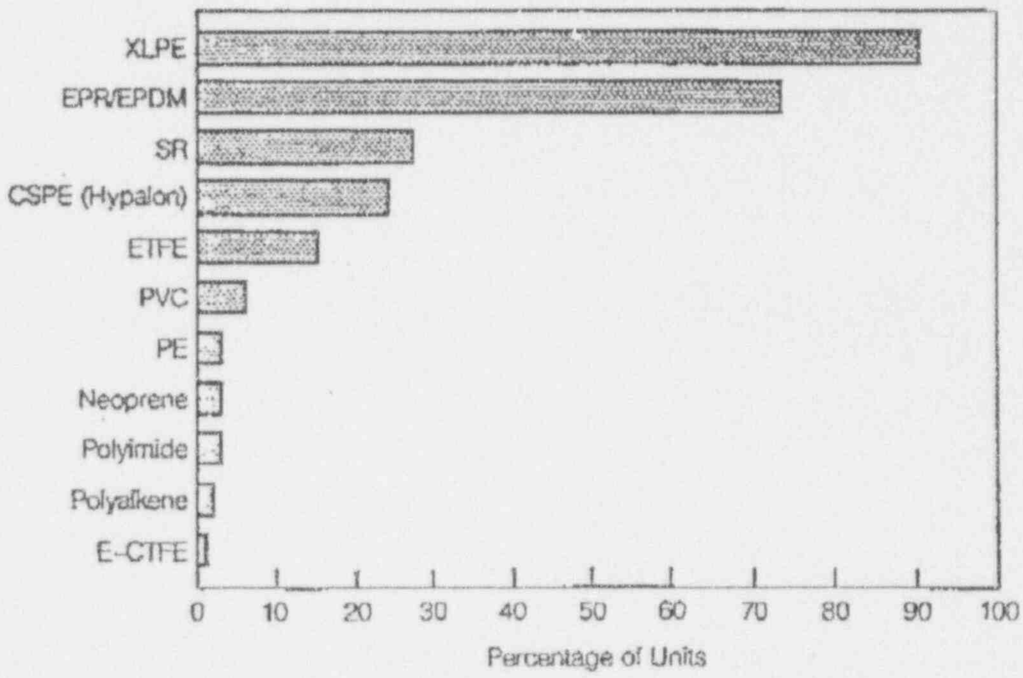

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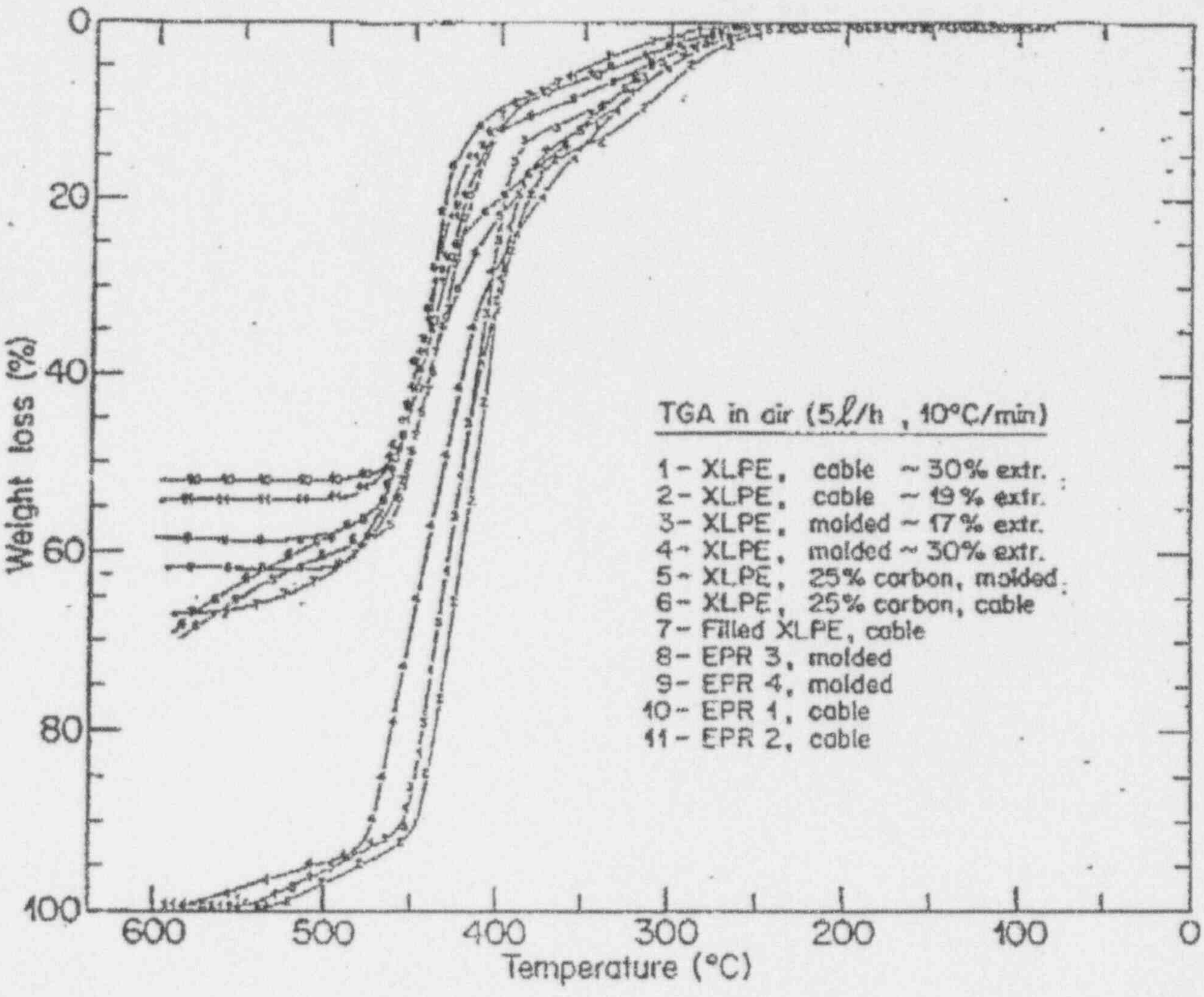
Figure 3.2



Thermogravimetric Analysis (TGA) of XLPE and EPR Compounds

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4.0 COMPARISON OF TEST METHODS

Table 4.1 provides a comparison of the proposed test protocol with the requirements of ASTM E-119/NFPA 251. This comparison shows which portions of ASTM E-119/NFPA 251 should not be applied to cable system fire barrier enclosures. These differences are explained below.

4.1 Sample Size

In ASTM E-119/NFPA 251 tests, the sample size for walls and floors are flat rectangular samples with a minimum specified area of 100 ft^2 for walls and 180 ft^2 for floors, and a minimum dimension of 9 ft for walls and 12 ft for floors. Columns are required to have a minimum length dimensions of 8 or 9 ft. Beams are required to have a minimum length of 12 ft. For cable system fire barrier enclosures, the size of the sample will be bounded by the smallest and the largest raceway to be protected. The length or area of the barrier enclosure need not be limited except that the test sample should represent field installation variables such as joints and supports.

4.2 Temperature Measurement

ASTM E-119/NFPA 251 require a minimum of 9 thermocouples on the unexposed side of the wall, partition, roof, or ceiling. These thermocouples are <u>outside</u> the furnace and, therefore, are required to be covered with insulating pads to reduce the heat loss (cooling) to the environment outside the furnace. For beams and columns, which are immersed in the furnace, temperature measurements are made on the steel, <u>not</u> on the inside of the covering material. Cable system fire barrier enclosures are also immersed in the furnace. Also, like beams and columns, the performance measure proposed is the temperature of the cables, not that of the inside wall of the barrier material. The use of insulating pads

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is unnecessary since the enclosure is immersed in the furnace and not exposed to an outside heat sink.

For steel beams and columns, the thermal mass (surface area to mass ratio) will have a significant influence on temperature rise of the steel. The same is true of electrical cables. The greater the thermal mass of the cable(s) inside the fire barrier enclosure, the slower they will heat up and the lower the peak temperature will be. To develop a conservative maximum heating rate and maximum peak temperature, the NUMARC protocol for cable system fire barrier enclosures uses bare copper wires which represent extremely low thermal mass compared to grouped insulation cables.

4.3 Hose Stream Test

ASTM E-119/NFPA 251 do not require hose stream tests for three-dimensional assemblies immersed in the furnace (e.g., beams and columns). The application duration based on the area of the barrier (e.g., 1 to 2-1/2 minutes per 100 sq ft) can not be applied to a three dimensional assembly. The location of the nozzle, perpendicular to the sample surface, also applies only to a two dimensional sample and can not be applied as written to three dimensional cable system fire barrier enclosures. Because of these application problems, combined with the lack of a rational basis or performance objective for a hose stream test, no hose stream test is proposed as part of the cable system fire barrier enclosure test protocol. (See Appendix III for supporting information.)

TABLE 4.1

Comparison of Test Protocols

	NUMARC Protocol Based on UL 1724	ASTM E-119/NFPA 251
1. Fire Exposure	Standard Time-Temperature Curv	Standard Time-Temperature Curve
2. Sample Size	Representative of largest and smallest raceways.	walls - 9' min. dimension 100 ft^2 minimum floors and roofs - 12' min. dimension 180 ft^2 protective membranes - same as wall or floor columns - not less than 9' for loaded, 8' for unloaded beams - not less than 12'
3. Sample Conditioning	Moisture content equivalent to equilibrium resulting from drying in air at 50% relative humidity at 73°F (23°C).	Moisture content equivalent to equilibrium resulting from drying in air at 50% relative humidity at 73°F (23°C).
4. Temperature Measurements	Thermocouples will also be placed on bare copper conductors inside fire barrier enclosure, spaced a maximum of 12 inches on center. Thermocouples will also be placed on the bottom, side and, if applicable, the top surfaces of the raceway (1) at a point 1 inch (25 mm) from the floor or wall surface, (2) immediately adjacent to the intermediate raceway support, (3) at a point 12 inches (305 mm) from the floor or wall surface on the leg of the raceway run (if applicable), (4) at the center of the raceway elbow (if applicable), and (5) at a point 12 to 18 inches (305 to 457 mm) from and on both sides of the intermediate raceway support (if applicable).	Thermocouples are to be placed on the unexposed side of the barrier, outside the furnace, and are to be covered by 6" x 6" insulating pads. Temperature readings shall be taken at not less than nine points on the surface. Five of these shall be symmetrically disposed, one to be approximately at the center of the specimen and four at approximately the center of its quarter sections. The other four shall be located at the discretion of the testing authority to obtain representative information on the performance of the construction under test. None of the thermocouples shall be located nearer to the edges of the test specimen than one and one-half times the thickness of the construction, or 12 in. (305mm). An exception can be made in those cases where there is an element of the construction that is not otherwise represented in the remainder of the test specimen. None of the thermocouples shall be located opposite or on top of beams, girders, pilasters, or other structural members if temperatures at such points will obviously be lower than at more representative locations. None of the thermocouples shall be located opposite or on top of fasteners such as screws, nails, or staples that will be obviously higher or lower in temperature than at more representative locations if the aggregate area of any part of such fasteners projected to the unexposed surface is less than 0.8 percent of the area within any 5-in. (127-mm) square. Such fasteners shall not extend through the assembly.
5. Hose Stream Test	None	None for beams, columns, floors, and roofs. For walls and protective membranes for walls, a duplicate specimen shall be subjected to a fire exposure test for a period equal to one-half of that indicated as the resistance period in the fire endurance test, but not for more than 1 hour, immediately after which the specimen shall be subjected to the impact, erosion, and cooling effects of a hose stream directed first at the middle and then at all parts of the exposed face, changes in direction being made slowly.

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TABLE 4.1

Comparison of Test Protocols

	NUMARC Protocol Based on UL 1724	ASTM E-119/NFPA 251
5. Hose Stream Test (Cont'd)	None	The stream shall be delivered through a 2-1/2 in. (64 mm) hose discharging through a national standard play pipe as described in ANSI/UL 385. The play pipe shall have an overall length of 30 in. (762 mm) and be equipped with a 1-1/8 in. (295-mm) discharge tip of the standard-taper, smooth bore pattern without shoulder at the orifice. The play pipe shall be fitted with a 2-1/2 in. (64-mm) inside diameter by 6 in. (153 mm) long nipple mounted between the hose and the base of the play pipe. The nozzle orifice shall be 20 ft (6 m) from the center of the exposed surface of the test sample if the nozzle is so located that when directed at the center its axis is normal to the surface of the test sample. Nozzle pressure and discharge duration are as follows: - for 1 hour, 30 psig at base of nozzle for 1 min per 100 sq ft - for 3 hour, 30 psig at base of nozzle for 2½ min per 100 sq ft
6. Acceptance Criteria		
6.1 Temperature	Maximum temperature does not exceed 250°C (482°F) measured on bare copper wire.	Transmission of heat through the <u>floors, ceilings, wall, or partition</u> during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250°F (121°C) above its initial temperature. The temperature end point of the fire endurance period shall be determined by the average of the measurements taken at individual points, except that if a temperature rise 30 percent in excess of the specified limit (325°F or 157°C) occurs at any one of these points, the remainder shall be ignored and the fire endurance period judged as ended. For <u>steel beams</u> the temperature of the steel shall not have exceeded 1300°F (704°C) at any location during the classification period nor shall the average temperature recorded by four thermocouples at any section have exceeded 1100°F (593°C) for reinforcing steel during the classification period. For a <u>column</u> the test shall be regarded as successful if the transmission of heat through the protection during the period of fire exposure for which classification is desired does not raise the average (arithmetical) temperature of the steel at any one of the four levels above 1000°F (530°C) or does not raise the temperature above 1200°F (649°C) at any one of the measured points.
6.2 Hose Stream	None	The assembly shall be considered to have failed the hose stream test if an opening develops that permits a projection of water from the stream beyond the unexposed surface during the time of the hose stream test.

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4.4 Acceptance Criteria

The thermal transmission limit of ASTM E-119/NFPA 251 on wall, partitions, floor, and roofs is based on the ignition of cellulosic materials (e.g., wood, paper, cotton waste). The initial temperature established in 1918 was 149°C (300°F). This was based on a study of piloted ignition temperatures of nine species of wood which range from 157°C (315°F) to 194°C (383°F). The concern at the time was that combustible materials, such as storage and furniture, would be against the fire wall. This evolved into the current criteria of an average increase of 250°F (121°C), with no single point increase greater than 325°F (181°C).

For beams and columns, the acceptance criteria are based on the structural element being able to perform its intended function during and after the fire. The temperature acceptance criterion, measured on the steel element itself, is much higher than that of walls or floors, (see Table 4.1). Similarly, for cable system fire barrier enclosures, the acceptance criteria reflects the ability of the cables to perform their intended function during and after the fire. The test protocol uses a peak temperature of 250°C (482°F) as measured on a thermally thin bare copper wire.

4.5 Summary of Conservatisms

The test protocol as described above is a conservative measure of the performance of cable system fire barrier enclosures. The following elements of the protocol are conservative:

1. Standard Time-Temperature Curve - This standard furnace exposure, though not replicating an actual compartment fire, is a severe and conservative exposure. Compartment fires in nuclear power plants, based on the combustibles present, the ventilation conditioning, and the compartment geometries, will be

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significantly less severe than the standard time-temperature curve (see Appendix II).

2. Sample Size - The smallest and largest raceway sizes are the bounds of configuration. All other sizes between the bounds will perform better than these extremes.

3. Temperature Measurement Technique - Measuring the temperature on a bare copper wire is a conservative representation of the heating of cable inside the enclosure. The temperatures recorded on the bare wire will exceed that of any insulated and jacketed cable regardless of the cable fill or type of raceway.

4. Peak Temperature Criteria - The 250°C peak temperature is a conservative performance criteria for cables installed in nuclear power plants. The failure threshold temperatures contained in Table 3.2 resulted from constant exposures to these high temperatures for at least 80 minutes. The proposed peak, not-to-exceed value is well below the temperature value for an 80 minute exposure, and therefore is a conservative measure of performance assurance.

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APPENDIX I

SUMMARY OF REGULATORY REQUIREMENTS

APPENDIX I

Summary of Regulatory Requirements

USNRC Branch Technical Position (BTP) APCSB 9.5.1, "Guidelines for Fire Protection for Nuclear Power Plants" 5/1/76 required that redundant safety-related cable systems be separated from each other and from potential fire exposure hazards by fire barriers. The separation referenced in the BTP were "traditional" walls, floors, and partitions with a fire resistive rating of 3 hours. Strict compliance with these requirements would have required significant plant layout changes, which were not practical. BTP APCSB 9.5.1, 5/1/76 defined fire rating in terms of the period of resistance to a standard fire exposure before the first critical point in behavior is observed and references NFPA 251, "Standard Methods of Fire Tests of Building Construction and Materials."

BTP CMEB 9.5.1, Rev. 2., July 1981, also defines fire resistance rating in terms of assemblies which have withstood a fire exposure in accordance with the test procedures of "Standard Methods of Test of Fire Tests of Building Construction and Materials" (NFPA 251). The Scope of NFPA 251 is as follows:

> 1-1.1 These methods of fire tests are applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including bearing and other walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units that constitute permanent integral parts of a finished building.
>
> 1-1.2* It is the intent that classifications shall register performance during the period of exposure and shall not be construed as having determined suitability for use after fire exposure.
>
> 1-1.3 The results of these tests are one factor in assessing fire performance of building construction and assemblies. These methods prescribe a standard fire exposure for comparing the performance of building construction assemblies. Application of these test results to predict the performance of actual building construction requires careful evaluation of test conditions.

The scope of NFPA 251 does not cover protection of openings in barriers, such as doors, dampers, or penetration seals. Nor does it apply to cable system fire-rated enclosures.

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Appendix R to 10 CFR 50, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," allows for fire separation of cable systems by a fire barriers having a 3-hour or 1-hour rating. The following requirements related to barriers are contained in section III.G, *Fire protection of safe shutdown capability*:

> 1. Fire protection features shall be provided for structures, systems, and components important to safe shutdown. These features shall be capable of limiting fire damage so that:
>
>   a. One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage, . . .
>
> 2. Except as provided for paragraph G.3 of this section, where cables or equipment, including associated non-safety circuits that could prevent operation or cause maloperation due to hot shorts, open circuits, or shorts to ground, or redundant trains of systems necessary to achieve and maintain hot shutdown conditions are located within the same fire area outside of primary containment, one of the following means of ensuring that one of the redundant trains is free of fire damage shall be provided:
>
>   a. Separation of cables and equipment and associated non-safety circuits of redundant trains by a fire barrier having a 3-hour rating. Structural steel forming a part of or supporting such fire barriers shall be protected to provide fire resistance equivalent to that required of the barrier; . . .
>
>   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; . . ."

Appendix R does not specifically define fire resistance rating test acceptance criteria but requires that at least one train remain "free of fire damage."

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The commentary on Appendix R in the Federal Register provides a discussion of separation criteria:

> G. *Protection of Safe Shutdown Capability Technical Basis.* The objective for the protection of safe shutdown capability is to ensure that at least one means of achieving and maintaining safe shutdown conditions will remain available during and after any postulated fire in the plant. Because it is not possible to predict the specific conditions under which fires may occur and propagate, the design basis protective features are specified rather than the design basis fire . . .
>
> M. *Fire Barriers. Technical Basis.* The best fire protection for redundant trains of safe shutdown systems is separation by unpierced fire barriers -- walls and ceiling-floor assemblies. Because these barriers are passive fire protection features, they are inherently reliable provided they are properly installed and maintained. Fire barriers have been used successfully for many years to subdivide large potential fire losses into smaller, more acceptable risks. Even fire barriers with openings have successfully interrupted the progress of many fires provided the openings were properly protected by fire doors or other acceptable means.
>
> Fire barriers are "rated" for fire resistance by being exposed to a "standard test fire." This standard test fire is defined by the American Society for Testing and Materials in ASTM E-119, "Standard for Fire Resistance of Building Materials." Fire barriers are commonly rated as having a fire resistance of from 1 to 8 hours . . .
>
> If specific plant conditions preclude the installation of a 3-hour fire barrier to separate the redundant trains, a 1-hour fire barrier and automatic fire suppression system for each redundant train will be considered the equivalent of 3-hour barrier.

The prescriptive separation criteria of 1-hour and 3-hour barriers was considered conservative because of the severity of the standard test fire exposure and the low fire loading in nuclear power plants. However, neither ASTM E-119, NFPA 251, or 10 CFR Part 50, Appendix R defines a suitable test or acceptance criteria for cable system fire barrier enclosures.

The USNRC staff provided additional documented guidance in Generic Letter 86-10, Implementation of Fire Protection Requirements dated April 26, 1986.

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Enclosure 1, Section 3, on Fire Damage, reads in part as follows:

> Appendix R to 10 CFR 50 utilizes the term "free of fire damage." In promulgating Appendix R, the Commission has provided methods acceptable for assuring that necessary structures, systems and components are free of fire damage (see Section III.G.2a, b and c), that is, the structure, system or component under consideration is capable of performing its intended function during and after the postulated fire, as needed.

Section 3.2, <u>Fire Barrier Qualifications</u> reads as follows:

3.2.1 Acceptance Criteria

<u>QUESTION</u>

Recently the Staff has applied a 325°F cold side temperature criterion to its evaluation of the acceptability of one-hour and three-hour fire barrier cable tray wraps. This criterion is not in Branch Technical Position (BTP) APCSB 9.5-1, Appendix A as an acceptance criterion and why is it applicable to electrical cables where insulation degradation does not begin until jacket temperatures reach 450°F to 650°F?

<u>RESPONSE</u>

Fire barriers relied upon to protect shutdown related systems to meet the requirements of III.G.2 need to have a fire rating of either one or three hours. §50.48 references BTP APCSB 9.5-1, where the fire protection definitions are found. Fire rating is defined:

> Fire Rating - the endurance period of a fire barrier or structure; it defines the period of resistance to a standard fire exposure before the first critical point in behavior is observed (see NFPA 251).
>
> The acceptance criteria contained in Chapter 7 of NFPA 251, "Standard Methods of Fire Tests of Building Construction and Materials," pertain to non-bearing fire barriers. These criteria stipulate that transmission of heat through the barrier "shall not have been such as to raise the temperature on its unexposed surface more than 250°F above its initial temperature." The ambient air temperature at the beginning of a fire test usually is between 50°F and 90°F. It is generally recognized that 75°F represents an acceptable norm. The resulting 325°F cold side temperature criterion is used for cable tray wraps because they perform the fire barrier function to preserve the cables free of fire damage. It is clear that cable that begins to degrade at 450°F is free of fire damage at 325°F.

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During the Appendix A review, licensees began to propose fire barriers to enclose cable trays, conduit, fuel lines, coolant lines, etc. Industry did not have standard rating tests for such components or for electrical, piping or bus duct penetrations. The NRC issued a staff position giving acceptance criteria for electrical penetration tests. These criteria require an analysis of any temperature on the unexposed side of the barrier in excess of 325°F. In the past, manufacturers designed their own qualification tests. Nuclear Insurers, and the Institute of Electrical and Electronic Engineers have issued tests for some of these components. These tests usually exposed the component to the ASTM E-119 time-temperature curve, but all had different acceptance criteria. Conduit and cable tray enclosure materials accepted by the NRC as 1 hour barrier prior to Appendix R (e.g., some Kaowool and 3M materials) and already installed by the licensee need not be replaced even though they may not have met the 325°F criteria. However, for newly identified conduit and cable trays requiring such wrapping new material which meets the 325°F criterion should be used, or justification should be provided for use of material which does not meet the 325°F criterion. This may be based on an analysis demonstrating that the maximum recorded temperature is sufficiently below the cable insulation ignition temperature.

The guidance of Generic Letter 86-10 is reiterated in NRC Information Notice 92-46, Thermo-Lag Fire Barrier Material Special Review Team Final Report Findings, Current Fire Endurance Tests and Ampacity Calculation Errors" dated June 23, 1992. In the review team's report, two significant misrepresentations of NFPA 251 and ASTM E-119 applicability to cable system fire barrier enclosure are made.

1. The staff response to PP&L test report Thermo-Lag Barriers indicated "that the simulated test differed from ASTM E-119 test method in several areas, such as . . . the type and the number of thermocouples used for measuring test specific temperature . . . and therefore, was not acceptable."

2. The staff indicates under Fire Barrier Qualification, "This standard, ASTM E119 or NFPA 251, specifies that a test specimen representative of the construction for which the fire rating is desired, as to materials, method of assembly, dimensions and configuration, be exposed to a standard test fire."

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As was discussed in Section 1.2 of this document, NFPA 251 and ASTM E-119 have provisions that cannot be applied to cable system fire barrier enclosures. These provisions include sample size (dimensions), thermocouple numbers and location, and acceptance criteria. (See section 4.0 for a comparison of test methods.)

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APPENDIX II

Evaluation Actual Compartment Fire Time-Temperature Exposure

APPENDIX II

Evaluation Actual Compartment Fire Time-Temperature Exposure

The fire exposure to which cable system fire barrier enclosures could be exposed to in nuclear power plants will be very low if the fire can be extinguished before it reaches the fully developed stage. This likelihood is supported by the additional provisions of automatic fire detection systems, automatic fire suppression systems, and manual fire suppression by plant fire brigades. In the unlikely event a fire goes unmitigated, the fire will be controlled either by the surface area of the fuels that are exposed or the rate of combustion air available to support combustion.

In large open areas of the plant (e.g., Auxiliary Buildings, Reactor Buildings), the fire growth rate and peak fire heat release rate will depend on the spread of the fire across the surface area of continuous fuels, such as cables in trays. In these cases, the total surface area of cable trays burning will control the fire. In smaller compartments (e.g., switchgear rooms, pump rooms), the fire size could be bounded by the air available to support combustion.

The greatest amount of in-situ combustibles in nuclear power plants is cables. Although a few compartments contain combustible liquids such as lubricants, cables dominate. Based on the fire propagation rate of cables in trays, the loading of cables in the trays (pounds of insulation per square foot of tray), the peak size of a fire controlled by fuel surface can be calculated. Whether the fire is controlled by the fuel surface or by the ventilation available, the temperature will be influenced by the heat loss area (ceiling and walls) of the compartment.

T.T. Lie (8) in the SFPE Fire Protection Engineering Handbook describes the influence of ventilation openings and heat loss surface in terms of an opening factor F:

$$F = \frac{A\sqrt{H}}{A_t}$$

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where A is the area of the openings in an enclosure, H is the height of the opening and A_t is the bounding surface area (walls, floor, and ceiling). He further states that for a ventilation controlled fire, the heat release rate can be estimated by the ventilation parameter, $A\sqrt{H}$ as follows in SI units:

$$R = 300\ A\sqrt{H}$$

If the fire loading is known, the duration of the fire can be approximated by dividing the total heat value Q, by the heat release rate, R:

$$T = \frac{Q}{R}$$

If the fire loading is expressed in terms of fire load per unit area of bonding surface (not just floor area), the duration can be expressed in terms of fire load (L) and opening factor F:

$$T = L/330F$$

Compartment temperature can be calculated using a heat balance around the compartment. Lie shows temperature time curves for enclosures bounded by heavy materials (i.e., concrete) as shown in Figure A-II.1 (Figure 3-5.4 from the SFPE Handbook).

As an example, for a room 10 m (32.8 ft) by 10 m (32.8 ft) by 3 m (9.8 ft) high, with an open door 1 m (3.28 ft) by 2 m (6.56 ft) high, the opening factor, F, is .0088, so the compartment temperature would be less than 750°F after one hour and less than 1000°F after three hours. This example demonstrates the conservative nature of the standard time temperature curve in nuclear power plant compartments. One could increase the door opening area by a factor of 4 and still be below the standard time-temperature curve.

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As can be seen, for compartments in nuclear power plants with small ventilation openings (no windows, closed doors) and for larger compartment surfaces, the calculated exposures are much cooler than the standard time temperature curve.

A similar approach for both fuel surface controlled fires and ventilation controlled fires was used to bound compartment temperature for evaluation of structural steel heating.(9) This methodology used a heat balance, using conservative assumption regarding heat loss area (e.g., no heat loss through the floor) and no heat loss from escaping combustion gases to calculate time-temperature curve for compartments. Figure A-II.2 shows the heat release rate per unit heat loss area, Q/A_t, necessary to reach 1100°F within 1 hour to 3 hours. Any point above the curve represents a fire potentially exceeding 1100°F. Any point below the curve represents a fire not reaching 1100°F. For example, for the same room described above (10 m x 10 m x 3 m), for the temperature to exceed 1100°F within the first hour, the fire would require a heat release rate of 2.42 megawatts. Applying this to numerous compartments in multiple nuclear power plants showed that the likelihood of unmitigated cable fires in nuclear power plant compartments exceeding compartment temperature of 1100°F is very low.

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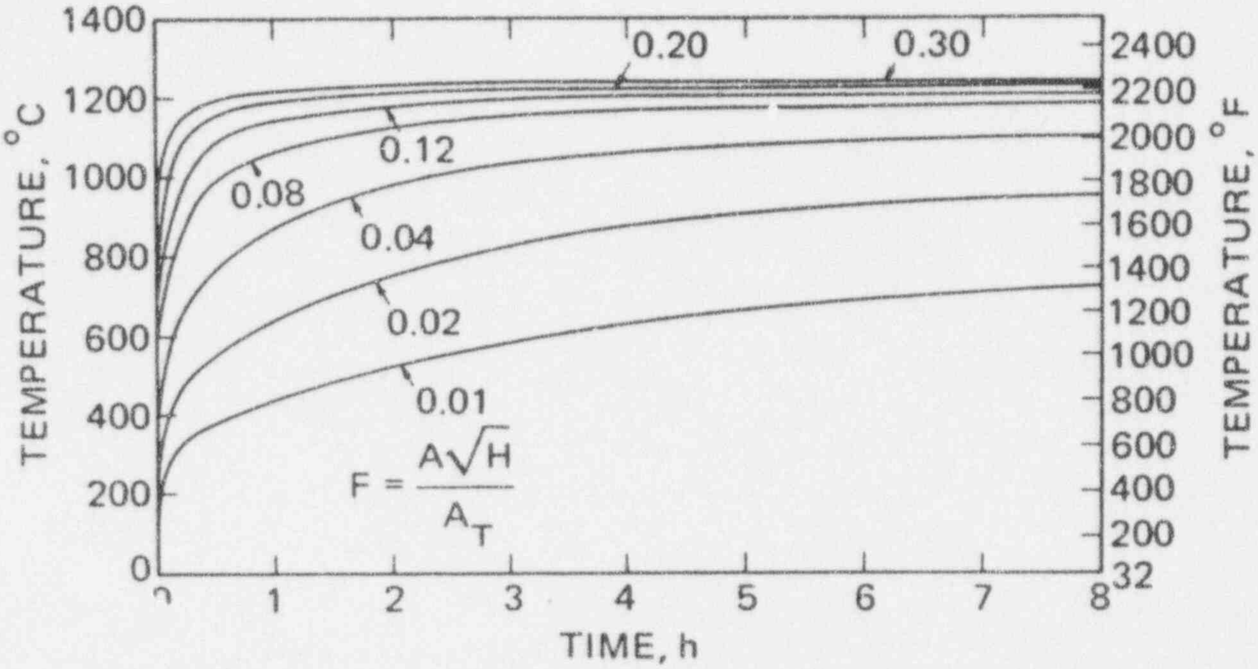

Fig. 3-5.4. Temperature-time curves for ventilation-controlled fires in enclosures bounded by dominantly heavy materials ($\rho \geq 1600\ kg/m^3$), calculated for various opening factors by solving a heat balance for the enclosure.

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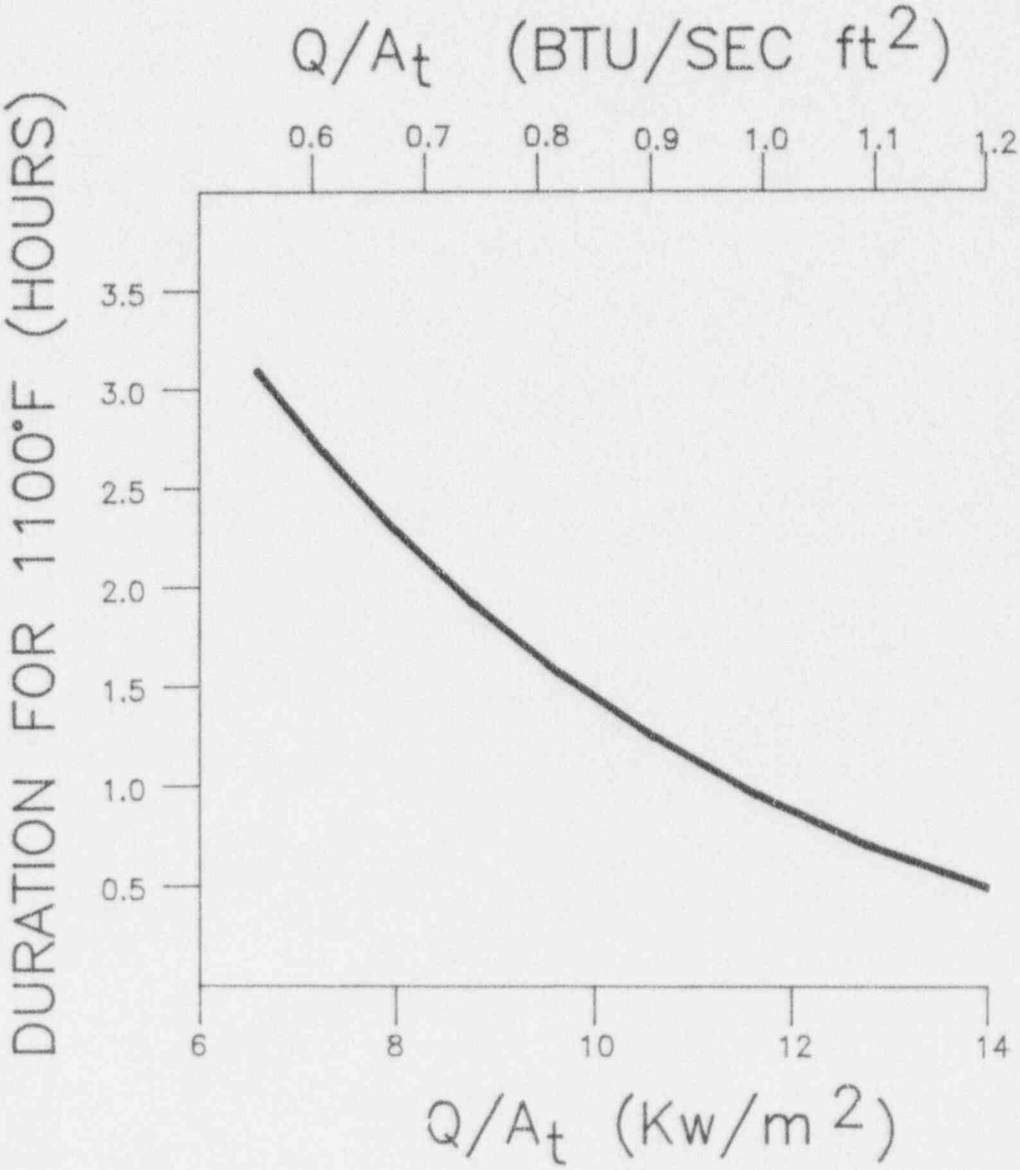

Figure A-II.2

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APPENDIX III

Hose Stream Testing of Cable System Fire Barrier Enclosures

APPENDIX III

Hose stream Testing of Cable System Fire Barrier Enclosures

A requirement for hose stream testing has been included as a condition of acceptance for certain fire resistive elements when tested in accordance with ASTM E-119/NFPA 251. Hose stream tests are not required for structural elements such as columns and beams or for floors and ceilings which perform as barriers or for protective membranes in wall, partition, floor, or roof assemblies. Each of these elements may be qualified by the ASTM and NFPA test methods as "fire-resistive" without being subject to a standard hose stream test.

Only fire barrier walls and partitions are required by ASTM E-119/NFPA 251 to be subjected to a hose stream test. The hose stream test is not required for fire barrier walls with a fire endurance rating of less than 1-hour and is not required for fire barrier floor/ceilings at any fire endurance rating. The standard hose stream test is not applied to the actual specimen subjected to the fire endurance test for the rated duration but rather is applied to a duplicate specimen exposed to the fire test for one-half the fire endurance rating. The standard hose stream test is an 1-1/8 inch Underwriters play pipe (as defined by ANSI/UL 385) at 30 to 45 psi applied at distance of 20 ft. Some test standards for penetration seals (i.e., the ANI standard and IEEE-634) allow an alternative nozzle and pressure for the hose stream test.

This test procedure was developed in 1917. The standard hose stream test is not intended to replicate or simulate any particular fire suppression action or activity. Rather, it is intended to provide a standard exposure to the impact, erosion, and cooling effects to assure the integrity of the fire endurance rated barriers.

On a world-wide basis, the North American test standards are unique in employing a hose stream test for fire endurance rating of barriers. The international standard, ISO 834, does not include a hose stream test. The British and German fire standards deleted requirements for hose stream testing. British Standard BS 476 deleted the hose stream test requirement in 1953 for the following reasons:

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1. The application of the jet caused failure of a specimen only if it was in such a state that a further few minutes of heating would have caused failure.

2. The damage caused to the exposed face of a specimen by impact of the jet often removed valuable evidence of the effect of the heating.

3. The test did not reproduce conditions in an actual fire.

4. The test did not permit continuation of the test to determine actual time of failure since the fire test was terminated before failure.

The German test specification, DIN 4102, replaces the impact aspects of the hose stream with a spherical mass on a pendulum, calibrated to provide an impact on the wall of 20 N-m (14.75 ft -lb). This is applied only to walls and is applied to the unexposed surface of the wall three minutes before the end of the rating test duration, while the wall is still in the furnace.

The rationale for continuing hose stream testing for fire barrier walls continues to be questioned in North America. In his Doctoral dissertation at the University of California at Berkeley on the subject of Fire Endurance in Buildings, Dr. Vytenis Babrauskas (10) reviewed hose stream testing as applied to fire endurance rated barriers. Dr. Babrauskas concluded that hose stream testing requirements should be replaced. In his dissertation, Dr. Babrauskas states,

> Hose stream testing in the last century was initially applied to all components. It served two functions. Foremost was to exclude those materials (mainly cast and wrought iron and certain types of terra cotta) which shattered when hit by water in a building fire. A brittle collapse of this nature is undesirable; its possibility had to be investigated as long as building materials were commonly available which might collapse by shattering. Current building materials do not shatter under hose streams, thereby obviating the need for continued hose stream testing. The second function of the hose stream test was to ascertain whether components were not so flimsy as to fall when orthogonal loading was added. This test objective remains valid for walls. It is not relevant for floors since here hose stream loading is in the same direction as the service loading and is but a small additional increment.

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The hose stream test is still also applied to doors. Here an additional stability requirement (beyond staying in place) can be justified on the grounds that it might exclude excessively flimsy components, but by itself this is not a sufficient reason since no falling objects or shifting loads could normally be imposed on doors. Thus, no hose stream or similar requirement should be contemplated.

For walls it is desirable to maintain a horizontal loading requirement in order to exclude components of poor reliability. This objective can, and should, be reached by means that are more precisely controllable than a hose stream, and also that represent more clearly a calculable horizontal loading condition.

Minor and Berry (1) at Sandia National Laboratories, published a review of fire endurance test standards under NUREG/CR-0468, Nuclear Power Plant Fire Protection - Fire Barriers. Section 2 of their report reads as follows:

While it is apparent that the hose stream test might eliminate excessively flimsy structures by applying a horizontal load, the force delivered by the hose stream and the application of that force to the wall are not readily calculable or precisely controllable.

With specific reference to cable fire stops, NUREG/CR-0468 concluded,

As in the case of door tests the hose stream test may have some validity as a method for eliminating inadequate materials or poor installations. However, the criticism given in Section 2.2 of this report remains applicable to hose stream tests of penetration seals. The unevenness of forces resulting from the hose stream and the lack of repeatability of the test complicate the performance of an engineering analysis of test results. Therefore, the test represents only a factor upon which a subjective judgement may be based.

NUREG/CR-0468 also quote Harmathy and Lie as stating,

The results of the hose stream test and cotton waste test are very difficult to interpret in strict scientific terms. If unbiased scrutiny were to indicate that there is need for tests of this kind in the standard specification, they would have to be respecified to yield well-defined quantitatively expressible results.

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Dr. Tibor Harmathy, former head of the Fire Research Section of the Division of Building Research at the National Research Council of Canada, conducted considerable research into fire endurance of materials. As Chairman of the ASTM Task Group on Rewrite of ASTM E-119, Dr. Harmathy lobbied for removal of the hose stream test in the proposed revision, and stated the following reasons (11):

> The hose stream test has been omitted from the E119 rewrite because:
>
> 1. The hose stream test is inconsistent with the spirit of the fire endurance test standard. The purpose of the fire test is to determine the ability of building elements to contain a fully-developed fire. It should not be construed as a test yielding information on fire endurance <u>and</u> something else, e.g., the response of building elements to conditions that may arise following the fire.
>
> 2. Being prescribed only for walls and partitions of more than 1 h fire endurance, the hose stream test is inequitable with respect to its sphere of application.
>
> 3. Since the fire endurance test is an <u>idealized</u> simulation of fully-developed compartment fires, many aspects of the possibly harmful effect of these fires are, by necessity, left out of consideration. Some of these neglected factors are much more important than the effect of hose stream.
>
> 4. Even if exposure to hose stream were accepted as part of a fire exposure, the present hose stream test, because of its confused logical foundation, would still not be acceptable. Having found a plausible logic, we will discover that the present practice penalizes certain types of construction, e.g., wood and light plasterboard partitions, while benefits some other, e.g., steel sheet panels protected with sprayed-on insulation.
>
> 5. As the Ingberg study and his survey of hundreds of test results have indicated the hose stream test
>
>   - can have only a marginal effect on the results of combined fire hose stream tests,
>   - may impair the utility of fire tests, and
>   - is inadequate if construed as a test probing the resistance of building elements to impact load.
>
> Based on these and possibly other considerations, the hose stream test requirement was deleted years ago from all national and international fire test standards (except in North America). Clearly, the deletion of the hose stream test cannot possibly invalidate existing test results, though it may validate a few results relating to a handful of structures that passed the fire endurance test but failed the hose stream test.

These comments with respect to hose stream testing also apply to cable systems fire barrier enclosures. Fire endurance rated structural elements of building systems do not require hose stream testing, and structural portions of cable system fire barrier enclosures should not require hose stream testing.

It is a misunderstanding to believe that the hose stream test is intended to simulate fire fighting activities. If that were the intention, water would be applied with a typical spray nozzle used in manual fire fighting around electrical equipment. Additionally, fire fighting activities would not and could not occur within a compartment where temperatures are approaching 1000°F to 1700°F, which are the furnace temperature ranges for a 1-hour exposure.

Neither do the cooling effects of the hose stream test simulate water from an automatic sprinkler system. Automatic sprinkler systems will actuate at temperatures between 200°F and 300°F depending on their temperature ratings. If operating, they would be delivering water in a fine spray on a barrier surface at or below 300°F, well below the furnace exposure temperature.

Based on these considerations, a hose stream test is unnecessary and offers no insight to fire endurance testing of cable system fire barrier enclosures.

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APPENDIX IV

INSTRUMENT CIRCUIT ERROR CALCULATIONS

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Instrument Circuit Error Calculations

Section 9.0 Electric Circuit Performance Characteristics, of EPRI NP-7485s, "Power Plant Practices to Ensure Cable Operability," (7) outlines the method for assessing cable insulation resistance effect on instrument transmitters. In the US, two transmitter loop current ranges are standard, 4 to 20 mA and 10 to 50 mA with the former being most common. System voltage and instrument loop resistance vary for different transmitters with a range from 24 to 50 volts for power supplies and a range in resistance values from 1000 to 125400 ohms.

The error created by a drop in insulation resistance of cable can be calculated if the system voltage, loop current, and loop resistance are know using the following equation

$$e = (V_s - R_e I_t)/(I_t(R_c + R_e)) \tag{1}$$

where
e = error
V_s = system voltage in volts
R_e = loop series resistance, in Ω
I_t = transmitter loop current, in Amps, and
R_c = cable insulation resistance

Voltage and current have a greater influence on the error calculation than transmitter loop resistance. The highest voltage and lowest amperage will introduce the greatest error from a reduction in cable insulation resistance. Figure A-III.1 provides a bar graph of error for various insulation resistance values and currents. Figure A-III.2 is a plot of equation 1 for specific values of V_s and R_e.

Based on an insulation resistance value of 10 k Ω over 100 m of cable, the insulation resistance of a 20 foot section of cable would be $R_c = 1.64 \times 10^5$ Ω. For a V_s = 50 volts, R_e = 250 Ω and I_t = 4mA the error would be 7.45% or 0.30mA, at the low end of the scale. At 20mA, the error would be 1.37% or 0.27mA. An order of magnitude change in R_c introduces an order of magnitude change in the error. System voltage of 25 volts halves this error. The error is less sensitive to the transmitter loop resistance. Increasing R_e to 1000 Ω reduces the error to 6.97% at 4mA and 0.91% at 20mA.

Based on the results of Sandia National Laboratories high temperatures steam exposure tests previous mentioned in Section 3, XLPE and SR isolation maintains insulation resistance of $\leq$ 10 k Ω over 100 meters at temperatures of 268°C and 396°C, respectively. For EPR, insulation resistance of $\leq$ 10k Ω over 100 m is maintained at 203°C. At 250°C, the EPR cables tested will have an insulation resistance of approximately 1k Ω over 100 m, for $R_c = 1.64 \times 10^4\ \Omega$ for a 20 ft section. This lower insulation resistance could introduce an error of 73% at 4mA or 2.9mA and 13.5% at 20mA or 2.7mA, for the V_s = 56 volts and R_e = 250 Ω.

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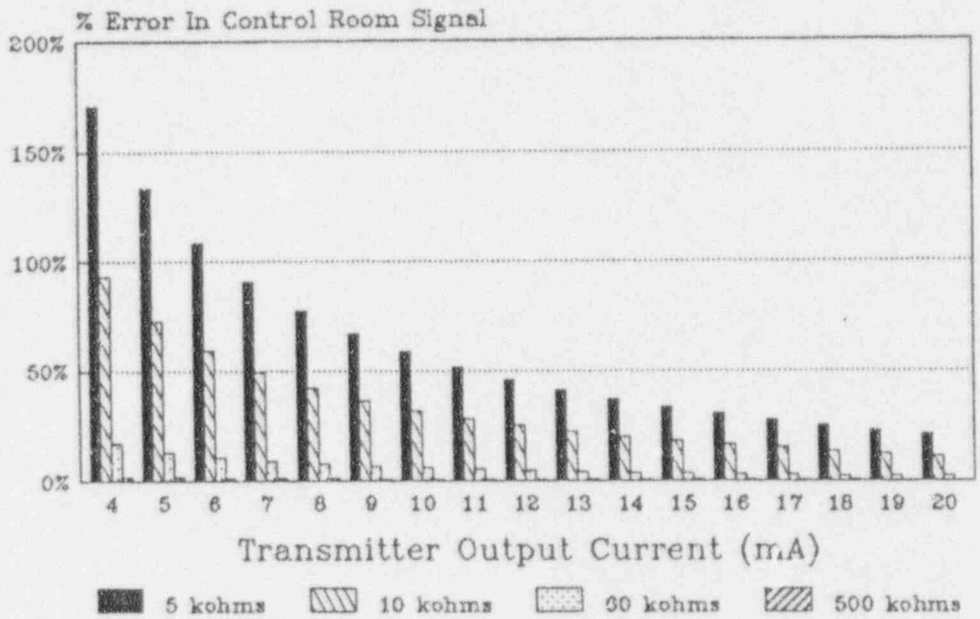
Graph 2 -- Percent Error As A Function of IR -- From Sandia Lab Data



Reference NUREG /CR-3691

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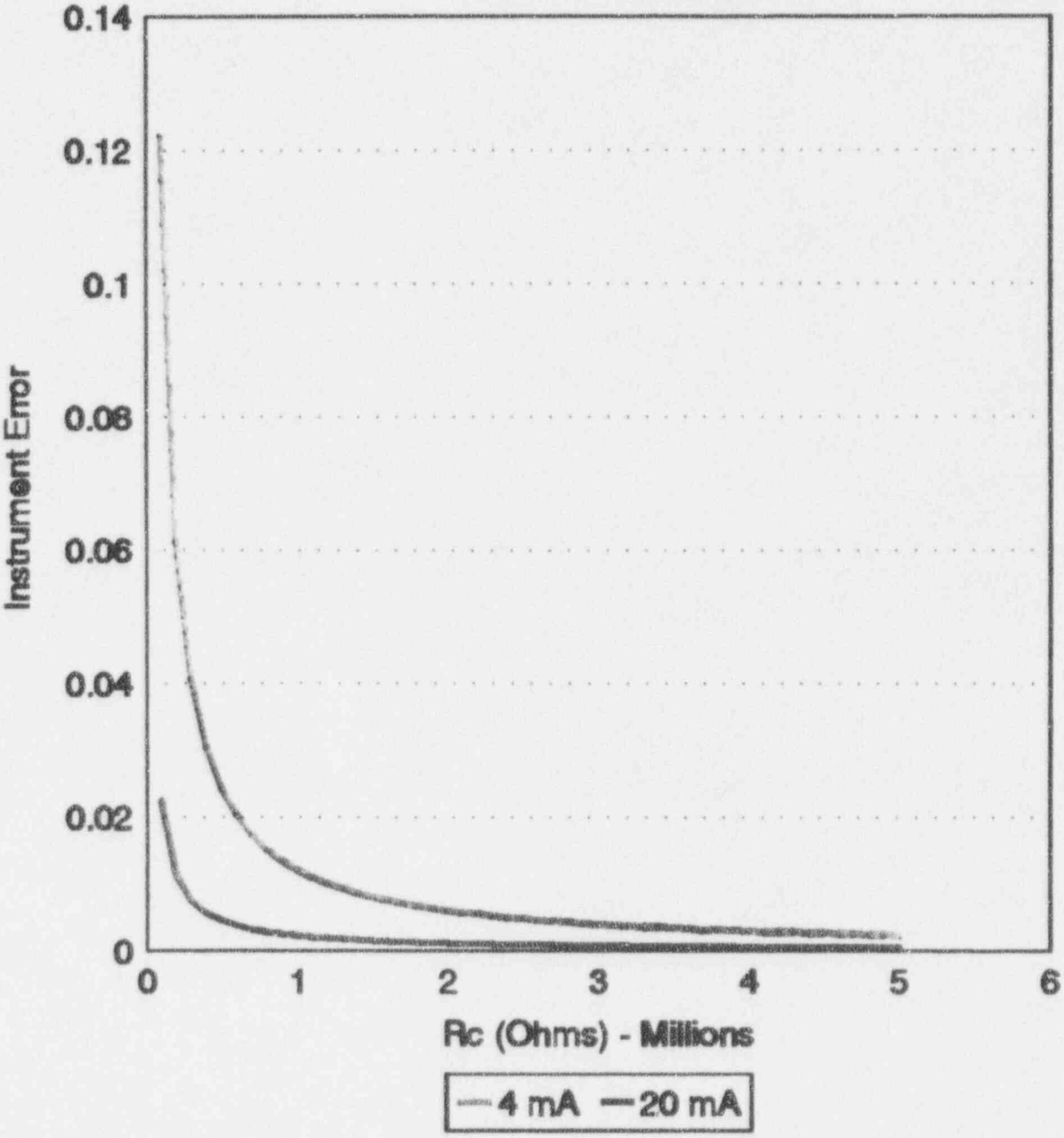
Instrument Error vs. Insulation Resistance



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Appendix V

THERMAL RESPONSE OF CABLES INSIDE FIRE BARRIER ENCLOSURES

Heat transfer calculations were conducted to demonstrate the rapid response of an 8 gauge wire to the thermal exposure within a test specimen cable system fire enclosure barrier. These calculations were worst case calculations, assuming the inside of the test specimen starts at 250°C and stays there throughout a one hour exposure. The simple lumped heat capacity approach was used. This assumes the heat transfer through the wire is rapid so the heat transfer to the wire dominates. This first order equation is as follows:

$$hA_s(T_f - T) = mC_p \frac{\partial T}{\partial t}$$

where
T_f = enclosure temperature
T = wire temperature
h = heat transfer
m = wire mass
C_p = specific heat

The solution to this equation is given as follows:

$$\theta = \theta_o e^{\tau t}$$

where
$\theta = t_f - T$

$\theta_o = T_f - T_o$

$\tau = \frac{hA_s}{mC_p}$

Calculations were conducted for 8 gauge and 14 gauge bare copper wire. Each case was run with an initial temperature of 23°C and 90°C. The results are shown in table 1 and figure 1. In all cases, the wire heated very rapidly to equilibrium with the inside of the chamber. Within 15 minutes, all the wires are tracking the enclosure temperature. Two other examples were calculated for a 4/0 copper power cable, single conductor with SLPE jacket and insulation

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(90 mils insulation, 110 mils jacket). The first used an initial temperature of 23°C. The second used 90°C. The results as shown in table 2 demonstrate that the single insulated conductor lags significantly behind the bare copper conductor. This clearly shows the bare copper conductor to be a conservative measurement technique. The results also show that the high starting temperature of 90°C creates only a 12°C or 12% increase in the final temperature reached. Both readings lag well behind the bare copper wire, even for insulated cable preheated to 90°C. If the calculations are carried out to 3 hours the resulting final cable temperatures are 248.4°C and 248.9°C for 0.5°C or 0.2%.

These calculations, clearly demonstrate the temperatures measured on the bare 8 gauge copper wire are conservative for uses as a peak temperature seen by an insulated cable (or group of insulated cables) and that increasing the temperature measured by 90°C or preheating the cable to 90°C is unnecessary to represent worst case heating conditions.

TABLE 1

Uninsulated Cables Temperature Response

time in min.	1	3	5	7	9	11	13	15
T_o = 23°C, 8g	97	180	218	235	243	247	249	249
T_o = 23°C, 14g	146	228	245	249	250	250	250	250
T_o = 90°C, 8g	142	201	227	240	245	248	249	250
T_o = 90°C, 14g	177	235	247	249	250	250	250	250

TABLE 2

Insulated Cable Temperature Response

XLPE 4/0 time in min.	10	20	30	40	50	60
T_v = 23	77	119	150	174	192	206
T_o = 90	128	158	180	197	209	218

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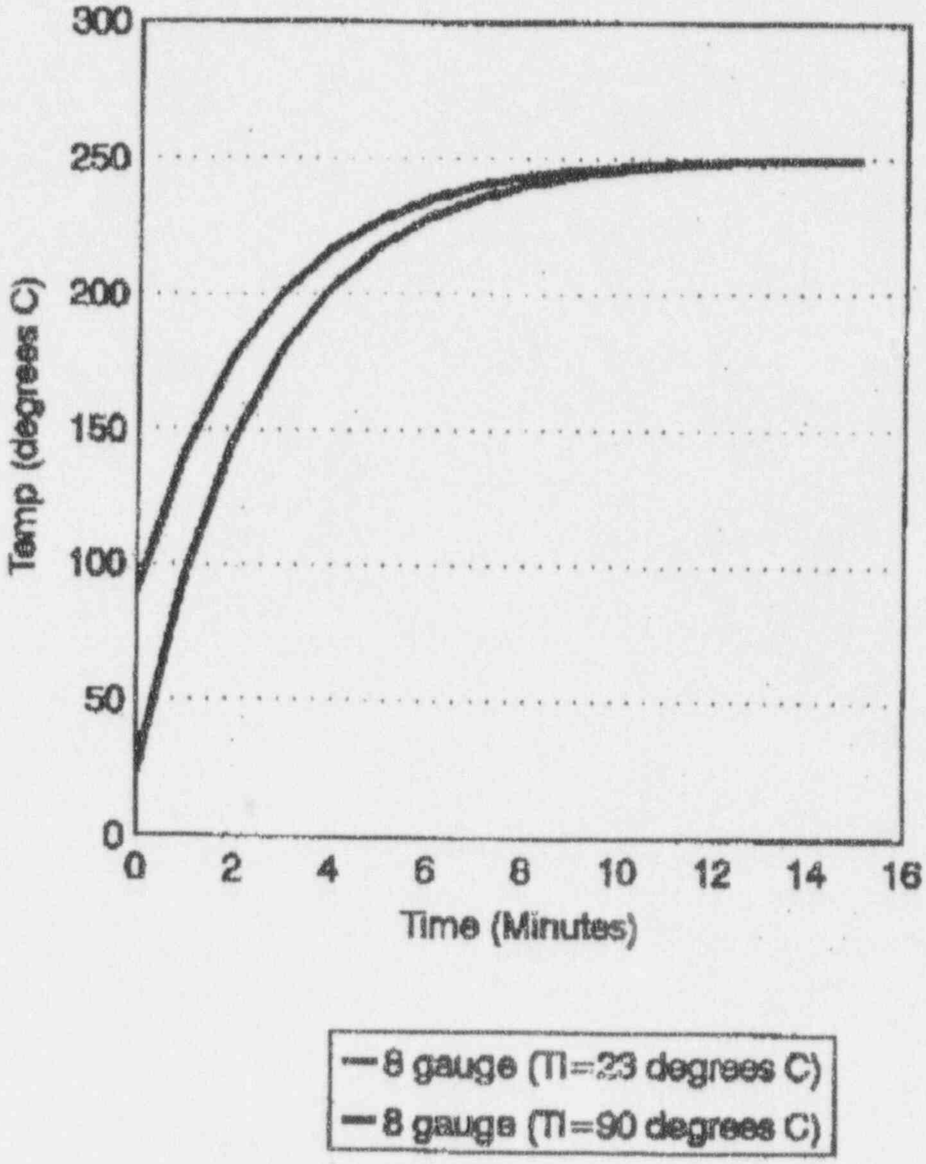
Thermal Response of Copper Wire



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