Condition-Based Qualification Research and EPRI Cable Research Updater

Nuclear

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LWRS Spring Meeting
May

Background

- EPRI, National Lab's DOE LWRS, NRC Research have been coordinating and collaborating on EMDA identified knowledge gaps since around 2013
- While we have improved our understanding on those knowledge gaps, we as a group would like to transition away from time-based qualified life to condition-based qualified life
- U.S. NUCLEAR REGULATORY COMMISSION REGULATORY GUIDE 1.89, REVISION 2 endorses IEEE/IEC 60780-323 2016
- EPRI held a meeting in January 2023 to evaluate the transition to CBQ using a "change management" approach
- AMS has a proposed an NRC endorsed Topical Report on the methodology for performing CBQ

Background (continued)

- International interest is growing
  - Shanghai Nuclear Engineering Research and Desing Institute (SNERDI) has completed a CBQ as documented in EPRI report 3002026361
  - IAEA has incorporated this into their International Generic Aging Lessons Learned (IGALL) Electrical Working Group AMP for condition monitoring, and
  - The Life Management of Nuclear Power Plants (LMNPP) network has initiated a working group on CBQ
- If successful, a condition-based qualification may:
  - Improve licensee understanding of the actual cable condition in the plants and provide additional confidence in re-analysis results
  - Improve regulatory confidence based on actual data rather than just re-analysis
  - Optimize the value of initial qualifications for new and existing facilities

SNERDI CBQ Research

Condition-Based Qualification

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01 Summarize best practices for condition-based qualification for cables

02 Record complete qualification procedure and share experience and lessons learned

03 Identify age conditioning , end-point approaching and data analysis methodology for CBQ

Qualified Life

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Combined Qualification

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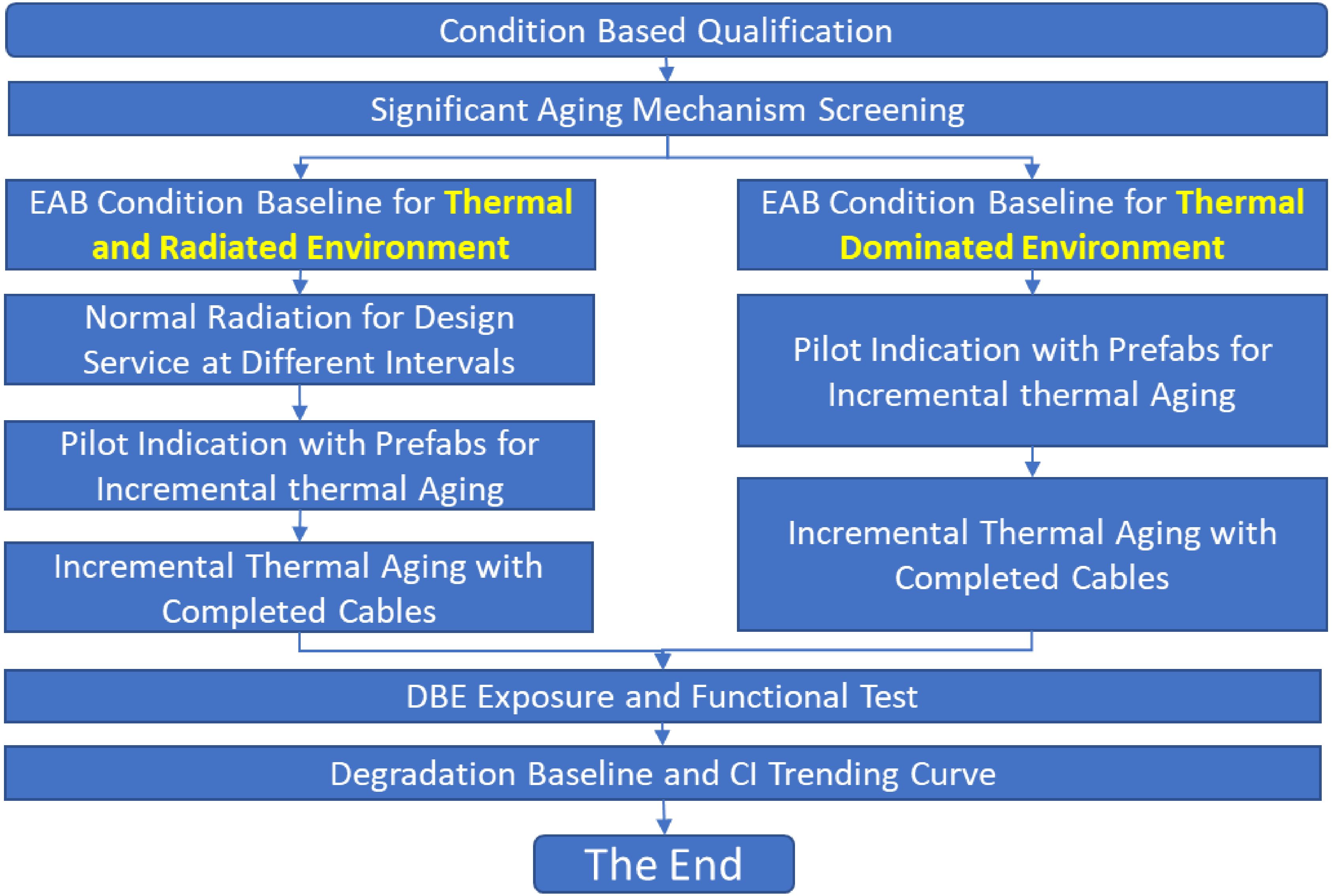
Qualified Condition

Background: SNERDI Condition-Based Qualification (CBQ)

A qualification and licensing program was conducted for in-containment Class 1E cables to be used for a new-build CAP 1400 nuclear power plants.

- **Manufacturer:** Bayi Cable , located in Jiangsu Province, China PR.
- **Cable Products:** Dual-layer construction with a XLPO insulation and Low smoke zero halogen flame retardant XLPO jacket.
- **Cable types evaluated:** Low-voltage power, control & instrumentation cables
- **Qualification Methods Used:** EQ and CBQ were developed in parallel per their regulator's licensing program by NNSA
- **Condition Indicator(CI) :** Elongation at break (EAB, ***<u>baseline</u>***), indenter modulus (IM), oxidation induction time (OIT), oxidation induction temperature (OITP).
- **Additional condition monitoring test evaluated:** Time-domain reflection technology (TDR), Fourier Transform Infrared Spectrometer(FTIR), Thermal gravimetric analysis (TGA).

Strategy and Methodology



Summary of Findings and Potential Follow-Up Study

Summary of Findings

- Use of unaged samples and aged samples required by IEEE 383 conservatively represent the most severe operating conditions in design
- EAB is monotonically related to the deterioration of insulating materials, and EAB is appropriate as Baseline Benchmark and determination of end of qualified life
- The cable jacket ages at a faster rate than the insulation, so degradation of the jacket can be used as a leading indicator initially
- Aged cable samples have been retained from the study to be used to identify future possible CIs
- Use the CMs that are either non-destructive (IM) or semi-destructive (i.e., jacket micro-samples like used for OIT/OITP, TGA) and compare actual condition of the cable to one or more CI to make a conservative judgment on status of the Qualified Condition (critical degradation point when replacement is necessary)

Follow-up Study Under Consideration

- Use retained samples and determine if the Low Voltage Cable Test Methodology (3002020818) can be used as a non-destructive CI

Final report 3002026361 is available at no charge

EPRI CBQ Brainstorming

CBQ Brainstorming

- EPRI held a meeting in January 2023 to brainstorm hoe to shift from qualified life to condition-based life for EQ components and the challenges to do so:
  - US industry demonstration case for first of a kind (FOAK)
  - Creation of a universally understandable CBQ framework implementation guide that for use in developing in standards, regulatory guidance, etc.
  - Challenges or resistance for industry implementation of a CBQ (e.g., testing difficulty, outage management challenges)
  - Need for CI data (test data measurements) for transition, accelerate CBQ implementation
  - Costs (we can list later)
  - Need to obtain cable samples for CI development (harvesting)
  - Regulatory involvement and endorsement to ensure certainty may reduce fear of licensee willingness to test regardless of the results

Present and "To Be State"

- **Reliance on TBQ, re-analysis and on-going qualification**
- **CBQ is permitted if the criteria of a CI are met.**

How do we establish use or improve our methods for CBQ

- **Reliance on TBQ for new cables with CBQ CI's established.**
- **Method for developing CI's for in-service cables and how to implement CBQ**

Where We Are Now for Cable CBQ

Major Issues

- Familiarity of how to do it CBQ to-date relies on destructive approaches (EAB) mostly and some use IM and electrical
- No established use global non-destructive methods for low voltage
- Establishing Acceptance Criteria for cables (in general or specific)
- License commitments restriction

Minor Issues

- Cable deposits or removal of section of installed cables is not regular practice everywhere
- Differences between EQ requirements for different licensees or Re-analysis no longer demonstrates qualified life or mitigate uncertainties

How We Get From Here to There

- Use CBM to supplement Qualified Life (DOR plants)

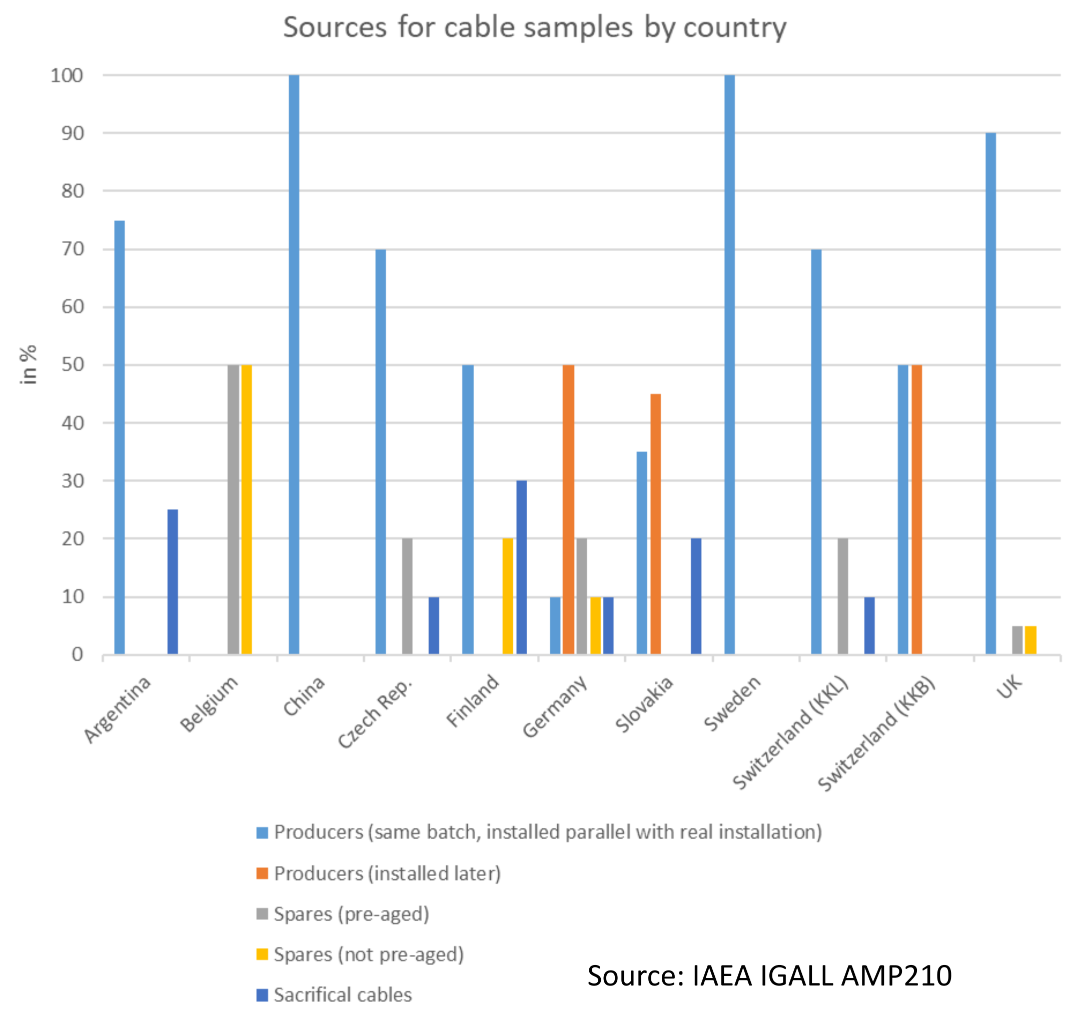
Where We Want to Be

- CI data available for cables
- Destructive and Non-destructive tests for CBQ and Methods for determining QLD acceptance criteria
- Option to limit replacement to degraded section rather than whole cable
- Correlation of CM to QLD
- CM can discriminate between global and local degradation and degree of degradation for each case
- Methodology for frequency of "next test" when near QLD
- Industry-wide acceptance of CBQ methodologies
- Access to industry data to validate CBQ
- Move to real time monitoring that is trendable
- Universal language for CBQ terms/concepts(e.g., trendable, monotonic, conservatism, margin)
- CBM method needs to address consistent, reliable data can be obtained throughout (e.g., software changes, equipment, etc. effect on CI) property being measured and applicability to the stressor affecting the cable

IAEA CBQ Efforts

IGALL AMP 210: CONDITION MONITORING OF ELECTRICAL AND I&C CABLES SUBJECT TO EQUIPMENT QUALIFICATION REQUIREMENTS

- Many are using cable deposits located in adverse environments to monitor aging
- The majority rely on elongation at break as their condition indicator (CI)
- Intervals range from 4.5 to 10 years
- Slovakia, Czech Republic, and Germany have performed aged type tested the samples to validate CI's



Source: IAEA IGALL AMP210

IAEA LMNPP Working Group 5

- IAEA held a side meeting at last year's International EQ meeting at UJV/REZ
- CBQ was selected as the initial subject to be addressed by the group
- A workshop for CBQ will be held in Vienna from June 3-5 to discuss CBQ approaches and value with IAEA member state regulators, EQ persons from the plants, and others
  - Case histories will be presented with regulatory positions if available on CBQ efforts by several member states
  - Goal will be to create a Technical Document or some other document to provide guidance on the value and methodology

Summary

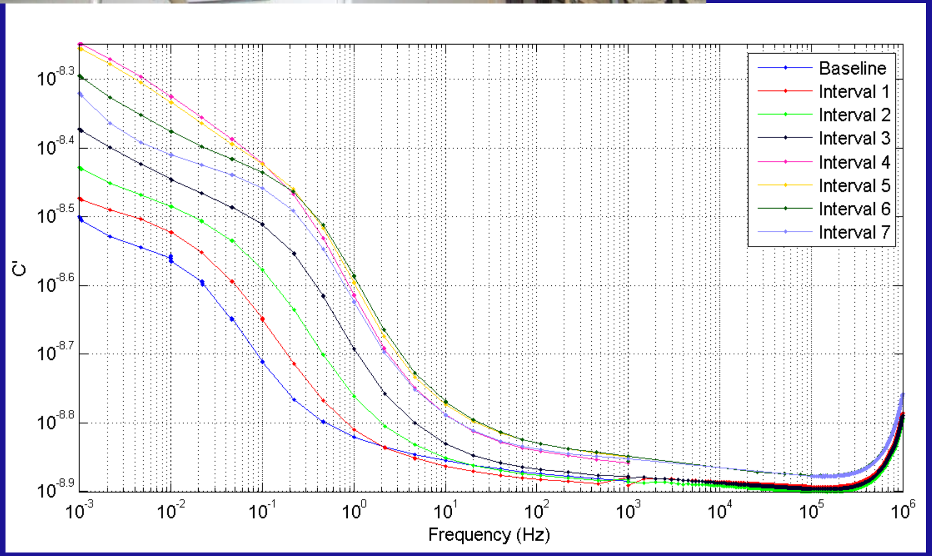
Summary and Next Steps

- There is an interest in implementing CBQ
- Several countries have implemented use of condition-monitoring to inform remaining life of EQ cables
- SNERDI has demonstrated a process to develop CI's during a qualification
- EPRI will research the use of low voltage test methods for condition-monitoring and where possible develop CI's
- EPRI will support the development of the IAEA Tech Doc on CBQ
- Communicate the research and technical document to
  - Socialize the effort
  - Obtain interested parties' input and involvement to initial steps(e.g., value statements, gap/barriers to CBQ)

Related EPRI Research Update

Future Low Voltage Methodology Focus

- More Pilot Trials, Europe and Elsewhere
  - 2024: Two European facilities participated.
  - 2025: South American trials planned.
  - We are looking for plants that would like to try this methodology, please contact me if interested.
- Phase 3 Study, focusing on improving applied techniques
- Condition-based Qualification (CBQ) Evaluation
- Scoping Study for Online Monitoring
- Machine Learning for Defect Localization

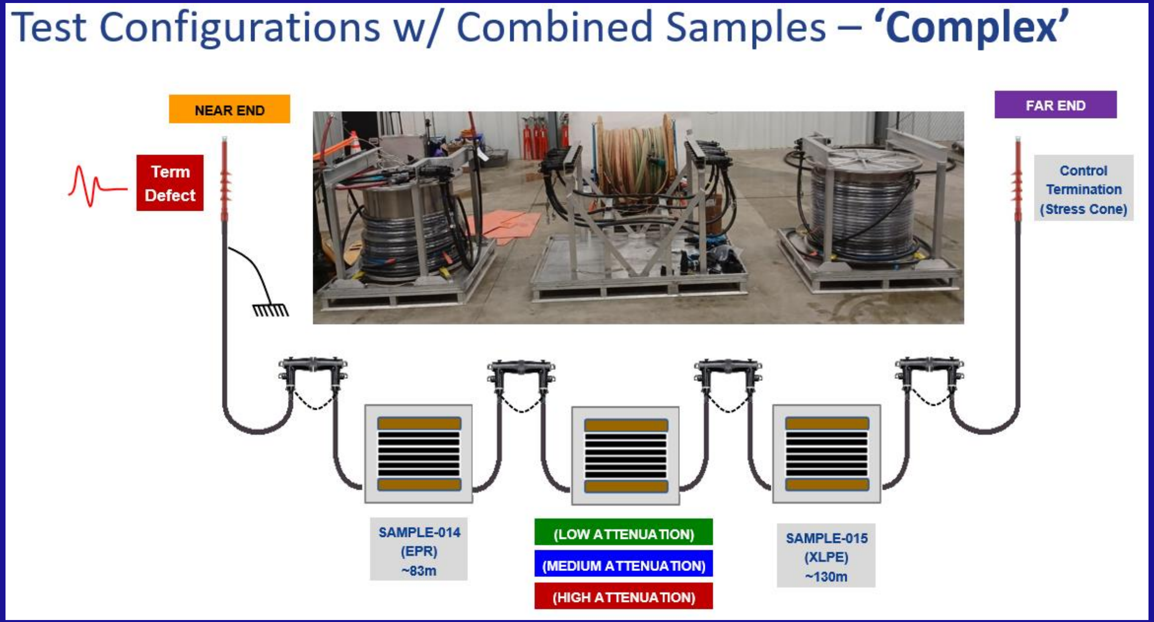


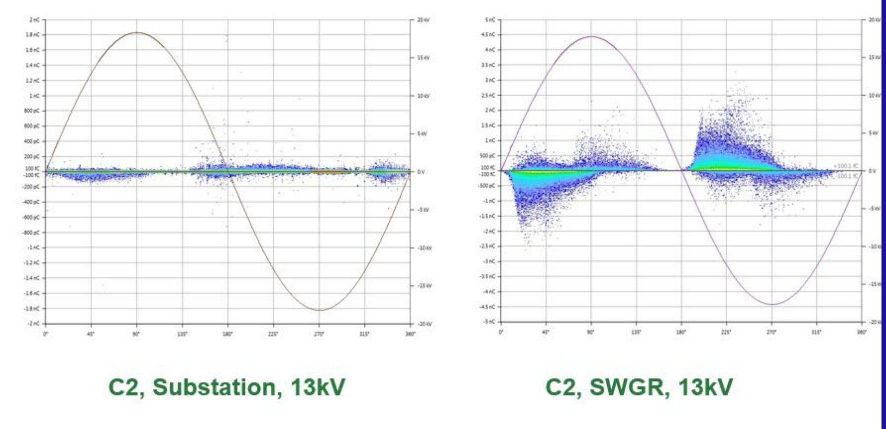
MV High Frequency Attenuation Study

- Aimed at understanding impact of shield attenuation on High Frequency (HF) measurement techniques such as Partial Discharge (PD) and Reflectometry (TDR, FDR).

- Goals of research include creating and field trialing mitigation strategies for highly attenuating cables.

- Combination of experimental simulation studies and field application.





Report: 3002029258

Study Outcomes

- Set of "Do's and Don'ts" for mitigating impacts of attenuation on cable systems

- **How can one characterize high frequency attenuation in NPP MV cables, using reflectometry-based methods, balancing accuracy and practical constraints?**
  - **DO** – Start with TDR (single-ended) for attenuation characterization but consider TDT (dual-ended) for higher accuracy where needed.
  - **DO** – Consider utilizing more accuracy signal injection methods (e.g., impedance streamliner) to increase accuracy of HF characterization
  - **DO** – Use open versus short testing of Far End to help clarify the Far End location
  - **KNOW** - Energy of a pulse (e.g., area under a curve) attenuates less than the actual peak value of the pulse (e.g., in mV)

- **Once PD is identified, how does one accurately determine where it is originating from in attenuating cables, while lowering the risk of False Positive (F+) locations?**
  - **DO** – Start with TDR based localization and localized probing as a starting point, if PD is detected.
  - **DO** - If TDR + localized probing is NOT successful, proceed with more advanced techniques including Time-of-Flight across intermediate points, or NE/FE
  - **DON'T** – Rely on a single localization technique on PD signal(s) (especially TDR) – significantly increases the risk of **F+** results and wasted time, $$
  - **KNOW** – Accurate PD identification and assessment are core objectives of a PD measurement, followed by localization (not the other way around!!!)

Beyond Tan Delta: Medium Voltage Applications of Low Voltage Test Methodology

- Include applications of Dielectric Spectroscopy, Pol/Depol, and other techniques.
- Intended to discriminate, localize, and assess issues in medium voltage cables.
- More information to decision makers to facilitate prioritization of intervention.
- Work began in 2024 and expected to take several years.

Questions

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