ISSUE STATEMENT

Concerns exist that cable aging-related failures may impact nuclear plant safety and reliability. As a result, plant owners and regulators are requiring the implementation of electrical cable aging management programs and processes. Improvements to cable aging management processes, condition monitoring techniques, acceptance criteria, and aging models are necessary to support resolution of cable aging concerns.

DRIVERS

Safety
A nuclear plant’s safety-related electrical cable system must be reliable. Cable failures can challenge safety system operability.

Equipment Reliability
Medium voltage off-site feed cable and safety-related motor feed cable failures have caused outages of 2 to 3 weeks in duration. Medium voltage cable replacement is costly and generally difficult.

Regulatory
The U.S. Nuclear Regulatory Commission (NRC) is requiring per Reg Guide 1.218 that cable aging management and condition monitoring be put in place. Non-U.S. regulators are following the NRC lead regarding aging cable systems. While some differences in cable materials and installation practices exist from country to country, deterioration of low and medium voltage cables is a concern to the world nuclear community.

Limitations of Inspection Technology
The design of nuclear plant cables limits the types of tests that may be used. While standardized, the tests provide information on cable condition, but limited information on long-term operability of the cable and cannot estimate remaining life. Condition monitoring acceptance criteria is providing value but more data analysis is required to determine if it can be useful in determining the rate of aging.

Limitations of Applicable Standards
IEEE, ICEA, and AEIC have established cable testing and manufacturing standards, but these standards provide little information on aging management of nuclear plant cable systems.

RESULTS IMPLEMENTATION

This research effort will result in knowledge and methodologies to effectively implement cable aging management programs. The following will be provided:

• Resolution of issues that arise during implementation of cable aging management programs.
• Recommended testing methodologies applicable to specific cable types and vintages.
• Advanced testing and predictive methodologies.
• Additional understanding of electrical cable failure modes allowing improved testing methodology and acceptance criteria to be developed.
• Test applicability matrices and ongoing EPRI technical support.

PROJECT PLAN

Utility Actions
Utilities are in process of implementing their cable aging management program. Medium voltage cables in adverse environment have mostly been identified and condition assessment through dissipation factor (tan delta testing) is ongoing. Identification of low voltage cable scope is in progress and condition assessment is expected to continue on through the next several refueling cycles.

Another important effort is collecting actual, field aged cables to assess their current condition compared to the actual environmental conditions they saw in service. Utilities are urged to supply EPRI their abandoned, failed, or replaced low and medium voltage cables to support condition evaluation through forensic investigation of the cable condition. Such research will provide insight into cable aging and failure mechanisms known or yet to be identified. This forensics work very likely is one of the key means of supporting cable capability assessments for long term operation.

Failure Mechanism Research
Through a pilot project started in 2010, EPRI will produce age-accelerated medium voltage cable specimens. The hope was that these specimens would permit accelerated testing and forensics, accelerated development of aging models, and development of improved condition monitoring techniques. This project did not prove successful in creating specimens that would degrade due to accelerated aging, but they failed due to random manufacturing issues.
Failure mechanism research for wet cables has completed for cable types from plants in service in the 1970s. Results have shown that tan delta testing has been successful in identifying degraded cables. A correlation has been established between the level of cable degradation and tan delta test results. A forensic method has been developed to isolate the degraded insulation and the level of degradation can be confirmed by ac breakdown testing. The final report, 3002005232, showed that elemental metal (Al, Fe, Pb, Si, Ti, Zn) were found at water tree roots. These elements are believed to act as catalyst (along with water and dielectric stress).

A field guide for proper harvesting of service aged cables was issued in 2014. Report 3002003994 is a web-based guide that can be used on a desk-top, laptop, or tablet device (for electronic work package usage). This document was in September 2014. Sufficient funding was available to perform testing of two harvested cables in 2014. Additionally funding is available through 2017 to continue evaluations of service aged cables harvested from operating or plants entering recommissioning.

The second evaluation and assessment of medium voltage Tan δ test results was completed and issued in September 2015. The report summarizes the data analyzed so far. Key insights are the correlation of poor tan delta results to reduced ac breakdown values of the degraded cable identified through the failure mechanism research (see above). The report also provides guidance for members to use in analyzing their test results.

To support the development of advanced testing practices/technologies, EPRI’s Nuclear Sector continues to look for opportunities to collaborate and coordinate activities and research with the Power Delivery and Utilization Sector. No activities are currently planned.

**Cable Program Support, Implementation, and Sustainability**

Cable program implementation support is being managed through issuance of EPRI guidance such as the aging management guides (1020804, 3002000557, and 10216929), implementation lessons learned guide (1022968) and support provided via the Cable User Group semi-annual meetings. In addition, in August, 2012 the end of life guide (1025259) was issued, as well as research into the effects of dewatering cable (1025263). An update to report 1020805 for the medium voltage cable aging management guide (3002000557) was issued in the June of 2013. The revision clarifies some issues identified during initial implementation such as testing methodology, frequency, and analysis. Revisions to the low voltage power cable and I&C cable aging management implementation guides will be performed in 2017 to address lessons learned to-date by member implementation efforts to-date.

**Cable Diagnostics**

Condition monitoring of low and medium voltage cable is the key to establishing the current state of cables. Much has been learned about medium voltage cables in wet adverse environments by evaluating the tan delta test data that members have been supplying EPRI. The initial report (1025262) evaluating this data was issued in July, 2012. Additional insights into degradation rate can be gathered if we can evaluate second and third test data from the same equipment. Funding has been obtained to continue this effort through 2015 when a second report will be issued to include the additional insights of this additional data.

EPRI will continue to identify and evaluate condition monitoring and diagnostic techniques, both existing and new, to ensure that our members have the best techniques available to them to evaluate the condition of their cable systems and obtain information needed to make informed decisions on those cables that are approaching end of life. This will be done through staying abreast of research in other EPRI sectors, involvement with the Insulated Conductors Committee of the IEEE, and through collaboration, monitoring or supporting the research projects of the NRC, the Department of Energy, and the National Laboratories.
**Long Term Operations**

Support of long term operations is indirectly covered by many of the project in the other swim lanes. Items such as submergence qualification, Black EPR rejuvenation experiments, developing a methodology for assessing risk and reliability for cables are specific to this area.

EPRI is continuing the submergence qualification project based on IEEE Std 323-1974 qualification methodology to provide a basis for allowing medium voltage cables to be submerged. The initial qualification activities for brown ethylene propylene rubber (EPR) are now in the accelerated aging stage. The second insulation type, pink EPR, via supplemental funding began in June, 2015. This qualification is only being considered for modern cable types that are known to never have failed in submerged conditions. Manufacturer and insulation specific qualifications will be performed; generic insulation type qualification is not possible. Because certain cable types, such as most black EPRs and butyl rubber, have experienced water related degradation at about 30 years, submergence qualification will not be attempted.

Little information is available on longevity of low-voltage cable under wet and submerged conditions. In late 2011, a year long, pilot test program was begun that subjects common low voltage insulations to energized, submergence testing in 90°C water to determine if these insulations are susceptible to long-term wet aging. This work was completed in 2016. Report 3002007791 was issued and research results indicate that low voltage cable insulation did not degrade under the conditions they were exposed to during the project.

Funding was obtained for 2013 for the development of a guidance document for performing an evaluation of a plant’s specific cable infrastructure aging and how that can be used to understand the risk and reliability that can be expected in the period of long term operation. Information will be gathered via site visits to both a pressurized water reactor and boiling water reactor to obtain cable condition assessment information. That data will be used to estimate current cable condition and estimated remaining life and then extrapolated to estimate the degree of exposure of the site. The associated cost of maintaining the cable system at acceptable risk levels through long term operation will be demonstrated. This report will serve as a guide for others to repeat such analysis for their sites. This work has been delayed to allow performance of a gap analysis of EPRI cable research and develop an integrated research plan with DOE, NRC, and the National Laboratories. This work will be re-evaluated upon completion of this integrated research roadmap.

**RISKS**

It may not be possible to develop accelerated aging techniques for EPR insulations or an enhanced cable test methodology.

**RECORD OF REVISION**

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

<table>
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<tr>
<th>REVISION</th>
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| 0        | Original Issue: August 2011  
Roadmap Owner: Gary Toman |
| 1        | Revision Issued: November 2011  
Roadmap Owner: Gary Toman  
Changes: Revised to update for 2012  
added Design Recommendations for Longevity of Cable Systems |
| 2        | Revision Issued: August, 2012  
Roadmap Owner: Andrew Mantey  
Changes: The roadmap has been completely redesigned. The previous roadmap flowchart revision had a single swim lane for equipment reliability. The revised roadmap flowchart has five swim lanes covering utilities roles, failure mechanism research, cable program support, cable diagnostics, and long term operations. In addition, the 2011 year has been removed and 2012–2016 have been modified to include milestones and both funded and unfunded work. |
| 3        | Revision Issued: December 2012  
Roadmap Owner: Andrew Mantey  
Changes: Research work completed in 2012 has been annotated on the flowchart. Cable user group meetings in second half of years when International Cable Symposia occur have been removed (2013 and 2015). Research for project in 2013 that were shown as not being funded have been updated to show funding in 2013. |
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| 4        | Revision Issued: August 2013  
Roadmap Owner: Andrew Mantey  
Changes: Research work completed so far in 2013 has been annotated on the flowchart. Research for project work to be requested in 2014 has been added to the flowchart (Cable Materials Handbook, Service-Aged Cable Evaluation) and flowchart have been adjusted for projects extended due to need for additional information (Low Voltage Wet Susceptibility, MV Failure Mechanism). |
| 5        | Revision Issued: December 2013  
Roadmap Owner: Andrew Mantey  
Changes: Update provided on negative results of age accelerated medium voltage cable samples and the September issuance of MV failure mechanism report 3002000554. Dates were revised for funding of Tan Delta test data analysis. Added information on newly approved funding for cable harvesting guidance and testing for 2014–2016. Sustainability section updated to reflect funding for cable polymer handbook. The delay of LTO funded guidance for evaluating cables to replaced for long term operation to perform gap analysis of research and coordinate with DOE, NRC and National Labs research was done instead. |
| 6        | Revision Issued: August 2014  
Roadmap Owner: Andrew Mantey  
Changes: Revised roadmap to show LTO support for DOE/NRC/EPRI research goes out to mid-2017 and that the Cable Polymer Handbook and Harvesting guide are funded projects. |
| 7        | Revision Issued: December 2014  
Roadmap Owner: Andrew Mantey  
Changes: Updated projects competed in 2014 and provided status updates for on-going research out to 2017 (medium voltage cable submergence, low voltage wet cable study, evaluation of service aged cables). Identified 2015 deliverables for Tan delta analysis report, failure mechanism research and medium voltage cable portion of the cable polymer handbook. |
| 8        | Revision Issued: August 2015  
Roadmap Owner: Andrew Mantey  
Changes: Updated project status for submergence, low voltage wet aging, failure mechanism research and IAEA CRP project status. |
| 9        | Revision Issued: December 2015  
Roadmap Owner: Andrew Mantey  
Changes: Update project status for final failure mechanism research, summarized results of tan delta evaluation update report, and updated the cable polymer handbook project noting completion of medium voltage cable section. |
| 10       | Revision Issued: December 2016  
Roadmap Owner: Andrew Mantey  
Changes: Update project status for cable polymer handbook project, completion of Low Voltage Wet aging project and added updates to low voltage and I&C cable aging management program implementation guides in 2017. |