IN USE: CABLE AGING MANAGEMENT

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 condtion, 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. These specimens will permit accelerated testing and forensics, accelerated development of aging models, and development of improved condition monitoring techniques.

For cable types from plants in service in the 1970s, forensic evaluation of failed cables will continue through 2014. Results will allow tests to be tailored to the observed failure phenomenon and acceptance criteria to be improved. Five

documents have been issued to-date. The latest (3002000554, issued September 30, 2013) summarized previous key findings and also identified two failure mechanisms in compact design cables.

The initial evaluation and assessment of medium voltage Tan δ test results was completed and issued in July, 2012. This data evaluation is funded and will continue to be funded through 2015. A review of the second round of tan delta testing is hoped to provide insight into understanding the cable aging rate, as well as a way to identify cables for failure mechanism research.

To support the development of advanced testing practices/ technologies, EPRI's Nuclear Sector will coordinate activities and research with the Power Delivery and Utilization Sector.

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 voltaged cable aging management guidance (3002000557) was issued in the June of 2013. The revision clarifies some issues identified during initial implementation such as testing methodology, frequency, and analysis.

Funding has been approved for 2014-2015 to develop a handbook of medium, low and instrument and control cables describing there formulation, aging degradation mechanisms for EPR insulations to allow differentiation of them for aging management. Initial work in 2014 will focus on medium voltage cables and the other low and instrument cables will be addressed in 2015.

In addition, EPRI attended the initial International Atomic Energy Agency (IAEA) meeting for development of an international guidance on low voltage cable qualification, condition monitoring and aging management. This effort, supported by over 14 international cable experts, will continue through 2014. The second meeting was recently held at AMS in Knoxville Tennessee. Baseline testing results were reviewed and further work was done towards developing the format and responsible persons for final report development. Supporting the IAEA in this effort allows EPRI to influence the research and identify information on diagnostic and condition monitoring testing techniques to see if they can be applied by our membership.

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, Plans to add a second insulation type, pink EPR, via supplemental funding is in the offering for 2013. This qualification is only being considered for modern cable types that are known to never have failed in submerged conditions. Manufacturer and insulation specific qualifica¬tions 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 degra¬dation 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 is ongoing and a second phase will be added in 2014 to gather data on

jacketed, multi-conductor cables and the results will be evaluated and reported in 2014.

Funding was obtained for 2013 for the development of a guidance document for performing an evaluation of a plants 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.

The Integrated Life Cycle Management group has a project that will provide an analytical tool for determining the probability, risk of a cable failure. This work was to be completed by year end 2012 and is based on the statistical analysis of available industry failure data. This will be evaluated and, if practical, leveraged by integrating it into future cable program studies such as the guidance for plant evaluation of risk for long term operation mentioned above.

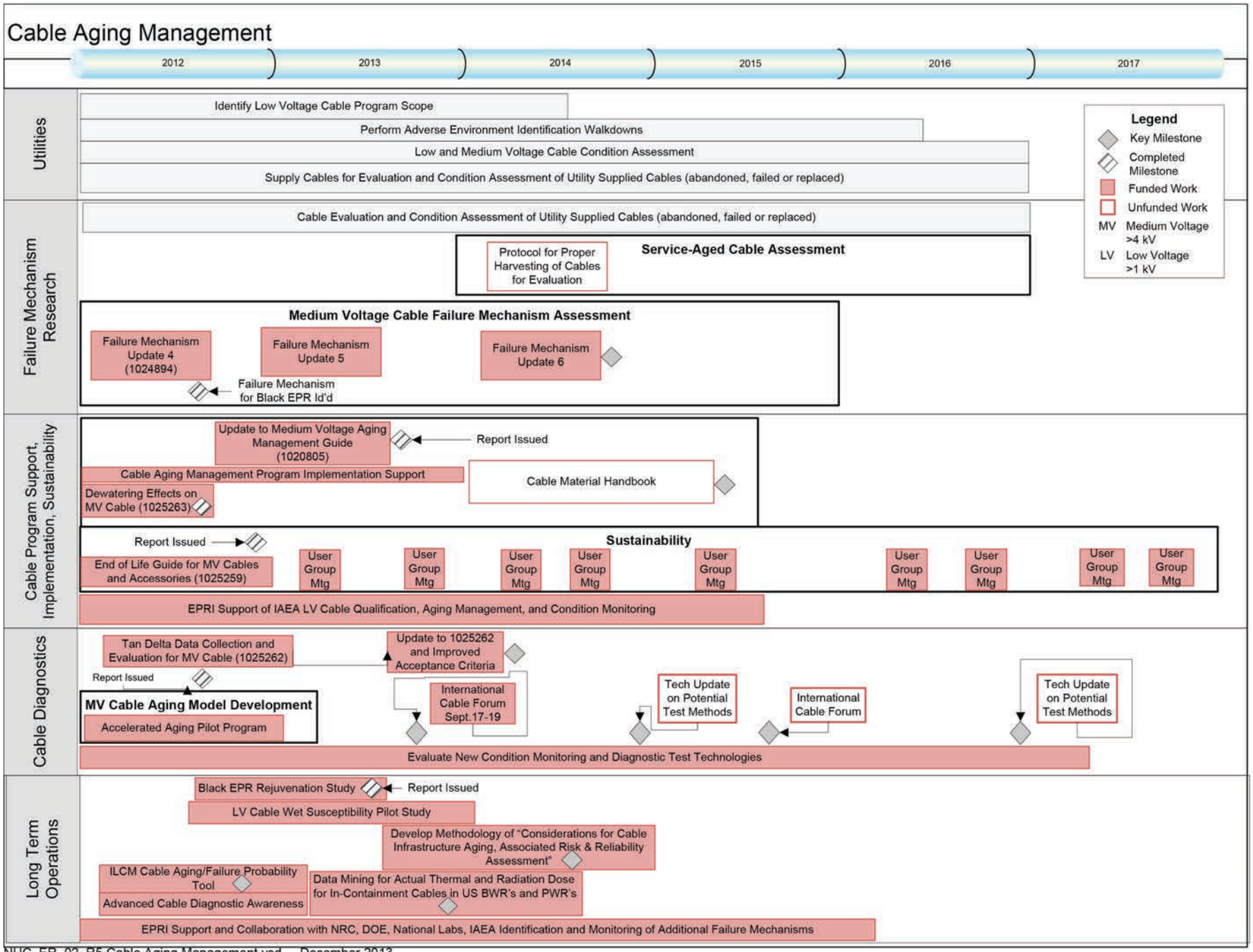
RISKS

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.

REVISION	DESCRIPTION OF CHANGE
0	**Original Issue:** August 2011 **Roadmap Owner:** Gary Toman
1	**Revision Date:** November 2011 **Roadmap Owner:** Gary Toman **Changes:** Revised to update for 2012 added Design Recommendations for Longevity of Cable Systems
2	**Revision Date:** 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 Symposiums 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.
4	**Revison Date:** 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 Date:** December 2013 **Roadmap Owner:** Andrew Mantey **Changes:** Update provided on negative results of age accelerated medium voltage cable samples and the September issueance 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.


Cable Aging Management
2012
2013
2014
2015
2016
2017
Utilities
Identify Low Voltage Cable Program Scope
Perform Adverse Environment Identification Walkdowns
Low and Medium Voltage Cable Condition Assessment
Supply Cables for Evaluation and Condition Assessment of Utility Supplied Cables (abandoned, failed or replaced)
Legend
Key Milestone
Completed Milestone
Funded Work
Unfunded Work
MV Medium Voltage >4 kV
LV Low Voltage >1 kV
Failure Mechanism Research
Cable Evaluation and Condition Assessment of Utility Supplied Cables (abandoned, failed or replaced)
Protocol for Proper Harvesting of Cables for Evaluation
Service-Aged Cable Assessment
Medium Voltage Cable Failure Mechanism Assessment
Failure Mechanism Update 4 (1024894)
Failure Mechanism Update 5
Failure Mechanism Update 6
Failure Mechanism for Black EPR Id'd
Cable Program Support, Implementation, Sustainability
Update to Medium Voltage Aging Management Guide (1020805)
Report Issued
Cable Aging Management Program Implementation Support
Cable Material Handbook
Dewatering Effects on MV Cable (1025263)
Report Issued
Sustainability
End of Life Guide for MV Cables and Accessories (1025259)
User Group Mtg
EPRI Support of IAEA LV Cable Qualification, Aging Management, and Condition Monitoring
Cable Diagnostics
Tan Delta Data Collection and Evaluation for MV Cable (1025262)
Update to 1025262 and Improved Acceptance Criteria
Report Issued
MV Cable Aging Model Development
Accelerated Aging Pilot Program
International Cable Forum Sept.17-19
Tech Update on Potential Test Methods
International Cable Forum
Tech Update on Potential Test Methods
Evaluate New Condition Monitoring and Diagnostic Test Technologies
Long Term Operations
Black EPR Rejuvenation Study
Report Issued
LV Cable Wet Susceptibility Pilot Study
Develop Methodology of "Considerations for Cable Infrastructure Aging, Associated Risk & Reliability Assessment"
ILCM Cable Aging/Failure Probability Tool
Advanced Cable Diagnostic Awareness
Data Mining for Actual Thermal and Radiation Dose for In-Containment Cables in US BWR's and PWR's
EPRI Support and Collaboration with NRC, DOE, National Labs, IAEA Identification and Monitoring of Additional Failure Mechanisms
NUC_ER_02_R5 Cable Aging Management.vsd December 2013