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CHARACTERIZATION OF IN-CONTAINMENT CABLES FOR NUCLEAR PLANT LIFE EXTENSION*

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ABSTRACT

Electrical cable is made by a large number of manufacturers and used for a variety of applications in nuclear plants. Cables have been identified in the Monticello and Surry Pilot Plant life extension studies and the NRC Nuclear Plant Aging Research Program as components important to the economic and safety aspects of life extension. Currently, fitness for service is largely determined by preoperational testing.

The U.S. Department of Energy is supporting work at Sandia National Laboratories to assess the technical basis for the life extension of cables found inside containment at U.S. nuclear plants. The work is being performed in coordination with the Nuclear Management and Resource Council's (NUMARC) NUPLEX Working Group. The initial task of this effort is to characterize the design attributes of in-containment cables. This has been completed via development of a data base depicting the manufacturer, type, material composition, use, qualification, and relative popularity of cables installed in containment. Other ongoing work is focussed on a review of cable operational experience and assessment of the issues affecting cable life extension. In the long term, the work aims to identify the technical criteria and life extension strategies needed to support continued cable qualification by nuclear plant owner/operators.

BACKGROUND

Electrical cable is made by a large number of manufacturers and used for a variety of applications in nuclear plants. A new BWR may have nearly 2 million feet of cable within primary and secondary containment [1]. An older BWR has been found to have 150,000 feet of cable installed inside containment for both safety and non-safety applications [2]. Nuclear plant cables in containment may be located in trays or conduits and used for a variety of power, control, or instrumentation applications.

This paper summarizes the design characterization of in-containment cables. The first section summarizes the current cable types found inside the containments of currently licensed U.S. plants. The second section summarizes current cable qualification bases. The third section indicates other aspects of cable design that may be important to life assurance. Finally, the fourth section summarizes insights gained by this design review that may be important to cable life extension.

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TYPES OF CABLES

An in-containment cable data base was developed to characterize cable types for the U.S. nuclear power industry. The data were developed from expansion and validation of the Electric Power Research Institute (EPRI) Equipment Qualification Data Bank (EQDB) with more detailed information gathered over the years by Sandia cable experts. The combined information sources cover 120 plants, including all currently operating Light Water Reactor (LWR) plants, plants under construction, as well as plants on hold that have not been formally cancelled or deferred. The data include cable manufacturer, cable designation (trade name or insulation/jacket), application type, qualification basis, and relative popularity. These data are compiled by an approximate cable "vintage" represented by the plant's construction permit date. The data, spanning the years 1957-1978, are compiled on a yearly basis except for the periods 1957-1966 and 1977-1978, which cover more than one year to preserve individual plant anonymity. An example of the data gathered is illustrated in Table 1, which shows the results of the compilation of information for the year 1971. Table 1 exemplifies the variety of cable types, uses, and qualification bases commonly found throughout the In-Containment Cable Data Base. It should be pointed out here that some utility reports did not clearly distinguish between in-containment and out-of-containment applications; also, some utilities qualify *all* in-containment cables, whether they are safety cables or not.

Table 1. Cables In Containment
(Plants with Construction Permits Issued in 1971)

Manufacturer	Designation	Type	Qualification	No. of Plants
American (AIW)	EPR/CSPE or NEO	power	D	1
BIW	Bostrad 7E (EPR)			1
BIW	PE/NEO			2
BIW	XLPE/NEO	inst	D, N2	3
Brand-Rex	XLPE/CSPE	inst	D, N2	2
Cerro	PE/NEO			2
GE	Vulkene (XLPE) or Vulkene Supreme	ctrl	D, N2, N1	3
General Cable	EPR/NEO or CSPE	power, ctrl	D, N2	3
Kerite	FR/FR	power, ctrl	D	1
Kerite	HTK-FR (EPR)			1
Okonite	EPR/NEO			3
Okonite	PE/CSPE			2
Raychem	Flamtrol (XLPE)	inst	C	2
Rockbestos	coax	inst	C	1
Rockbestos	Firewall III (XLPE)	inst	D, N2	3
Rockbestos	Pyrotrol III (XLPE)	inst	D, N2	2
Samuel Moore	EP/CSPE	inst	D	1

C = 10CFR50.49 N1 = NUREG-0588 Category 1
D = DOR Guidelines N2 = NUREG-0588 Category 2

As shown in Table 2, the In-Containment Data Base shows 36 different manufacturer names. Several of these manufacturers have changed their name or have been acquired by other companies over the years. Cerro, for example, is the old name for the Rockbestos Company, and Eaton, Dekoron, and Samuel Moore are different names used at various times for the same cable manufacturer. The data base does not account for the complicated evolution of these companies, but simply lists the manufacturers by the names used by the utilities.

Table 2. Cable Manufacturers

1. American Insulated Wire
2. Anaconda-Ericsson
3. Boston Insulated Wire
4. Brand-Rex
5. Cerro
6. Collyer
7. Continental
8. Conax
9. Cyprus
10. Dekoron
11. Eaton
12. Essex
13. Galite
14. General Atomic
15. General Cable
16. General Controls
17. G&H Technologies
18. General Electric
19. Hatfield
20. ITT
21. Kaiser
22. Kerite
23. Lewis
24. Okonite
25. Plastic
26. Raychem
27. Rockbestos
28. Rome
29. Samuel Moore
30. Teledyne
31. Tensolite
32. Thermo-Electric
33. Termon
34. Times
35. Triangle
36. Whitmore

Table 3 lists the ten most popular manufacturers of in-containment cable as determined by the number of entries in the data base (i.e., not by footage).

Table 3. Most Popular In-Containment-Use Manufacturers

1. Rockbestos
2. Okonite
3. Boston Insulated Wire
4. Kerite
5. Anaconda
6. Brand-Rex
7. Raychem
8. Samuel Moore
9. Cerro
10. Continental

Table 4 lists the specific cables most used throughout the industry for in-containment applications as determined by the number of plants having this cable installed inside containment.

Table 4. Most Popular Cables Installed Inside Containments

Cable	Number of Plants
1. Rockbestos Firewall III	61
2. Anaconda EPR	35
3. Brand-Rex XLPE	30
4. BIW Bostrad 7 & 7E	28
5. Okonite EPR	26
6. Kerite HTK	25
7. Rockbestos Coax	24
8. Raychem XLPE	23
9. Samuel Moore EPR	19
10. Kerite FR	13

The In-Containment Data Base also reveals several materials commonly used for cable insulation and jacketing. Predominant materials for cable insulation are cross-linked polyethylene (XLPE), ethylene propylene rubber (EP or EPR), and, to a lesser extent, silicone rubber (SR). Chlorosulfonated polyethylene (CSPE), chlorinated polyethylene, and Neoprene are frequently used for jacketing. These materials have largely superseded (particularly at the newer plants) other materials such as polyethylene (PE) and polyvinyl chloride (PVC). PE and PVC still appear, however, in the data collected for some of the earlier plants. Also appearing in the data are mineral insulation, Kapton, ethylene-chlorotrifluoroethylene (E-CTFE), ethylene-tetrafluoroethylene copolymer (ETFE), and polyalkene.

Cable applications found in the In-Containment Data Base are grouped under power, control, and instrumentation. The cables found in the data are largely used for low voltage applications (600 V or less). Instrument cable includes, among others: coax, twisted shielded pairs, and thermocouple cable. Typical applications include radiation detection instruments (coax), resistance temperature devices (RTDs), pressure transmitters (twisted shielded pairs), and thermocouples (thermocouple cable).

CABLE QUALIFICATION

Qualification is the process employed to assure that a cable will function during all design basis conditions. Industry cable qualification standards and NRC qualification regulations have evolved during the construction period for U.S. nuclear plants. For the earliest plants, equipment qualification was initially based on the fact that electrical components were of high industrial quality. Industry standards for qualification emerged in 1971.

IEEE Standard 323-1974 [3] is the current NRC-endorsed standard for environmental qualification of safety-related electrical equipment, including cable. This standard was first issued as a trial use standard, IEEE Standard 323-1971, in 1971; a revised version was issued in 1974. Both versions of the standard set forth requirements for equipment qualification, but the 1974 version includes specific requirements for aging, margins, and maintaining documentation that were not included in the 1971 trial use standard. IEEE 323-1974 allows qualification to be accomplished through type testing, operating experience, analysis, or any combination of these approaches. IEEE supplemented 323-1974 with the issue of 383-1974 [4], which includes guidance for type testing cables.

Since the publication of these industry standards, cable type testing prior to plant operation or early after the start of plant operation has been the dominant method for demonstrating cable life. This approach to life assurance frequently employs an accelerated test (several weeks to several months) to demonstrate that a safety cable will function during accident conditions that might occur at any time during a 40-year plant life. A typical test might include sequential exposure to artificial thermal aging, normal and accident radiation, and a combined steam/chemical spray environment. Margin is applied to the type-test parameters to account for normal variation in cable production and reasonable errors in defining satisfactory performance. Type test rigor and documentation requirements depend strongly on specific utility commitments to satisfy various vintages of standards and NRC regulations.

The In-Containment Data Base illustrates utility commitments to four distinct qualification bases. These bases are defined in terms of the applicable NRC regulatory guidance: Division of Operating Reactors (DOR) Guidelines, NUREG-0588 Category 1, NUREG-0588 Category 2, and 10CFR50.49.

The DOR Guidelines and NUREG-0588 Category 2 requirements are quite similar, as are 10CFR50.49 and NUREG-0588 Category 1 requirements. The two groups differ substantially in that 10CFR50.49/NUREG-0588 Category 1 generally require a higher level of documentation and more rigorous test methods (e.g., type tests on a single specimen) than DOR Guidelines/NUREG-0588 Category 2.

The DOR Guidelines [5] were issued in November 1979 to be applicable to nuclear plants with an operating license issued prior to May 23, 1980. These guidelines generally endorse IEEE 323 as one acceptable qualification methodology, but they primarily emphasize and build on the General Design Criteria specified in Appendix A of 10CFR50. Among other things, the DOR Guidelines state that type testing is the preferred qualification method for in-containment equipment, but allow analysis to qualify for radiation and thermal aging environments. The DOR Guidelines provide general guidance and allow qualification approaches on a case-by-case basis. Since the DOR Guidelines were intended for use in qualifying existing equipment, less stringent requirements were imposed on the qualification type test. For example, successful tests using equipment that had not been pre-aged was considered acceptable if the equipment did not contain materials that were susceptible to significant degradation resulting from thermal and radiation aging.

NUREG-0588 [6] was issued for comment by the NRC in December 1979 and later endorsed by the Commission to apply to nuclear plants licensed after May 23, 1980. NUREG-0588 Category 1 requirements endorse IEEE 323-1974 (with some modifications) and apply to plants having construction permits issued after July 1, 1974. Category 2 requirements endorse IEEE 323-1971 (with some modifications) and apply to plants having construction permits issued prior to July 1, 1974.

10CFR50.49 was issued on January 17, 1983, to be effective for all plants having an operating license issued after February 22, 1983. It represents the latest NRC requirement for equipment/cable qualification. Similar to the requirements of NUREG-0588 Category 1, it requires, for example, that synergistic effects be considered when they are believed to influence equipment performance. It further requires that all replacement equipment be qualified to its provisions unless there are sound reasons to the contrary.

The NRC requires that each utility document the qualification for each of its safety-related cables. The manufacturer, architect-engineering firm, utility-licensee, and special test laboratories may all contribute to the final cable qualification documents. Often, the data base shows a given cable product has more than one qualification basis. This reflects differing commitments by various plants regarding their qualification requirements. In some cases, plants have voluntarily upgraded the qualification basis for selected cables. In other cases, early plants have replaced selected cables to meet the evolving NRC requirements. Hence, as indicated by the data base, the earliest plants do include significant quantities of cable that satisfy the more recent regulatory requirements.

OTHER ASPECTS OF CABLE DESIGN

As noted above, a diverse set of cable products were used by the U.S. nuclear industry for in-containment safety applications. It was also noted that these cables were typically qualified for a minimum 40-year life using one of four qualification bases that vary with respect to test rigor and documentation requirements. In addition to these differences, cables installed in safety applications may differ substantially with respect to design practices, application and installation practices, and life testing practices. Since these differences may affect a cable's ultimate life and hence its available life margin, a summary of the potentially relevant differences is provided.

Cable Design Practices

1. Some cable products have the jacket bonded to the insulation; others do not. Typically, jacket materials degrade more rapidly than insulation materials; hence jacket cracking may more easily propagate to the insulation for the bonded jacket configurations.

2. Some cable products include halogen fire-retardants in the insulation, others have halogens only in the jacket. Radiation degrades the halogen fire-retardants creating hydrogen chloride or hydrogen bromide. These compounds must be neutralized if long

insulation life is to be maintained. (This is a less significant issue for cable products with halogens in the jacket rather than the insulation.)

3. Suppliers of EPR-insulated cables usually mix crosslinkable insulation compounds according to their own proprietary recipes, while suppliers of XLPE-insulated cables usually buy crosslinkable PE compounds from one of a few compound suppliers [7]. Hence, life data for one cable (especially EPR) may not provide predictive information for another cable product of the same generic class.

4. Some cables employ copper shields while others employ aluminum/mylar shields. The aluminum/mylar shields are more susceptible to aging effects.

5. Some cables are armored; others are not. Armored cables may be more protected from oxidative aging degradation than are the non-armored cables.

Cable Application and Installation Practices

1. Some power cable inside containment is self-heated, but the vast majority is not. The self-heated cable will experience more severe thermal aging.

2. Some instrumentation cable must maintain adequate insulation resistance (IR); other cable applications are less sensitive to IR degradation and hence more tolerant of aging effects.

3. Some cables must continue to operate long after the initiation of harsh accident conditions; others must operate for only short accident durations. Cables subjected to the milder environments can, of course, tolerate more aging degradation prior to an accident.

4. Some cable applications require the jacket to protect the shield from multiple grounds; others do not. Since jackets are more susceptible to aging effects than insulations are, cable life will depend on application requirements with respect to multiple grounds.

5. Some cables are installed in conduit and hence protected from accident beta radiation; others are installed in open cable trays and must survive harsher accident radiation conditions. Hence, cables in conduit can tolerate more aging degradation prior to an accident.

Cable Life Testing Practices

1. Various end-of-life parameters were used to determine required accelerated-aging test conditions.

2. Some cable products were tested for 40-year, 90°C environments; others were tested to less severe environments.

3. Various plant-specific accident conditions were employed to determine whether cables would function during their design life.

IMPLICATIONS FOR CABLE LIFE EXTENSION

Historical utility practice was to use preoperational type testing to qualify cables for their design life, typically a minimum of 40 years. For plant operation beyond 40 years, demonstration of continued cable qualification will be necessary. This might be accomplished by reanalysis of the original qualification bases, by supplementing the original qualification bases with additional laboratory test data, by supplementing the original qualification bases with operational experience and data, by a combination of the above techniques, or by a cable replacement program. As demonstrated in this paper, the U.S. nuclear industry employed a diverse set of cable products for in-containment safety applications. These products were manufactured using diverse design practices, were employed in diverse applications, and were tested using diverse configurations, end-of-life assumptions, and environmental conditions. Because of this diversity, no single life extension approach is likely to be applicable for all cases. Hence, in order to maximize the amount of in-containment cable within the U.S. nuclear industry that might qualify for life extension, several life extension approaches need to be available. A related paper discusses the technical, institutional, and regulatory issues that affect the development of these cable life extension strategies.

SUMMARY

The cable inside the containments of U.S. LWRs has been characterized using published literature resources supplemented by information supplied by cable experts. The In-Containment Cable Data Base so compiled provides valuable information on cable manufacturers and designation, cable materials and applications, and cable qualification and popularity; it lists a diverse number of cables, qualified to at least one of four possible qualification bases, and used for a variety of power, control, and instrumentation applications. Cables vary significantly in construction, installation, testing, polymer formulation, and actual performance requirements. This diversity in cables must be accounted for as the nuclear industry develops cable life extension strategies.

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