UNITED STATES
NUCLEAR REGULATORY COMMISSION
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NRC REGULATORY ISSUE SUMMARY 2003-09 ENVIRONMENTAL QUALIFICATION OF LOW-VOLTAGE INSTRUMENTATION AND CONTROL CABLES

ADDRESSEES

All holders of operating licenses for nuclear power reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

INTENT

The U.S. Nuclear Regulatory Commission (NRC) is issuing this regulatory issue summary (RIS) to inform addressees of the results of the technical assessment of GSI-168, “Environmental Qualification of Low-Voltage Instrumentation and Control (I&C) Cables.” The scope of GSI-168 is limited to safety-related, low-voltage I&C cables. This RIS requires no action or written response on the part of an addressee.

BACKGROUND

In support of the resolution of GSI-168, the NRC sponsored cable test research at Wyle Laboratories and the Brookhaven National Laboratory. The resulting NRC technical assessment was essentially based on reviews and analyses of the research results of six loss-of-coolant-accident (LOCA) cable tests, condition-monitoring tests on I&C cables, and information provided by the nuclear industry. Technical assessments were coordinated with the nuclear industry and the Institute of Electrical and Electronics Engineers.

Following the completion of the NRC research effort, the staff concluded that typical I&C cable qualification test programs include numerous conservative practices that collectively provide a high level of confidence that the installed I&C cables will perform their intended functions during and following design basis events as required by 10 CFR 50.49, “Environmental Qualification (EQ) of Electric Equipment Important to Safety for Nuclear Power Plants.” These conservative practices continue to support the current use of a single prototype during qualification testing and, therefore, a successful test provides a high level of confidence that these cables will be able to perform their safety functions during and following a design basis event. However, cable LOCA test failures that occurred during the NRC-sponsored research program indicate that in certain cases the original margin and conservatism inherent in the qualification process have been reduced. Licensees have stated in a few cases that a reduction in margin can be addressed by monitoring operating service environments (temperature, radiation, and humidity) to ensure that operating conditions do not exceed the parameters that were assumed during qualification testing. In this regard, walkdowns to look for any visible signs of anomalies attributable to aging, with particular emphasis on localized adverse environments, coupled with the knowledge of the operating service environments, could be sufficient to ensure that qualification is maintained.

DISCUSSION OF TECHNICAL ASSESSMENT

The technical assessment of GSI-168 is based on reviews and analyses of the research results of six LOCA tests, condition-monitoring tests on I&C cables, and information provided by the nuclear industry. Summaries of significant research findings are presented below. Details of the NRC technical assessment of GSI-168 are available in the NRC Agencywide Documents Access and Management System (ADAMS), Accession No. ML021790551.

Current EQ Process (40 Years)

The current EQ process is adequate for assuring that low-voltage I&C cables will perform their intended functions for 40 years. When I&C cables are qualified in accordance with NRC regulations, the overall EQ process provides reasonable assurance that I&C cables will perform their intended safety-related functions during their qualified life. Specifically, 10 CFR 50.49(e) requires consideration of all significant types of aging degradation that can affect the component's functional capability. Compliance with 10 CFR 50.49 provides reasonable assurance that the cables will perform their intended functions during and following design basis events after exposure to the effects of service condition aging. Further, some licensees have implemented monitoring programs to ensure that service conditions will not exceed those assumed during the original qualification. Inspection, surveillance, condition monitoring, and trending of selected parameters for any installed safety-related cable system could increase the confidence in cable performance.

EQ Process for License Renewal (60 Years)

Licensees that have addressed license renewal recognize that knowledge of the operating service environments is essential to extending the qualified life of I&C cables. Where measured environmental service conditions are less severe than those used in the original qualification and when the cables are not degraded, the licensees assessed the difference between the operating environment and the original qualification environment to extend the qualified life of the cables to 60 years by reanalysis. This approach, based on the Arrhenius methodology, has been found acceptable by the staff during its review of license renewal applications.

Results of Cable LOCA Tests

Detailed information on the six cable LOCA tests conducted at Wyle Laboratories is provided in NUREG/CR-6704, "Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables." It should be noted that the LOCA conditions selected for the simulated tests were consistent with those used in the original qualification of the cables. All cable specimens in Test Sequences 1, 2, and 3 passed the LOCA test and the voltage withstand test. Samuel Moore cable specimens failed the voltage withstand test during Test Sequence 4, and Okonite bonded- jacket cable specimens failed the

LOCA test and the voltage withstand test in Test Sequence 5. All of the Test Sequence 6 cable specimens, aged to 60 years, exhibited high leakage currents and several cable specimens failed the voltage withstand test. The summary results of the six test sequences are discussed in Attachment 1.

Research Findings on Cable Condition-Monitoring Techniques

NRC research results on I&C cables indicate that meaningful information can be derived from testing samples of polymeric materials under controlled laboratory conditions. With certain limitations (accessibility being the biggest limitation), some of these test results can be applied in the in situ assessment of installed cable systems. The research concluded that a combination of condition-monitoring techniques could be effective since no single technique is currently adequate to detect insulation degradation of I&C cables. Based on the test results, conclusions were drawn regarding the effectiveness of the techniques studied for monitoring cable condition and are presented in the attachment.

Industry Good Practices for Condition-Monitoring

During the NRC review of GSI-168, the industry stated that cable aging evaluations are ongoing throughout plant life. When unexpected localized adverse conditions are identified, the condition of the affected cables is evaluated and appropriate corrective action is taken. Monitoring or inspection of environmental conditions or component parameters was generally conducted to ensure that the component is within the bounds of its qualification basis. The combination of licensee-specific activities and industry-supported activities that were developed for condition-monitoring can support a high level of confidence that installed safety-related cables would remain qualified to perform their safety functions in the event of an accident. In addition, the nuclear industry continues to advance the state-of-the-art in cable condition-monitoring from the simplest techniques to the most sophisticated. The staff has concluded that, although a single reliable condition-monitoring technique does not currently exist, walkdowns to look for any visible signs of anomalies attributable to cable aging, coupled with monitoring of operating environments, have proven to be effective and useful.

Risk Assessment

The state-of-the-art for incorporating cable aging effects into probabilistic risk assessment is still evolving and current assumptions that need to be made on the failure rate and common cause effects are based on sparse data. One of the key assumptions of the risk assessment is that operating environments are less severe than or the same as those assumed during qualification testing. These assumptions can be relied upon provided licensees have ongoing knowledge of environmental operating conditions at the nuclear power plants.

SUMMARY OF ISSUE

The technical assessment of GSI-168 is complete and the research findings are published in NUREG/CR-6704, Vols. 1 and 2 (Accession Nos. ML010460247 and ML010510387). The significant research findings that resulted from this effort are as follows:

- The current equipment qualification process for low-voltage I&C cables is adequate for the duration of the current license term of 40 years.
- Because of the failures of some I&C cables in the NRC LOCA tests, the original margin and conservatism inherent in the qualification process have been reduced. Adequate margin may be ensured through ongoing monitoring of plant operating environments to confirm that service conditions do not exceed those assumed during qualification testing and the cables are within the bounds of their qualification basis.
- Walkdowns, with particular emphasis on the identification of localized adverse environments, to look for any visible signs of anomalies attributable to cable aging, coupled with the monitoring of operating environments, were proven to be effective and useful for ensuring qualification of cables.
- For license renewal, a reanalysis (based on the Arrhenius methodology) to extend the life of the cables by using the available margin based on a knowledge of the actual operating environment compared to the qualification environment, coupled with observations of the condition of the cables during walkdowns, was found to be an acceptable approach.
- A combination of condition-monitoring techniques may be needed since no single technique is currently demonstrated to be adequate to detect and locate degradation of I&C cables. Monitoring I&C cable condition could provide the basis for extending cable life.

BACKFIT DISCUSSION

This RIS requests no action or written response. Consequently, the staff did not perform a backfit analysis.

FEDERAL REGISTER NOTIFICATION

A notice of opportunity for public comment was not published in the *Federal Register* because this RIS is informational.

PAPERWORK REDUCTION ACT STATEMENT

This RIS does not request any information collection.

If there are any questions concerning this RIS, please contact the person noted below.

/RA/
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Attachments:
1. Results of Cable LOCA Tests and Findings On Cable Condition-Monitoring Techniques
2. List of Recently Issued NRC Regulatory Issue Summaries

RESULTS OF CABLE LOCA TESTS AND FINDINGS ON CABLE CONDITION-MONITORING TECHNIQUES

CABLE LOCA TESTS

Detailed information on the six cable LOCA tests conducted at Wyle Laboratories is provided in NUREG/CR-6704, “Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables.” It should be noted that the LOCA conditions selected for the simulated tests were consistent with those used in the original qualification of the cables. The summary results of the six test sequences are presented below.

Test Sequence 1: XLPE Insulated Cables Aged to 20 Years

The samples tested in this sequence were #14 and #16 American wire gauge (AWG) XLPE-insulated cables with a Neoprene overall outer jacket manufactured by Rockbestos, with the trade name “Firewall III.” The preaging parameters for the four groups of specimens in this test sequence were as follows:

Group 1: No accelerated aging (control specimens)
Group 2: Accelerated aging to match naturally aged cable (2.86 hr @ 248 °F + 0.63 Mrad)
Group 3: Naturally aged cable (10 years old)
Group 4: Accelerated aging to 20 years (648.5 hr @ 302 °F + 26.1 Mrad)

The LOCA conditions simulated included exposure to 150 Mrad of accident radiation, followed by exposure to steam at high temperature and pressure (346 °F and 113 psig peak conditions, double-peak profile) and chemical spray. The test duration was 7 days. All cable specimens passed the LOCA test sequence, including the post-LOCA voltage withstand test.

Test Sequence 2. EPR-Insulated Cables Aged to 20 Years

The samples used in this sequence were three-conductor (3/C) and four-conductor (4/C) #16 AWG, 600v AIW cables with ethylene propylene (EPR) and unbonded chlorosulfonated polyethylene (CSPE, with the trade name Hypalon), covering the insulation of each conductor and the conductor bundle. The preaging parameters for the four groups of specimens in this test sequence were as follows:

Group 1: No accelerated aging (control specimens)
Group 2: Accelerated aging to match naturally aged cable (28.5 hr @ 250 °F + 3.3 Mrad)
Group 3: Naturally aged cable (24 years old)
Group 4: Accelerated aging to 20 years (82.2 hr @ 250 °F + 25.7 Mrad)

The LOCA conditions simulated included exposure to 150 Mrad of radiation followed by exposure to steam (340 °F and 60 psig peak conditions, single-peak profile) and chemical spray. The test duration was 7 days. All cable specimens passed the LOCA test sequence, including the post-LOCA voltage withstand test.

Test Sequence 3. XLPE-Insulated Cables Aged to 40 Years

The test specimens were cross-linked-polyethylene (XLPE)-insulated cables with a Neoprene overall outer jacket manufactured by Rockbestos, with the trade name “Firewall III.” The preaging parameters for the four groups of specimens in this test sequence were as follows:

Group 1. No accelerated aging (control specimens)
Group 2. Accelerated aging to simulate the exposure of the naturally aged specimens (9.93 hr @ 248 °F + 2.27 Mrad)
Group 3. Naturally aged 10-year-old cable
Group 4. Accelerated aging to simulate 40 years of qualified life (1301.16 hr @ 302 °F + 51.49 Mrad)

The LOCA conditions simulated included exposure to 150 Mrad of accident radiation followed by exposure to steam (using the same LOCA profile as used in Test Sequence 1) and chemical spray.

One of the Group 4 specimens did not hold the full 500 volts used for insulation resistance (IR) testing even after its splices were removed. The cause of this failure was determined to be human error in handling the test specimen. With the exception of the damaged specimen, all cable specimens passed the LOCA test sequence, including the post-LOCA voltage withstand test.

Test Sequence 4. Multiconductor Cables

The objective of this test sequence was to determine whether multiconductor cables have any unique failure mechanisms that are not present in single-conductor cables. The test specimens were #12 AWG, 3/C, 1,000V EPR-insulated cables with individual and outer CSPE jackets manufactured by Anaconda. In addition, this test sequence included #16 AWG, 2/C, 600V Samuel Moore cables with ethylene propylene diene monomer (EPDM) insulation and a CSPE bonded individual jacket with a Dekorad overall outer jacket. The preaging groups in this test sequence were as follows:

Group 1. Anaconda and Samuel Moore cables with no accelerated aging (control specimens)
Group 2. Samuel Moore cables with accelerated aging to simulate 20 years of qualified life (84.85 hr @ 250 °F + 25.99 Mrad)
Group 3. Anaconda cables (169.20 hr @ 302 °F + 53.60 Mrad) and Samuel Moore cables (169.05 hr @ 250 °F + 51.57 Mrad) with accelerated aging to simulate 40 years of qualified life.

The LOCA conditions simulated included exposure to 150 Mrad of accident radiation followed by steam (346 °F and 113 psig peak conditions, as used in Test Sequences 1 and 3) and chemical spray. During the post-LOCA voltage withstand test, all of the Anaconda cables and Samuel Moore cables aged to simulate 20 years performed acceptably. However, two out of three Samuel Moore specimens aged to simulate 40 years could not hold the 2,400V test voltage on one conductor. Inspection of the two specimens revealed a single pinhole in the insulation of each failed conductor. It was concluded that the failures were due to localized degradation of the insulation, which caused the high-potential test to puncture the insulation on the two failed conductors. There was no general degradation of the insulation along the length of the cable specimens and no unique failure mechanism was observed between the single-conductor and multiconductor cables. Therefore, based on these test results, the issue of a unique failure mechanism for multiconductor vs. single-conductor low-voltage I&C cables was not demonstrated.

Test Sequence 5. Bonded Jacket Cables

The samples used in this sequence were **A**naconda 3/C, #12AWG, 1,000V cables with EPR insulation and a CSPE jacket; **S**amuel Moore 2/C, #16 AWG, 600V cables with EPDM insulation and a CSPE jacket; and **O**konite 1/C, #12 AWG, 600V cables with EPR insulation and a CSPE jacket. The preaging groups in this test sequence were as follows:

Group 1. Specimens with no accelerated aging (control specimens)
Group 2. Specimens from A, S, and O with accelerated aging to simulate 20 years of qualified life (A: 84 hr @ 302 °F + 25.69 Mrad; S: 84 hr @ 250 °F + 25.99Mrad; and O: 252 hr @ 302 °F + 25.79 Mrad)
Group 3. Specimens from A, S, and O with accelerated aging to simulate 40 years of qualified life (A: 169 hr @ 302 °F + 51.35 Mrad; S: 169 hr @ 250 °F + 51.57 Mrad; and O: 504 hr @ 302 °F + 51.49 Mrad)

The LOCA conditions simulated included exposures to 150 Mrad of accident radiation, followed by steam (double-peak LOCA profile, as used in Test Sequences 1 and 3 with a test duration of 10 days) and chemical spray. After post-LOCA inspections, a voltage withstand test was conducted on each of the cable specimens. All of the Samuel Moore and Anaconda cables performed acceptably, while one of the two Okonite specimens in Group 2 and all 3 Okonite specimens in Group 3 failed the 2,400V voltage withstand test. It was observed that the insulation on the Okonite cables had split open along their length during the simulated LOCA, exposing the bare conductor underneath. It was concluded that the failures in the Okonite specimens were caused by differential swelling of the bonded CSPE individual jacket and the underlying EPR insulation.

The Okonite Company has subsequently requalified the 1/C, #12 AWG Okonite Okolon composite cable based on an Arrhenius activation energy of 1.24eV. Calculations using this activation energy (225 hr @ 150 °C + 200 Mrad and 300 hr @ 150 °C + 100 Mrad) extrapolate to a 40-year qualified life at 75 °C and 77 °C, respectively. Additional details of the recent Okonite cable requalification program are contained in Regulatory Issue Summary 2002-11 (ADAMS Accession No. ML022190099), issued August 9, 2002.

Test Sequence 6: EPR- and XLPE-Insulated Cables Aged to 60 Years

The test specimens were Rockbestos cables (same as Test Sequences 1and 3), AIW cables (same as Test Ssequence 2), Samuel Moore cables (same as Test Sequences 4 and 5), and Okonite cables (same as Test Sequence 5). The preaging groups in this test sequence were as follows:

Group 1: No accelerated aging (control specimens)

Group 2: Rockbestos cables (1366 hr @ 302 °F +77 Mrad), Okonite cables (756 hr @ 302 °F + 77 Mrads), AIW cables (252 hr @ 250 °F + 38 Mrad), and Samuel Moore cables (252 hr @ 250 °F + 77 Mrad) with accelerated aging to simulate 60 years of qualified life.

The LOCA conditions simulated included exposure to either 75 Mrad (AIW cables only) or 150 Mrad of accident radiation, followed by exposure to steam (double-peak LOCA profile, as used in Test Sequences 1 and 3, with peak conditions of 346 °F and 113 psig and a duration of 10 days) and chemical spray.

Following the post-LOCA investigation, the test specimens were subjected to a voltage withstand test. In general, *all* of the specimens aged to 60 years exhibited a weakening of the insulation, which was manifested in the form of high leakage currents. Some of the specimens were unable to hold the required 2,400V of the voltage withstand test.

Error in Irradiation Dose

Following the completion of cable LOCA testing at Wyle Laboratories, the Georgia Institute of Technology notified Wyle Laboratories of an error in irradiation dose that affected LOCA tests 2 through 6. All specimens received irradiations from 6% to 10.5% lower than previously reported. Prior to completion of the GSI-168 technical assessment, the reported error in irradiation dose was evaluated by the Brookhaven National Laboratory and the NRC staff to determine if this error would impact the research findings. The staff's review concluded that none of the conclusions of the GSI-168 technical assessment are impacted by this error. The staff recognizes that the radiation dose of 50 Mrad used for qualification is conservative when compared to the 40-year dose seen during normal service in a nuclear power plant.

RESEARCH FINDINGS ON CABLE CONDITION-MONITORING TECHNIQUES

Based on the results of the testing, the following conclusions were drawn regarding the effectiveness of the techniques studied for monitoring cable condition.

Visual Inspection

Visual inspection does not provide quantitative data; however, it does provide useful information on the condition of the cable that is relatively easy and inexpensive to obtain and that can be used to determine whether further investigation of the cable condition is warranted. Visual inspection is demonstrated to be a valuable source of information in any cable condition-monitoring program.

Elongation at Break (EAB)

EAB was found to be a reliable technique for determining the condition of the polymers studied. While EAB provides trendable data that can be readily correlated with material condition, it is a destructive test and cannot be used as an in situ means of monitoring electric cables unless sacrificial cable specimens are available.

Oxidation Induction Time Method (OITM)

OITM was found to be a promising technique for monitoring the condition of electric cables. Results show that aging degradation can be trended with this technique for both XLPE and EPR insulation. However, a small sample of cable material is needed to perform this test.

Oxidation Induction Temperature (OIT)

OIT, which is related to OITM, was found to be less sensitive for detecting aging degradation of the polymers studied. OITM is preferred at this time.

Fourier Transform Infrared (FTIR) Spectroscopy

In terms of ability to trend aging degradation in the polymers studied, FTIR spectroscopy was found to provide inconclusive results. The results tend to show a consistent trend with age. However, the technical basis for the trend remains questionable.

Indenter

The indenter was found to be a reliable device that provides reproducible, trendable data for monitoring the degradation of cables in situ. It is limited to accessible sections of the cable, but it was found to be effective for monitoring the condition of common cable jacket and insulation materials and can be used for monitoring localized and accessible segments of low-voltage electric cables.

Hardness

The results of the hardness test indicate that, over a limited range, hardness can be used to trend cable degradation. However, different probes must be used to accommodate the change in material hardness. Also, puncturing the cable insulating material is a potential concern with this technique and must be taken into consideration.

Insulation Resistance

Degradation of cable insulation can be trended with this technique. As cables degrade, a definite change in insulation resistance can be detected that can be correlated to cable condition. Using 1-minute and 10-minute readings to calculate the polarization index enables the effects of temperature and humidity variations to be accounted for. This technique can be used as an in situ condition-monitoring technique.

Dielectric Loss

This technique was found to provide useful data for trending the degradation of cable insulation. As the cables degrade, a definite change in phase angle between an applied test voltage and the circuit current can be detected at various test frequencies and correlated to cable condition. This technique can be used as an in situ condition monitoring technique. However, it is more effective when a ground plane is an integral element of a cable system.

Functional Performance

This technique alone does not provide sufficient data to determine the condition of a cable. It is a “go—no go” type of test and may not be effective in detecting degraded conditions and impending failures. Further, functional performance testing is not considered an effective method for determining, in situ, the LOCA survivabiltiy for a particular cable.

Voltage Withstand

The capability of the insulating materials to withstand the circuit voltage is an indication of its dielectric performance. In order to detect defects in an incipient state, applied voltages may have to be elevated considerably above the rated voltages of the systems; further, the equipment at both ends of a cable system under test must be either disconnected or protected. Voltage withstand tests may result in unanticipated degradation of cables and can result in failures. Therefore, the risk of causing either catastrophic or incipient damage to cable insulation makes this an unsuitable method for assessing the LOCA survivability of low-voltage electric cables in situ.