NUCLEAR ENERGY INSTITUTE

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Mail Stop T10-D20
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Washington, DC 20555-0001

SUBJECT: Technical Issues Related to Environmental Qualification of Low-Voltage I&C Cables

PROJECT NUMBER: 689

Dear Mr. Mayfield:

In your letter dated August 22, 2001, you requested our response to several technical issues concerning environmental qualification of safety-related, low-voltage instrumentation and control cables. The three topics identified in your letter, along with four related topics identified at an NRC public meeting on April 12, 2001, are addressed in this letter. This letter, and its associated enclosure, is intended to assist your ongoing efforts designed to resolve Generic Safety Issue (GSI) 168, *Environmental Qualification of Electrical Equipment.*

The seven topics addressed in this letter, which are discussed further in the enclosed report, are:

1. Need for Monitoring Plant Environments & Condition Monitoring
2. Testing of a Single Prototype
3. Post-LOCA Submerged Voltage-Withstand Test
4. Testing of I&C Cables for 60 Year Service Life
5. Samuel Moore Cables - Post-LOCA Test Results
6. 60 Year-Aged Cables - Post-LOCA Test Results
7. Bonded Jacket Cables - Generic Implications

Topics 1 through 4 were discussed at an April 12 public meeting, and are included because of the close relationship of all seven topics and responses. Topics 5 through 7 were identified in your August 22 request letter.

We developed this response with the support of the Nuclear Utility Group on Equipment Qualification. Our review included NUREG/CR-6704, *Assessment of*

Environmental Qualification Practices and Condition Monitoring Techniques for Low Voltage Electric Cables, which documents the results of the NRC Cable Research Program. We also considered relevant information from prior NRC cable research results, IEEE standards, cable manufacturer qualification reports, and license renewal documents. Detailed discussion on the seven topics is provided in the enclosed report, *Industry Input on Technical Topics Related to Environmental Qualification of Low-Voltage I&C Cables.*

Based upon our review, we conclude that the Cable Research Program results demonstrate the adequacy of the existing cable qualification licensing bases, IEEE standards, and licensee qualification practices for both the current and renewal terms. This perspective is based, in large part, on acceptable cable performance during NRC accident simulation tests. In six test programs the NRC subjected 96 cable specimens, most with accelerated aging, to the conservative accident conditions used in the original qualification reports. These conditions, originally used to generically qualify cables for all licensees, are inherently conservative when compared to plant-specific design basis accident conditions.

All of these 96 cables, except for certain Okonite bonded-jacket cables and a few isolated test artifacts, demonstrated acceptable performance in instrument circuits during the accident simulations. All of these cable specimens, acquired from licensees, DOE facilities and national laboratories, were manufactured from 1974 to 1986. None were new and most (85) were considered "unused." The remaining 11 cables were naturally aged in licensee facilities. The vast majority of these cables were subjected to accelerated aging conditions that represent 50%, 100% or 150% of the aging levels in the original qualification reports. Yet, with the few noted exceptions, all of the tested cables, including the 150%-aged cables, adequately performed during the NRC research program LOCA simulations.

Since licensees are obligated by their qualification programs and licensing basis to maintain plant cables for the current and renewal terms within the aging parameters established by the applicable qualification reports, these 150%-aged cable test results reflect significant over-aging, yet demonstrate the existence of significant margin. In our view, these results establish the adequacy of the existing qualification licensing bases and licensee qualification practices for both the current and renewal terms.

Several of the NRC topics relate to cable performance during the Cable Research Program *post*-LOCA dielectric tests that are performed *after* the full LOCA test simulation. One apparent concern involves differences between the original manufacturer's test results and the NRC research program results. We conclude that these differences could have resulted from differing test conditions. More significantly, we do not believe performance differences during the post-LOCA dielectric test are significant since all the cables performed adequately during the

LOCA simulation test and the post-LOCA test does not simulate accident or post-accident conditions.

According to the IEEE, the post-LOCA dielectric test is a margin provision. IEEE standards and NRC qualification guidance documents state that margin is intended, in part, to address variations in commercial production of equipment. Indeed, the post-LOCA dielectric test is unnecessary to satisfy the margin provisions of 10 CFR 50.49, NRC guidance documents, and IEEE 323 because cable qualification programs contain other margins that fully satisfy these regulatory bases. The objective of NRC regulations, IEEE standards, and industry qualification practices is to provide reasonable assurance of cable performance during accident conditions. Acceptable performance of the cable specimens during the research program accident simulations confirms the adequacy of these and similar cables.

Finally, it is important to emphasize that, as part of current or renewal terms, licensees are obligated to maintain cable aging within the limits established by existing qualification programs. Licensees can reanalyze cables for the renewal period using the Arrhenius method. By applying the same testing basis that established a 40-year cable life at one operating temperature, the reanalysis typically establishes a 60-year life at some lower operating temperature. If reanalysis cannot successfully establish a 60-year life then licensees must either replace the cable or re-qualify it for more severe aging conditions. With this understanding, the '60-year' test results from the Cable Research Program have little regulatory applicability or significance. The '60-year' tests were performed using cables that were over-aged by subjecting them to 150% of applicable qualification aging limits, well in excess of cable qualification bases used to support license renewals. Consequently, the '60-year' test results do provide evidence of margin beyond current qualification bases.

In summary, our review indicates that, except for certain Okonite bonded-jacket cables, the Cable Research Program results confirm the adequacy of licensee practices and the current licensing basis for I&C cable qualification, for both the current and renewal terms. Regarding bonded jacket cables, we believe the concern is largely limited to certain Okonite cables, which are currently being requalified. The enclosed report summarizes our understanding of the current status of GSI-168 efforts and places the NRC discussion topics and our responses into perspective with respect to resolution of GSI-168.

I trust that this information is useful to NRC efforts to resolve GSI-168. Should you have any questions on this letter or the enclosed report, please contact John Butler at 202-739-8108, jcb@nei.org, or me.

Sincerely,

Alex Marion

Alexander Marion

Enclosure
JCB/maa

c: Mr. Nilesh Chokshi, U. S. Nuclear Regulatory Commission
Mr. Jose Calvo, U. S. Nuclear Regulatory Commission
Mr. Satish Aggarwal, U. S. Nuclear Regulatory Commission
Mr. Neil Smith, Exelon Nuclear Corporation
Mr. William Horin, Winston and Strawn

Enclosure

Industry Input on Technical Topics Related To Environmental Qualification Of Low-Voltage I&C Cables

October 2001

Industry Input on Technical Topics Related to Environmental Qualification of Low-Voltage I&C Cables

Industry Input on Technical Topics Related to Environmental Qualification of Low-Voltage I&C Cables

1 Need for Monitoring Plant Environments & Condition Monitoring

Topic Description

For maintaining qualification throughout the qualified life of safety-related I&C cables, should the licensees provide information on how the environments are monitored to detect localized hot-spots and how to ensure that the original test conditions are not exceeded in operating nuclear power plants? Is it prudent to perform some kind of condition monitoring of I&C cables, that may include walkdowns to look for any visible signs of anomalies attributable to cable aging? What are the industry initiatives?[1]

Industry Input

The following information is provided in two parts. The first, **Typical Licensee Ongoing Actions**, summarizes licensee activities that are implemented to ensure that in-service equipment remains qualified to perform safety functions during design basis events and associated harsh environments after taking into account the effects of in-service aging. The description is based in large measure on the contents of the NRC approved Generic Aging Lessons Learned (GALL) Report, Chapter X.[2] The second, **Supporting Industry Activities,** summarizes historic and ongoing industry groups and activities that provide licensees with information, resources, training, and forums to facilitate the establishment and maintenance of 10 CFR 50.49 compliant qualification programs.

- **Typical Licensee Ongoing Actions**

Typical ongoing licensee actions related to the establishment and maintenance of equipment qualification programs provide reasonable assurance that existing equipment, including cables, are maintained in a condition consistent with their qualification parameters. EQ programs have been structured, implemented and maintained for that purpose. In addition, EQ equipment is subject to existing licensee programs related to maintenance and quality assurance/quality control (including design control and corrective action elements) as are other programs dealing with safety-related systems, structures and components.

The NRC has conducted numerous inspections focused on licensee implementation of EQ programs, and have included EQ as a component of routine inspections. Further, within the last few years the NRC has conducted additional programmatic reviews of the EQ programs of selected licensees as part of the EQ Task Action Plan. In that context, the NRC found that these programs are adequately

1 The Topic Descriptions for topics 1 through 4 are taken directly from the NRC summary of an April 12, 2001 public meeting to discuss environmental qualification of safety-related low voltage cables. [NRC Accession Number ML011510470]

2 NUREG-1801, Generic Aging Lessons Learned (GALL), USNRC, April 2001

implemented.[3] Finally, as licensees have applied for license renewal, the NRC has reviewed their EQ programs and accepted the programs as capable of providing reasonable assurance that equipment qualification will be maintained throughout the renewal term.

Accordingly, as discussed below, typical licensee ongoing actions for EQ programs provide reasonable assurance that EQ equipment is being adequately managed in accordance with the requirements of 10 C.F.R. 50.49.

Compliance with NRC Regulations Provides Reasonable Assurance of EQ Equipment Performance Following an Accident

The Nuclear Regulatory Commission (NRC) has established nuclear station environmental qualification (EQ) requirements in 10 CFR Part 50, Appendix A, Criterion 4, and 10 CFR 50.49. 10 CFR 50.49 specifically requires that an EQ program be established to demonstrate that certain electrical components located in harsh plant environments (that is, those areas of the plant that could be subject to the harsh environmental effects of a loss of coolant accident [LOCA], high energy line breaks [HELBs] or post-LOCA radiation) are qualified to perform their safety function in those harsh environments after the effects of in-service aging. 10 CFR 50.49 requires that the effects of significant aging mechanisms be addressed as part of environmental qualification. Compliance with 10 CFR 50.49 provides reasonable assurance that the component can perform its intended function during accident conditions after experiencing the effects of in-service aging.

All operating plants must meet the requirements of 10 CFR 50.49 for certain electrical components important to safety. 10 CFR 50.49 defines the scope of components to be included, requires the preparation and maintenance of a list of in-scope components, and requires the preparation and maintenance of a qualification file that includes component performance specifications, electrical characteristics, and the environmental conditions to which the components could be subjected. 10 CFR 50.49(e)(5) contains provisions for aging that require, in part, consideration of all significant types of aging degradation that can affect component functional capability. 10 CFR 50.49(e) also requires replacement or refurbishment of components prior to the end of designated life, unless additional life is established through ongoing qualification. 10 CFR 50.49(f) establishes four methods of demonstrating qualification for aging and accident conditions. 10 CFR 50.49(k) and (l) permit different qualification criteria to apply based on plant and component vintage.[4]

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3 NRC Memorandum, Holahan to Thadani, Licensee Implementation Practices Relative To EQ (EQ-Tap Action Item 3.F), October 7, 1994.

4 Supplemental EQ regulatory guidance for compliance with these different qualification criteria is provided in the DOR Guidelines, *Guidelines for Evaluating Environmental Qualification of Class 1E Electrical Equipment in Operating Reactors*; NUREG-0588, *Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment*; and Regulatory Guide 1.89, Rev. 1, *Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants.*

10 CFR 50.49 does not require (a) actions that prevent aging effects, (b) the detection of aging effects for in-service components, or (c) monitoring or trending of component condition or performance parameters of in-service components in order to manage the effects of aging. However, to provide assurance of 10 C.F.R. 50.49 compliance, EQ programs do include actions that (a) establish the component service condition tolerance and aging limits (for example, qualified life or condition limit) and (b) where applicable, require specific installation, inspection, monitoring or periodic maintenance actions to maintain component aging effects within the bounds of the qualification basis. Monitoring or inspection of certain environmental conditions or component parameters may be used to ensure that the component is within the bounds of its qualification basis, or as a means to modify the qualified life. When monitoring is used to modify a component qualified life, plant-specific acceptance criteria are established based on applicable 10 CFR 50.49(f) qualification methods.

EQ Program Implementation is Consistent with Station Program Implementation Practices

EQ programs are implemented through the use of station policy, directives, and procedures. EQ programs must continue to comply with 10 CFR 50.49 throughout the licensed period, including development and maintenance of qualification documentation demonstrating reasonable assurance that a component can perform required functions during harsh accident conditions. EQ program documents identify the applicable environmental conditions for the component locations. EQ program qualification files are maintained at the plant site in an auditable form for the duration of the installed life of the component. EQ program documentation is controlled under the station's quality assurance program.

EQ programs manage component thermal, radiation, and cyclical aging through the use of aging evaluations based on 10 CFR 50.49(f) qualification methods. As required by 10 CFR 50.49, EQ components are to be refurbished, replaced, or have their qualification extended prior to reaching the aging limits established in the evaluation.

Consistent with other licensee programs, EQ programs include consideration of operating experience and other supplemental information. This information may be used in EQ programs to modify qualification bases and conclusions, including qualified life. Reanalysis of an aging evaluation to modify the qualified life of components under 10 CFR 50.49(e) is performed on a routine basis as part of an EQ program. The reanalysis of an aging evaluation is normally performed to either (a) extend the qualified life by reducing excess conservatism incorporated in the prior evaluation or (b) shorten the qualified life to account for operating conditions that do not fully conform to the prior evaluation assumptions. The reanalysis of an aging evaluation is documented according to the station's quality assurance program requirements (e.g., design control provisions), which require the verification of assumptions and conclusions.

EQ Equipment Aging Evaluations are Ongoing Throughout Plant Life

While a component's life-limiting condition may be due to thermal, radiation, or cyclical aging, the vast majority of component aging limits are based on thermal conditions. Differences in aging evaluation parameters which may prompt a reanalysis include differences identified between the assumed and actual ambient temperature of the component, an unrealistically low activation energy, or in the application of a component (e.g., de-energized versus energized, heat rise values, operational duration).

The analytical models used in the reanalysis of an aging evaluation are typically the same as those applied during the prior evaluation. The Arrhenius methodology is an acceptable thermal model for performing a thermal aging evaluation. The common analytical method used for a radiation aging evaluation is to demonstrate qualification for the total integrated dose (that is, normal radiation dose for the projected installed life plus accident radiation dose). For cyclical aging, the evaluation typically demonstrates qualification for a conservatively estimated number of operational cycles.

Temperature data used in an aging evaluation (or other operational data relevant to the aging evaluation) is to be conservative and based on plant design temperatures or on actual plant temperature data. When used, plant temperature data can be obtained in several ways, including monitors used for technical specification compliance, other installed monitors, measurements made by plant operators during rounds, and temperature sensors on large motors (while the motor is not running). A representative number of temperature measurements are conservatively evaluated to establish the temperatures used in an aging evaluation. Plant temperature data may be used in an aging evaluation in different ways, such as (a) directly applying the plant temperature data in the evaluation, or (b) using the plant temperature data to demonstrate conservatism when using plant design temperatures for an evaluation. Any changes to material activation energy values as part of a reanalysis are to be justified on a plant-specific basis. Similar methods of establishing the component service conditions are used for radiation and cyclical aging evaluations.

EQ component aging evaluations contain sufficient conservatism to account for most environmental changes occurring due to plant modifications and events. When unexpected adverse conditions are identified during operational or maintenance activities that adversely affect the normal operating environment or other aging analysis assumptions (e.g., operational duration) of a qualified component, the affected EQ component is evaluated and appropriate corrective actions are taken. These actions may include changes to the qualification bases and conclusions.

The reanalysis of an aging evaluation could extend or shorten the qualification of the component. The component is to be refurbished, replaced, or requalified prior to exceeding the period for which the reanalysis remains valid. The reanalysis is generally performed in a timely manner (that is, sufficient time is available to refurbish, replace, or requalify prior to exceeding the period for which the reanalysis remains valid). If an unexpected adverse condition is identified (whether through maintenance activities, inspections, normal performance monitoring or other means) and the reanalysis indicates that the component has already exceeded the period for which the reanalysis remains valid, then the licensee promptly makes an operability determination in accordance with applicable regulatory guidance and plant procedures and takes appropriate and timely corrective actions, in accordance with the station's corrective action program. These actions include component replacement, refurbishment or requalification.

When unexpected adverse environmental conditions or evidence of unexpected component degradation are identified during operational or maintenance activities that affect the environment of a qualified component, the affected EQ component is evaluated and appropriate corrective actions are taken, which may include changes to the qualification bases and conclusions. When an emerging industry aging issue is identified that affects the qualification of an EQ component, the affected component is evaluated and appropriate corrective actions are taken, which may include changes to the qualification bases and conclusions. Confirmatory actions, as needed, are implemented as part of the station's corrective action program, pursuant to 10 CFR Part 50, Appendix B.

- **Supporting Industry Activities**

As discussed above, implementation of EQ programs is an ongoing activity for individual <u>licensees</u> at their facilities. Significantly, the nuclear <u>industry</u> also supports on an ongoing basis many EQ-related activities. These activities serve (1) to inform licensees of potential areas for additional focus with respect to specific EQ equipment or processes, (2) to assist those same licensees in addressing EQ-related questions that may arise on a plant-specific or generic basis, and (3) to provide information that allows licensees to enhance their programs in a cost-effective manner throughout plant life. Fundamentally, the combination of licensee-specific activities, and industry supported activities supports a conclusion that there is a high level of confidence that installed EQ equipment remains qualified to perform its design functions in the event of an accident. These industry activities are discussed below.

<u>The Nuclear Utility Group on Equipment Qualification</u>

The Nuclear Utility Group on Equipment Qualification (NUGEQ) is comprised of over 30 utilities, in the United States and Canada, representing almost 100 of the NRC-licensed nuclear power reactors. The NUGEQ has been in existence since 1981. Initially, the NUGEQ actively participated in the original rulemaking concerning 10 CFR 50.49 and its implementation, including activities and issues derived from NRC inspection and enforcement practices. Subsequently, the NUGEQ has served as a vehicle to communicate regulatory, technical and policy information that may impact EQ programs to and among its member utilities, other industry organizations and the NRC.

Support of Licensee Coordination and Communication on EQ Topics
The NUGEQ pursues a range of regulatory, technical and policy topics and issues involving equipment qualification as such topics and issues are identified by its membership. The NUGEQ communicates regularly with its utility members through correspondence and meetings (3 – 4 held each year) concerning relevant questions that may arise and are appropriate for the NUGEQ to address. The meetings also provide opportunities for utilities to share ideas, questions and concerns on EQ topics – both on specific equipment and EQ program elements. In addition to these regular meetings the NUGEQ has held several symposia on maintaining qualification with a focus on resource and cost-saving methods. More recently, along with EPRI and the Equipment Qualification Data Bank (EQDB), the NUGEQ is sponsoring an annual Joint EQ Meeting. The NUGEQ has facilitated communication and information sharing among its members at both NUGEQ meetings, through a broadcast fax and an e-mail based request service that allows its members to inquire directly of other EQ personnel with respect to EQ-related questions. Recently, the NUGEQ has established a web site to facilitate notification, communication, and document access for all members.

Development of Topic-Specific Direction and Guidance
The NUGEQ also has provided its members with topic-specific analysis and guidance, as well as provided for NRC consideration evaluations of specific issues. For example, the NUGEQ, in conjunction with Limitorque, developed clarifying information on valve actuator configurations during the various Limitorque qualification tests. The NUGEQ has also compiled and distributed to its members qualification data for various EQ devices, including nonstandard Raychem splice configurations. More recently the NUGEQ submitted an extensive analysis to the NRC that was accepted for application by licensees regarding the use of Arrhenius to analyze accident conditions. The NUGEQ has actively participated in public meetings throughout the EQ Task Action Plan and GSI-168 resolution processes.

Coordination with Other Industry Activities Related to EQ
With respect to assuring the appropriate consideration of EQ matters in industry initiatives, the NUGEQ has coordinated with other industry organizations in providing input to the NRC with respect to a variety of EQ-related regulatory initiatives including license renewal, leak-before-break, marginal to safety, and alternative source terms. The NUGEQ coordinates with and supports the Nuclear Energy Institute (NEI) with respect to generic industry issues being addressed by NEI (e.g., alternate source term, license renewal). The NUGEQ is represented on NEI industry task forces in reviewing various NRC regulatory developments (where

NUGEQ representatives evaluate the impact on EQ programs of those developments). The NUGEQ also monitors activities by and provides input to other entities that deal with issues related to equipment qualification, including IEEE (standards development) and EPRI (research).

The NUGEQ is represented by legal counsel (Winston & Strawn) and is supported by a technical consultant (Strategic Technology and Resources). Both representatives have been involved in the EQ arena for over 20 years.

Electric Power Research Institute (EPRI)
EPRI has been involved in research, training, information compilation, and workshop presentations related to environmental qualification in general, and with respect to various types of specific EQ equipment, including cables, since 1977. The following information provides a summary of the significant EQ-related activities and information made available to licensees in support of their on-going 10 CFR 50.49 compliance activities.

General Equipment Qualification Guidance and Research
EPRI research in equipment qualification began in 1977. This research has been focused on providing information to EPRI members that will assist in the implementation and maintenance of EQ equipment and programs in a cost-effective manner. Fundamentally, the research is aimed at advancing the state of knowledge with respect to the EQ equipment and programs. The first research report, NP-1558, *A Review of Equipment Aging Theory and Technology*, has been one of the primary reference sources in the qualification field from the time of its publication in 1980. In 1992 EPRI published the *Equipment Qualification Reference Manual* which compiles three decades of nuclear plant experience in qualifying equipment.

Since 1997, EPRI qualification-related programs have generated over 40 reports covering a wide range of qualification topics. The topics covered by these EPRI reports include programmatic guidance, aging technology, equipment qualification experience, radiation effects on materials/lubricants, hydrogen burn effects, equipment sealing, environmental monitoring, equipment condition monitoring, cable condition monitoring, mechanical equipment qualification, natural vs. artificial aging, cable submergence effects, polyimide insulation, radiation monitor coaxial cables, and motor qualification. Well over half of these reports have direct applicability to establishing and maintaining cable qualification.

In recent years, EPRI equipment qualification activities have focused on the maintenance and management of EQ programs with emphasis on nuclear plant license renewal and cables. EPRI has issued reports dealing EQ programs in license renewal, equipment replacement interval optimization, and management of adverse localized environments.

Qualification Databases
In the late 1970s, in response to the need for a central computerized system of equipment qualification information, EPRI sponsored the establishment of the Equipment Qualification Data Bank (EQDB). EQDB is now operated by Scientech under license to EPRI. The information in the data bank assists in environmental and seismic qualification of electrical and mechanical equipment.

In 1996 EPRI initiated efforts which have culminated in the Equipment Qualification Management System (EQMS). The EPRI EQMS is an electronic EQ program management tool that provides a standard platform for generating and maintaining environmental qualification program information. Included in EQMS are standardized evaluations of EQ test reports for common equipment types.

Cable-Specific EQ Guidance and Research
The majority of EPRI's EQ-related cable programs have involved assessing the aging of cable materials. Other projects have reviewed the use of Kapton (polyimide) insulated wires and radiation monitor coaxial cables.

In 1985, EPRI started the Natural versus Artificial Aging program that placed cable specimens in 15 locations in nine nuclear power plants in the US. Under the program, specimens are periodically removed from the power plants and sent to the University of Connecticut for evaluation and testing. Although there have been minimal changes in cable properties, even for the most severe normal environments, during the first 15 years, the program continues.

EPRI cable condition monitoring research efforts were initiated to provide additional cable monitoring tools for licensees to use either as an ongoing component of their EQ programs in relevant applications or to assess specific conditions that may be identified in the plant. Since 1985 EPRI has investigated and in some instances developed cable condition monitoring techniques, including the Indenter (that evaluates compressive modulus, a form of hardness measurement), Oxidation Induction Time (OIT) testing of cable polymers, electrical techniques for unshielded cables, and ionizable gas testing to bring the ground plane to the surface of a cable within a conduit (potentially useful for detecting cable damage from improper installation).

DOE NEPO Cable Program
Under the U.S. Department of Energy's Nuclear Energy Plant Optimization (NEPO) Program, which is jointly managed and performed with EPRI, two major initiatives in cable research are under way. The first is developing improved aging models for cable polymers including evaluation of Arrhenius behavior of cable polymers down to room temperature. The second effort is developing and evaluating condition-monitoring techniques, including nuclear magnetic resonance, using milligram specimens. In addition, research is

being conducted on bonded-jacket cables and coaxial connector performance during LOCA. Also, the program is preparing training aids for manual/visual inspection, developing a Cable Condition Monitoring Database, and beginning a study of medium voltage cables.

Equipment Qualification Training and Workshops
EPRI's Nuclear Safety Analysis Center (NSAC) has conducted nationwide equipment qualification training seminars in 1983 and 1985. Since 1990, EQ training workshops using EPRI license material have been held one or twice yearly. During this time approximately 600 utility personnel have attended the courses. EPRI also has sponsored several cable and environmental monitoring workshops since 1988.

Cable Working Groups
In 1996, EPRI initiated the Cable Condition Monitoring Working Group to coordinate among various groups performing research related to the assessment of cable aging. EPRI initiated the Cable Users Group in 2000 to provide a forum for utility personnel responsible for cable system aging management and practical applications of cable monitoring techniques.

Peer Reviews
EPRI's Plant Support Engineering Group provides EQ Program Peer Assessments, performed at four to eight plants each year to review plant EQ programs. These assessments utilize both a facilitator/EQ expert and personnel from sister utilities. The assessments help both the plant being evaluated and the assessors by affording an opportunity to exchange information on good program practices.

2 Testing of Single Prototype

Topic Description

Based on IEEE standards, single prototype testing has been used for many applications and will almost certainly be used in future applications. However, based on recent research results, the staff believes that the use of single cable specimen for environmental qualification warrants further discussion with the nuclear industry.[1]

The analysis of test failures into random and common-mode categories is significantly enhanced by testing multiple specimens. If one of these specimens fails but the others perform throughout the program, the justification that the failure was random becomes significantly more sound.

Shouldn't the IEEE standards be revised to require testing of multiple specimens?

Industry Input

The industry agrees with the response and observations provided by the IEEE[5]. Additional complementary information is provided below. In summary, we do not believe the results of the NRC Cable Research Program bring into question the adequacy of the industry's existing cable qualification practices or suggest the need for changes to IEEE 383 or IEEE 323 to require multiple specimens.

• IEEE Methodology Relies on Conservatism not Statistical Significance

The IEEE, industry, and the NRC have all concurred with the testing methodology described in IEEE 323. That methodology relies on conservatism in test conditions and performance requirements to achieve reasonable assurance that production devices will function during realistic design basis accidents. The IEEE methodology was not intended to develop statistical confidence levels. Additional information on the conservatisms in industry cable qualification practices is provided in Appendix A.[6]

• NRC Cable Research Confirms Adequacy of Existing Methodology

Confidence in cable performance during accidents is achieved by qualification test program margins and conservatisms combined with manufacturer quality practices and utility controls. Adequate functional performance of installed cables <u>during accident conditions</u> is the ultimate objective of the IEEE standards and 10 CFR 50.49. The NRC research demonstrates acceptable accident performance for all the tested cable types, except for the Okonite bonded jacket specimens, during accident simulations that were considerably more severe than typical plant specific conditions. Therefore, the adequacy of existing IEEE standards and regulatory

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5 IEEE letter from Neil Smith (Chair, Nuclear Power Engineering Committee) to Satish Aggarwal (NRC) dated September 28, 2001.

6 Appendix A was developed by the NUGEQ and previously transmitted to the NRC as Attachment 1 to a January 15, 2001, letter from William Horin to Michael Mayfield.

requirements/guidance is confirmed. This successful performance includes the 60-year specimens aged to 150% of the manufacturer's qualification program aging.

• **Most Multi-Specimen Sets Exhibited Consistent Performance**
NUREG/CR-6704, *Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low Voltage Electric Cables,* ("NUREG") summarizes the results of the NRC Cable Research program. Evaluation of the NUREG data indicates that only four of the 23 multi-specimen sets (i.e., same manufacturer and same aging) exhibited inconsistent performance (i.e., some specimens passed and others failed) during the NRC LOCA or post-LOCA tests. Two of these four sets were the 60-year specimens that were over-aged.[7] These results are a relatively weak basis to suggest that the IEEE consider revising its standards. In addition, it is likely that the NRC post-LOCA test results would have been more consistent if they had more closely followed the IEEE 383 test protocol that establishes both mechanical durability and dielectric capability of the test cables. There could be other root causes for these few performance differences, including unidentified damage to the unused but relatively old cables used in the program.

Based on the NUREG, the sets of multiple samples in each of the NRC test sequences have been evaluated and those with inconsistent results within a multi-specimen set (i.e., samples with the same manufacturer and aging conditions) have been identified. The following table summarizes the results.[8]

Multi-Specimen Sets with Performance Differences

Test Sequence	Multi-Specimen Sets With Different Results
1	none in 3 sets (several splice test artifacts)
2	none in 3 sets
3	none in 4 sets (one mechanical damage test artifact)
4	1 (40 year Samuel Moore) -of 3 sets - different post-LOCA results
5	1 (20 year Okonite) of 6 sets -- different LOCA & post-LOCA results*
6	2 (60 year Samuel Moore & Rockbestos) of 4 sets -- different post-LOCA results

* Different LOCA results assumed but not measured due to wiring problem.

In summary a total of 23 multi-specimen sets were tested in the NRC program. Of these 23 sets only 4 sets had inconsistent results. Only 1 set had inconsistent LOCA test results (20 year Okonite) while all 4 sets had inconsistent post-LOCA test results. The inconsistent <u>LOCA performance</u> of the two 20 year Okonite specimens strongly suggests that these cables were at the aging threshold for LOCA-induced splitting failures of that bonded-jacket construction. Except for this

7 The response to Topic #6 describes why these specimens are considered over-aged.

8 Appropriately excluded from this compilation are inconsistent results due to test program artifacts, such as improperly fabricated splices or mechanically damaged test specimens.

20-year Okonite set, all the other multiple test specimens in the research program demonstrated similar performance during the LOCA test.[9] Only 4 sets exhibited inconsistent results during the post-LOCA dielectric test.[10] Two of these four involved 60-year aged cables and one was the 20-year Okonite set. As noted, it is likely that the NRC program would have achieved more consistence post-LOCA test results if it had rigorously followed the IEEE 383 post-LOCA test protocol which requires a demonstration of mechanical durability as part of the post-LOCA dielectric test. This opinion is based on the fact that the cables in these 4 sets had experienced significant aging and had lost much of their flexibility. Some, like the 20-year Okonite specimens, were significantly embrittled.

- **Most NRC Multi-Specimens were from the Same Cable**

Based on the NUREG most of the specimens in each multi-specimen set were from the same cable source. This is particularly true for the 4 multi-specimen sets with inconsistent results discussed above.[11] Pragmatically, there is little or no difference in the level of confidence achieved by testing a single 30 foot specimen or cutting a cable into three 10 foot specimens and testing all three specimens. There is no evidence that increasing the IEEE 383 specified minimum specimen length from 10 feet to 30 feet or even 100 feet provides significant additional assurance of cable functionality. Consequently, it is reasonable to conclude that little additional confidence would be achieved by testing multiple specimens from the same source cable. The IEEE methodology achieves adequate assurance that production cables will function during realistic design basis accidents by relying on margins and conservatism in test conditions and performance requirements.

9 All the specimens in the same set either functioned adequately or failed during the LOCA simulation.

10 The response to Topic #3 contains information on the low safety significance of these post-LOCA test failures.

11 The specimen sources for these 4 sets are: all Okonite specimens - LNI81OK020, Rockbestos 60-year – PNI79RB188, 60-year Samuel Moore – DNI80SM010; 40-year Samuel Moore – PNI82SM008.

3 Post-LOCA Submerged Voltage-Withstand Test

Topic Description
IEEE standards require a submerged voltage-withstand test (80V/mil ac or 240V/mil dc) for 5 minutes. This is a post- LOCA test. For a 30 mil thickness, the test voltage is 2400 V. The industry has vigorously argued that this is an extremely severe test and I&C cables would never be exposed to this voltage. According to IEEE standard (IEEE Std. 383-1974), the post-LOCA simulation test demonstrates an adequate margin of safety. It should be noted that the several test specimens, which were preaged to 40 and 60 years of equivalent service life, in NRC tests failed submerged voltage- withstand test. What are the technical bases for this post-LOCA test? Should this requirement be changed?[1]

Industry Input
The industry agrees with the response and observations provided by the IEEE[5]. Additional complementary information is provided below and in Appendix B. In summary, the results of the NRC Cable Research Program do not bring into question the adequacy of the industry's existing cable qualification practices or suggest the need for a change to IEEE 383, (i.e., deleting the post-LOCA testing requirement). Such action would appear to have little if any safety or cost benefit. The research program confirms the adequacy of the standard since all the cables, except for certain bonded jacket Okonite cables, adequately performed during the accident simulation conditions which were extremely conservative when compared to realistic design basis accident conditions.

- **Overview**

The NRC correctly observes that the IEEE 383 post-LOCA test is intended as margin and that installed I&C cables would never be exposed to these voltage levels during operation. The IEEE 383 post-LOCA test protocol was not intended to simulate conditions or performance during accidents. It was intended to demonstrate that after aging and accident simulations the cable test specimens still had additional capabilities (i.e., they were not at the threshold of failure). The NRC also correctly reflects the general observation that this post-LOCA test is an extremely severe test, particularly for I&C cables. No other IEEE qualification standards require post-LOCA dielectric testing as part of the test acceptance criteria. Importantly, the margin provisions of 10 CFR 50.49, NRC guidance documents, and IEEE 323 can all be fully satisfied without performing this post-LOCA test since cable test programs typically contain other margins.

As discussed in the IEEE and industry responses to Topic 2, the IEEE qualification methodology that underpins 10 CFR 50.49 applies conservative assumptions and margin to provide confidence that production equipment will adequately function during realistic accidents. Except for certain bonded jacket cables, the NRC cable research program demonstrates acceptable I&C cable performance during accident conditions that are quite conservative when compared to realistic accident conditions.

Regarding changes to the post-LOCA test provision of IEEE 383, numerous cable manufacturers and others have successfully qualified cables to the IEEE 383 qualification protocol, including the post-LOCA test. Given this successful qualification experience, the very conservative protocol, and successful LOCA performance of production cables in the NRC research program, there do not appear to be compelling technical, safety, or cost reasons to change the standard.

- **NRC Tests Achieve Qualification Objective – Accident Performance**

The NRC research testing, with the exception of certain bonded-jacket cables, has confirmed that previously qualified cable styles adequately perform during simulated accident conditions after being subjected to accelerated aging. Some of these cables did not subsequently pass the post-LOCA dielectric test. However, adequate functional performance of installed cables <u>during accident conditions</u> is the ultimate objective of 10 CFR 50.49 and the IEEE standards. Since the NRC research demonstrates acceptable performance for these cable types, except for certain Okonite bonded-jacket cables, during accident simulations that were considerably more severe than typical plant-specific conditions, the adequacy of existing IEEE standards and regulatory requirements/guidance is confirmed.

Failures during the post-LOCA portion of the NRC research program should not bring into question either the adequacy of the cables or the need to change IEEE 383. The IEEE qualification methodology that underpins the requirements of 10 CFR 50.49 applies conservatism and margin, in lieu of a statistically significant number of test samples, in order to develop reasonable assurance of performance during realistic accident conditions. It is inappropriate to assume that all production equipment will pass this demanding test protocol, particularly those margin provisions that, in part, are intended to account for production variations. This is particularly true of I&C cables since the post-LOCA test is an extremely severe test compared to anticipated service conditions in I&C applications. It is appropriate to expect all production equipment to function during realistic accident conditions. The NRC testing confirms the LOCA performance of production cables, except for certain Okonite cables, to aging and accident conditions that are more severe than those anticipated during realistic DBE LOCA scenarios.

- **Technical Basis for the Post-LOCA Test**

IEEE 383 specifies a post-LOCA test which demonstrates "*. . . an adequate margin of safety by requiring mechanical durability (mandrel bend) following the environmental simulation . . . .*" This note provided as part of IEEE 383-1974 Section 2.4.4, *Post LOCA Simulation Test,* clearly and unambiguously states that this test is a margin requirement. Recently, the vice-chairman of the IEEE 383 working group performed a review of IEEE 383-1974 work group records.[12] This review confirms the standard's language regarding margin and illuminates the original working group's intentions. Very early drafts of the proposed standard, developed to meet the criteria of IEEE 323 1974, did not contain a post-LOCA test. Subsequently, the working group believed such a test would be used to demonstrate long-term (i.e., in excess of the test duration) post-accident capability recognizing that many accident simulation tests were limited to approximately 30 days. These working group records are consistent with the Section 2.4.4 note that states that the post-LOCA test is a margin requirement. During its deliberations the working group considered various mandrel bend and dielectric test options. According to the records none of these options were related to simulating operational conditions or required performance during accidents. All the options focused on demonstrating additional mechanical and dielectric capabilities at the end of the accident simulation. Based on engineering judgment the working group established consensus and the 1974 version was issued.

- **No Benefit to Changing the Post-LOCA Test Requirement**

Subsequent to the issuance of IEEE 383 1974 numerous manufacturers have successfully qualified cable products to the standard's provisions. Since issuance of the standard there have not been significant questions or concerns regarding the post-LOCA testing requirement for cables. During the last eight years the IEEE 383 working group has been developing a revised standard. A number of issues and proposed changes were discussed during this revision process; however, no significant concerns were raised regarding the post-LOCA test provision. Although the post-LOCA test as a margin requirement is a very severe test, cable accident performance during NRC research tests supports its adequacy. Given that numerous cable styles have been qualified using the IEEE 383 guidance, the lack of significant concerns about the post-accident test, and confirming research test results, there does not appear to be a technical basis supporting changes to the post-LOCA testing provision.

- **Regulatory Margin Requirements Met Without the Post-LOCA Test**

10 CFR 50.49, NRC guidance documents, and IEEE 323 clearly state that margin is intended, in part, to compensate for variations in commercial production of equipment.[13] Further, NUREG-0588 concludes that test program margin to account for such production variations is not needed if NRC-approved methods or values are used to establish required accident conditions. In other words, such required accident conditions already contained sufficient margin, when compared to realistic accident conditions, to account for production variations. Consequently, the post-LOCA test provisions of IEEE 383 are not required in order to achieve compliance

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12 Information regarding the IEEE 383 Working Group was provided by its current vice-chairman, John L. White.

13 Additional information on the margin provisions of IEEE and NRC documents is provided in Appendix B.

with 10 CFR 50.49 and associated NRC guidance documents.[14] Further, most cable test programs contain sufficient accident margin to meet the provisions of IEEE 323 1974 without the post-LOCA test.

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14 Although two "for comment" versions of Regulatory Guide 1.131 have been issued for IEEE 383 and cable qualification, the NRC has never formally issued this regulatory guide.

4 Testing of I&C Cables for 60 Year Service Life

Topic Description

If one uses the Arrhenius equation to calculate thermal aging conditions, the ratio of accelerated aging time to simulated service time remains constant as long as there is no change in activation energy, aging temperature, and service temperature. Therefore, one can clearly obtain the 60 -year aging time by multiplying the 40-year aging time by 1.5.

This was the technical basis for choosing 60-year accelerated aging time. Of the twelve cables preaged and tested, eight experienced failures during the post-LOCA submerged voltage withstand tests. The results indicate that some low-voltage I&C cables may not have sufficient margins beyond the 40 years of their qualified life. If the service environmental conditions are assumed to be those used in the original qualification, then these cables may not perform their intended functions at the end of the 60 year service life, and subjected to LOCA conditions. The staff has concluded that many I&C cables, at their existing ratings, will not have sufficient margins for 60 years of their service life.

Should the cable aging be addressed as part of an aging management program for detecting aging degradation of safety-related I&C cables, for licensees seeking to renew their operating license? How to ensure that the service environmental conditions will not exceed the environmental conditions assumed in the analysis for demonstrating requalification to 60 years for license renewal?[1]

Industry Input

- **Maintaining the EQ CLB during the Renewal Period**

The information provided in Topic 1 applies equally to the renewal term since licensees will maintain the current CLB with respect to 10 CFR 50.49 compliance activities during the renewal period. The typical licensee ongoing activities described in Topic 1 are consistent with the views expressed by the NRC in Section 4.4.2.1.3 of the draft "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants", August 2000, (SRP-LR) and GALL Chapter X. Further, the NRC has evaluated licensee practices for maintaining qualification, including environmental monitoring, in support of several license renewal applications. Relevant information has been provided by licensees in applications, responses to NRC requests for additional information, and in meetings with the NRC. The NRC has found these licensee activities to be supportive of establishing and maintaining I&C cable qualification during the renewal period. The activities described by these licensees are representative of practices throughout the industry.

- **Cable Operation at the 40 Year Operating Limit**

The industry agrees with the NRC observation that some plant I&C cables cannot be qualified for 60 years <u>if</u> they are continually operated at the limiting service conditions (e.g., 90°C) used to establish a shorter qualified life (e.g., 40 years). The NRC cable research program results demonstrate that cable types may not exhibit the same amount of margin when challenging their performance during new qualification tests with aging conditions that are 150% of the prior qualification levels. However, the vast majority of cables, particularly I&C cables, are not continually operated at or near the limiting service conditions used to establish their qualified life during the current license term (e.g., 40 years). Consequently, the qualified life of virtually all I&C cables can be extended into the renewal period by reanalyzing existing qualification information. Since reanalysis uses existing qualification information, there is no technical need to apply or basis to require the 150% pre-aging test protocol used by the NRC.

- **Cable Reanalysis**

Extending cable qualified life to the renewal period can be accomplished in a number of ways; however, the two primary methods are a) reanalysis of existing qualification information (e.g., accelerated aging test data) and b) new qualification tests with more severe aging conditions. Reanalysis will be the primary method of establishing cable qualification for the renewal period because virtually all 10 CFR 50.49 plant cables are <u>not</u> continuously operated at the limiting service condition used to establish qualification during the current license term. This is particularly true for I&C cables such as are being evaluated under GSI-168 since these cables do not experience significant ohmic heating and the ambient temperatures at most cable locations, including hot spots, are substantially below the 40 year limiting operating temperature (e.g., 90°C) established by the cable qualification documents. Replacement or requalification, using new qualification tests with more severe aging, would be the most common methods for the few cables that are continuously operated near their 40 year limiting temperature and cannot be qualified for the renewal term using reanalysis. In either case, licensees will apply known service conditions in determining which approach is appropriate for their cables.

- **Maintaining Adequate Margin**

For the I&C cables being evaluated by GSI-168 the ambient temperatures at most cable locations, including hot spots, are substantially below the 60 year limiting operating temperature. Adequate margin will continue to exist during the renewal period since the difference between the 40 year and 60 year limiting operating temperatures (i.e., maximum continuous operating temperature based upon the qualification testing and aging analysis) for typical cable styles is relative small and should be less than 5°C.[15] The continued existence during the renewal period of adequate margin combined with ambient and limiting operating temperatures that

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15 A 4.5°C difference in 40 year and 60 year limited operating temperatures exists for an activation energy of 1.0eV and a 40 year operating limit of 90°C. This is conservative since the temperature difference will be smaller for lower operating temperature limits and higher activation energy values. At a more representative value of 1.3eV the difference will be 3.5°C or less.

are similar to those during the current license term supports licensees' continued reliance on those ongoing actions, implemented during the current term, to ensure that equipment remains qualified during the renewal period. These actions are described in the response to Topic #1 and include activities intended to ensure that the service environmental conditions will not exceed the limiting environmental conditions assumed in the reanalysis.

- **Cable Aging Management Programs**

Regarding aging management programs, the industry agrees with the NRC conclusions in the SRP-LR and GALL Chapter X. Specifically, EQ programs manage component thermal, radiation, and cyclical aging through the use of aging evaluations based on 10 CFR 50.49(f) qualification methods. As required by 10 CFR 50.49, EQ components not qualified for their installed duration are to be refurbished, replaced, or have their qualification extended prior to reaching the aging limits established in the evaluation.

Under 10 CFR 54.21(c)(1)(iii), plant EQ programs, which implement the requirements of 10 CFR 50.49 (as further defined and clarified by the DOR Guidelines, NUREG-0588, and Regulatory Guide 1.89, Rev. 1), are viewed as aging management programs for license renewal.

As stated in the GALL, reanalysis of an aging evaluation to extend the qualification of components under 10 CFR 50.49(e) is routinely performed as part of an EQ program. Important attributes for the reanalysis of an aging evaluation include analytical methods, data collection and reduction methods, underlying assumptions, acceptance criteria, and corrective actions (if acceptance criteria are not met). These attributes are discussed in the "EQ Component Reanalysis Attributes" section of GALL Chapter X.

Aging evaluations for EQ components that specify a qualification of at least 40 years are considered time-limited aging analyses (TLAAs) for license renewal. As stated in the GALL, these TLAAs are considered an acceptable AMP for license renewal. According to the GALL and SRP-LR, no further evaluation is recommended for license renewal if an applicant elects this option under 10 CFR 54.21(c)(1)(iii) to evaluate the TLAA of EQ of electric equipment.

5 Samuel Moore Cables - Post-LOCA Test Results

Topic Description

The significance of the Samuel Moore cable failures during the submerged voltage withstand test needs to be evaluated. It should be noted that (1) the cables successfully passed the LOCA phase of the test without failure, and (2) the failures in two specimens occurred during the submerged voltage withstand test due to dielectric breakdown at 1000 V and 1200 V AC (per IEEE Std. 383-1974, for 30 mil insulation the voltage withstand requirement is 30X80 V/mil = 2400 V AC). The NRC staff is interested in obtaining any industry information that may explain the failures and address the performance of multiconductor bonded-jacket Samuel Moore cables.[16]

Industry Input

- **Six Considerations Relevant to Evaluating Performance**

The industry has identified the following six considerations that may help the NRC evaluate performance of the Samuel Moore cables during the post-LOCA dielectric test. In summary these considerations indicate that the post-LOCA test failures of 3 insulated conductors (two aged to 40 years in Sequence 4 and one aged to 60 years in Sequence 6) from a total of 34 conductors in 19 cables; (1) are not safety significant, (2) do not bring into question the qualification of the Samuel Moore Dekoron Dekorad cable style, (3) do not have generic implications regarding other cable styles, and (4) are not a basis for changes in industry qualification practices for I&C cables.

1. There are several differences between the test conditions in the NRC research program and those used when the manufacturer established qualification for the Samuel Moore Dekoron Dekorad cables. Both aging and accident condition differences make the NRC program more severe and may account for the differences in post-LOCA performance of the Dekoron Dekorad cables. Based on prior Sandia testing, differences in LOCA test conditions may be particularly significant for this cable type. Additional information is provided below (See *Additional Information on Differences in Test Conditions*).

2. Both the manufacturer qualification test and the NRC research tests used test methods more severe than those specified by IEEE 383. Both programs used too high a post-LOCA dielectric test voltage (2,400 Vac). IEEE 383 only requires 1,600 Vac for cables with 20 mil of insulation. The bonded jacket is not considered as insulation when performing the post-LOCA test. Both programs also subjected the cable samples to two transients during the LOCA simulation. IEEE 383 specifies that a single accident transient in combination with the post-LOCA dielectric test provides adequate test margin.

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16 Descriptions for Topics 5 through 7 were extracted from NRC letter from Michael Mayfield, NRC, to Alexander Marion, NEI, dated August 22, 2001.

3. The NUREG identifies the 40-year aged Samuel Moore cables that failed the post-LOCA test as being manufactured in 1982, unused, and acquired from a licensed PWR facility. Although unused these cables clearly aged during the 18 years between manufacture and NRC testing and were not fully representative of new cables. Depending on shipping and storage conditions the cables could also have been subjected to conditions causing more significant degradation such as cyclical high ambient temperatures and ultraviolet radiation (sunlight). Unfortunately, the NUREG provides no information on storage conditions at the PWR facility or during the research program.
4. The NRC research testing demonstrates adequate performance of <u>all</u> the Samuel Moore cables during very conservative LOCA simulations. The objective of qualification is to establish reasonable assurance of performance during real LOCAs. The NRC program included 19 Samuel Moore cables representing 34 insulated conductors. These specimens were accident tested in unaged, 20 year, 40 year, and 60 year simulated conditions. All of these Samuel Moore cables, including those aged to the equivalent of 60 years, adequately performed during LOCA simulations that were substantially more severe than best estimate DBE LOCAs.
5. Failures of the two 40-year aged specimens during the post-LOCA dielectric test portion of this research test have little safety significance since the post-LOCA dielectric test is; (1) a margin requirement intended, in part, to address production variations and (2) not meant to duplicate any post-LOCA service conditions, performance, or configurations. Additional information on test conservatisms is contained in the response to Topic 2. Additional information on the post-LOCA dielectric test is contained in the response to Topic 3. Additionally, these failures are not safety significant since they occurred at voltages (1,000 Vac and 1,200 Vac) that significantly exceed typical operating voltages in I&C circuits.
6. 10 CFR 50.49 and associated NRC guidance documents do not require post-LOCA testing to conditions, configurations, or performance requirements that are not representative of those encountered during DBE LOCA or post-LOCA scenarios. The immersion high-potential test does not represent post-LOCA conditions, configurations, or performance requirements. Consequently, successful post-LOCA testing is not necessary in order to achieve regulatory compliance. Additional information regarding the regulatory significance of the post-LOCA test is contained in the response to Topic 3.

• Additional Information on Differences in Test Conditions

According to the NUREG, qualification of the Samuel Moore Dekoron Dekorad cable is established in Isomedix Inc. report, *Qualification Test of Electric Cables Under a Simulated LOCA/DBE by Sequential Exposure to Environments of Radiation, Thermal Aging, Steam and Chemical Spray*, May, 1978 ('Isomedix report'). A review of the Isomedix report and discussions with Furon (successor to Samuel Moore and Dekoron) have identified test specimens #7, #13, and #14 as representing the Dekorad cable style.[17] The following table summarizes the sequential aging and accident exposures for these test specimens.

Isomedix Report Test Conditions

Radiation Aging	Thermal Aging	Radiation Accident	LOCA Simulation
25 Mrad (34 hours @ 90°F)	7 days @ 121°C (169 hours)	175 Mrad (234.4 hours @ 90°F)	Double peak 3 hr. - 340°F/105 psig then -3 hrs - 320°F/75 psig -4 hrs - 300°F/55 psig -to 4 days - 250°F/15 psig -to 30 days - 200°F/10 psig (continuous chemical spray)

During the LOCA simulation the cables were energized at rated voltage, loaded with 0.5 amps, and insulation resistance readings were periodically made. Failure of one conductor of one sample during the LOCA was attributed to a short of the cable in the test vessel's potted penetration. This failure cause (a test configuration artifact) was confirmed by all samples successfully passing the IEEE 383 post-LOCA test protocol except that progressive test voltages up to 2400 Vac were used instead of the IEEE 383 specified 1,600 Vac.

The NRC research program included Samuel Moore Dekorad test samples in Test Sequences 4, 5, and 6. Nineteen Samuel Moore cables representing 34 insulated conductors were tested in "unaged," 20 year, 40 year, and 60 year simulated conditions in both single conductor and two conductor shielded cable configurations. According to the NUREG, all the Samuel Moore samples, including the 60 year aged specimens, performed acceptably during all LOCA simulations, with circuit currents and voltages remaining at their nominal values. Three of the 34 conductors failed the post-LOCA test (2 aged to 40 years in Sequence 4 and 1 aged to 60 years in Sequence 6) at voltages less than 1,600 Vac. The following table summarizes the sequential aging and accident exposures for these test specimens.

17 The test samples were 2/C 16 gauge, stranded copper, with 20 mils EPDM primary insulation and 10 mil Hypalon primary jacket, 16 gauge drain/shield, and a 45 mil. Hypalon overall jacket

NUREG Test Program – Samuel Moore

Age Condition	Thermal Aging	Radiation Aging	Radiation Accident	LOCA Simulation
20 years	84.85 hrs @ 121°C	21.99 Mrad	154.4 Mrad	Double peak 3 hr. - 346°F/113 psig then -3 hrs - 335°F/93 psig -4 hrs - 315°F/69 psig -to 4 days - 265°F/28 psig -to 10 days - 212°F/10 psig (24 hr chemical spray @ 265°F)
40 years	169.05 hrs @ 121°C	51.57 Mrad	154.4 Mrad	
60 years	252.1 hrs @ 121°C	77.28 Mrad	155.63 Mrad	

Inspection of the test conditions summarized in these two tables identifies several important differences indicating that the NRC test program was more severe than the Isomedix test sequence. These differences include:

1. The Isomedix program involved two radiation exposures with the first (aging radiation) performed prior to thermal aging (i.e., *radiation then thermal aging* sequence). The NRC program used a *thermal then radiation aging* sequence which is more severe for this cable style according to Sandia research. Sandia, in NUREG/CR-2553, subjected the Samuel Moore EPR material (EPR E) to different types of aging sequences.[18] The *thermal then radiation aging* sequence resulted in greater elongation degradation (29% e/e_0) than the *radiation then thermal aging* sequence (34% e/e_0). Both sequential tests produced greater degradation than the more realistic simultaneous aging exposure (42% e/e_0). Based on this Sandia data the NRC aging sequence was <u>*more severe*</u> than the Isomedix program sequence for the Samuel Moore EPR insulating material and <u>*substantially more severe*</u> than the more realistic simultaneous exposure.
2. The total integrated dose for the Isomedix program was 200 Mrad. For the NRC program the total doses were 176.39 Mrad (20 year), 205.97 Mrad (40 year), and 232.91 Mrad (60 year). Total integrated radiation in the NRC program was <u>*more severe*</u> than the Isomedix program for the 40 year and 60 year specimens.
3. The NRC program temperature and pressure conditions during the entire 10 day LOCA simulation were more severe than those in the Isomedix program. Peak conditions were 346°F/113psig (NRC) and 340°F/105psig (Isomedix). During each of the subsequent plateaus the NRC test temperatures exceeded those in the Isomedix test by 12°F - 15°F. NRC test pressures were also higher during these plateaus. These higher steam temperatures and pressures increase chemical reaction rates and result in more rapid degradation of the test specimen materials. Sandia, based on its testing of Samuel Moore cables reported in NUREG/CR 5772 Vol. 2, observed that: ". . . *there was considerable evidence that the accident environment was a more important factor in failures*

18 EPRI Report TR-103841 Appendix E correlates the NUREG test specimens designations with manufactured products.

than was the amount of aging that the cable received."[19] Given Sandia's observation, the *more severe* LOCA conditions in the NRC program are clearly significant for the Dekoron Dekorad cable style.

[19] NUREG/CR-5772 Vol. 2 page 51.

6 Sixty Year-Aged Cables - Post-LOCA Test Results

Topic Description

Nine of twelve specimens (AIW, Samuel Moore, Rockbestos, and Okonite cables) failed the submerged voltage withstand test (after the cable specimens were pre-aged to an equivalent of 60 years and subjected to LOCA tests). The significance of these failures needs to be evaluated. Any industry information that may explain these failures would be useful for appropriate considerations in the resolution of GSI-168.[16]

Industry Input

- **Considerations Relevant to Evaluating Performance of "60" Year Specimens**

Several considerations are identified below that may assist the NRC evaluation of the significance of post-LOCA test failures of some test specimens pre-aged to the equivalent of 60 years. Based on these considerations the industry concludes that the results of the 60-year testing; (1) provide confidence that significant aging margin, beyond the aging limits established by existing qualification tests, exists for many cable styles, (2) support the continued use of existing qualification methods, including reanalysis, to establish and maintain qualification during the renewal period, and (3) are not a basis for changes in the CLB or industry qualification practices for I&C cables. These considerations are:

1. The 60-year simulated aging conditions in the NRC research program are overly severe and do not reflect licensee obligations to maintain operating temperature conditions within the limits established by available qualification tests.
2. Since the 60-year aged cables adequately functioned during the LOCA simulation, the test results provide added confidence in the ability of qualified cables, maintained within the aging limits established by licensee's qualification programs, to adequately function during realistic LOCA conditions. Even though the NRC over-aged the 60-year specimens, all those specimens, except for the Okonite Okolon single conductor cables, adequately performed during the LOCA simulation.
3. Eight conductors out of twenty-four, 60-year aged conductors failed the post-LOCA test but three of these were Okonite Okolon specimens. The remaining five failures out of twenty-one conductors occurred at voltages (500 Vac – 1,500 Vac) that substantially exceed typical I&C circuit operating voltages. These five failures occurred after the cables adequately performed during the LOCA simulation.
4. During their qualification testing programs many cable manufacturers subjected their cable materials to severe aging, while still retaining the cables' ability to function under LOCA conditions. Some of these cable materials do not have large amounts of additional aging capability beyond the aging limits established

by the manufacturer test programs. The fact that these cables functioned throughout the NRC LOCA simulation after exposure to 150% of the original qualification thermal aging is a testimony to the acceptability of these cable materials. The fact that some of these 150%-aged cables failed a post-LOCA dielectric test is neither surprising nor unexpected.

5. The NUREG indicates that the 60-year samples were fabricated from unused cables that were manufactured between 1974 and 1981. Although unused, these cables clearly aged during the roughly 18 - 25 years between manufacture and NRC testing and were not fully representative of new cables.[20] Depending on shipping and storage conditions the cables could also have been subjected to conditions causing more significant degradation such as cyclical high ambient temperatures and ultraviolet radiation (sunlight). Unfortunately, the NUREG provides no information on storage conditions at the original purchasers' locations or during the research program.

6. As discussed more fully in the response to Topic 3, failures during the post-LOCA dielectric test portion of this research test have little safety significance since the post-LOCA dielectric test (1) is a margin requirement intended, in part, to address production variations and (2) is not meant to duplicate any post-LOCA service conditions, performance, or configurations.

• Overly Severe 60-Year Aging Conditions in NRC Program

During several public meetings and discussions with the NRC on the Cable Research Program the industry stated that the 60 year test simulation should not be performed because (1) licensees intended to maintain cable aging within the cumulative aging limits established by existing qualification programs, (2) some cable manufacturers had already subjected their cables to very severe aging conditions and (3) any failures during a "60 year" test could be misinterpreted as suggesting cable qualification could not be extended into the renewal period.

Qualified life limits are typically established by licensees using the Arrhenius method. Arrhenius calculations can be used to establish numerous operating temperature/time limits that are equivalent to the qualification test's accelerated temperature/time conditions. Simply stated, longer operating times can be established for lower operating temperatures. For example, the same qualification test data that establish a cable qualified life of 40 years at 90°C can also establish a qualified life of 60 years at 86.5°C.[21] Throughout the Cable Research Program the industry has urged the NRC to help educate and minimize confusion for those not intimately involved in cable qualification by explaining this important element of qualification practice.

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20 Per the NUREG, the manufacture dates for the 60-year samples were Rockbestos (1979), AIW (1974), Samuel Moore (1980), Okonite Okolon (1981).

21 Additional information on licensee practices, including the use of reanalysis to establish 60-year operating temperature limits, is provided in responses to Topics #1 and #4.

The NRC established aging conditions for the research program's 60 year simulation by multiplying the duration of the manufacturers' qualification, test accelerated thermal aging by 1.5. This is equivalent to assuming that licensees will use the 40-year operating temperature limit established by their qualification programs as the 60-year operating temperature limit. This assumption is not consistent with either licensee practices or regulatory requirements. Consequently, the 60-year simulated aging conditions in the NRC research program are merely hypothetical conditions that are fundamentally overly severe and do not reflect licensee obligations to maintain operating temperature conditions within the limits established by available qualification tests.

• Acceptable LOCA Performance of the "60-Year" Specimens

The "60-year" results provide added confidence in the ability of qualified cables to adequately function during realistic LOCA conditions. The NRC Cable Research Program over-aged the 60-year specimens when compared to the aging limits established by licensees. Yet, all these 60-year specimens, except for the Okonite Okolon bonded-jacket style, adequately performed during the entire LOCA simulation. This performance demonstrates significant margin in the cables' existing qualification limits since (1) the over-aged 60-year cables adequately performed during accident simulations that were considerably more severe than typical plant specific conditions and (2) functional performance of installed cables during accident conditions is the ultimate objective of 10 CFR 50.49.

• Further Information on the Post-LOCA Dielectric Test Failures

Regarding the Post-LOCA failures of nine of the twelve 60-year cables and based on the information in the NUREG the following should be noted:

1. Eight of twelve 60-year aged cables failed the post-LOCA dielectric test. These failures involve only eight of the twenty-four insulated conductors in these eight cables.
2. The "ninth" failure in LOCA Simulation #6 involved one conductor of a three conductor unaged AIW cable. According to the NUREG, during a subsequent wet insulation resistance test the cable exhibited acceptable performance and the results of a second wet dielectric test were inconclusive due to excessive surface moisture and tracking near the test connections. Additionally, numerous other AIW unaged, 20-year, and 40-year specimens passed the post-LOCA dielectric test during the Sequence #2 test.
3. Three of these eight cables are the bonded jacket Okonite style that is addressed by Regulatory Issue Summary 2000-25 and is being requalified by Okonite. These cables also failed during the LOCA simulation and therefore the post-LOCA dielectric failures are expected.
4. The other five failures occurred at test voltages ranging from 500 Vac and 1,500 Vac. All these voltages are significantly higher that the operating voltages in I&C circuits.

7 Bonded Jacket Cables - Generic Implications

Topic Description

While the LOCA test failures of Okonite single conductor bonded- jacket cables are being addressed separately, the generic implications of similar Okonite cables of different wire gauge size, and similar single conductor and multiconductor cables of other manufacturers need to be evaluated. This issue was identified in Regulatory Issue Summary 2000-25 dated December 26, 2000.

As stated in Mr. Jack Strosnider's letter[16]...dated August 10, 2001, the staff found the NEI survey results on Okonite single conductor bonded-jacket cable acceptable. The survey indicated there was limited application of this cable type in nuclear power plants and the service temperatures in general were lower than the 90 degree C, the rated temperature specified by the manufacturer. However, because of the differential transition temperatures associated with the conductor insulation and the jacket material and the bonded interface, the NRC is interested in obtaining information and additional data on the behavior of single and multiconductor bonded-jacket cables of other manufacturers.[16]

Industry Input

- **Root Cause – No Qualification Test of Representative Construction**

The root cause of the qualification problem with the 12 awg, Okonite Okolon single conductor, EPR-Hypalon, bonded-jacket cable is the lack of qualification testing for a representative bonded jacket cable construction. NRC sponsored testing has appropriately called into question the existing qualification basis (Okonite Test Report NQRN-1A) for the 12 awg, Okonite Okolon single conductor, bonded-jacket cable style because no thin wall (0.015 inch) jacketed specimen was included in the Okonite test program. In response Okonite is currently requalifying this cable style with a bonded jacket. Regarding generic implications for other bonded jacket cable styles, we generally agree with the following NRC observation in Information Notice 92-81:

> "Other bonded jacket cables . . . may be susceptible to the same type of failures if not specifically tested in the bonded configuration. The difference in aging rates between the jacket and the insulation may be a factor in the failure of bonded-jacket cables. Therefore, qualification testing that does not use the jacketed configuration may not be representative of actual cable performance."

As described below, the generic implications of the Okonite bonded jacket problem are very limited because both Okonite, for other Okonite Okolon cable sizes, and other manufacturers of EPR-Hypalon bonded jacket cable styles have performed qualification testing with representative cable test specimens in the bonded jacket configuration. In summary we conclude the following:

1. Larger sizes of Okonite Okolon single conductor cables with thicker jackets (0.030 inches and larger) are adequately qualified by NQRN-1A testing of the 6 awg cable samples.
2. Multiconductor Okonite Okolon cables are adequately qualified by the single conductor test results of NQRN-1A and the ongoing Okonite requalification program for the 12 awg construction.
3. It appears that other manufacturers of similar EPR-Hypalon bonded jacket cable styles tested the cables in the thin-wall bonded jacket configuration. This adequately establishes qualification for larger sizes (i.e., thicker bonded-jackets) in both single and multiconductor configurations.
4. If licensees utilize other bonded jacket styles they should either establish qualification based on testing that uses a representative bonded jacketed configuration or establish aging limits, such as the 60°C operating temperature limit used in the NEI survey for Okonite Okolon single conductor cables, that would preclude a similar bonded jacket failure mechanism.

• Implications for Other Size Okonite Okolon Single Conductor Cables

NQRN-1A was intended to establish qualification for all the Okonite Okolon cables by testing two specimen styles. One was a single conductor, 600 V, 12 awg cable with 0.030 inches of Okonite (EPR) insulation but without the bonded jacket used in production cables. The second was a single conductor 2kV, 6 awg cable with 0.055 inches of Okonite insulation and a 0.030 inch bonded Okolon (Hypalon) jacket. According to NQRN-1A both types of test specimens passed the qualification test program, including the post-LOCA dielectric test.

The NRC sponsored research testing of similar 12 awg cables but with a bonded jacket suggests that the NQRN-1A testing did not adequately simulate the interaction between a thin wall (i.e., 0.015 inch) bonded Okolon jacket and the Okonite (EPR) insulation. However, successful NQRN-1A testing of the 6 awg specimens with a 0.030 inch bonded jacket demonstrates that the splitting phenomenon observed in the NRC programs for the thin wall jackets does not exist for thicker jackets at the tested aging and accident conditions. Consequently, NQRN-1A remains a valid qualification basis for the Okonite Okolon single conductor cables which are supplied with 0.030 inch or thicker bonded jackets. These test results suggest that successful qualification testing of thicker bonded-jackets may not be applicable to thinner bonded jackets. Conversely, successful qualification testing of thinner jackets can be considered as representative of thicker jackets.

According to Okonite catalog information, the Okonite Okolon single conductor cables are supplied in 600 V and 2000 V ratings. The following table summarizes the insulation and jacket sizes on these cables. All these cables, except for those with 0.015 inch bonded jackets, are qualified by the NQRN-1A 6 awg test specimen.

Okonite Okolon Single Conductor Sizes

Rating (V)	size (awg/kcmil)	insulation (mils)	bonded jacket (mils)	total thickness (mils)
600	14 – 9	30	15	45
600	8	45	15	60
600	6 – 2	45	30	75
600	1 – 4/0	55	45	100
600	250 – 500	65	65	130
600	750 – 1000	80	65	145
2000	14 – 9	45	15	60
2000	8 – 2	55	30	85
2000	1 – 4/0	65	45	110
2000	250 – 500	75	65	140
2000	750 – 1000	90	65	155

Based on this table, #14awg - #8 awg single conductor cables use the thin wall (0.015 inch) jacket. Okonite is currently requalifying the 600 V, single conductor, 12 awg cable with all test specimens containing both insulation and a thin wall (0.015 inch) bonded jacket. Successful qualification of these cables will establish qualified life limits for all these thin wall (0.015 inch) Okonite Okolon cables. NQRN-1A remains the successful qualification basis for the thicker wall (0.030 inch and thicker) bonded jacket Okonite Okolon cables.

- **Implications for Multiconductor Okonite Okolon Cables**

Adequate qualification of Okonite Okolon multiconductor cables is based on qualification testing of the #6 awg (NQRN-1A) and #12 awg (new ongoing testing) bonded jacket single conductors. The single conductor qualification can conservatively be applied to multiconductor cables because the overall (outer) jacket is not bonded, no adverse interactions should occur between the insulated conductors and the overall jacket, and the overall jacket provides some aging protection to the insulated individual conductors.

Okonite supplies multiconductor versions of the 600 V cable under the style designation Okonite/Okolon-Okolon Type TC cable. This multiconductor cable utilizes the same composite (bonded jacket) insulation design described above for each of the insulated conductors (i.e., Okonite/Okolon). The multiconductor cable also uses an overall Okolon jacket. This overall jacket is not bonded in any way to the composite-insulated conductors. Separating the insulated conductors and the overall jacket are fillers (as needed) and binder tapes. Therefore, cracking failures of the unbonded overall jacket do not propagate to the insulated conductors.

Additionally, the outer jacket in the multiconductor configuration provides some protection of the composite-insulated conductors against thermal oxidative degradation. Therefore, the life limits established for the single conductor cable can be conservatively applied to the multiconductor constructions. According to Okonite catalogs, the thickness of the overall jacket varies based on the cable diameter in accordance with ICEA/NEMA standards. The minimum overall jacket thickness, 0.045 inch, is used for 2 or 3 conductor, #14 awg and #12 awg cables. The overall jacket thickness for other multiconductor control cables is typically 0.060 – 0.080 inch. The maximum thickness for multiconductor power cable jackets is 0.140 inch. Adequate performance of the single conductor #6 awg cable with the 0.030 inch jacket in NQRN-1A provides evidence of the aging protection provided by an overall jacket.[22] Additionally, NQRN-1A Appendix 2 page 5 contains information demonstrating that the use of an overall jacket in a multiconductor cable provides some aging protection to the conductor insulation.

- **Implications for Other Manufacturers' Bonded-Jacket Cables**

Generic implications of the bonded-jacket EPR-Hypalon concern are limited to those constructions that are supplied as bonded-jacket cables but are not qualified based on testing of representative bonded-jacket cables. Available information suggests that there should not be generic implications for EPR-Hypalon bonded-jacket cable configurations manufactured by others because these cables were appropriately tested in representative configurations.

Several manufacturers supplied the industry with environmentally qualified EPR-Hypalon composite insulation systems similar to the Okonite Okolon style. Importantly, not all of these composite insulation systems utilize bonded jackets. For example, the EPR-Hypalon composite insulation cables manufactured by Anaconda and AIW and used in the NRC Cable Research Program are identified as unbonded jacket cables.

We have not attempted to identify all of the qualified EPR-Hypalon composite insulation systems used by licensees or to determine which of these systems use bonded jackets. However, available information, including Appendix A to EPRI Report TR-103841, *Low-Voltage Environmentally-Qualified Cable License Renewal Industry Report; Revision 1* and associated manufacturer qualification reports, indicates that all the readily identified EPR-Hypalon composite systems were appropriately tested with the composite insulation on the individual conductors. The following table summarizes the identified composite insulation cable styles and tested configurations.

22 The 0.030" bonded-jacket 6 awg cable performed acceptably in NQRN-1A but the thinner, 0.015" bonded-jacket cables failed in the essentially equivalent NRC-sponsored program.

Composite EPR-Hypalon Qualified Cables

Manufacturer	Style	Test Report	Tested Configuration
BIW	Bostrad 7E	B915	2/c #16 – 25 mil EPR & 15 mil CSPE individual, 45 mil CSPE overall
Anaconda	Flame-Guard EP	F-C4350-3	7/c #12 awg -- 30 mil EPR & 15 mil CSPE individual, 60 mil CSPE overall
Anaconda	Durasheath EP	F-C4350-3	1/c #12 awg -- 30 mil EPR & 15 mil CSPE
AIW	unspecified	F-C4197-2	7/c #12 & 3/c #16 – EPR & Hypalon individual; Hypalon overall
Samuel Moore	Dekoron Dekorad	Isomedix	2/c #16 - 25mil EPR & 15mil CSPE individual, 45 mil CSPE overall

All of these cable manufacturers used test specimens with a composite insulation that is representative of the cable styles being qualified. According to the NUREG several of these EPR-Hypalon composites (Anaconda and AIW) do not have bonded jackets. Except for the Okonite Okolon thin wall construction, we are unaware of any other EPR-Hypalon composite construction currently used in EQ applications that was not qualified by testing a composite (EPR-Hypalon) cable. Consequently, we do not believe that the Okonite Okolon problem (i.e., no testing of a representative thin-wall bonded jacket construction) extends to other composite EPR-Hypalon constructions.

We have limited information regarding generic implications for bonded-jacket cable constructions other than the EPR-Hypalon composite style. We are unaware of other testing information suggesting that a similar bonded jacket concern (i.e., propagation of jacket cracks into the insulation sufficient to expose the metallic conductor) exists for other bonded-jacket cable constructions. However, if any licensee utilizes other bonded jacket styles it would be appropriate for the licensee to either establish qualification based on testing of a representative bonded jacket configuration or establish aging limits, such as the NEI survey limit of 60°C Okonite Okolon single conductor cables, that would preclude a similar bonded jacket failure mechanism, if it exists, in other than the EPR-Hypalon composite style.

Appendix A - Cable EQ Program Conservatisms and Margins

This attachment provides examples of the conservatism and margins contained in nuclear power plant cable equipment qualification test programs. Based on the guidance of IEEE-323 and IEEE-383, such cable qualification test programs typically involve subjecting the cable test samples to the following sequential exposures.

- Thermal Aging Simulation
- Combined Aging and Accident Radiation Simulation
- LOCA/MSLB Steam Simulation
- Post-LOCA Dielectric Test

During this qualification testing numerous conservatisms are applied. This attachment describes ten such conservatisms that collectively provide confidence that cable qualification test results can be applied to plant installed cables.

1. **Conservative insulation temperature assumptions reflect power applications (e.g., 90°C) compared to ambient temperature conditions for I&C cables:**
   Most cable qualification tests have been designed to establish qualification for power, control, and instrument applications. For power applications the effects of ohmic heating are considered and a continuous use conductor temperature, typically 90°C (194°F), is defined. The thermal aging simulation is designed to appropriately accelerate the effects of continuous exposure of the insulation to 90 °C. This is a significant test conservatism for instrument and control (I&C) applications which experience virtually no ohmic heating. For these I&C applications significant thermal aging conservatism exists because plant operating temperatures will be substantially lower than 90°C. Conservatism also exists for power cable applications because derating factors and other conservative cable sizing assumptions result in cable operating temperatures well below the 90°C cable rating. Importantly, the vast majority of EQ inside containment power cables are used in normally de-energized motor operated valve (MOV) power circuits where ohmic heating is insignificant.

2. **Accident Test Margins:**
   Both the IEEE standards and NRC guidance documents specify that margin be added to required accident temperature, pressure, radiation, operating time, and electrical parameters to account for equipment production, environmental definition, and test measurement variations/uncertainties.

3. **Enveloping LOCA steam/temperature/pressure conditions:**

Typical qualification test steam temperature/pressure accident profiles represent conditions substantially more severe than any single design basis LOCA or MSLB event. The accident steam simulation profile typically used during cable qualification tests conforms to the recommendations of IEEE 323-1974. The cable test profile was intended to establish combined qualification for both PWR and BWR inside containment conditions by enveloping various hypothetical LOCA and MSLB events from different plant designs and different break size assumptions. Consequently, a typical test profile is conservative with respect to any single design basis event.

4. **Long term operability and 30 day test results:**

Cable qualification test accident simulations are typically run for 30 days or longer even though risk significant equipment functions only occur with the first few hours or days post-event. Because test failures during the 30 day period generally resulted in a cable being considered unqualified, demonstrating performance for the full 30 days or longer is conservative for risk significant accident mitigation functions.

As noted, accident mitigation occurs within the first few hours or days of the accident. Subsequently, plant conditions change slowly, permitting a range of accident management scenarios. Most PRAs conclude that the risk of further radiation release during subsequent periods is insignificant. From a risk perspective, operability only needs to be demonstrated for several days or possibly weeks. Demonstrating qualification for longer times is not relevant to overall accident risk. This risk perspective on EQ is consistent with the NRC views presented in NUREG/CR-5313, *Equipment Qualification (EQ) - Risk Scoping Study,* Sandia National Labs, January 1989. In a paper presented during an international EQ conference [SAND88-2171C], the EQ Risk Scoping Study authors made the following recommendation: *"The U.S. nuclear industry practice of specifying long duration equipment mission times during harsh accident conditions might be reduced when appropriate so that test resources focus on assuring equipment operability for the first few days of an accident exposure."*

5. **TID 14844 significant core damage and instantaneous release assumptions:**

The accident radiation dose assumptions for LOCA qualified inside containment cables are based on the guidance of TID14844. This results in containment source terms that represent a severely damaged core and non-mechanistic instantaneous release assumptions. Both these considerations substantially increase the calculated accident integrated radiation dose values that are required for cable qualification.

6. **Exposure to entire accident radiation dose prior to LOCA steam simulation:**

Subjecting test cables to 100% of the accident radiation dose prior to the steam exposure is an important test conservatism for the risk significant functions occurring early in the accident sequence. Typical qualification test methodologies subject the cable samples to the entire accident radiation exposure prior to the accident steam simulation. This is conservative because the cumulative effect of the thermal aging and radiation simulations is a significant loss of elongation to both typical insulation and jacket materials. This loss of elongation promotes cracking and cable failures during the LOCA exposure. BNL test results confirm prior data that the radiation exposure alone results in a significant reduction in insulation and jacket elongation. Using conservative, non-mechanistic, instantaneous release assumptions (i.e., TID 14844) roughly 10% - 15% of the total dose (based on NUREG 0588) is assumed to occur within the first 8 hours and roughly 20% - 30% is assumed to occur during the first 24 hours. Consequently, exposing the cables to the entire accident dose prior to the steam simulation is an important program conservatism.

7. **Exposure to equivalent gamma + beta dose vs. effective dose at insulation and jacket:**

The accident radiation levels (150 - 200 Mrd) typically used during qualification test gamma simulations (e.g., ^{60}CO) represent the sum of Gamma (γ) and Beta (β) total integrated dose (TID) values at the cable surface. This $\gamma+\beta$ TID has been shown to be a very conservative simulation for both insulation and jacket materials. Sandia in NUREG/CR 5231, *Cobalt-60 Simulation of LOCA Radiation Effects,* describes the results of a joint U.S./French program studying the effects of β and γ radiation on cable insulation and jacket materials. They conclude that the appropriate γ equivalence dose for a β exposure can be conservatively defined based on average absorbed radiation dose rather than surface exposure dose. For a representative cable insulation and jacket geometry exposed to a typical inside containment combined $\gamma+\beta$ LOCA radiation exposure qualification test simulation, Sandia estimates that the jacket is overstressed by a factor of roughly two and the insulation by a factor of roughly five. This overstressing represents a significant cable qualification program conservatism.

8. **Accident Simulation Testing at 300V or 600V when actual I&C circuits operate below 140V:**

   Cable qualification tests performed in accordance with IEEE 383 establish cable performance during accident conditions at rated cable voltage plus margin. Low-voltage power and control cables are typically rated at 600V or 1000V, while instrument cables are typically rated at 300V or 600V. For inside containment instrument and control applications the voltages used during accident simulation tests provide an important performance margin over the operating voltages in typical control circuits (48 - 132 V) and instrument circuits (<50 V).

9. **Cable Insulation Resistance Values Based on Peak Temperature Conditions:**

   The cable insulation resistance (IR) values measured during LOCA steam tests should be conservatively lower than expected values during actual accident conditions. Because cable IR tends to be inversely related to cable temperature, virtually all cable styles exhibit significantly lower insulation resistance (IR) values during LOCA conditions than at room temperature. In order to establish qualification licensees must determine that the cable IR values measured during the accident steam test do not adversely affect instrumentation and control circuit performance. Licensees typically use the IR values measured at peak LOCA temperatures to establish cable qualification. Based on Sandia test data (NUREG/CR-5772), a typical cable's IR will increase approximately an order of magnitude for roughly a 30°C decrease in temperature. Accident simulation peak temperatures should contain significant conservatism when compared to likely containment conditions during realistic accident conditions for design basis accidents. This conservatism stems from numerous factors including containment T/H code assumptions, mass and energy release assumptions, IEEE margin requirements (see discussions above), and operation of containment heat removal equipment.

10. **Post-LOCA mandrel bend test with 80 V/mil (2400V for typical I&C cable):**

    IEEE 383 specifies a post-LOCA mandrel bend, immersion, high potential test which, according to the standard, demonstrates ". . . *an adequate margin of safety by requiring mechanical durability (mandrel bend) following the environmental simulation* . . . ." The standard requires the LOCA tested cable to be straightened and recoiled around a metal mandrel and immersed in room temperature tap water. While immersed the cable sample must pass an 80 V/mil ac or 240 V/mil dc 5 minute voltage withstand test. This results in a 2,400 Vac test voltage for the typical insulation thickness (30 mil) on representative instrument and control cables (e.g., 12 awg - 18 awg). This 2,400 Vac test voltage is a significant stress when compared to operating voltages in typical control circuits (48 - 132 V) and instrument circuits (<50 V). Because brittle materials cannot pass this test, it demonstrates both residual material flexibility and dielectric capability. The margin and conservatism associated with this post-accident test provide yet further confidence that manufactured cables will adequately perform under actual accident conditions.

Summary

Typical cable qualification test programs include numerous conservative practices which collectively provide a high level of confidence that installed plant cables will adequately perform during accident events. These conservative practices also support the adequacy of using a small number of test specimens during the qualification test program.

Appendix B - Technical and Regulatory Information on Post-LOCA Testing

IEEE 383 Post-LOCA Test: IEEE 383-1974 Section 2.4.4, *Post LOCA Simulation Test,* requires mandrel-bend, water immersion, high potential testing of the cable qualification specimens at 80 V/mil ac or 240V/mil dc. The section's note states:

> "The post-LOCA simulation test demonstrates an adequate margin of safety by requiring mechanical durability (mandrel bend) following the environmental simulation and is more severe than exposure to two cycles of the environment."

The high potential test results in a 2,400 Vac test voltage for the typical insulation thickness (30 mil) on representative instrument and control cables (e.g., 12 awg - 18 awg). This 2,400 Vac test voltage is a significant stress when compared to operating voltages in typical control circuits (48 - 132 V) and instrument circuits (<50 V). The margin and conservatism associated with this post-accident test are intended to provide confidence that manufactured cables will adequately perform under actual accident conditions.

The post-LOCA testing provision of IEEE 383 as a margin requirement is unique among the IEEE equipment qualification standards. Except for IEEE 317, all the other IEEE standards, including IEEE 323, do not specify post-LOCA testing as a margin or qualification requirement.[1] The post-LOCA dielectric test is also unique since it is not intended to simulate conditions or performance during accidents and the voltage, submergence, configuration and performance criteria associated with this test are unrelated to conditions or performance during accidents. The test achieves its stated objective of establishing margin by demonstrating mechanical durability and dielectric strength after the accident exposures.

It does not appear possible to infer inadequate performance during accident conditions based on post-LOCA test failures. For example, Sandia reported on research test results for several EPR cable styles in NUREG/CR-5772 Vol. 2. Regarding the IEEE 383 1974 post-LOCA test Sandia observed that the test was very severe for several EPR cable styles and the *"tests induced failures of EPR cables that were otherwise functional throughout the accident tests. Note that this conclusion does not imply a criticism of the IEEE 383 requirements, which are intended to provide a level of conservatism in the testing."*[2] Similarly, for one bonded jacket cable style that experienced several failures during the post-LOCA dielectric test, Sandia observed that the cables had among the highest insulation resistances

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1 IEEE 317 1983 specifies qualification requirements for containment penetrations and requires a post-LOCA gas leak rate test. The standard states that the post-LOCA test is necessary because gas leakage cannot be accurately measured during the LOCA simulation.

2 NUREG/CR-5772 Vol. 2 page 75.

(IR) values during the LOCA simulation of any of the cables tested. IR is an important performance attribute for I&C cables during accident conditions.

IEEE 323 Margin Provisions: IEEE 323-1974, Section 6.3.1.5, *Margin,* defines margin as the *"difference between the most severe specified service conditions of the plant and the conditions used in type testing to account for normal variations in commercial production of equipment and reasonable errors in defining satisfactory performance."* It also states that qualification testing must verify adequate margin and that *"increasing levels of testing, number of test cycles, and test duration shall be considered as methods of assuring adequate margin does exist."* Neither this or other relevant sections of IEEE 323 1974 identify post-LOCA testing as a margin basis.

Section 6.5.4, *Determination of Qualification,* states that equipment is considered qualified if the equipment performance meets or exceeds its specified values, *"for the most severe environment or sequence of environments in the equipment specification during it installed life."* Section 6.7, *Criteria of Failure,* states that, *"any sample equipment is considered to have failed when the equipment does not perform the Class IE functions required by the equipment specification."* IEEE 323 1983 expresses similar considerations. IEEE 323 does not require performance during post-LOCA tests that is functionally unrelated to performance during accident conditions.

NRC Margin Provisions: Regarding margin both 10 CFR 50.49 and Regulatory Guide 1.89 Rev. 1 state that margin accounts for variations in equipment commercial production and test equipment inaccuracies. Except for the one hour minimum operating time provision, the regulatory guide accepts the margin guidance of IEEE 323 1974, Section 6.3.1.5 as meeting 50.49(e)(8).

Neither the EQ rule nor regulatory guide require performance during post-LOCA tests that is functionally unrelated to performance during accident conditions. 10 CFR 50.49 j(2) states that each item must be qualified to verify the equipment, *"meets its specified performance requirements when it is subjected to the conditions predicted to be present when it must perform its safety function up to the end of its qualified life."* Regulatory Guide 1.89 Rev. 1, B. *Discussion*, states that qualification, *"is a verification of design limited to demonstrating that the electric equipment is capable of performing its safety functions under significant environmental stresses resulting from design basis accidents in order to avoid common-mode failures."*

NUREG-0588 contains guidance on margin in Section 3(3) and Resolution of Comment 70. The margin guidance does not identify the need for cable post-LOCA testing. In summary, this guidance states that if staff-approved methods or values are used for establishing accident pressure, temperature, and radiation conditions then sufficient conservatism exists to account for variations in commercial production and uncertainties associated with defining adequate performance and environmental conditions. Additional margin is only required to account for inaccuracies in test equipment.

Regulatory Acceptance of IEEE 383: It is of some significant that the NRC has never formally issued a final regulatory guide endorsing the IEEE cable qualification standard, IEEE 383 1974. The NRC issued two "For Comment" versions of Regulatory Guide 1.131, *Qualification Tests of Electric Cable, Field Splices, and Connections for Light-Water-Cooled Nuclear Power Plants*, in August, 1977 and August, 1979.