UNITED STATES
NUCLEAR REGULATORY COMMISSION
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# FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION FOR ANALYSIS AND MEASUREMENT SERVICES CORPORATION'S TOPICAL REPORT AMS-CABLE-TR0226-R0, "CONDITION MONITORING METHODOLOGY FOR LIFE EXTENSION AND AGING MANAGEMENT OF ELECTRICAL CABLES"

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## 1. INTRODUCTION

By letter dated August 20, 2024 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML24233A208), as supplemented on December 4 2024 (ML24339B786 (package)) and October 6, 2025 (ML25279A025 (package)), Analysis and Measurement Services Corporation (AMS) submitted Topical Report (TR) AMS-CABLE-TR0226-R0, "Condition Monitoring Methodology for Life Extension and Aging Management of Electrical Cables," to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. By email dated March 11, 2025 (ML25066A189), the NRC staff accepted the TR for review.

The purpose of this TR is to provide a method for monitoring the condition of polymer-insulated electrical cables. The condition monitoring (CM) methods described in the TR would support life extension, aging management, and condition-based qualification of electrical cables used in nuclear power plants.

## 2. BACKGROUND AND SCOPE OF THE REVIEW

The NRC staff's review of the TR evaluates the AMS CM methodology for its general applicability in nuclear power plant safety systems in accordance with NRC regulations. TR AMS-CABLE-TR0226-R0 describes a systematic cable CM methodology intended to support life extension and aging management of electrical cables installed in nuclear power plants, including safety-related and non-safety related cables governed by the General Design Criteria (GDC) in Appendix A of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, the quality assurance (QA) criteria in Appendix B of 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," and by the regulations in 10 CFR 50.49, 10 CFR 50.55a(h), 10 CFR 50.69, and 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants."

The methodology is targeted to environmental qualified cables and cables in aging management programs (AMPs) and time-limited aging analysis (TLAAs) described in NUREG-1801, Revision 2, and NUREG-2191, Revision 1, and can be used in lieu of, or in addition to, existing time-based qualified life determinations and AMPs/TLAAs. The TR provides a non-exclusive list of CM techniques and discusses advantages/limitations, emphasizing that no single technique is universally applicable; licensees must select methods that trend for the cable's polymers and construction and validate correlation by testing.

In accordance with an audit plan dated June 23, 2025 (ML25169A148 (package)), the NRC staff performed an audit to support its review of the TR. The audit summary report (ML26016A537 (package)) was issued on February 11, 2026.

2.1 Scope of the NRC Staff Review

The TR proposes a structured approach to periodically assess the condition of installed cables (including those within the scope of 10 CFR Part 50 and 10 CFR Part 54) to establish acceptance criteria linked to design basis event (DBE) performance, and determine monitoring intervals that provide reasonable assurance that cables remain capable of performing their safety and design functions throughout their service life.

The NRC staff's review was performed to determine whether the proposed methodology provides an acceptable technical basis, consistent with NRC regulations and endorsed guidance, for licensees to (1) establish condition-based qualification of cables; (2) extend qualified life or ongoing qualification; and (3) implement aging management consistent with 10 CFR Part 54 and applicable GDCs in Appendix A and QA criteria in Appendix B to 10 CFR Part 50.

## 3. **REGULATORY EVALUATION**

The regulations and guidance relevant to the review of the TR are summarized below.

- 10 CFR 50.49, "Environmental qualification of electric equipment important to safety for nuclear power plants," (the environmental qualification (EQ) rule) requires, in part, licensees to establish a program for qualifying the electric equipment important to safety. The electric equipment under the scope of this section includes safety-related electric equipment, non-safety-related electric equipment whose failure under postulated environmental conditions could prevent satisfactory accomplishment of safety functions specified by the safety-related equipment, and certain post-accident monitoring equipment. 10 CFR 50.49(e)(5), "Aging," requires licensees to account for aging effects and maintain qualification during service life, and recognizes reanalysis and ongoing qualification with surveillance/testing to demonstrate that equipment has additional life.

- 10 CFR 50.55a(h), "Protection and safety systems," states that protection systems must meet, as applicable, the requirements of the Institute of Electrical and Electronics Engineers (IEEE) Standard (Std.) 603-1991, "Criteria for Safety Systems for Nuclear Power Generating Stations," or IEEE Std 279–1968, "Proposed IEEE Criteria for Nuclear Power Plant Protection Systems," or IEEE Std. 279-1971, "Criteria for Protection Systems for Nuclear Power Generating Stations," contingent on the date of construction permit issuance. The design-basis criteria identified in those standards or, for nuclear power plants with construction permits issued before January 1, 1971, the criteria identified in the licensing basis for such facilities, include the range of transient and steady state environmental conditions during normal, abnormal, and accident conditions during which the equipment must perform its safety functions.

- 10 CFR 50.69, “Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors,” states, in part, that a holder of a license to operate a light-water reactor (LWR) nuclear power plant under 10 CFR Part 50; a holder of a renewed LWR license under 10 CFR Part 54; an applicant for a construction permit or operating license under 10 CFR Part 50; or an applicant for a design approval, a combined license, or manufacturing license under 10 CFR Part 52; may voluntarily comply with the requirements in 10 CFR 50.69 as an alternative to compliance with 10 CFR 50.49 for risk-informed safety class (RISC)-3 and RISC-4 structures, systems, and components (SSCs).

  In the *Federal Register* (FR) notice (69 FR 68008) for the final rule establishing 10 CFR 50.69, the Commission stated that RISC-3 (safety-related low safety significant) and RISC-4 (non-safety-related low safety significant) SSCs will be exempt from the special treatment requirements for qualification methods for environmental conditions and effects and seismic conditions. Nevertheless, the Commission stated that RISC-3 SSCs continue to be required to be capable of performing their safety-related functions under applicable environmental conditions and effects and seismic conditions, albeit at a lower level of confidence as compared to RISC-1 (safety-related safety significant) SSCs. As specified by the Commission in the FR notice, a licensee implementing 10 CFR 50.69 must consider operating life (aging) and combinations of operating life parameters (synergistic effects) in the design of RISC-3 electrical equipment. The Commission noted that this is particularly important if the equipment contains materials which are known to be susceptible to significant degradation due to thermal, radiation, and/or wear (cyclic) aging including any known synergistic effects that could impair the ability of the equipment to meet its design basis function. The Commission direction in the FR notice regarding the capability of RISC-3 SSCs to be able to perform their safety functions under applicable environmental and seismic conditions is clear for licensees who have received a license amendment to implement a 10 CFR 50.69 program. With respect to both RISC-3 and RISC-4 SSCs, the Commission decided to remove the RISC-3 and RISC-4 SSCs from detailed, specific requirements that provide the high level of assurance. However, the Commission stated in the FR notice that the functional requirements for these SSCs remain.

- 10 CFR Part 50, Appendix A, “General Design Criteria for Nuclear Power Plants,” GDC 4, “Environmental and dynamic effects design bases,” states, in part, that SSCs important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents.

- 10 CFR Part 50, Appendix A, GDC 1, “Quality standards and records,” GDC 2, “Design bases for protection against natural phenomena,” and GDC 23, “Protection system failure modes,” contain general requirements associated with equipment qualification.

- 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," requires, in part, that the pertinent requirements of this appendix apply to all activities affecting the safety-related functions of the SSCs that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. These activities include designing, purchasing, fabricating, handling, shipping, storing, cleaning, erecting, inspecting, testing, operating, maintaining, repairing, refueling, and modifying.

- 10 CFR Part 54 requires applicants to show that the effects of aging on long-lived, passive, in-scope SSCs are adequately managed so intended functions are maintained in the period of extended operation. For electrical cables, this is accomplished by identifying cable types and environments within the scope of license renewal and crediting AMPs consistent with NUREG-1801, "Generic Aging Lessons Learned (GALL) Report — Final Report," Revision 2, NUREG-2191, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report," Revision 1 and related guidance. These AMPs focus on aging stressors (temperature, moisture, radiation, chemistry), aging mechanisms (embrittlement, insulation degradation, water-treeing), and periodic inspection or testing so cable functional capability is preserved through the extended term. A TLAA is a current-licensing-basis analysis that meets the six criteria in 10 CFR 54.3, "Definitions," including explicit consideration of aging, time-limited assumptions tied to the original license term, and use to demonstrate that aging does not prevent intended functions. For electrical cables, examples include EQ or thermal/radiation life calculations that establish a finite qualified life for Class 1E equipment (including EQ-subject cables) under 10 CFR 50.49; these are treated as TLAAs when they meet the 10 CFR 54.3 criteria. Under 10 CFR 54.21(c)(1), the license renewal application must list such electrical cable-related TLAAs and for each either (1) show the analysis remains valid for the period of extended operation, (2) show it is projected to be valid to the end of the period of extended operation, or (3) adequately manage the effects of aging on the intended functions for the period of extended operation through an AMP and/or replacement so the current licensing basis is maintained.

- NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 3.11, "Environmental Qualification of Mechanical and Electrical Equipment," identifies NRC staff guidance for determining that all items of equipment that are important to safety (mechanical, electrical, and instrumentation and control (I&C) equipment) are capable of performing their design safety functions under all normal environmental conditions, anticipated operational occurrences, and accident and post-accident environmental conditions. It includes all environmental conditions that may result from any normal mode of plant operation, anticipated operational occurrences, design-basis events (DBEs) (as defined in 10 CFR 50.49(b)(1)(ii)), post-DBEs, and containment tests.

- Prior to the 1983 issuance of the 10 CFR 50.49 final rule (48 FR 2730), the Commission (in Petition for Emergency and Remedial Action, CLI-80-21, 11 NRC 707 (1980)) directed the NRC staff to use NUREG-0588, "Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment," Revision 1, and the Division of Operating Reactors (DOR) Guidelines, "Guidelines for Evaluating Qualification of Class 1E Electrical Equipment in Operating Reactors," November 3, 1979, as requirements that licensees and applicants must meet in order to satisfy the equipment qualification requirements of 10 CFR Part 50. At that time, NUREG-0588 consisted of what is now Part I of NUREG-0588 (i.e., only the "for comment version" of NUREG-0588).

- Upon its issuance, 10 CFR 50.49, which is based on Part I of NUREG-0588 (hereinafter "NUREG-0588") and the DOR Guidelines, did not require requalification of electric equipment by applicants for, and holders of, operating licenses for nuclear power plants previously required by the NRC to qualify equipment in accordance with the DOR Guidelines or NUREG-0588 (Category I or II).

  According to NUREG-0588, all nuclear reactors with operating licenses as of May 23, 1980, would be evaluated by the NRC staff against the DOR Guidelines. As the Commission stated in the preamble to the 10 CFR 50.49 final rule, Category I requirements of NUREG-0588, which supplement the recommendations of, and apply to, equipment qualified in accordance with IEEE Std. 323-1974, "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations," apply to nuclear power plants for which the construction permit safety evaluation report was issued after July 1, 1974. Category II requirements, which supplement the recommendations of, and apply to, equipment qualified in accordance with IEEE Std. 323-1971, "IEEE Trial-Use Standard: General Guide for Qualifying Class I Electric Equipment for Nuclear Power Generating Stations," apply to nuclear power plants for which the construction permit safety evaluation report was issued prior to July 1, 1974. For nuclear power plants whose safety evaluation reports for construction permits were issued since July 1, 1974, the NRC has used Regulatory Guide (RG) 1.89, "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants," Revisions 1 and 2.

- RG 1.89, Revisions 1 and 2, describe an approach that is acceptable to the NRC staff to meet EQ of certain electric equipment important to safety for nuclear power plants.

- RG 1.211, "Qualification of Safety-Related Cables and Field Splices for Nuclear Power Plants," describes a method that the NRC staff considers acceptable for complying with the regulatory requirements for the qualification of safety-related cables and field splices for nuclear power plants.

- RG 1.218, "Condition-Monitoring Techniques for Electric Cables Used in Nuclear Power Plants," describes a method and techniques that the NRC staff considers acceptable for use in implementing the regulatory requirements regarding monitoring the performance of electric cables used in nuclear power plants.

- RG 1.248, "Guide for Assessing, Monitoring, and Mitigating Aging Effects on Electrical Equipment Used in Production and Utilization Facilities," describes an approach that is acceptable to the NRC staff to meet regulatory requirements for managing, monitoring, and mitigating aging effects on electrical equipment.

- Regulatory Issue Summary 2003-09, "Environmental Qualification of Low-Voltage Instrumentation and Control Cables," provides information on the results of the technical assessment of Generic Safety Issue (GSI)-168, "Environmental Qualification of Low-Voltage Instrumentation and Control (I&C) Cables."

- RG 1.188, “Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses,” describes an approach that is acceptable to the NRC staff for the format and content of an application to renew or subsequently renew an NRC-issued operating license.

- NUREG/CR-6704, “Assessment of Environmental Qualification Practices and Condition Monitoring Techniques for Low-Voltage Electric Cables,” Volumes 1 and 2, documents the results of a research program addressing issues related to the qualification process for low-voltage I&C electric cables used in commercial nuclear power plants.

- NUREG/CR-7000, “Essential Elements of an Electric Cable Condition Monitoring Program,” provides recommendations for a comprehensive cable CM program consisting of nine essential elements that consolidate a core program of periodic CM inspections and tests, together with the results of in-service testing, environmental monitoring and management activities, and the incorporation of cable-related operating experience.

- NUREG/CR-7300, “Radiation Accident Dose and Simulated Loss-of-Coolant Accident [LOCA] Test of Low Voltage Cables,” provides an updated technical basis for how low-voltage cables respond to combined accident radiation and simulated LOCA environments, supporting NRC positions on cable aging management and EQ for long-term operation. The report documents integrated testing of representative low-voltage cable constructions subjected to radiation accident dose followed by simulated LOCA conditions to characterize degradation mechanisms, performance margins, and failure modes relevant to DBEs. The report addresses knowledge gaps from prior research on cable aging and LOCA performance and is intended to inform NRC staff evaluations, licensee EQ programs, and CM approaches under existing regulations (e.g., 10 CFR 50.49 and license renewal aging-management requirements).

## 4. TECHNICAL EVALUATION

The TR emphasizes compliance with NRC regulations and guidance associated with condition-based qualification and CM program elements. Sections 7 and 8 of the TR include an evaluation of the methodology against NRC requirements, RGs, and NUREGs related to EQ, license renewal, and CM. The referenced regulatory guidance documents collectively describe methodologies and program attributes that, if properly implemented, are considered acceptable means to meet the requirements listed in Section 3 of this safety evaluation. The NRC staff reviewed the TR to determine the impact of the proposed cable CM methodology on the qualification of electrical equipment.

The fundamental basis for 10 CFR 50.49, which governs EQ of electrical equipment important to safety for nuclear power plants, is to ensure that such equipment can reliably perform its safety functions under normal environmental conditions, anticipated operational occurrences, and accident and post-accident environmental conditions. This includes qualification that considers environmental stressors such as temperature, pressure, humidity, chemical exposure, radiation, and aging over the electrical equipment's installed life. The EQ rule requires license holders and applicants to establish programs that verify the equipment's capability to function under the most severe DBEs, thereby maintaining the integrity of safety systems essential for reactor coolant pressure boundary, safe shutdown, and prevention of significant radioactive release. EQ under 10 CFR 50.49 is grounded in protecting against environmentally induced common cause failures and ensuring that electrical equipment can meet its safety requirements throughout the nuclear power plant's operational life in accordance with QA criteria specified in Appendix B to 10 CFR Part 50 and GDCs 1, 2, 4, and 23 in Appendix A to 10 CFR Part 50.

## 4.1 Evaluation of the Four Elements

The methodology comprises of four elements: (1) select installed cables and group them; (2) identify CM measurements that trend monotonically with age for each group; (3) establish acceptance criteria by correlating CM data to DBE test outcomes; and (4) perform in-plant CM, compare results to criteria, and set testing intervals (with increased frequency as cables approach acceptance criteria), implementing corrective actions when criteria are reached. The methodology is intended for polymer-insulated cables (e.g., crosslinked polyethylene, Ethylene propylene rubber, Chloro-sulfonated polyethylene, Silicone rubber) and is not applicable to mineral-insulated, fiber optic, and oil-filled cables (i.e., paper-insulated lead sheath cables).

*Element 1 (Selection/Grouping)*: The TR directs licensees to compile cable information (design, materials, routing, environment, function) and perform similarity analyses to form groups with documented technical bases. Conservatism requires that the harshest environment segments be included in sampling/assessment (distributed tests like frequency domain reflectometry (FDR)), or localized lab measurements if inaccessible; if none are feasible, the methodology is not applicable.

*Element 2 (Identify Trendable CM Tests)*: The TR requires CM tests that: (i) are measurable; (ii) change monotonically with age; (iii) correlate to DBE performance; and (iv) have consistent trends from unaged through the limit of qualified pre-accident condition, consistent with RG 1.89 attributes. It describes accelerated aging with witness samples and requires at least three statistically unique, monotonic data points to establish correlation curves.

*Element 3 (Acceptance Criteria)*: The methodology's acceptance criteria are established through accelerated aging of cable samples and periodically exposing them to a simulated DBE. The methodology accounts for accelerated aging artifacts (diffusion-limited oxidation (DLO), inverse temperature, interfacial interactions) by profiling oxidation through thickness and applying time-shift compensation so acceptance criteria reflect natural aging equivalent condition indicators. Acceptance criteria can also be established for situations where other requirements, such as the ability of cables to survive a flame test, are the primary concern or where cables are aged under natural environmental conditions (i.e., aged under normal service temperatures and radiation dose). The testing performed to establish acceptance criteria needs to consider all applicable elements of the test standard being applied (e.g., RG 1.211). The acceptance criteria establish the point at which corrective actions (e.g., implementation of cable replacement plans) are required, because the rate of degradation has been demonstrated to increase significantly once those criteria are exceeded, such that the cable condition rapidly approaches the end-of-life state observed when the cable failed the DBE test during establishment of the acceptance criteria.

*Element 4 (Evaluation & Test Intervals):* Initial in-plant CM establishes conditions and sets periodic testing intervals based on condition and risk/safety significance, with increased frequency as cables approach acceptance criteria. Intervals are informed by AMP frequencies (e.g., 6-10 years) and conservative consideration of polymers with fast aging rates (induction then rapid degradation). As cables begin to approach the acceptance criteria, licensees need to develop a plan of corrective action to address cable aging in accordance with their corrective action program, with full documentation under QA requirements, to ensure that subject cables are removed and replaced prior to reaching the end-of-life condition. This action shall be implemented when the cables reach the acceptance criteria.

The NRC staff finds that the four-element structure provides clear controls to (1) select appropriate CM techniques per cable group; (2) demonstrate trendability and monotonic behavior; (3) establish acceptance criteria directly tied to DBE pass/fail; and (4) implement conservative monitoring intervals, risk-informed sampling, and corrective actions. These elements are consistent with RG 1.89 and RG 1.211, which accept condition-based qualification where condition indicators meet the defined criteria and ongoing surveillance informs the establishment of remaining qualified life.

## 4.2 Consistency with EQ Regulatory Guidance

### 4.2.1 RG 1.89 and RG 1.211

Sections 8.1.1 and 8.1.2 of the TR describe how the methodology aligns with RG 1.89, Revision 2, and IEEE Std. 60780-323, "Nuclear facilities – Electrical equipment important to safety – Qualification," Edition 1, 2016-02.

RG 1.89, Revision 1, endorses IEEE Std. 323-1974. While RG 1.89, Revision 1, does not directly mention CM for the purposes of condition-based qualification, condition-based testing and analysis, like the approaches discussed in the AMS CM methodology, represents a current state-of-the-art technique that provides an alternative for monitoring the condition of cables for purposes of satisfying regulatory requirements. RG 1.89, Revision 2, endorses IEEE Std. 60780-323, Edition 1, 2016-02. NRC staff position 1.g under section C, "Staff Regulatory Guidance," of RG 1.89, Revision 2, states that CM and associated condition-based qualification methodologies discussed in Section 6.3 of IEC/IEEE Std. 60780-323, Edition 1, 2016-02, represent approaches for extending or establishing the qualified life of electrical equipment.

Both versions of RG 1.89 describe methodologies and program attributes that, if properly implemented, are considered acceptable means to meet applicable requirements in 10 CFR Part 50, including 10 CFR 50.49 and GDC 4 of Appendix A to 10 CFR Part 50.

Sections 8.1.3 and 8.1.4 of the TR describe how the methodology aligns with RG 1.211, which endorses, with clarifications and enhancements, IEEE Std. 383-2003, "IEEE Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations." IEEE Std. 383-2003 recognizes "monitoring programs" as an acceptable means to extend qualified life, provided that (a) aging-sensitive characteristics are periodically measured, (b) acceptance criteria are based on characteristics of qualified, age-conditioned cables, and (c) monitoring intervals are set such that corrective actions occur before deterioration exceeds acceptance criteria.

The CM methodology supports 10 CFR 50.49(e)(5) via ongoing qualification using periodic CM correlated to DBE performance, enabling reanalysis to extend qualified life. CM recognizes the fact that the aging process in a 10 CFR 50.49 test method qualification program can be an acceptable process of determining end of qualified life, if it is proven during a qualification by test program to be a condition indicator that must be measurable, change monotonically with time, be correlated with the safety function performance under DBE conditions, be linked to the functional degradation of the qualified equipment, have a consistent trend from unaged through the limit of the qualified pre-accident condition, and considers margin. The methodology's acceptance criteria (derived from DBE conditions) and monitoring periodicity align with RG 1.89 and RG 1.211 (i.e., monitoring program to extend qualified life; acceptance criteria based on post age conditioning characteristics; monitoring intervals set to prevent deterioration beyond criteria prior to corrective action).

Based on its review of the TR, the NRC staff finds that the methodology is consistent with RG 1.89, Revisions 1 and 2, and RG 1.211, including aging simulation, DBE testing, margin, qualification documentation, and condition-based monitoring, and therefore it is an acceptable method of condition-based qualification within the EQ framework of 10 CFR 50.49 and the environmental-effects design-basis expectations of GDC 4 of Appendix A to 10 CFR Part 50.

#### 4.2.2 RIS 2003-09, NUREG-0588, and DOR guidelines

Sections 8.1.5–8.1.7 of the TR explain that the methodology is consistent with the EQ practices described in RIS 2003-09, NUREG-0588, and the DOR guidelines. These documents provide historical EQ practices and acceptance criteria, which AMS uses as a foundation for selecting DBE profiles, test conditions, and margins that are then linked to CM indicators. The methodology does not replace, but rather builds upon, the existing test-based EQ basis by adding condition-based monitoring consistent with these historical EQ documents.
Based on its review, the NRC staff finds that the methodology is consistent with RIS 2003-09, NUREG-0588, and the DOR guidelines.

### 4.3 Consistency with License Renewal and Aging-Management Guidance

#### 4.3.1 RG 1.188, NUREG-1801, and NUREG-2191

The TR describes how the methodology can supplement or serve as the technical basis for AMPs XI.E1, “Insulation Material for Electrical Cables and Connections Not Subject to 10 CFR 50.49 Environmental Qualification Requirements,” XI.E2, “Insulation Material for Electrical Cables and Connections Not Subject to 10 CFR 50.49 Environmental Qualification Requirements Used in Instrumentation Circuits,” XI.E3, “Inaccessible Power Cables Not Subject to 10 CFR 50.49 Environmental Qualification Requirements,” and XI.E6, “Electrical Cable Connections Not Subject to 10 CFR 50.49 Environmental Qualification Requirements,” and TLAA X.E1, “Environmental Qualification of Electric Equipment,” in NUREG-1801 and NUREG-2191, especially where RG 1.218 is referenced for CM techniques.

Sections 8.2.1–8.2.3 of the TR show how the methodology could provide the technical basis for the development of cable-related AMPs and TLAAs described in RG 1.188, NUREG-1801, and NUREG-2191. These documents define attributes of acceptable AMPs/TLAAs and analytical methods used to manage aging effects for cables in the scope of license renewal and subsequent license renewal, including (a) use of data-driven methods to assess aging, (b) clear acceptance criteria tied to design-basis functions, (c) periodic monitoring and trending, and (d) corrective actions when criteria are approached or exceeded.

The NRC staff finds the methodology acceptable to meet license renewal/subsequent license renewal AMP elements for detection of aging effects, monitoring/trending, and corrective action, and to inform TLAAs associated with EQ programs under X.E1. The TR clarifies that while CM may replace some visual inspections where justified, manhole water inspections and submergence considerations remain required because the methodology does not qualify cables for submerged service.

Based on its review, the NRC staff finds that the methodology could be used as a technical basis to support the development of AMPs and TLAAs consistent with RG 1.188, NUREG-1801, and NUREG-2191.

#### 4.3.2 RG 1.218 and RG 1.248

Sections 8.3.1 and 8.3.2 of the TR describe how the methodology aligns with RGs 1.218 and 1.248. RG 1.248 endorses IEEE Std. 1205-2014, "IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Electrical Equipment Used in Nuclear Power Generating Stations and Other Nuclear Facilities." RG 1.218 identifies elements of effective cable CM programs and acceptable techniques (e.g., elongation at break (EAB), indenter modulus (IM), FDR, oxidation induction time (OIT)) for aging management.

The TR includes examples of CM techniques (EAB, IM, Fourier-transform infrared spectroscopy (FTIR) Carbonyl Index, FDR, low frequency dielectric spectroscopy (LFDS), OIT/oxygen induction temperature (OITP), impedance/tan δ), a process to address differences between accelerated and natural aging, and results demonstrating how acceptance criteria are derived by correlating CM to LOCA/DBE survivability.

Based on its review, the NRC staff finds that the methodology is consistent with RG 1.218 and RG 1.248.

#### 4.3.3 NUREG/CR-6704, NUREG/CR-7000, and NUREG/CR-7300

Appendix B of the TR notes that the findings and conclusions of the AMS research are consistent with the findings and conclusions in NUREG/CR-6704. As in NUREG/CR-6704, the AMS research also showed that EAB, OIT, and IM demonstrate a trend with age-related degradation for a wide range of cable polymers. NUREG/CR-6704 also states that further research was needed to establish FTIR as a useful cable CM tool. Since the publication of NUREG/CR-6704, improvements in FTIR data analysis methods have enhanced the capabilities of the method. Specifically, a more in-depth understanding of how the absorption peaks in the infrared spectrums of polymers correspond to age-related oxidation has improved the applicability of the test.

As stated in the TR, the proposed AMS methodology recognizes that there is no single CM method that can by itself identify and quantify the degradation of all varieties of insulation materials, cable configurations, and installation types. Moreover, the methodology does not endorse a single CM test or a specific group of CM tests for determining the condition of all cable types. Rather, the methodology provides a process for identifying CM tests that trend with age and developing acceptance criteria for CM tests that can be used to determine if a cable is in a qualified condition. Once CM tests and acceptance criteria are identified after applying the methodology, measurements can then be performed on installed cables to determine initial condition and establish appropriate testing intervals. The TR recognizes that engineering judgments related to the integrity and soundness of an electric cable must be made by experienced personnel. If no CM test can be shown to trend with aging for a specific cable, then the methodology cannot be applied. Based on this information, the NRC staff finds that the TR is consistent with NUREG/CR-6704.

Section 8.3.4 of the TR notes that the methodology aligns with the recommendations identified in NUREG/CR-7000. Based on its review, the NRC staff finds that the four primary elements of the methodology (i.e., (a) selection of cables and environments, (b) selection and validation of

CM techniques, (c) establishment of acceptance criteria, and (d) periodic assessment, trending, and use of results in maintenance and decision-making) and its programmatic implementation process is consistent with the recommendations identified in NUREG/CR-7000.
Appendix B of the TR compared the results identified in NUREG/CR-7300 against AMS research that was used to develop this methodology. The TR includes explanations of differences in conclusions regarding the eight CM tests common to both projects. Importantly, the work conducted in the AMS research to account for the effects of the accelerated aging process observed in the different CM methods was not performed in the NUREG/CR-7300 research. According to AMS, based on comparisons of CM data from NISTIR 8391, “Assessment of Condition Monitoring Methods of Electrical Cables,” and the research summarized in Appendix A of the TR for the cables shared between the two projects, the insulation materials for the cables in the AMS project reached a higher level of oxidation. Had the NUREG/CR-7300 testing and aging program continued (i.e., the cables reached a higher level of oxidation), the NRC staff agrees with AMS that more significant changes in tests such as OITP, FDR, and line impedance resonance analysis (LIRA) may have been observed. The NRC staff finds that it is reasonable to conclude that if tests such as FTIR and thermogravimetric analysis (TGA) were conducted using different sample preparation and measurement and data analysis methods, the results might have demonstrated a trend with cable aging. Based on this and the information provided in the TR, the NRC staff finds that AMS has adequately justified the differences in results between this methodology and NUREG/CR-7300.

## 5. **SUMMARY AND CONCLUSIONS**

Based on the above evaluation, the NRC staff concludes that the methodology described in TR AMS-CABLE-TR0226-R0 provides an acceptable method for condition-based qualification and aging management of polymer-insulated electrical cables in nuclear power plants, with reasonable assurance that such cables remain capable of performing their safety and design functions throughout their service life. The methodology’s CM indicators, monotonic trend requirement, and acceptance criteria based on DBE conditions meet the attributes of RG 1.89 and RG 1.211 for condition-based qualification, and the periodic surveillance/testing results can be used to modify qualified life with documented margin and conservatism. Furthermore, the methodology supports GDC 1, 2, 4, and 23 by ensuring qualified condition and compatibility with environmental/dynamic effects and by considering failure modes in protection systems. Implementation under Appendix B to 10 CFR Part 50 and within the stated limitations and application-specific action items identified in this safety evaluation and TR AMS-CABLE-TR0226-R0 will ensure appropriate design/test control and auditable records. Additionally, the NRC staff finds the methodology provides an acceptable technical basis to support or supplement cable AMPs XI.E1, XI.E2, XI.E3, and XI.E6 and TLAA X.E1, consistent with NUREG-1801 and NUREG-2191. Implementation of RG 1.218 CM techniques within a comprehensive program and periodic assessment/trending meets AMP expectations for detection, monitoring, and corrective action. The TR provides reasonable assurance that cables within the methodology’s scope will remain capable of performing their safety functions during and after postulated accidents for the established qualified or design life, which may be extended based on CM results.

Therefore, the NRC staff finds that the proposed methodology is an acceptable method to support compliance with 10 CFR 50.49, 10 CFR 50.55a(h), 10 CFR 50.69, GDC 1, 2, 4, and 23 of Appendix A to 10 CFR Part 50, Appendix B to 10 CFR Part 50, and 10 CFR Part 54.

## 6. LIMITATIONS AND CONDITIONS

The TR limits applicability to polymer-insulated cables and explicitly excludes mineral-insulated, fiber optic, and oil-filled cables (i.e., paper-insulated lead sheath cables); it does not qualify cables for submerged environments or eliminate manhole water inspections in NUREG-1800 or NUREG-2191 XI.E3. The TR requires implementation under Appendix B to 10 CFR Part 50, including design/test control and records.

6.1 The NRC staff finds the above limitations appropriate, and the following plant-specific action items must be satisfied by an applicant or a licensee when referencing the methodology in the TR:

6.1.1. *Program Documentation*: Licensees shall establish and maintain a CM program document (or EQ/license renewal/subsequent license renewal basis document) that identifies cable groups, selected CM methods, correlation curves, DBE test bases, acceptance criteria, accelerated aging compensation factors, sampling plans, and test intervals, with traceability to standards and the nuclear power plant's licensing basis.

6.1.2. *Condition Indicator Attributes*: Documentation that demonstrates, for each cable group, that selected CM indicators are measurable, monotonic, and correlated with DBE performance, consistent with RG 1.89; maintain at least three statistically unique, monotonic points for correlation curves.

6.1.3. *Qualified Condition Traceability*: Establish acceptance criteria with documented margin; include accelerated aging compensation (e.g., DLO time shift) supported by oxidation profiling/tests; link criteria to functional performance (e.g., IEEE Std. 383-2003 dielectric withstand).

6.1.4. *Harshest Segment Assessment and Sampling*: Where feasible, use distributed or lumped methods to assess the entire cable length, ensuring harshest environment segments are captured; if inaccessible, obtain localized samples or alternative evidence; if non-feasible, this methodology should not be applied to that cable. Document sampling rationale and representativeness.

6.1.5. *Test Control & QA*: Conduct CM and DBE basis testing under Appendix B to 10 CFR Part 50 QA requirements with written procedures, instrument control, calibration, and data validation, data retention (i.e., auditable records) of CM/DBE basis and program decisions.

6.1.6. *Periodic CM Intervals and Corrective Actions*: Define and set conservative test thresholds and intervals based on measured condition and risk significance; increase frequency as cables approach criteria; implement corrective actions when criteria are met, and document per Appendix B to 10 CFR Part 50 QA requirements.

## 7. LIST OF ACRONYMS

| Acronym | Definition |
|---|---|
| ADAMS | Agencywide Documents Access and Management System |
| AMPs | Aging management programs |
| AMS | Analysis and Measurement Services Corporation |
| CM | Condition monitoring |
| DBE | design basis event |
| DLO | diffusion limited oxidation |
| EAB | Elongation at break |
| EQ | Equipment Qualification |
| FDR | Frequency domain reflectometry |
| FR | Federal Register |
| FTIR | Fourier-transform infrared spectroscopy |
| GDC | General Design Criteria |
| IEEE | Institute of Electrical and Electronics Engineers |
| IM | Indenter modulus |
| LFDS | Low frequency dielectric spectroscopy |
| LIRA | Line impedance resonance analysis |
| LOCA | Loss-of-Coolant Accident |
| LWR | light-water reactor |
| NRC | Nuclear Regulatory Commission |
| OITP | OIT/oxygen induction temperature |
| QA | Quality Assurance |
| RG | Regulatory Guide |
| RISC | risk-informed safety class |
| SSCs | Structures, systems, and components |
| TLAAs | Time-limited aging analysis |
| TR | Topical Report |

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