Nuclear Energy Standards Coordination Collaborative

Final Report of the Electrical Cable Task Group:

Electrical Cable Aging and Condition Monitoring Codes and Standards for Nuclear Power Plants

Current Status and Recommendations for Future Development

2013

NIST National Institute of Standards and Technology • U.S. Department of Commerce

ANSI American National Standards Institute

Nuclear Energy Standards Coordination Collaborative (NESCC)

Electrical Cable Aging and Condition Monitoring Codes and Standards for Nuclear Power Plants: Current Status and Recommendations for Future Development

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Contacts:

Stephanie Watson
National Institute of Standards and Technology, Engineering Laboratory
Email: Stephanie.watson@nist.gov

Corey McDaniel
Marmon Engineered Wire & Cable
Email: corey.mcdaniel@r-scc.com

Edited by:

Casandra Robinson, NESCC Federal Co-chair
National Institute of Standards and Technology
Email: casandra.robinson@nist.gov

Preparation of This Report

This report was prepared by the Nuclear Energy Standards Coordination Collaborative (NESCC) Electrical Cable Task Group (ECTG). Membership on the ECTG was open to all interested nuclear power plant stakeholders, and members and their organizations are listed in Table 1. The ECTG was co-chaired by Stephanie Watson of the National Institute of Standards and Technology's Engineering Laboratory in Gaithersburg, MD (USA) and Corey McDaniel of the Marmon Engineered Wire & Cable Group, Hartford, CT (USA).

Table 1. Membership of the ECTG

Name	Organization	Representative Category
1. Jan Pirrong	CableLAN Products	Cable or Connection Manufacturer
2. Mark St. Onge	RSCC Wire and Cable	Cable or Connection Manufacturer
3. Robert Gehm	RSCC Wire and Cable	Cable or Connection Manufacturer
4. Steve Sandberg	RSCC Wire and Cable	Cable or Connection Manufacturer
5. Robert Konnik	Marmon Innovation & Technology Group	Cable or Connection Manufacturer
6. Robert Fleming	Marmon Innovation & Technology Group	Cable or Connection Manufacturer
7. Corey McDaniel	Marmon Engineered Wire & Cable Group	Cable or Connection Manufacturer
8. Charles Hills	TE Connectivity Ltd.	Cable or Connection Manufacturer
9. Shin June	University of South Carolina	Education
10. Robert Bernstein	U. S. Department of Energy (DOE) Sandia National Laboratory (SNL)	Federal Government
11. Greg Von White	U. S. DOE SNL	Federal Government
12. Jason Neely	U. S. DOE SNL	Federal Government
13. Jason Brown	U. S. DOE SNL	Federal Government
14. Mathew Celina	U. S. DOE SNL	Federal Government
15. S. F. Glove	U. S. DOE SNL	Federal Government
16. Kevin McGrattan	National Institute of Standards and Technology (NIST)	Federal Government
17. Stephanie Watson	NIST	Federal Government
18. Darrell Murdock	U.S. Nuclear Regulatory Commission (NRC)	Federal Government
19. Gabriel Taylor	U. S. NRC	Federal Government
20. Sheila Ray	U. S. NRC	Federal Government
21. Daniel Chalk	U. S. DOE	Federal Government

Name	Organization	Representative Category
22. Satish Aggarwal	U. S. NRC	Federal Government
23. Bryan McConkey	AMS Corporation	Industry
24. Chris Campbell	AMS Corporation	Industry
25. Jim Gleason	ARES Corporation; Institute of Electrical and Electronics Engineers (IEEE) Working Group	Industry
26. John Merando	Bechtel Power	Industry
27. Brian Grimes	Brian K Grimes Consulting	Industry
28. Bruce Bernstein	Bruce Bernstein Consulting	Industry
29. Jim Raines	Fauske & Associates, LLC	Industry
30. Sue Burnay	John Knott Associates	Industry
31. Keith Petty	Shaw Group	Industry
32. Charles Larosche	Wiss, Janey, Elstner Associates, Inc.	Industry
33. Drew Mantey	Electric Power Research Institute (EPRI)	Industry Association
34. Gary Toman	EPRI	Industry Association
35. Sinnathurai Gajanetharan	Entergy Services	Owner/Operator
36. Camilo Rodriguez	FirstEnergy Nuclear Operating Company	Owner/Operator
37. William Hinton	Florida Power and Light Company (Next Era Energy)	Owner/Operator
38. D. Dayton	South Texas Project Electric Generating Station	Owner/Operator
39. Kent Brown	Tennessee Valley Authority (TVA)	Owner/Operator
40. Douglas DePriest	TVA	Owner/Operator
41. John White	IEEE Power and Energy Society, Nuclear Power Energy Committee, Subcommittee 2	Standards Development Organization (SDO)
42. Kjell Spang	International Electrotechnical Commission (IEC)	SDO
43. Sandra Bershad	National Fire Protection Association (NFPA)	SDO
44. Paul May	NFPA	SDO
45. Pravin Gandhi	Underwriters Laboratories Inc. (UL)	SDO
46. Thomas Chapin	UL	SDO

Contents

1. Introduction

The Nuclear Energy Standards Coordination Collaborative (NESCC) is a joint initiative established under the sponsorship of the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) in coordination with the National Institute of Standards and Technology (NIST) and the American National Standards Institute (ANSI). More details on the NESCC and its activities can be found at the website below:
http://www.ansi.org/standards_activities/standards_boards_panels/nescc/overview.aspx?menuid=3

NESCC discussions revealed electrical cable aging and condition monitoring to be two common concerns with nuclear power plant cables as plants age and as plant life spans potentially increase to 60 years. Electrical cables, especially their insulation and jacket materials, are susceptible to aging degradation under service conditions in nuclear power plants. Historically, cables for this application have been subjected to accelerated thermal and radiation aging and testing to demonstrate a qualified life of 40 years. Installed cables have subsequently been qualified for an extended life of 60 years or more. Improved methods are needed for monitoring and assessing the in-service performance and condition of cables.

To address these issues, NESCC formed a task group in July 2011 to focus on codes and standards for electrical cables used in nuclear power plants, specifically addressing cable aging and condition monitoring. Appropriate representation for the task group was solicited from industry, cable and connector manufacturers, plant owners and operators, researchers, the federal government, and standards development organizations (SDOs).

2. Objectives and Scope

The Electrical Cable Task Group (ECTG) began with a very broad scope of work but quickly recognized that the scope needed to be more focused in order to effectively address the topic of standards for electrical cable aging and condition monitoring. Therefore, the ECTG modified the scope to include the goals noted below:

i. Identify SDOs, industry associations, and research organizations publishing relevant standards or technical documents.
ii. Identify and define terms relevant to this work.
iii. Identify and review documents related to electrical cables for nuclear power plants, including:
    - NRC regulatory documents.
    - Standards for assessing and qualifying electrical cables that are cited (i.e., endorsed or referenced) by the NRC document collections[1].
    - Cited standards that need to be updated with rationale for the change.
    - New standards that should be cited with rationale for the change.

[1] nrc.gov. 2013. *NRC: Document Collections*. [online] Available at: http://www.nrc.gov/reading-rm/doc-collections/ [Accessed: 13 Dec 2013].

iv. Identify gaps in research and standards related to assessing and qualifying electrical cables.
v. Provide recommendations and short, medium, and long-term goals.

This report summarizes the results of the ECTG efforts in addressing each of the above goals.

3. Publishers of Relevant Standards and Technical Documents

This section provides a brief listing of the SDOs, industry associations, and research organizations that are involved in developing standards and technical reports for electrical cable materials, conditioning monitoring, and ancillary systems or components.

SDOs:

- British Standards Institute (BSI)
- European Committee for Electrical Standardization (CENELEC)
- Danish Standards Foundation (DS)
- Electronic Industries Alliance (EIA)
- Institute of Electrical and Electronics Engineers (IEEE)
- Insulated Cable Engineers Association (ICEA)
- International Electrotechnical Commission (IEC)
- National Electrical Manufacturers Association (NEMA)
- National Fire Protection Association (NFPA)
- Telecommunications Industry Association (TIA)
- Underwriters Laboratories (UL)
- U.S. Department of Defense

Industry Associations:

- Electric Power Research Institute (EPRI)

Research Organizations:

- DOE Brookhaven National Laboratory (BNL)
- DOE Sandia National Laboratory (SNL)
- Japan Nuclear Energy Safety Organization (JNES)

The SDOs publish voluntary consensus standards, and the industry associations and research organizations publish technical reports and guidance documents.

4. Terms and Definitions

The ECTG identified terms and definitions relevant to this report, and the list is provided in Appendix A. The definitions were taken from the IEEE standards indicated with each definition, and references to the standards are provided in Appendix B.

5. Key Issues

Two key issues were identified by the ECTG: (1) NRC regulatory documents that cite outdated standards and (2) research and standards gaps.

5.1. Priority NRC Regulatory Documents

A comprehensive review of all electrical cable standards cited within NRC regulatory documents would be difficult to compile within one report; therefore, the ECTG focused its efforts on specific standards for cable qualification and condition monitoring.

The ECTG attempted to catalog all relevant standards in the tables provided in Appendix C. Seven tables detail the NRC regulatory documents and the cited standards for cable qualification and condition monitoring. Each table is focused on a specific topic:

- Table 2: Standards for Cable Assemblies.
- Table 3: Standards for Fiber Optic Cables.
- Table 4: Standards for Cables with Fire Related Tests.
- Table 5: Standards for Cable Design and Installation.
- Table 6: Standards for Cable Service Life Prediction.
- Table 7: Standards for Loss of Coolant Accident (LOCA) Assessments.
- Table 8: Military Specifications for Cable Systems.

Each table also provides the status of each standard with respect to NRC regulatory documents as either (1) up-to-date, (2) outdated but appropriate for application, or (3) in need of revision.

The ECTG identified numerous regulatory guides and other NRC documents related to cable aging and condition monitoring as shown in Appendix C, Table 9 through Table 13; however, the following three Regulatory Guides (RGs) were prioritized as requiring attention.

5.1.1. RG 1.218, *Condition Monitoring Techniques for Electric Cables Used in Nuclear Power Plants* (Revision 0, April 2012).

It is recommended that the NRC revise RG 1.218 to more clearly distinguish between techniques that can be used to give an indication of the current condition of a cable and those techniques that may be useful for condition-based qualification and projection of life. Many times the techniques listed find installation damage or poor workmanship of splices and terminations even after years of installation.

Section B of RG 1.218, addressing cable monitoring methods and techniques,[2] should be updated as follows:

i. The list of twelve cable monitoring techniques should be expanded to include two less common diagnostics as options:

[2] NRC RG 1.218, *Condition Monitoring Techniques for Electric Cables Used in Nuclear Power Plants* (Revision 0, April 2012), pages 4 – 9.

- Dielectric spectroscopy. This method measures losses as a function of various voltage stresses and frequency.
- On-line partial discharge. This method does not require the cables to be disconnected and should be added to the section on partial discharge.

These diagnostics have had more exploration for transmission and distribution applications as compared to nuclear, and their inclusion in any broad discussion is warranted.

ii. The cable monitoring technique listed as item 1, *Direct Current (dc) High Potential Test (dc High Voltage)*, cites prior EPRI work, and clarification is needed. The potentially harmful influence of dc high potential testing is related to cable located in a wet environment.

It should be noted that the EPRI guides for aging management program development (EPRI 1020804[3], EPRI 1020805[4], and EPRI 1021629[5]) listed under non-NRC documents are being used by U.S. nuclear power plants to implement the aging management program described in RG 1.218. Discussed are the programmatic and condition monitoring techniques recommended for cables by type (i.e., low voltage instrument and control, low voltage power, and medium voltage power).

iii. For the cable monitoring technique listed as item 6, *Compressive Modulus (Polymer Indenter)*, there is an apparent contradiction regarding application of the cable indenter. The beginning of the discussion implies that the indenter is suitable for polyethylene (PE) insulation, but later discussion indicates that it is not suitable for cross linked polyethylene (XLPE) insulation. The issue is further complicated since polyolefin materials often age with pronounced "induction time behavior," and modulus may only change just before a rapid embrittlement status. The suitability may be more related to crystallinity and formulation than material type. PE and generally XLPE are semi-crystalline, but ethylene propylene rubber (EPR) formulas can also be crystalline. This technique is generally associated with elastomers, since elastomers often show a more gradual increase in hardness with aging that can be evaluated using an indenter. Moreover, for XLPE cables with jacket materials such as chlorosulfonated polyethylene, neoprene, or similar elastomers, a risk is given for low aging rate environments, precisely where the indenter should offer monitoring confidence. If the degradation rates are sufficiently low so that the jacket does not act as a complete oxygen barrier and sufficiently hardens (meant to be picked up by the indenter), then oxygen and temperature will act on the XLPE insulation underneath. The degradation then becomes a competitive process in aging behavior between XLPE insulation and the jacket. Whichever material is more susceptible will fail

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[3] EPRI 1020804, *Plant Support Engineering: Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants*, June 2010.

[4] EPRI 1020805, *Plant Support Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants*, June 2010.

[5] EPRI 1021629, *Plant Support Engineering: Aging Management Program Development Guidance for Instrument and Control Cable Systems for Nuclear Power Plants*, November 2010.

first. Hence, it is possible that the interior is affected while the jacket shows no degradation, or vice versa. For power cables, internally generated heat should be considered as well as where the accessible areas are. At higher aging rates, the indenter offers a suitable condition monitoring approach only when the jacket acts as a protective oxygen barrier that is hardened so that inert aging of the XLPE beneath the jacket is of little concern.

New techniques are available that use relaxation, and these should be included as the technology gets more mature.

Caution in seeking to apply any single diagnostic tool to achieve the goal is clearly stated and timely. There is currently activity in combining the very low frequency (VLF) testing method with other diagnostics for transmission and distribution applications.

5.1.2. RG 1.89, *Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants* (Revision 1, June 1984).

It is recommended that the NRC revise RG 1.89 by updating the reference for IEEE Standard 323, *Standard for Qualifying Class 1E Equipment of Nuclear Power Generating Stations*, from the 1974 version to the current version, IEEE Standard 323-2003. Since IEEE Standard 323 was first published, there have been two revisions, and Appendix D provides a description of the changes between the two published revisions.

As a precedent, RG 1.209, *Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants*, has been revised to reference the 2003 version of IEEE Standard 323.

5.1.3. RG 1.189, *Fire Protection for Nuclear Power Plants* (Revision 2, October 2009).

It is recommended that the NRC revise 1.189 by updating the references to IEEE Standard 323 and IEEE Standard 1202, neither of which have version dates associated with the reference. It is assumed that the NRC referenced undated standards intentionally for the purpose of making the RG a living and dynamic document that would be understood to reference the most current versions of undated standards. Licensees are required to use the versions of the standards that were committed to in their licenses. To avoid confusion for licensees, testing laboratories, and others, it is recommended that the NRC revise RG 1.189 to include references to the most current versions of the standards, ensuring that the date is attached to each reference.

5.1.4 RG 1.131, *Qualification Tests of Electric Cables, Field Splices, and Connections for Light-Water-Cooled Nuclear Power Plants* (Withdrawn, April 2009).

In as much as draft RG 1.131 has been withdrawn and superseded by RG 1.211, *Qualification of Safety-Related Cables and Field Splices for Nuclear Power Plants*, it is recommended that the NRC provide more guidance to existing nuclear plants that are committed to RG 1.131 with regards to applying the requirements of RG 1.211 to their plants for new cables being procured or for life extension applications.

5.2. Research and Standards Gaps for Electric Cables in Existing Nuclear Power Plants

The ECTG identified four critical research and standards gaps related to electrical cables in existing nuclear power plants, and recommendations for addressing these gaps are provided below.

i. ***Cable aging studies***. Aging of cables has become a great concern as licenses for nuclear power plants are renewed to allow plants to continue operating for an additional 20 years beyond their initial 40-year life. Accelerated aging studies are typically performed in extreme conditions (e.g., heat, radiation) to rate the life expectancy of cables, but extrapolation to 60 years is not an easy task using existing accelerated aging data.

   The Japanese have conducted research that describes differences between thermal exposure only and simultaneous thermal plus gamma radiation exposure[6]. Different results may be observed if aging steps are done in sequence versus simultaneously. There is a balance between natural, lower temperature aging and the time required to perform the testing, and fundamental research is lacking for aging at low temperature and lower doses of gamma radiation. A recent presentation from the Japanese after Fukushima showed that the results presented by this Japanese research did not correlate with natural aging. Cables that had been in operation were tested and found to have no correlation with the results provided.

   In addition, the ECTG discussed three other documents dealing with the complexity of accelerated aging approaches:

   - SAND 2010 -7266, *Review of Nuclear Power Plant Safety Cable Aging Studies with Recommendations for Improved Approaches and for Future Work*.
   - IEEE Standard 775, *IEEE Guide for Designing Multi-stress Aging Tests of Electrical Insulation in a Radiation Environment (withdrawn).*
   - *SAND 2013-2388, Nuclear Power Plant Cable Materials: Review of Qualification and Currently Available Aging Data for Margin Assessments in Cable Performance.*

   These three documents should be reviewed for inclusion in current cable qualification standards (see Appendix E for more detail). This information needs to be reviewed against actual plant conditions and cable performance in plants to see if the information is valid.

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[6] T Yamamoto & T Minakawa, Final Report on "Assessment of Cable Aging for Nuclear Power Plant", JNES-SS-0903, Japan Nuclear Safety Organization, July 2009.

Consideration should also be given for what information applies to qualification standards and what should be included in condition monitoring guides. The qualification should be practicable since the technique cannot take 60 years to qualify a cable for use. Discussions are encouraged within the community regarding situations where current standards-based testing or qualification approaches may not capture long-term aging processes, such as when the existence of intrinsic limits in lifetime predictability should be considered. Federal and/or industry association funding is needed to perform research and testing in this area so that improved test methods may be developed by SDOs based on the research data. Standards should be developed that include more aspects of the current science of accelerated polymer aging. Qualification standards that are in direct conflict with what is known for the long-term aging behavior of some materials should be revised as appropriate. There is a long track record of cables and equipment being tested to current standards and being robust. Condition monitoring programs would be helpful to validate this; however, changing qualification testing may not be the best approach. There is at least 40 years of history with some materials, so this may be required to validate models for certain materials.

ii. ***Water submergence.*** The ECTG noted that cables need to be assessed during testing in realistic environmental conditions, including water submergence, and the cables must be energized to produce relevant results. It is recommended that federal and/or industry association funding be made available to perform research and testing in this area and that improved test methods be developed by SDOs based on the research data. Water submergence testing of energized cables (including non-Class 1E cables) located in duct banks and underground conduits in non-harsh environments is a great concern to the NRC and also needs further study. Operating experience may be used to get information on past and future operating conditions. Some programs are already underway, such as the EPRI submergence program. Additionally, industrial committees have been initiated to assess these needs, such as the IEEE International Conference on Communications (ICC) discussion group on submergence testing of nuclear facilities cables. These should be taken into consideration.

iii. ***Activation energy***. Several standards, including IEEE Standard 1205, specify the Arrhenius equation to predict the service life, and activation energy may be used in the calculations. It should be noted that IEEE Standard 1205 is currently under review and provides examples of aging testing. There can be issues with oxygen diffusion, second order reactions, length of test, and other factors. IEEE Standard 98 and other standards provide guidance, but such guidance is not always followed. It is recommended that federal and/or industry association funding be made available to perform research and testing to address this concern.

iv. ***Adequacy of cable characterization techniques***. Characterization techniques, particularly destructive versus non-destructive ones, are of concern. The ECTG members agreed that there are numerous techniques available, and many of those can be improved. It was noted that strategies to better link observed long-term aging phenomena with various methods of condition monitoring should be developed. The idea of a micro sample approach is of interest, but in many cases, one cannot access or even know the exact location to sample on the cable. There are also radiation exposure concerns with trying to access cable that is located in the appropriate environment. Development and optimization of acceptance criteria for cable condition monitoring test methods are still required.

Novel in situ, non-destructive electrical test methods, such as Line Resonance Analysis (LIRA), are utilized in industries other than nuclear to locate thermal damage before failure of the cable insulation, and these test methods should be investigated for application in nuclear power plants. EPRI has studied LIRA, and their findings should be considered. Complementary to LIRA, Joint Time-Frequency Domain Reflectometry (JTFDR) initial testing is promising, but additional verification and validation of the method are necessary before it can be used in nuclear power plants.

In addition, there are no standardized test methods for unshielded medium voltage cables, a cable type that utilities have found suitable for submersion. Industry and utilities need a different process of approval for these types of situations. Universal procedures for walk downs of cable installations are needed to help pinpoint the locations of trouble (e.g., heat or radiation). The initial inspection appears to work well enough. Previous work done by EPRI should be built upon, and SDOs, such as IEEE, need to develop these types of methods. There are also no standardized test methods for non-shielded low voltage power and control cables.

5.3. Research and Standards Gaps for Electrical Cables in New Nuclear Power Plants

New plants will most likely use materials similar to the current fleet for 60-year cables because there is field experience, 40 years of documented use, and data on the lifetime of those materials. Some of these materials have already passed 60-year qualified life for life extensions.

The following recommendations to address electrical cables in new plants are offered:

i. Research on low smoke zero halogen (LSZH) materials is ongoing, and EPRI reports indicate that LSZH cables can be used if there is a fire; however, these cables have many disadvantages if there is no fire and may not be suitable for some U.S. plant designs. The idea should be to prevent the fire instead of anticipating having a fire. There may be many disadvantages of LSZH cables which include lower dielectric strength, less fire retardancy, and higher water absorption (i.e., less stable in long term water performance) so that it becomes a balancing act on which properties licensees are willing to give up.
ii. For materials qualification, the performance correlation must be determined between fast non-oxidative diffusion limited oxidation (DLO) controlled exposure with materials driven by oxidative degradation during long-term plant exposure under low

dose rate, low temperature conditions. It is recommended that a consensus be facilitated on the meaning of published aging data showing "inverse temperature and DLO dominant aging behavior" and its relevance to standards-based testing/qualification approaches. If applicable, avenues should be identified to develop and support research programs to better deal with "inverse temperature" and pronounced DLO behavior and the resulting correlation challenges between ambient aging and rapid qualification testing.

iii. It is recommended that SDOs come to commonly accepted definitions of low, medium, and high voltage. IEEE varies on the classification of low, medium, and high voltage. ICEA classifies low voltage as less than 2000 Volts (V), and this is cable rated voltage as opposed to operating or system voltage. A 480-V circuit may use a cable rated for 2000 V because of voltage spikes. Typical system voltages are: 2.4 kV to 35 kV/46 kV for medium voltage, ≥46 kV for high voltage, and ≥ 250 kV for extra high voltage.

6. Summary of Recommended Actions

6.1. Short-Term Actions (< 3 years)

Recommendations, detailed in Section 5, are highlighted below:

- Revise RG 1.89 as indicated in Section 5.1.2 of this report.
- Revise RG 1.189 as indicated in Section 5.1.3 of this report.
- Provide NRC guidance on RG 1.131 as indicated in Section 5.1.4 of this report.
- Perform cable aging studies as indicated in Section 5.2, i of this report.
- Perform research on adequacy of cable characterization techniques as indicated in Section 5. 2, iv of this report.
- Perform research into LSZH cables as indicated in Section 5.3, i of this report.

6.2. Medium-Term Actions (3 to 8 years)

- Revise RG 1.218 as indicated in Section 5.1.1 of this report.
- Perform research on water submergence as indicated in Section 5.2, ii of this report.
- Perform research on activation energy as indicated in Section 5.2, iii of this report.
- Develop definitions of low and medium voltage as indicated in Section 5.3, iii of this report.

6.3. Long-Term Actions (> 8 years)

- Determine correlation between accelerated exposure and natural aging conditions as indicated in Section 5.3, ii of this report.

Appendix A, Terms and Definitions

Aging Assessment: Evaluation of appropriate information for determining the effects of aging on the current and future ability of systems, structures, and components to function within acceptance criteria. (IEEE Standard 1205-2000)

Aging Degradation: Gradual deterioration in the physical characteristics of a system, structure, or component, that is due to aging mechanisms, which occurs with time or use under pre-service or service conditions, and could impair its ability to perform any of its design functions. (IEEE Standard 1205-2000, modified)

Aging Effects: Net changes in characteristics of a system, structure, or component that occur with time or use and are due to aging mechanisms. (IEEE Standard 1205-2000)

Cable Description: The specification should include as a minimum 1) *conductor*: material identification, size, stranding, coating, 2) *insulation*: material identification, thickness, method of application, 3) *assembly* (multiconductor cables only): number and arrangement of conductors, fillers, binders, 4) *shielding*: tapes, extrusions, braids, or others, 5) *covering*: jacket or metallic armor or both, material identification, thickness, method of application, 6) *characteristics*: voltage and temperature rating (normal and emergency); for instrumentation cables, capacitance, attenuation, characteristic impedance, microphonics, insulation resistance, as applicable, 7) *identification*: manufacturer's trade name, catalog number. (IEEE Standard 383-1974)

Cable Type: A cable type for purposes of qualification testing shall be representative of those cables having the same materials similar construction, and service rating, as manufactured by a given manufacturer. (IEEE Standard 383-1974)

Class 1E: The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment. The terms *Class 1E equipment* and *safety-related electric equipment* are synonymous. (IEEE Standard 323-2003)

Components: Items from which the equipment is assembled, e.g., resistors, capacitors, wires, connectors, transistors, tubes, switches, and springs. (IEEE Standard 323-2003)

Condition-Based Qualification: Qualification based on measurement of one or more condition indicators of equipment, its components, or materials for which an acceptance criterion can be correlated to the equipment's ability to function as specified during an applicable design basis event. (IEEE Standard 323-2003)

Containment: That portion of the engineered safety features designed to act as the principal barrier, after the reactor system pressure boundary, to prevent the release, even under conditions of a reactor accident, of unacceptable quantities of radioactive material beyond a controlled zone. (IEEE Standard 323-1974)

Design Basis Events: Postulated events used in the design to establish the acceptable performance requirements for the structures, systems, and components. (IEEE Standard 323-2003)

Design Life: The time period during which satisfactory performance can be expected for a specific set of service conditions. (IEEE Standard 323-2003)

Equipment: An assembly of components designed and manufactured to perform specific functions. (IEEE Standard 323-2003)

Equipment Qualification: The generation and maintenance of evidence to ensure that equipment will operate on demand to meet system performance requirements during normal and abnormal service conditions and postulated design basis events. Equipment qualification includes environmental and seismic qualification. (IEEE Standard 323-2003)

Field Splice: A permanent joining and reinsulating of conductors in the field to meet the service conditions required. (IEEE Standard 383-1974)

Field Splice Description: The specification should include as a minimum 1) identify as factory or field assembled to cable, 2) *conductor connection*: type, material identification, and method of assembly and 3) all information listed in cable description. (IEEE Standard 383-1974)

Harsh Environment: An environment resulting from a design basis event, i.e., loss-of-coolant accident (LOCA), high-energy line break (HELB), and main steam line break (MSLB). (IEEE Standard 323-2003)

Mild Environment: An environment that would at no time be significantly more severe than the environment that would occur during normal plant operation, including anticipated operational occurrences. (IEEE Standard 323-2003)

Qualified Condition: The condition of equipment, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions. (IEEE Standard 323-2003)

Qualified Life: The period of time, prior to the start of a design basis event (DBE), for which the equipment was demonstrated to meet the design requirements for the specified service conditions. (IEEE Standard 323-2003)

Representative Cable: A cable or group of cables used during qualification testing to represent a number of cable styles. The representative cables shall contain the following characteristics of the cable styles: a) manufactured by a specific manufacturer using the same processes and controls; b) contains the same materials, including insulation, jackets, fillers, binder tape, shields, and factory splices (if appropriate); c) the same or higher service rating; d) the same or higher volts per mil operating level; and e) construction or configuration features (e.g., number or type of conductors) that conservatively represent the features of the cable styles being qualified. (IEEE Standard 383-2003)

Representative Splice: A splice or group of splices used during qualification testing to represent a number or range of splice styles. The representative splices shall contain the following characteristics of the splice styles: a) materials manufactured by a specific manufacturer using the same processes and controls, b) the same materials, c) the same or higher service rating, d) the same or higher volts per mil operating level, and e) construction or configuration features (e.g., number of conductor break-outs, V-type or inline type) that conservatively represent the features of the splice styles being qualified. (IEEE Standard 383-2003)

Residual Life: The remaining period of time during which a system, structure, or component is expected to perform its intended function under specified service conditions. (IEEE Standard 1205-1993)

Service Conditions: Environmental, loading, power, and signal conditions expected as a result of normal operating requirements, expected extremes (abnormal) in operating requirements, and postulated conditions appropriate for the design basis events of the station. (IEEE Standard 323-2003)

Service Life: The time period from initial operation to removal from service. (IEEE Standard 323-2003)

Significant Aging Mechanism: An aging mechanism that, under normal and abnormal service conditions, causes degradation of equipment that progressively and appreciably renders the equipment vulnerable to failure to perform its safety function(s) during the design basis event conditions. (IEEE Standard 323-2003)

Stressor: An agent or stimulus that stems from fabrication or pre-service and service conditions and can produce immediate degradation or aging degradation of a system, structure, or component. (IEEE Standard 1205-1993)

Type Tests: Tests made on one or more units to verify adequacy of design. (IEEE Standard 380-1972, IEEE Standard 383-1974)

Appendix B, References

This appendix includes all publications cited within the body of this report and Appendix A; publications cited within the other appendices are not included here.

EPRI 1020804, *Plant Support Engineering: Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants*, June 2010.

EPRI 1020805, *Plant Support Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants*, June 2010.

EPRI 1021629, *Plant Support Engineering: Aging Management Program Development Guidance for Instrument and Control Cable Systems for Nuclear Power Plants*, November 2010.

IEEE Standard 98, *Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ.

IEEE Standard 323-1974, *IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, 1974.

IEEE Standard 323-2003, *IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, 2003.

IEEE Standard 380-1972, *Definitions of Terms Used in IEEE Nuclear Power Generating Station Standards*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, 1972.

IEEE 383, *IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations*, Institute of Electrical and Electronics Engineers, Piscataway, NJ.

IEEE 383-1974, *IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations*, Institute of Electrical and Electronics Engineers, Piscataway, NJ, 1974.

IEEE Standard 775, *IEEE Guide for Designing Multi-stress Aging Tests of Electrical Insulation in a Radiation Environment*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, Withdrawn.

IEEE Standard 1202, *IEEE Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ.

IEEE Standard 1205, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ.

IEEE Standard 1205-1993, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, 1993.

IEEE Standard 1205-2000, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations*, Institute for Electrical and Electronics, Engineers, Piscataway, NJ, 2000.

Regulatory Guide 1.218, *Condition Monitoring Techniques for Electric Cables Used in Nuclear Power Plants,* Revision 0, U.S. Nuclear Regulatory Commission, Washington, DC, April 2012.

Regulatory Guide 1.89, *Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants*, Revision 1, U.S. Nuclear Regulatory Commission, Washington, DC, June 1984.

Regulatory Guide 1.189, *Fire Protection for Nuclear Power Plants*, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, October 2009.

Regulatory Guide 1.209, *Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants*, Revision 0, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

Regulatory Guide 1.211, *Qualification of Safety-Related Cables and Field Splices for Nuclear Power Plants*, Revision 0, U.S. Nuclear Regulatory Commission, Washington, DC, April 2009.

Regulatory Guide 1.131, *Qualification Tests of Electric Cables, Field Splices, and Connections for Light-Water-Cooled Nuclear Power Plants*, Withdrawn, U.S. Nuclear Regulatory Commission, Washington, DC, April 2009.

SAND 2010 -7266, *Review of Nuclear Power Plant Safety Cable Aging Studies with Recommendations for Improved Approaches and for Future Work*, Sandia National Laboratories, Albuquerque, NM, 2010.

SAND 2013-2388, *Nuclear Power Plant Cable Materials: Review of Qualification and Currently Available Aging Data for Margin Assessments in Cable Performance*, Sandia National Laboratories, Albuquerque, NM, 2013.

T. Yamamoto & T. Minakawa, Final Report on "Assessment of Cable Aging for Nuclear Power Plant", JNES-SS-0903, Japan Nuclear Safety Organization, July 2009.

Appendix C, Tables

The tables within this appendix contain standards, NRC documents, and non-NRC documents. *Note: The information within the tables is not complete.*

- Table 2: Standards for Cable Assemblies.
- Table 3: Standards for Fiber Optic Cables.
- Table 4: Standards for Cables with Fire Related Tests.
- Table 5: Standards for Design and Installation.
- Table 6: Standards for Cable Service Life Prediction.
- Table 7: Standards for Loss of Coolant Accident (LOCA) Assessments.
- Table 8: Military Specifications for Cable Systems.
- Table 9: NRC Documents Referencing Cables, including Regulatory Guides, Information Notices and Generic Letters.
- Table 10: NRC Regulatory Guides Written by NRC Staff for Cables and Connections from an April 2013 Search of the NRC Website.
- Table 11: NRC Regulatory Guides Written by Contractors for Cables and Connections from an April 2013 Search of the NRC Website.
- Table 12: Information Notices Related to Cables from an April 2013 Search of the NRC Website.
- Table 13: Research Documents Related to Cables in Nuclear Applications.

Each table also provides the status each standard with respect to NRC regulatory documents as either (1) up-to-date, (2) outdated but appropriate for application, or (3) in need of revision.

Table 2. Standards for Cable Assemblies

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
IEEE 317-2013, IEEE Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations	Yes, June 14, 2013			Refer to NRC documents
IEEE 323-2003, IEEE Standard for Qualifying Class 1E Equipment of Nuclear Power Generating Stations	Active; September 9, 2003	Under revision; new IEEE and IEC joint project; entire sections on condition monitoring and cable monitoring—no changes in qualification		
IEEE 344-2004, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations		Under revision		
IEEE 384-2008, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits				
IEEE 383-2003, IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations		Under revision		
IEEE 572-2006, IEEE Standard for Qualification of Class 1E Connection Assemblies for Nuclear Power Generating Stations, with Errata July 2011				
IEEE 627-2010, IEEE Standard for Qualification of Equipment Used in Nuclear Facilities				
IEC 60780-1998, Qualification of Electrical Equipment of Safety Systems in Nuclear Power Plants		In revision with IEEE 323; to member states for changes		
BSI BS IEC 60313-2002, Coaxial Connectors Used in Nuclear Laboratory Instrumentation	Active, October 17, 2002(Confirmed 2005)			British Standards Institution

Standard	Status			
	Up-to-date	**Outdated but appropriate for application**	**Reference needs revision**	**Comments**
DS DS/IEC 60502-1/A1, Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) - Part 1: Cables for rated voltages of 1 kV (Um = 1,2 kV) and 3 kV (Um = 3,6 kV)	Active, January 8, 2010			Danish Standards Foundation

Table 3. Standards for Fiber Optic Cables

Standard	Status			
	Up-to-date	**Outdated but appropriate for application**	**Reference needs revision**	**Comments**
TIA/EIA-4720000-A-1993 Generic Specification for Fiber Optic Cable	ANSI Withdraw Approval, March 2004	EIA 472000-A: 1985, Cables, Generic Specification For Fiber Optic Cable		ICEA- check documents S104696, S87640
IEEE 1682-2011, IEEE Trial-Use Standard for Qualifying Fiber Optic Cables, Connections, and Optical Fiber Splices for Use in Safety Systems of Nuclear Power Generating Stations		trial, 2 year life being upgraded		
IEEE 1428-2004, IEEE Guide for Installation Methods for Fiber-Optic Cables in Electric Power Generating Stations and in Industrial Facilities	Yes, according to the year, just reaffirmed			
IEC/IEEE 62852-5 "Nuclear power plants — Instrumentation and control important to safety — Electrical equipment condition monitoring methods, Part 5: Optical time domain reflectometry"				under development and expected publication in 2014
BSI BS EN 60794-1-2, Optical fibre cables - Part 1-2: Generic specification - Basic optical cable test procedures - AMD 15456: November 26, 2004	Active December 11, 2003			British Standards Institution
DS DS/EN 60793-1-54, Optical fibres - Part 1-54: Measurement methods and test procedures - Gamma irradiation	Active December 2, 2003			Danish Standards Foundation
DS DSF/FprEN 60793-1-54, Optical fibres -- Part 1-54: Measurement methods and test procedures - Gamma irradiation	Draft N/A			Danish Standards Foundation

Table 4. Standards for Cables with Fire Related Tests

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
NFPA 701-2009, Standard Methods of Fire Tests for Flame Propagation of Textiles and Films				not applicable
IEEE 634-2004, IEEE Standard Cable-Penetration Fire Stop Qualification Test				Not applicable to cables specifically
UL 94-2013, Standard for Safety of Tests for Flammability of Plastic Materials for Parts in Devices and Appliances				Not a cable test; testing (plastic materials in general but could be applied to terminations and relevant cable systems)
IEEE 383-1974, IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Station		Newer version references a new technology		Older version discussed flame performance
IEEE 1202-1991, IEEE Standard for Flame Testing of Cables for Use in Cable Tray IEEE 1202-2006 and Corrigendum 1 - 2012: IEEE Standard for Flame-Propagation Testing of Wire and Cable	Revised in 2006, Corrigendum 1 - 2012	Reaffirmed, but modifications may apply; PAR open to revise		
UL 1581-2001, UL Standard for Safety Reference Standard for Electrical Wires, Cables, and Flexible Cords VW-1 Vertical Wire Flame Test	Yes			Small cable, equipment-current test method; used for small sized single insulated conductor without jacket.
UL 1581-2001, UL Standard for Safety Reference Standard for Electrical Wires, Cables, and Flexible Cords	Yes			Both Class 1E and non Class IE

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
UL 1685-2007, UL Standard for Safety Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables	Yes			similar IEEE 1202
NFPA 262-2011, Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces	Yes			
UL 1666-2007, UL Standard for Safety Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts	Yes			
DS DS/HD 604 S1, 0,6/1 kV power cables with special fire performance for use in power stations	Active October 22, 2002			Danish Standards Foundation
DS DS/HD 622 S1/A2, Power cables having rated voltages from 3,6/6 (7,2) kV up to and including 20,8/36 (42) kV with special fire performance for use in power stations	Active March, 24, 2006			Danish Standards Foundation

Table 5. Standards for Cable Design and Installation

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
IEEE 336-2010, IEEE Recommended Practice for Installation, Inspection, and Testing for Class 1E Power, Instrumentation, and Control Equipment at Nuclear Facilities				
IEEE 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations				1986 version used by current NPPs
IEEE 422-2012, IEEE Guide for the Design of Cable Raceway Systems for Electric Generating Facilities				
IEEE 690-2004, IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations				Currently in revision
IEEE 1185-2010, IEEE Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities				
IEEE 384-2008, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits	Active September 26, 2008			
IEEE 628-2011, IEEE Standard Criteria for the Design, Installation, and Qualification of Raceway Systems for Class 1E Circuits for Nuclear Power Generating Stations				
IEEE N45.2.4, Installation, Inspection, and Testing Requirements for Instrumentation, and Electric Equipment During the Construction of Nuclear Power Generating Stations			Withdrawn September 16, 1971	
IEEE 525-2007, IEEE Guide for the Design and Installation of Cable Systems in Substations				

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
NEMA/ICEA WC 3,5,7,8, Polymer Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (WC3: Rubber; WC5: Thermoplastic; WC7: Cross-linked Polyethylene; WC8: Ethylene Propylene)	Withdrawn; replaced by WC70, 71, 74		Replaced by joint ICEA/NEMA-standards not materials based language	relevant to old plants but not for new construction
NEMA WC74-2012/ANSI/ICEA S-93-639, 5-46 kV Shielded Power Cables for Use in Transmission and Distribution of Electric Energy	Yes			
NEMA WC70-2009/ANSI/ICEA S-95-658, Power Cables Rated 2000 Volts or Less for Distribution of Electrical Energy	Yes			
NEMA WC71-1999, ICEA S-96-659, Standard for Non-Shielded Cables Cables Rated 2001 - 5000 V for Use in the Distribution of Electric Energy		In revision (2013)		
ANSI/ICEA S-97-682-2013, Standard for Utility Shielded Power Cables Rated 5 Through 46 kV	Yes			
NEMA WC57-2004/ICEA S-73-532, Standard for Control, Thermocouple Extension and Instrumentation Cables		In revision		
UL 83-2008, UL Standard for Safety Thermoplastic-Insulated Wires and Cables				applies to thermoplastics not used in NPP, non-Class 1E
UL 44-2010, UL Standard for Safety Thermoset-Insulated Wires and Cables		In revision; periodic and proposed; fairly large right now		
UL 1072-2006, UL Standard for Safety Medium-Voltage Power Cables		In revision, quick changed		
UL 1277-2010, Standard for Safety Electrical Power and Control Tray Cables with Optional Optical-Fiber Members		In revision		

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
UL 1569-1999, UL Standard for Safety Metal-Clad Cables		In revision		
UL 444-2008, UL Standard for Safety Communications Cables				
IEC 60709-2004, Nuclear power plants —Instrumentation and control systems important to safety – Separation				
TSE TS IEC 60709-2003, Separation within the reactor protection system	Active April 29, 2003			
BSI BS EN 60325-2004, Nuclear power plants — Radiation protection instrumentation Alpha, beta and alpha/beta (beta energy > 60 keV) contamination meters and monitors	Active September 9, 2004			British Standard Institution
BSI BS EN 61500-2011, Nuclear power plants — Instrumentation and control important to safety — Data communication in systems performing category A functions - CORR: October 31, 2011	Active January 31, 2010			British Standard Institution
BSI BS IEC 61500-2010, Nuclear power plants — Instrumentation and control important to safety — Data communication in systems performing category A functions			Non-current 2010.01.31	British Standard Institution
CENELEC EN 60709-2010, Nuclear power plants - Instrumentation and control systems important to safety – Separation	Active May 1, 2010			European Committee for Electrotechnical Standardization
DS DS/EN 60709-2010, Nuclear power plants - Instrumentation and control systems important to safety – Separation	Active August 19, 2010			Danish Standards Foundation
DS DSF/FprEN 60709, Nuclear power plants - Instrumentation and control systems important to safety – Separation	Draft (pending)			Danish Standards Foundation

Table 6. Standards for Cable Service Life Prediction

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
IEEE 775-1993, IEEE Guide for Designing Multistress Aging Tests of Electrical Insulation in a Radiation Environment			Withdrawn in 1993; no task group	Any licenses based on it?
IEEE 1205-2000, IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects of Class 1E Equipment Used in Nuclear Power Generating Stations		In revision		
IEEE 400-2012, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above				Tan delta medium voltage application issues for Class1E; for EPR cables used EPRI guidance 1020805; XLPE unfilled
IEEE 400.1-2007, IEEE Guide for Field Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5 kV and Above With High Direct Current Voltage				
IEEE 400.2-2013, IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency(VLF) (less than 1 Hz)				In 2013, IEEE 400.2 adding "acceptance criteria" for EPR cable. However, EPRI recommends EPRI's criteria
IEEE 400.3-2006, IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment				

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
IEC TS 61244-2-1996, Determination of Long-Term Radiation Ageing in Polymers - Part 2: Procedures for Predicting Ageing at Low Dose Rates		due for revision in 2012		Low voltage cable
BSI BS IEC/IEEE 62582-1, 2012, Nuclear Power Plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods Part 1: General	Published 2012			
BSI BS IEC/IEEE 62582-2, 2012, Nuclear Power Plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods Part 2: Indenter Modulus	Published 2012			
BSI BS IEC/IEEE 62582-3, 2012, Nuclear Power Plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods - Part 3: Elongation at Break	Published 2012			
BSI BS IEC/IEEE 62582-4, 2012, Nuclear Power Plants - Instrumentation and control important to safety - Electrical equipment condition monitoring methods Part 4: Oxidation induction techniques	Published 2011			
IEC 62465-2010, Nuclear Power Plants-Instrumentation and control important to safety- Management of aging of electrical cabling systems	Published 2011			
BSI BS 7816-1-1995, Determination of Long-Term Radiation Ageing in Polymers - Part 1: Techniques for Monitoring Diffusion-Limited Oxidation				
BSI BS 7816-2-1997, Determination of Long-Term Radiation Ageing in Polymers - Part 2: Procedures for Predicting Ageing at Low-Dose Rates				
BSI BS 7816-3-1998, Long-Term Radiation Ageing in Polymers - Part 3: Procedures for In-Service Monitoring of Low-Voltage Cable Materials (note this is the same as IEC 61244-3 and is due for revision in the next 2 years – partially superseded by IEC 62582 series)	Active 1998.07.15			British Standards Institute

Table 7. Standards for Loss of Coolant on Accident (LOCA) Condition Assessments

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
IEEE 383-2003, IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations		In revision		
IEEE 323-2003, IEEE Standard for Qualifying Class 1E Equipment of Nuclear Power Generating Stations		Under revision; new IEEE and IEC joint project-entire sections on condition monitoring and cable monitoring--not changes in qualification		
IEC 60780-1998, Nuclear Power Plants - Qualification of Electrical Equipment of Safety Systems		In revision with IEEE Standard 323		
IEEE 98-2002, Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials		In revision		
IEEE 99-2007, IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment				
IEEE 101-1987, IEEE Guide for the Statistical Analysis of Thermal Life Test Data				

Table 8. Military Specifications for Cable Systems

Standard	Status			
	Up-to-date	Outdated but appropriate for application	Reference needs revision	Comments
MIL-C-19381A, Cable, Special Purpose, Electrical, (Nuclear Plant)	Canceled			Slash Sheets Revised 1957.01.15
MIL-STD-758C, Packaging Procedures for Submarine Support Items				Active 1990.04.13
MIL C-17, Coaxial Cable specifications/Shipboard cable specifications				

Table 9. NRC Documents Referencing Cables, including Regulatory Guides, Information Notices and Generic Letters

NRC Document Number	NRC Document Title	Standard Cited	Standard Title	Status			Comments
				Up-to-date	Outdated but appropriate for application	Reference needs revision	
RG 1.63	Electric Penetration Assemblies in Containment Structures for Nuclear Power Plants (Revision 3, 02/1987)	IEEE 317-1983	IEEE Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Station		Outdated - 2013 revision		
RG 1.89	Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants (Revision 1, 06/1984)	IEEE 323-1974	IEEE Standard for Qualifying Class 1E Equipment of Nuclear Power Generating Stations		outdated for 1974; using a different approach -profiles for the accident; NRC has not endorsed the 2003 for RG, but underway; different licenses so different versions apply		
RG 1.131	Qualification Tests of Electric Cables, Field Splices, and Connections for Light-Water-Cooled Nuclear Power Plants	IEEE 383-1974	IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Station	RG is Withdrawn			
RG 1.211	Qualification of Safety-Related Cables and Field Splices for Nuclear Power Plants (Revision 0, 04/2009)	IEEE 383-2003	IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations	up to date; but a revision is underway			
RG 1.156	Qualification of Connection Assemblies for Nuclear Power Plants (Revision 1, 07/2011)	IEEE 572-2006	IEEE Standard for Qualification of Class 1E Connection Assemblies for Nuclear Power Generating Station	up to date, but has a working group	AP1000-using the 1985 version		
RG 1.100	Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants (Revision 3, 09/2009)	IEEE 344-1987	IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations		344-2004; active PAR to Dec 2014		

NRC Document Number	NRC Document Title	Standard Cited	Standard Title	Status			Comments
				Up-to-date	Outdated but appropriate for application	Reference needs revision	
RG 1.189	Fire Protection for Nuclear Power Plants (Revision 2, 10/2009)	IEEE 835-1994					
		IEEE 383-2003					
		IEEE 634-2004	IEEE Standard Cable-Penetration Fire Stop Qualification Test				
		IEEE 690-1984	Flame Testing Of Cables for Use in Cable Tray				
		IEEE120 2-2006	Flame Testing Of Cables for Use in Cable Tray				
		UL 1724, Appendix B	Qualification Test for Circuit Integrity of Insulated Electrical Wires and Cables in Electrical Circuit Protection Systems				
		NU REG/CR-6776	Cable insulation resistance measurements made during cable fire tests (2002)				
		NFPA 701 (no date)	Standard Methods of Fire Tests for Flame Propagation of Textiles and Films				
		IEEE 627-2010	IEEE Standard for Qualification of Equipment used in Nuclear Facilities				
Safety Guide 30	Quality Assurance Requirements for the Installation, Inspection, and Testing of Instrumentation and Electric Equipment (August 1972)	IEEE 336-1971	IEEE Guide for Installation, Inspection, and Testing for Class 1E Power, Instrumentation, and Control Equipment at Nuclear Facilities				
		UL94	Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances testing				
		ULVW-1	Vertical Wire Flame Test				
		UL1581	Reference Standard for Electrical Wires, Cables, and Flexible Cords				
RG 1.75	Criteria for Independence of Electrical Safety Systems (Revision 3, February 2005)	IEEE 279, 1971			still utilized for the plants		
		IEEE 603-1991			still utilized for the plants		

NRC Document Number	NRC Document Title	Standard Cited	Standard Title	Status			Comments
				Up-to-date	Outdated but appropriate for application	Reference needs revision	
RG 1.131 Withdrawn	Qualification Tests of Electric Cables, Field Splices, and Connections for Light-Water-Cooled Nuclear Power Plants				Withdrawn		
RG 1.218	Condition Monitoring Program for Electric Cables Used In Nuclear Power Plants (Revision 0, 04/2012)	IEEE					
Sandia 2013-2388; ML13127A0 88	Nuclear Power Plant Cable Materials: Review of Qualification and Currently Available Aging Data for Margin Assessments in Cable Performance						
ML1202606 54	Joint Time-Frequency Domain Reflectometry for Diagnostics/Prognostics of Aging Electrical Cables in Nuclear Power Plants						
NUREG/CR -0381; ML0716900 19	Diagnostics/Prognostics of Aging Electric Cables						
NUREG/CR -0654; ML0716503 49	Nuclear Power Plants Fire Protection						
NUREG/CR -1682	Electrical Insulators in a Reactor Accident Environment						
NUREG/CR -2927	Nuclear Power Plant Electrical Cable Damageability Experiments						
NUREG/CR -6794; ML0301302 68	Evaluation of Aging and Environmental Qualification Practices for Power Cables Used in Nuclear Power Plants						

NRC Document Number	NRC Document Title	Standard Cited	Standard Title	Status			Comments
				Up-to-date	Outdated but appropriate for application	Reference needs revision	
NUREG/CR -7000	Essential Elements of an Electric Cable Condition Monitoring Program						
NUREG/CR -7010	Vol. 1 Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE) Volume 1: Horizontal Trays (Draft Report for Comment)						
NUREG/CR -6776	Cable Insulation Resistance Measurements Made During Cable Fire Tests						
NUREG/CR -6931	Cable Response to Live Fire (CAROLFIRE)						
NUREG/CR -7102	Kerite Analysis in Thermal Environment of Fire						
NUREG/CR -7100	Direct Current Electrical Shorting In Response to Exposure Fire						
NUREG/CR -5384	A Summary of Nuclear Power Plan Fire Safety Research at Sandia National Laboratories						
NUREG/CR -5772	Aging, Condition Monitoring, and Loss-of-Coolant Accident (LOCA) Tests of Class 1E Electrical Cables						
NRC INFO NOTICE 2010-26	Submerged Electrical Cables						
NRC INFO NOTICE 93-33	Potential Deficiency of Certain Class 1E Instrumentation and Control Cables						
NRC GENERIC LETTER 2007-01	Inaccessible or Underground Power Cable Failures that Disable Accident Mitigation Systems or Cause Plant						

NRC Document Number	NRC Document Title	Standard Cited	Standard Title	Status			Comments
				Up-to-date	Outdated but appropriate for application	Reference needs revision	
	Transients						
SUM REP/GEN LET 2007-01	Inaccessible or Underground Power Cable Failures that Disable Accident Mitigation Systems or Cause Plant Transients						

Table 10. NRC Regulatory Guides Written by NRC Staff for Cables and Connections from an April 2013 Search of the NRC Website

NUREGs	Title
NUREG-1482	Guidelines for In-Service Testing at Nuclear Power Plants
NUREG-1801	Generic Aging Lessons Learned (GALL) Report
NUREG-2128	Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE), A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011

Table 11. NRC Regulatory Guides Written by Contractors for Cables and Connections from an April 2013 Search of the NRC Website

NUREGs	Title
NUREG/CR-0152	Development and Verification of Fire Tests for Cable Systems and System Components: Quarterly Reports 2 and 3, September 1, 1977 – February 28, 1978
NUREG/CR-1552	Development and Verification of Fire Tests for Cable Systems and System Components: Quarterly Report 12, March – May 1980
NUREG/CR-1682	Electrical Insulators in a Reactor Accident Environment
NUREG/CR-2377	Test and Criteria for Fire Protection of Cable Penetrations
NUREG/CR-2431	Burn Mode Analysis of Horizontal Cable Tray Fires
NUREG/CR-2927	Nuclear Power Plant Electrical Cable Damageability Experiments
NUREG/CR-3263	Status Report: Correlation of Electrical Cable Failure with Mechanical Degradation
NUREG/CR-3532	Response of Rubber Insulation Materials to Monoenergetic Electron Irradiations
NUREG/CR-3629	The Effect of Thermal and Irradiation Aging Simulation Procedures on Polymer Properties
NUREG/CR-4112	Investigation of Cable and Cable System Fire Test Parameters
NUREG/CR-4570	Description and Testing of an Apparatus for Electrically Initiating Fires Through Simulation of a Faulty Connection
NUREG/CR-4638	Transient Fire Environment Cable Damageability Test Results
NUREG/CR-5546	An Investigation of the Effects of Thermal Aging on the Fire Damageability of Electric Cables
NUREG/CR-5609	Electromagnetic Compatibility Testing for Conducted Susceptibility Along Interconnecting Signal Lines
NUREG/CR-5619	The Impact of Thermal Aging on the Flammability of Electric Cables
NUREG/CR-5655	Submergence and High Temperature Steam Testing of Class lE Electrical Cables
NUREG/CR-6095	Aging, Loss-of-Coolant Accident (LOCA), and High Potential Testing of Damaged Cables
NUREG/CR-6681	Ampacity Derating and Cable Functionality for Raceway Fire Barriers
NUREG/CR-6776	Cable Insulation Resistance Measurements Made During Cable Fire Tests
NUREG/CR-6869	A Reliability Physics Model for Aging of Cable Insulation Materials
NUREG/CR-6904	Evaluation of the Broadband Impedance Spectroscopy Prognostic/Diagnostic Technique for Electric Cables Used in Nuclear Power Plants
NUREG/CR-7000	Essential Elements of an Electric Cable Condition Monitoring Program
NUREG/CR-7010	Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE)
NUREG/CR-7150	Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE) – Final Report

Table 12. Information Notices Related to Cables from an April 2013 Search of the NRC Website

Information Notice	Title
in2011-12	Reactor Trips Resulting From Water Intrusion Into Electrical Equipment, June 16, 2011.
in2010-26	Submerged Electrical Cables, December 2, 2010.
in2010-25	Inadequate Electrical Connections, November 17, 2010.
in2010-02	Construction-Related Experience With Cables, Connectors, And Junction Boxes, January 28, 2010.
in200602	Use of Galvanized Supports and Cable Trays with Meggitt Si 2400 Stainless-Steel-Jacketed Electrical Cables, January 19, 2006.
in02012	Submerged Safety-Related Electrical Cables, April 12, 2002.
in97091s1	Recent Failures of Control Cables Used on Amersham Model 660 Posilock Radiography Systems, August 10, 1998.
in97091	Environmental Qualification Deficiency for Cables and Containment Penetration Pigtails, December 31, 1997.
in97045	Environmental Qualification Deficiency For Cables and Containment Penetration Pigtails, July 2, 1997.
in92081	Potential Deficiency of Electrical Cables With Bonded Hypalon Jackets, December 11, 2002.
in92001	Cable Damage Caused by Inadequate Cable Installation Procedures and Controls, January 3, 1992.
in91020	Electrical Wire Insulation Degradation Caused Failure in a Safety-Related Motor Control Center, March 19, 1991.
in89063	Possible Submergence of Electrical Circuits Located Above the Flood Level Because of Water Intrusion and Lack of Drainage, September 5, 1989.
in88063s2	High Radiation Hazards From Irradiated Incore Detectors and Cables, June 25, 1991.
in88063s1	High Radiation Hazards From Irradiated Incore Detectors and Cables, October 5, 1990.
in88063	High Radiation Hazards from Irradiated Incore Detectors and Cables, August 15, 1988.
in84001	Excess Lubricant in Electric Cable Sheaths, January 19, 1984.
in82040	Deficiencies in Primary Containment Electrical Penetration Assemblies, September 22, 1982.
in81020	Test Failures of Electrical Penetration Assemblies, July 13, 2981.
in79032	Separation of Electrical Cables for HPCI and ADS, December 18, 1979.
in79014	Safety Classification of Electrical Cable Support Systems, June 4, 1979.

Table 13. Research Documents Related to Cables in Nuclear Applications

Document Number	Document Title
SAND 2005-7331	Nuclear Energy Plant Optimization (NEPO) Final Report on Aging and Condition Monitoring of Low-Voltage Cable Materials
SAND 2010-7266	Review of Nuclear Power Plant Safety Cable Aging Studies with Recommendations for Improved Approaches and for Future Work
SAND 2013-2388,	Nuclear Power Plant Cable Materials: Review of Qualification and Currently Available Aging Data for Margin Assessments in Cable Performance
PNL-10717	A Review of Information for Managing Aging in Nuclear Power Plants
EPRI TR106394	Evaluation of Gases Generated by Heating and Burning of Cables
EPRI 1022638	Plant Engineering: 2011 Complete Product List
EPRI 1000444	Fiber Optic Cables in High Voltage Environments
EPRI 1002036	Extruded Dielectrics for Transmission Cables Evaluation of Aging Models
EPRI 1002037	Review of Materials and Materials Technologies for Transmission Cable Applications
EPRI 1003062	Natural Versus Artificial Aging of Electrical Components
EPRI 1008211	Initial Acceptance Criteria Concepts and Data for Assessing Longevity of Low-Voltage Cable Insulations and Jackets
EPRI 1008560	Equipment Failure Model and Data for Underground Distribution Cables A PM Basis Application
EPRI 1010497	Formation of Nanovoids in Extruded Dielectrics Caused by Mechanical Fatigue and Fracture
EPRI 1011273	Procedures for the Examination of the Metals Used in Electrical Power Cables
EPRI 1011873	Cable Polymer Aging and Condition Monitoring Research at Sandia National Laboratories Under the Nuclear Energy Plant Optimiza tion (NEPO) Program
EPRI 1020804	Plant Support Engineering: Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants
EPRI 3002000557	Plant Support Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants
EPRI 1021629	Instrument control (must pay for)
EPRI 113557	Assessment of Insulation Quality in115 kV XLPE Cables
IAEA TECDOC1147	Management of ageing of I&C equipment in nuclear power plants
IAEA TECDOC1188	Assessment and management of ageing of major nuclear power plant components important to safety: In-containment instrumentation and control cables Volume I and II
IAEA NP-T-3.6	Assessing and managing cable ageing in nuclear power plant
JNES2009	Aging Management of Nuclear Power Plant
JNES-SS-0903	The Final Report of the Project of Assessment of Cable Aging for Nuclear Power Plants
EPRI 1006961	Spurious Actuation of Electrical Circuits Due to Cable Fire

Appendix D, Revisions to IEEE Standard 323

IEEE Standard 323: *IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations*
This standard, which addresses Class 1E equipment for nuclear generating stations, was identified as a priority for updating within NRC regulatory documents, and a brief review was completed to demonstrate specific changes made to the subsequent versions of the standard. Changes resulting in the use of updated technology to provide a more accurate cable qualification are highlighted.

IEEE Standard 323-1974:

- The standard describes basic requirements for qualifying Class 1E equipment and interfaces to be used in nuclear power generating stations, and those requirements include principles, procedures, and methods of qualification. The qualification requirements confirm adequacy of equipment design under normal, abnormal, design basis event (accident), post design basis event (post-accident), and containment test conditions for performance of Class 1E functions.

IEEE Standard 323-1983:
Changes within this version include the following:

- Addition of in-service test conditions for performance of *safety functions.*
- Referencing of other related IEEE standards, such as ANSI/IEEE *Standard 497-1981, Standard Criteria for Post-Accident Monitoring Instrumentation for Nuclear Power Generating Stations*, ANSI/IEEE Standard 308-1980, *Criteria for Class 1E Power Systems for Nuclear Power Generating Stations*, and IEEE Standard 603-1980, *Criteria for Safety Systems for Nuclear Power Generating Stations*.
- Mentions more clearly that other standards ("daughter standards") for specific equipment that are not specifically discussed but fall within the generic requirements in IEEE 323 and that equipment performance specifications and interfaces are considered as *system integrity* as required by IEEE Standard 279-1971 and IEEE Standard 603-1980.
- Mentions nuclear power generating safety analysis and its presumptions of:
  a) Equipment designs actually performing designated safety functions in postulated service environments.
  b) In-service aging not degrading Class 1E equipment to where the required designated safety function is not achievable.
- Notes industrial concern for positive and negative synergistic effects and ionizing dose-rate effects and that more research in the area is needed or being conducted.
- Through collaboration with IEEE and ASME to create a general qualification document for electrical and mechanical equipment, a new standard, IEEE Standard 627-1980, *Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations*, was developed, and hence electrical equipment qualified with IEEE Standard 323 - 1974 or 1983 will meet the requirements of IEEE Standard 627-1980.
- Defines requirements that are adequate to qualify Class 1E equipment located in all areas of a nuclear power generating station including areas of *harsh* and *mild environments*.

- Notes that seismic conditions are the only design basis event with the potential for common cause failure for mild environments, but other environmental service conditions may contribute to failure. On-going research and knowledge gained from operating experience will continue to be evaluated.
- Better defines the parts necessary to achieve an appropriate qualification program and includes the variable of natural aging in addition to age conditioning used to predict cable service life, a concept of *Combined Qualification*, equipment qualification by combination of tests, analysis or previous operating experience, and a section of *Extension of Qualified Life*.

IEEE Standard 323-2003:
Changes within this version include the following:

- Incorporates current practices and lessons learned from the implementation of previous versions of this standard by the nuclear industry.
- Definitions for methods of equipment qualification now focused on *harsh environments* and for certain post-accident monitoring equipment, but it may also be used for qualification of equipment in mild environments.
- Includes seismic events as design basis events.
- Clarifies the test margins to better identify the parameters that achieve test margin on design basis event profiles; since quantitative margin can be adequately identified by increasing in temperature, pressure, radiation, and operating time, the performance of two transients is no longer recommended.
- As existing instrumentation and control equipment in nuclear power plants may be replaced with computer based digital systems or advanced analog systems, new technologies may exhibit greater *vulnerability to nuclear power plant electromagnetic interference/radio frequency interference and power surge environments* as documented by several NRC NUREGs (NUREG/CR-5700-1992, NUREG/CR-5904-1994, NUREG/CR-6384-1996,Vols 1 and 2, NUREG/CR-6406-1996, NUREG/CR-6579-1998, NRC IN 94-20). Guidelines for ensuring electromagnetic compatibility of safety systems are directed to IEEE Standard 603-1998 and IEEE Standard 7-4.3.2-2003.
- The concept of *qualified service life continues* and now includes the recognition that significant degradation could be caused by aging mechanisms in environments during service life, and therefore, safety related equipment should be in a state of degradation prior to imposing design basis event simulations.
- This revision recognizes that the condition of equipment for which acceptable performance was demonstrated is the qualified condition and license renewal and life extension options are available by assuring that qualified equipment continues to remain in a qualified condition. *Industry research in equipment qualification* and *decades of its application* have greatly benefited this standard and impact of condition monitoring, performance, safety function assessment and qualified life precision, significance of refinements in aging mechanisms, equipment sealing, interfaces, extrapolation similarity test sequence and parameters (ramp rates, time duration, timing of spray initiation and duration) and qualification documentation have been updated.

Appendix E, Explanation for Changes to Cable Material Qualification

IEEE Standard 775, *IEEE Guide for Designing Multi-stress Aging Tests of Electrical Insulation in a Radiation Environment (withdrawn),* attempted to introduce a scientific approach to conducting accelerated aging tests in which factors of synergistic interactions, radiation dose-rate effects, oxygen diffusion rates, etc., are considered. SAND 2010-7266, *Review of Nuclear Power Plant Safety Cable Aging Studies with Recommendations for Improved Approaches and for Future Work*, offers insight into the complexity of combined low and high dose rate/temperature conditions and more appropriate testing approaches.

An important unresolved issue for materials qualification and lifetime prediction, as well as assessing the remaining margins in existing cables, is the unknown performance correlation between fast, non-oxidative DLO controlled exposures with the more oxidative driven degradation of materials during long-term plant exposure under low dose rate, low temperature conditions. There are reports published in the late 1990s of inverse temperature phenomena. IEEE Standard 323 does not predict aging, and the inverse temperature phenomenon has to do with crystalline material (some XLPE and some EPR). This is a crystal orientation that can be annealed out, not the same as thermal oxidation. This study used radiation and thermal exposure together, which is not endorsed by IEEE Standard 98. It is general consensus of the ECTG that testing to IEEE Standard 323 is the most appropriate that can be done today because more suitable standards currently don't exist. IEEE Standard 323 testing may not reflect plant conditions, but is generally done to more stringent conditions.

A discussion of the efficacy of IEEE Standard 323 qualification testing based on current knowledge of polymer material aging under different environmental conditions is needed. In blind studies for XLPO materials showing inverse temperature behavior, OIT condition assessments had failed to establish the true aging state of the material. A new version of IEEE Standard 323 may contain additional condition monitoring approaches. Studies by the Brookhaven National Laboratory and the Japanese mostly used inert aged materials. Sandia National Laboratory has done work with aged specimens, but additional work is required.

For accelerated aging, when exposing materials to temperature, radiation, and humidity, is this exposure performed simultaneously or sequentially? IEEE Standard 323 addresses the sequence of age conditioning, but the steam is applied after thermal and radiation aging.

A possible better method for oxidative aging of EPR materials is the use of limiting accelerated aging. The idea is to determine what environment allows oxidative aging. There are also conflicts in temperature conditions: some standards require materials to be tested in a 70°C to 80°C environment; others require testing in a 60°C environment. Cables are rated and qualified at 90°C, but most materials are not actually utilized at 90°C. The normal operating conditions are 45°C to 50°C. Arrhenius methodology is used to determine a reasonable time frame for aging. However, there is a trade-off with the manufacturer to qualify and the utility to apply the methodology.

Research on truly oxidative aging of materials and their subsequent LOCA performance for many materials does not exist. For example, industrial cable material tests results have shown that in the LOCA chamber, the chemical spray appears to rehydrate the polymer. As a result, normal aging is separated from accident aging.