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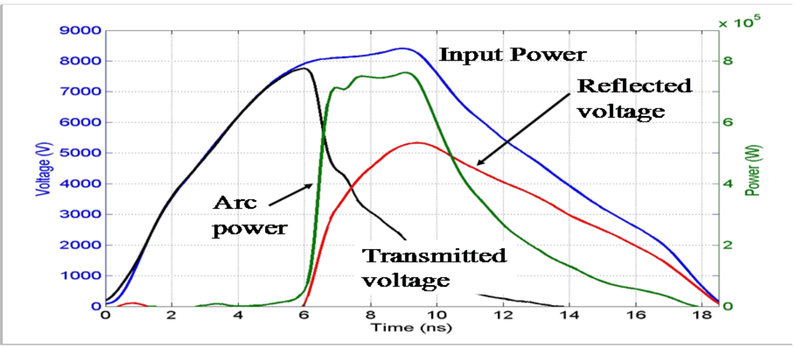

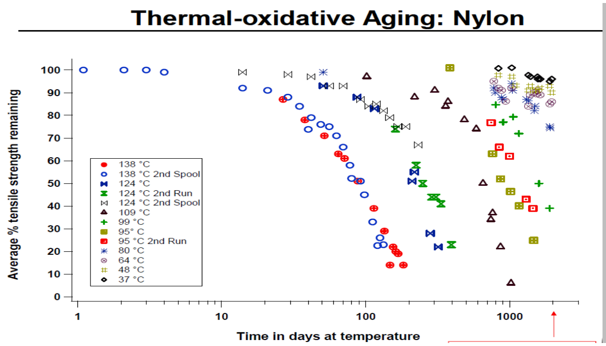

Research Recommendations Relevant to Aging Mechanisms and Condition Monitoring in 'Submerged' Medium Voltage Cable

Samuel Durbin, Robert Bernstein, Steve Glover, and Jason Neely

Joint LWRS-EPRI LTO Cable R&D Meeting

Albuquerque, NM

July 10th, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Many People Impacted this Project

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Materials Aging Lead

Jason Neely
Condition Monitoring Lead

- Darrell Murdock, NRC
- Fred Zutavern, Sandia Physicist
- Ken Williamson, Sandia Plasma Physicist
- Gary Pena, Sandia Pulsed Power Expert
- Fred Gelbard, Sandia Material Science

- Drew Mantey, EPRI
- Previous ICC meeting participants
- Corresponding authors
- Internal peer review committee

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Submerged Cable Research Roadmap

Primary Questions

1) What are the underlying causes/mechanisms of submerged cable failures?

2) Based on the understanding of the underlying causes/mechanisms, how can submerged cables be forced to undergo accelerated aging, repeatedly?

3) Using artificially aged cable samples at various stages of "lifetime," what condition monitoring (CM) techniques could be developed to measure insulation integrity?

4) How can "remaining useful lifetime" (RUL) models be developed from accelerated aging cable samples?

5) How can field aged cables be used to validate both the CM techniques and the RUL models?

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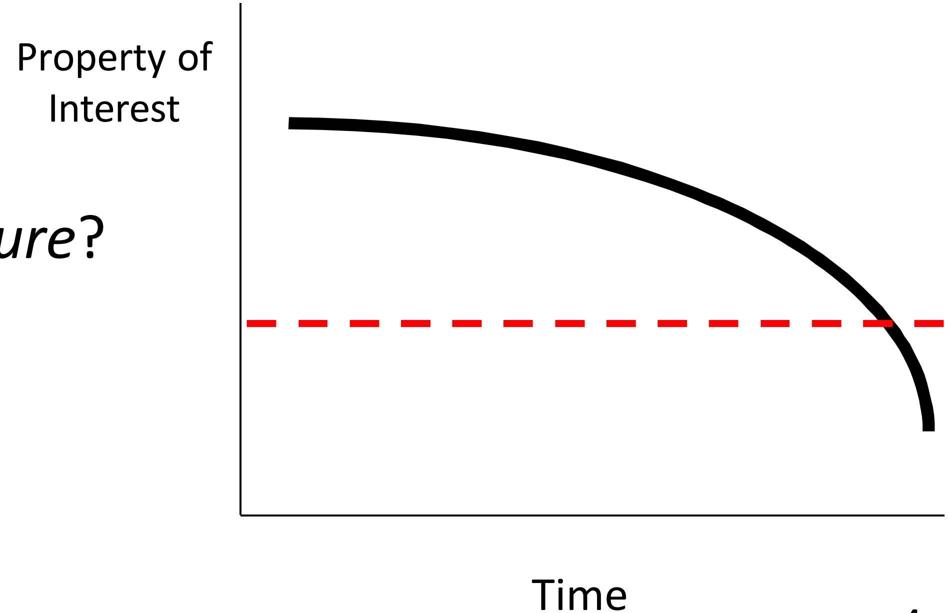
Goals of a Material Aging Program

Objective: Provide a technical basis to predict performance as a function of time

Usually multi-year programs modeled after previous programs resulting in material performance predictions validated with field returned samples



- What is the performance *measure*?
- What is the performance *limit*?
- Basis for "Lifetime" predictions

Phased Technological Approach

- Phase 1 – Literature Review (~Complete)
  - Identified current status of research and path forward
  - Fundamental studies needed to systematically understand variables/stressors
- Phase 2 –Plaque Testing and CM Diagnostic Development
  - Build prototype apparatus
  - Examine Stressors
    - Study role of molecular dioxygen versus water (isotopic studies)
    - Temperature/pressure studies (?)
  - Develop CM diagnostics to measure the presence of water trees and bulk degradation
- Phase 3 – Accelerated Aging Protocol Development
  - Transform from plaque to cable sample testing
  - Develop new accelerated aging protocol
  - Produce cable samples aged to various stages of "life" for CM evaluation
- Phase 4 – Remaining Useful Lifetime (RUL) Model Development and Validation
  - Validate initial Phase 3 data with field-returned samples
  - Complete comprehensive, empirical database to fully inform RUL models

Nuclear Reactor Reliability is Impacted by Submerged Cable Performance and Lifetime

- Project consisted of a technology review
  - Numerous experts were engaged
  - Hundreds of technical documents reviewed including journal articles, EPRI reports, academia, among others
- Community has been working the problems
- However, advances are needed in quantitative approaches to
  - Accelerating cable aging
    - Consistent with field aging
    - Clear understanding of stressors that cause aging
    - Clear understanding of aging mechanisms
  - Measurement of cable aging markers and relating to the cable age
  - Defining End of Life (EOL)
  - Defining Remaining Useful Life (RUL)

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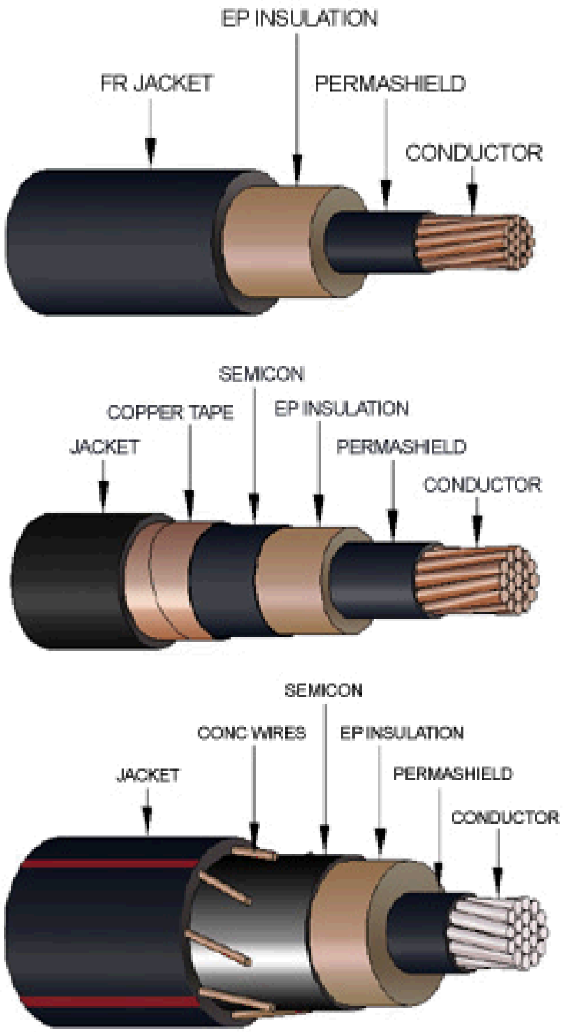
Cables Considered

- This study included shielded and unshielded submerged medium voltage cable with extruded insulation
  - EPR (e.g., black, pink, brown, old, new)
  - XLPE
- Most cables at nuclear power plants are shielded (~80%)
- All medium voltage (MV) cable (5 kV – 35 kV) in nuclear power plants is jacketed [1]
- Majority of cable shields are made with copper tape shield [1]



[Used by permission from Kerite]

[1] **3002000557, "**Plant Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants (Revision 1)," EPRI, Palo Alto, CA, June 2013.

Key Stressors Have Been Suggested

- Water:
  - Submerged or wet; solubility key issue?
  - Water line (triple point) issues
  - Clearly 'older' steam cured method and 'cleanliness' impacted performance
- Soluble Ions:
  - Ions clearly a major influence
  - Exact role not clear; but have a significant role
  - Always present
- Electrical Parameters:
  - Magnitude (electric field)
  - Rate of change / frequency
  - Transients / spikes

Additional Notable Areas for Consideration

- Voids:
  - Voids known to be in insulation
  - Void growth could be condition monitoring parameter
  - Not practical for field, but for laboratory?
- Defects:
  - Manufacturing processes
  - Installation
- Physical Stress:
  - Aging under ‘stress’ a potential degradation acceleration; path forward not clear
- ‘Pressure’ Aging:
  - High water pressure experiments performed
    - Data suggests high pressure collapses voids
    - Low Pressure may expand voids
  - Oxygen pressure?
- Temperature
  - High temperature

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Material Science: Suggested R&D Focus

- Accelerated Aging
  - Accelerated aging protocols useful for ‘lifetime’ predictions
  - ACLT and AWTT useful for comparison but not predictions, new method needed
- Mechanistic Understanding
  - Extensive studies, lack of fundamental understanding of degradation mechanisms
  - Mechanism(s) not understood; little insight into aging methodologies
  - Lack of understanding of parameters that ‘drive’ degradation
    - Magnitudes
    - Synergism
  - Mechanistic understanding needed to help acceleration (very complex)
  - Systematic and controlled environments over extended timeframes
- Definition
  - ‘End of life’ need definition incorporating remaining useful life
- Detection
  - Enhanced ability to detect and quantify (number, size) of water trees, voids, or defects
  - Rapidly, non-destructive and over large lengths of cable

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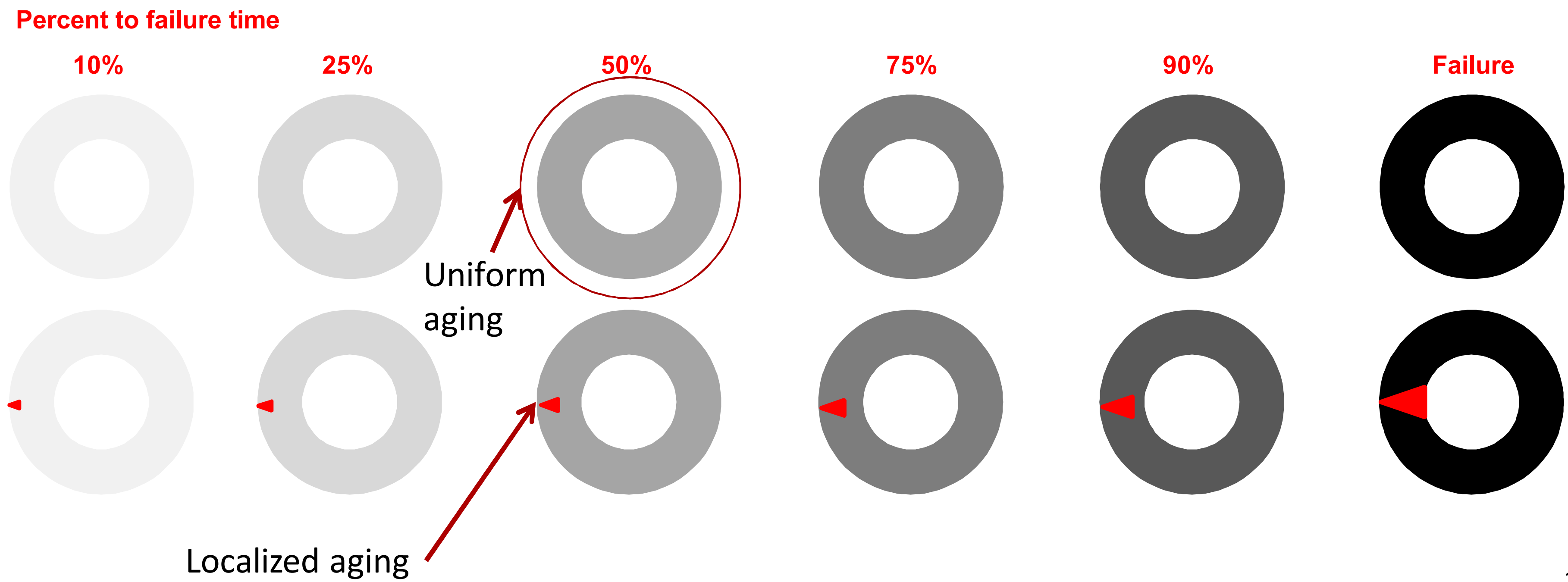
Stressors that can Impact Dielectric Aging

Number	Stressor	Source
1	Moisture	From humidity, ground water, or rain
2	Oxygen	From air, from water
3	Ions	Many sources
4	Triple points	Manufacturing defect, cable degradation, water interface
5	Electric field impulse	Lightning, line transients
6	Mechanical stress	Installation, manufacturing defect, degrading mechanical support
7	High electric field	Manufacturing defect, installation, cable degradation
8	Temperature	Enclosures, sources, loads
9	Oscillating electric field	Power system
10	High gradient electric field	Lightning, fault, switching equipment

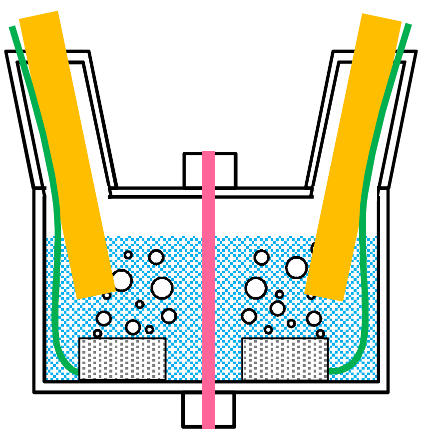
Incremental Laboratory Aging Would Impact Material Science and Condition Monitoring

- Better understand the ‘linearity’ (?) of the aging process
- Better understand the impact of combined stressors on aging
- Provide materials for condition monitoring sensitivity analysis
- Provide a data base for the end of life definition
- Provide a data base for the remaining useful life analysis

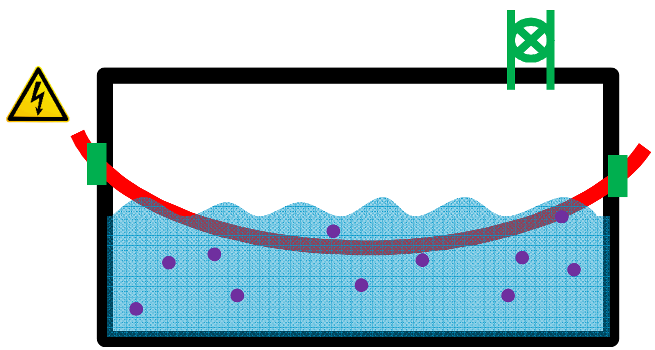


Various Testing Vessels

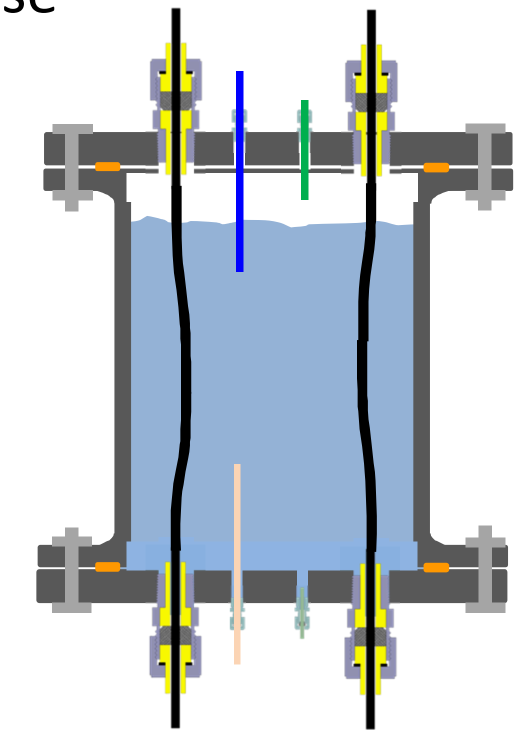
- Conceptually easy, technically challenging
  - Multi-disciplinary design required
- Each vessel represents different testing phase
  - Provide reinforcing, confirmatory research with separate effects testing



Plaque Testing



Unpressurized Cable Testing

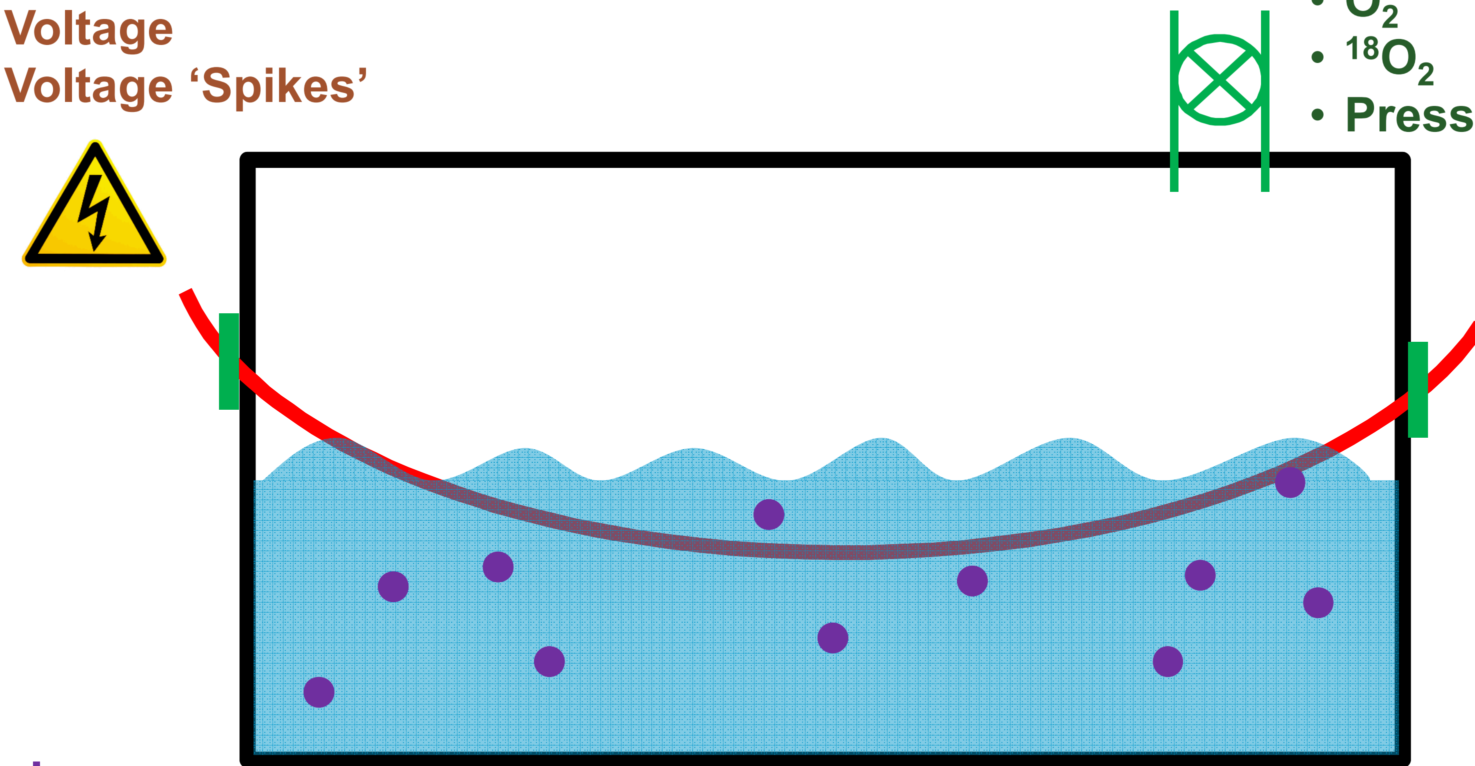


Pressurized Cable Testing

Laboratory Aging with Independent Stressors is Critical but Insufficient

Electrical
- Frequency
- Voltage
- Voltage 'Spikes'

Atmosphere
- Argon
- O_2
- $^{18}O_2$
- Pressure



Ions
- Concentration
- Type

Water
- Temperature
- Submerged vs RH

Similarities with other Degradation Studies

- Data reveals that carboxylate ions, trace of ketones and esters, and sulfate ions were all present within or near the surface of the water trees
- Oxidative products appear (by spectroscopy) to be similar to those from other degradation pathways
  - Thermal-oxidative, photochemical, gamma-irradiation
- Analytical Differences Laboratory vs. Field Aging
- Any theory needs field aged validation/verification

Patsch, R. *IEEE Conference on Solid Dielectrics,* Water Treeing in Cable Insulation -Are Laboratory Tests Meaningful? **1988**, 242-245.
Xu, J. J.; Boggs, S. A. *IEEE Electrical Insulation Magazine,* THE CHEMICAL NATURE OF WATER TREEING - THEORIES AND EVIDENCE **1994**, *10*, 29-37.

Isotopic Labeling can Provide Insight into Oxidation Based Aging

- First step: understand the source of 'oxidation'
  - Is it oxygen (O_2) or water (H_2O)? Is there a synergism?
  - Are they interconnected? What is relationship?
- Utilizing isotopic labeling, coupled with analytic studies can answer this question
- Oxygen 16 (normal) vs Oxygen 18 (heavier, non-radioactive isotope)

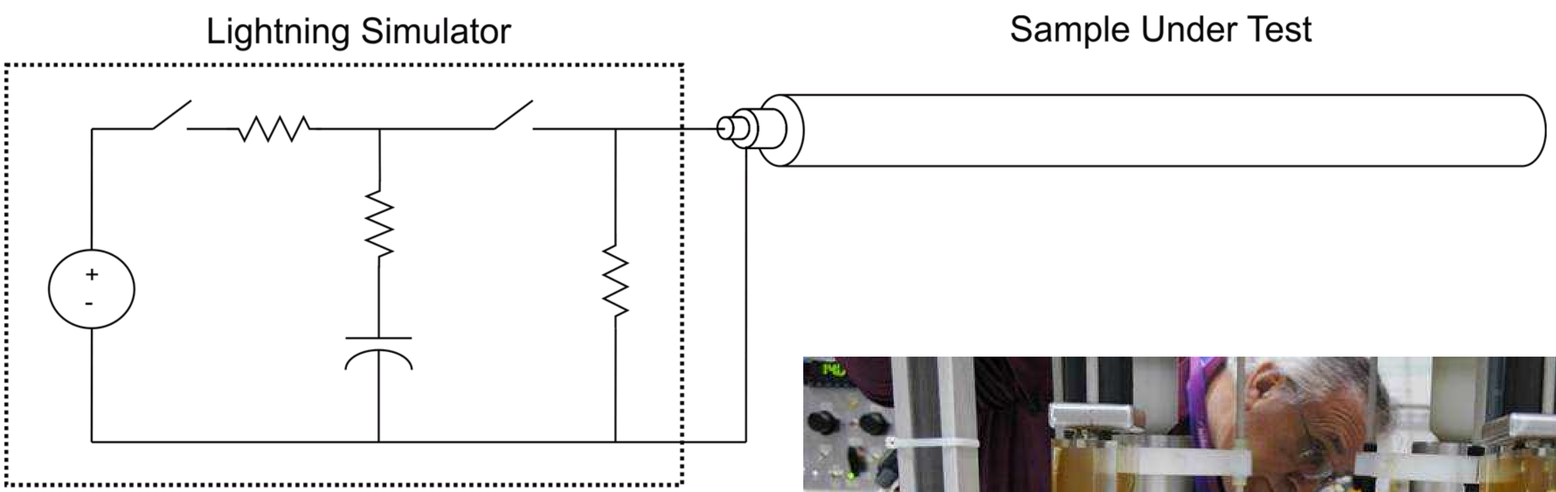
H_2O vs $H_2{}^{18}O$

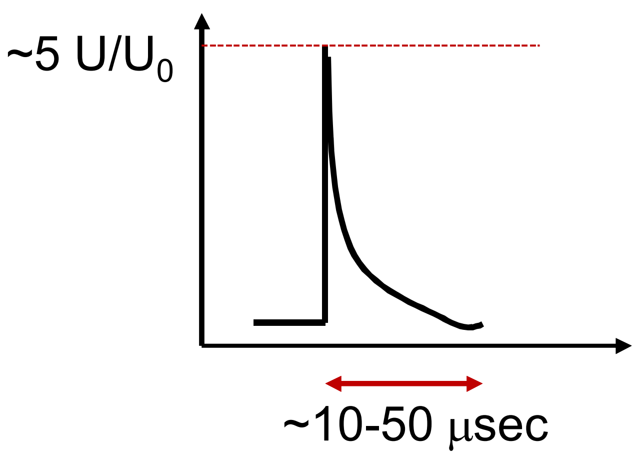
O_2 vs ${}^{18}O_2$

Argon

Many of the Stressors Can Be Created in the Laboratory

- Simulated lightning transients may be applied with varying frequency





200 kV dielectric test fixture

In Summary: The Complexity of the Problem Spans Material, Electrical, and Reliability Sciences

- Significant amounts of research has been conducted to address cable aging and its complexities
- Identification of a consistent End-of-Life (EOL) criteria is needed
- Advances in accelerated aging need to:
  - Link stressors to aging mechanisms
  - Enable accelerated aging that is consistent with field aging
  - Enable diagnostic and lifetime analysis development
- Advances in condition monitoring require:
  - Identification of the most sensitive markers that correlate to EOL
  - Selection of diagnostics that are sensitive to aging markers
  - Develop analysis techniques that predict remaining useful life with confidence/uncertainty measures

Submerged Cable Research Roadmap

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QUESTIONS AND DISCUSSION

SUPPLEMENTAL SLIDES

Candidate Aging Test Matrix

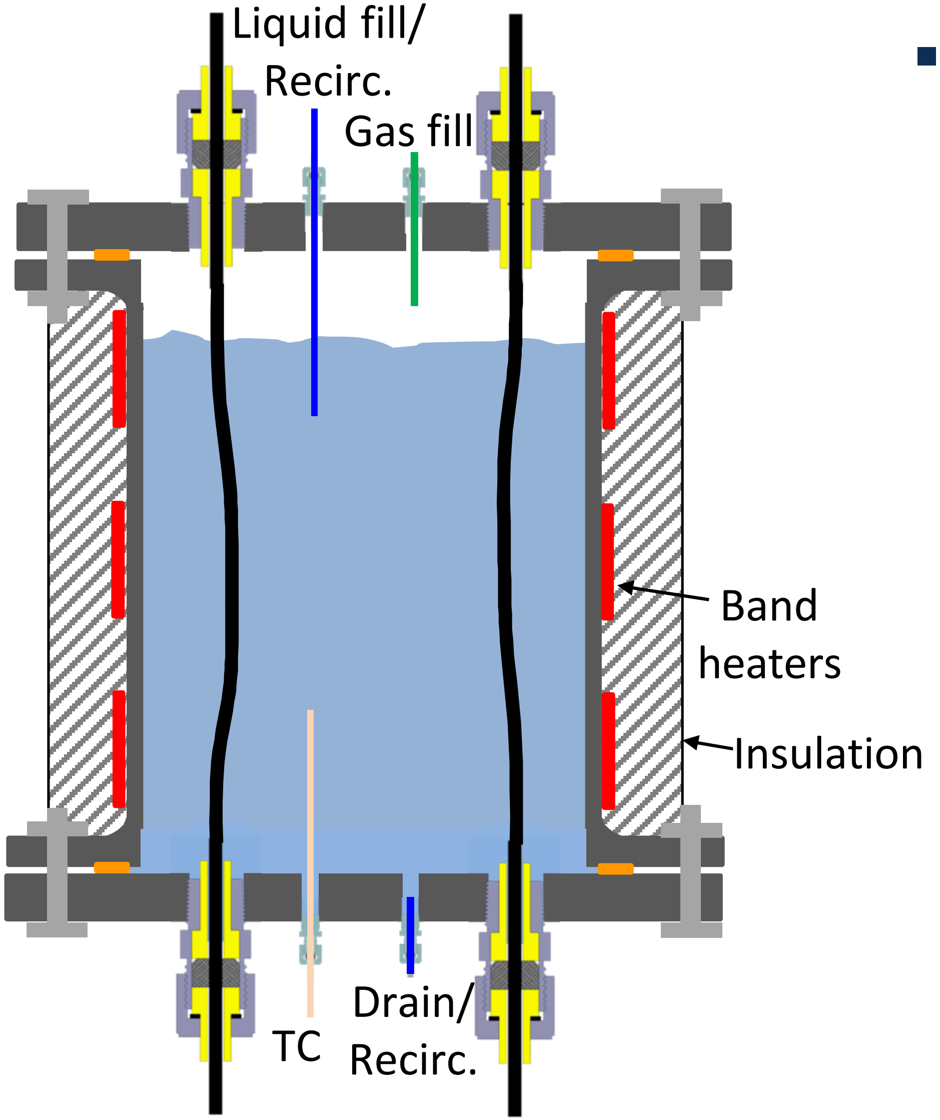
Controls | Single Variate | Multi-Variat

	Stressor								
1	Moisture		X	X	X	X	X	X	X
2	Air (oxygen)	X	X	X	X	X	X	X	X
3	Elevated Temperature			X	X	X	X	X	X
4	Elevated Voltage (E-field)			X	X	X	X	X	X
5	Ions				X				
6	Mechanical stress (tight coil)					X			
7	High electric field (unshielded)						X		
8	Triple Points							X	
9	Electric field impulse (Lightning)								X

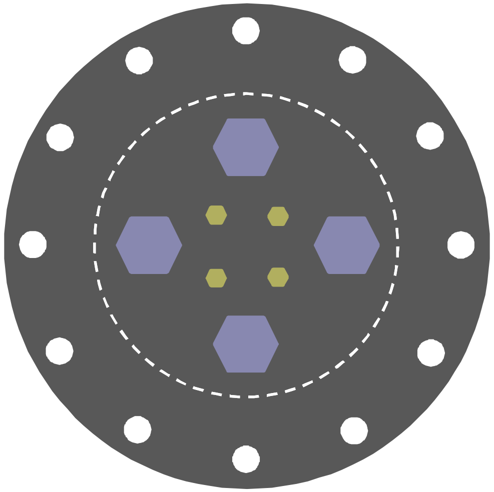
Eliminating the Gaps Will Require Continued Research

- Bench top accelerated aging and analysis to answer questions surrounding stressors and aging mechanisms
  - Different stressors are expected to excite different aging mechanisms (ex. low versus high frequency)
  - Link a chemical and physical explanation to aging mechanisms
- Accelerated aging experiments designed to establish consistency between field and laboratory aged cables.
- Identification of critical aging markers that have measurable characteristics
- Accelerated aging capabilities that enable a specified percentage of aging for diagnostic development
- Experimental validation of the Lifetime definition

Conceptual Pressurized Test Vessel



- Accelerated aging vessel
  - Capable of much higher temperatures and pressures
    - MAWP > 10 atm @ 150 ° C
  - Monel 400 construction
    - NPS Sch. 40 with Class 150 flanges
    - Corrosion resistant
    - COTS Monel fittings



In Summary There Are Many Variables That Require More Fundamental Understanding

- A community accepted performance measure must be identified to aid in end-of-life definition
  - EOL measure(s) must be consistent with performance and risk analysis
- A path forward should include:
  - Bench top and laboratory accelerated aging analysis
  - Down selection of condition monitoring techniques for RUL analysis

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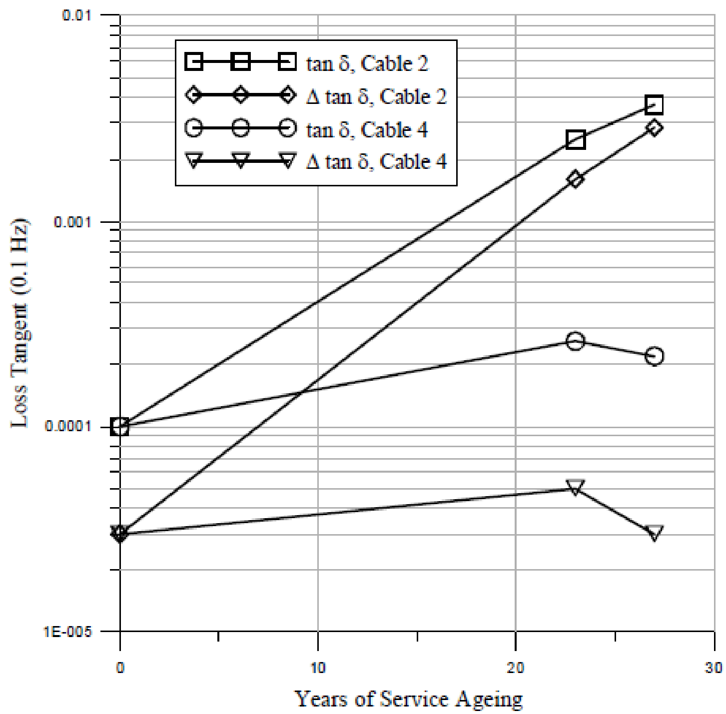
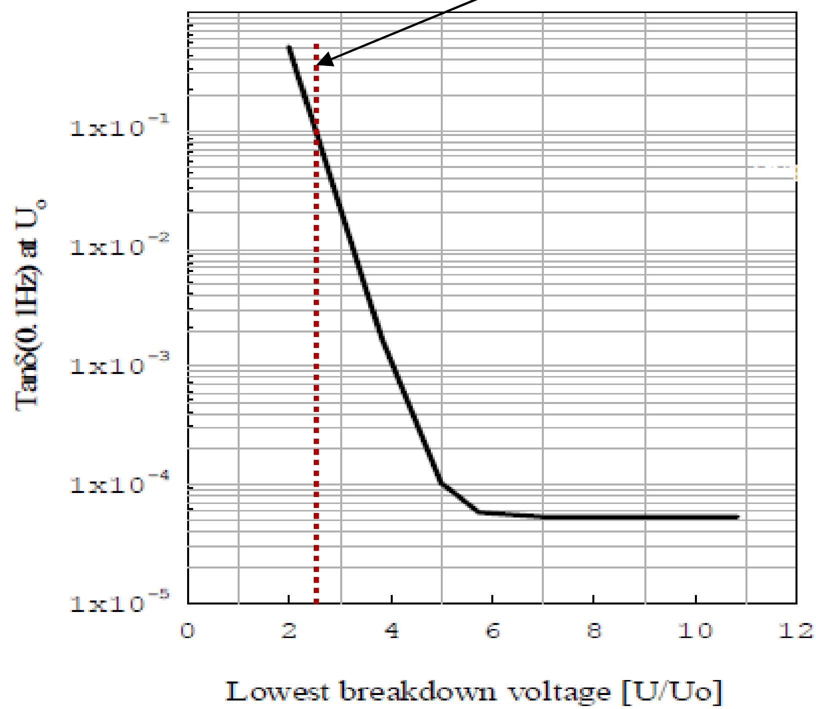
Lifetime Prediction from Condition Monitoring Results

- Sequential measurements have been used to predict useful life: example is VLF Tan δ
  - Therein, prediction error is unknown



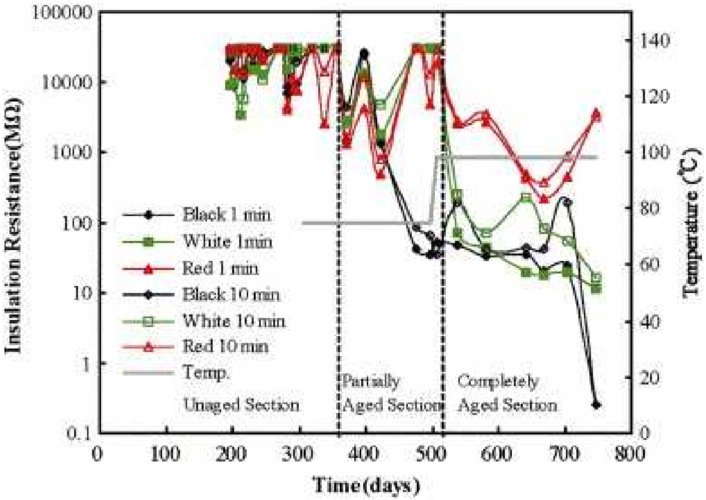
Criteria: $\frac{U}{U_0} \le 2.5$



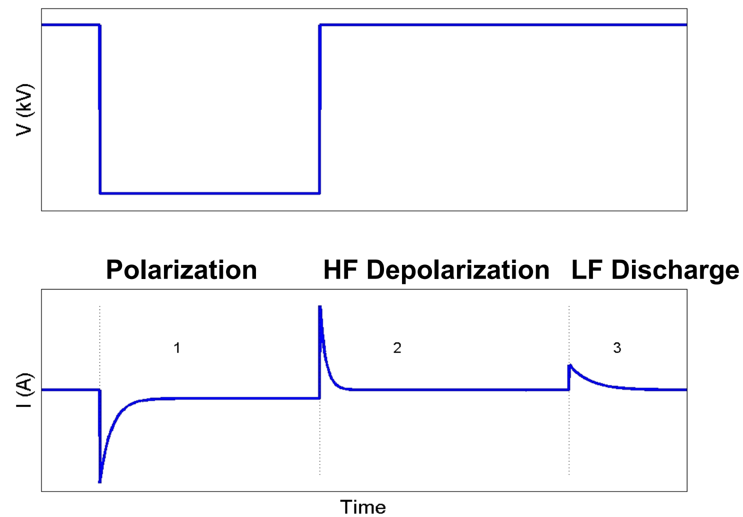
Werelius, P.; Tharning, P.; Eriksson, R.; Homgren, B.; Gafvert, U., "Dielectric Spectroscopy for Diagnosis of Water Tree Deterioration in XLPE Cables," *IEEE Trans. on Dielectrics and Electrical insulation,* Vol. I, No. 1, pp. 27-42, Feb. 2007.

CM Methods for Bulk Aging Assessment

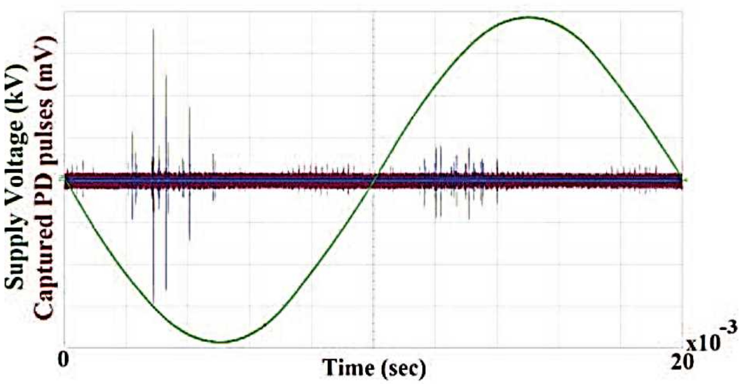
DC Insulation Resistance



Polarization/Depolarization Current



Partial Discharge

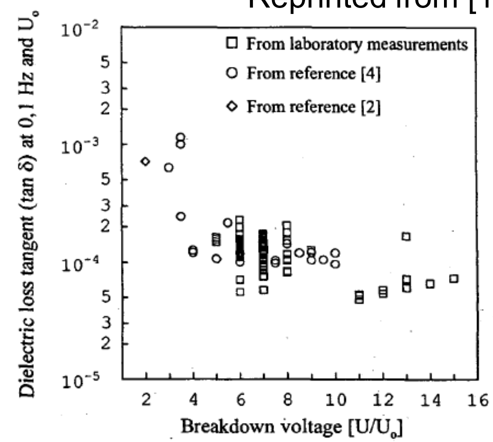


Dissipation Factor Tests

Reprinted from [1]

$$\varepsilon = \varepsilon' - j\varepsilon''$$

$$\tan\delta = \frac{\omega\varepsilon'' + \sigma}{\omega\varepsilon'}$$



[1] Hvidsten, S.; Benjaminsen, J.T., "Diagnostic testing of MV XLPE cables with low density of water trees," *Electrical Insulation, 2002. Conference Record of the 2002 IEEE International Symposium on,* pp.108-111, 7-10 Apr 2002.

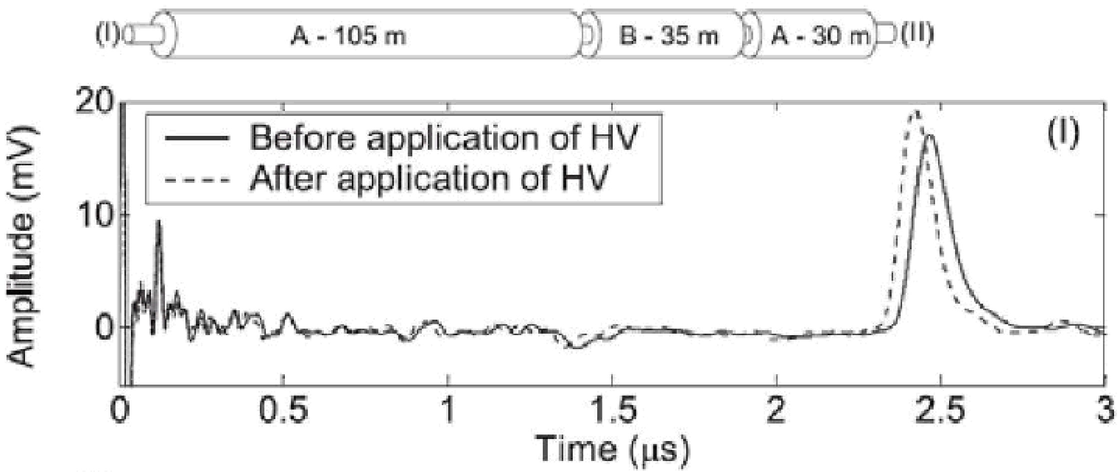
CM Methods for Local Degradation Detection

- Differential TDR
  - New method demonstrated with XLPE
  - Needs to be evaluated with EPR
- Pulse Arrested Spark Discharge (PASD) TDR
  - Commercial method used on aircraft LV wire (shielded and unshielded)
  - Needs to be evaluated on MV cable
- LIRA
  - Demonstrated for LV cables with thermal/mechanical damage, shielded and unshielded
  - Demonstrated for detecting water tree degradation in XLPE cable
  - Needs to be evaluated for EPR
- Flash Thermography
  - Commercial method for detecting water degradation of composites
  - May be used to quantify water ingress in MV cable jackets

Differential TDR Methods

- Recent research has established that high-frequency permittivity of water-tree degraded XLPE cable may be altered with application of high-voltage [1-2]
- A *Differential TDR* method has been developed that "… compare[s] the propagation properties for different applied voltages on the cable."
- Modeling and simulation efforts have begun to study water tree degraded cable
- High bandwidth and improved sensitivity

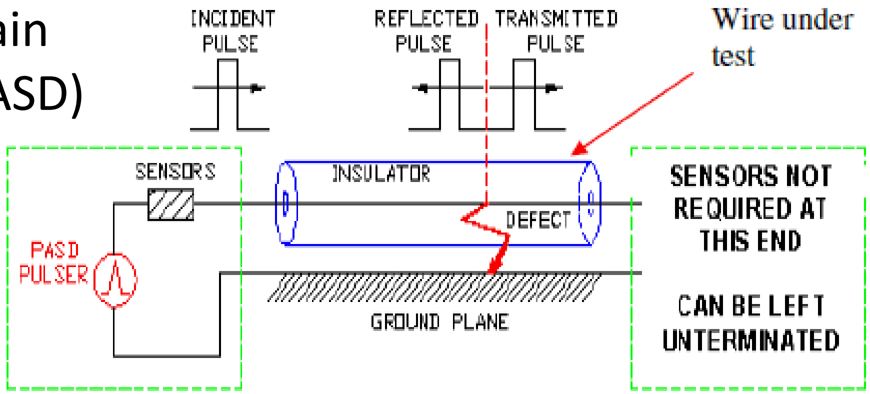
Reprinted from [2]



[1] Papazyan, R.; Eriksson, R.; "High Frequency Characterization of Water-treed XLPE Cables," *Proceedings of the 7th*"; *International Conference on Properties and Applications of Dielectric Materials,* Nagoya, June 2003.
[2] Eriksson, R.; Papazyan, R.; Mugala, G., "Localization of Insulation Degradation in Medium Voltage Distribution Cables," *Industrial and Information Systems, First International Conference on Industrial and Information Systems*, pp.167-172, Aug. 2006.

Pulse Arrested Spark Discharge TDR Method

- Recently developed high voltage time domain scheme: Pulse Arrested Spark Discharge (PASD)
  - Low voltage (100 V) then high voltage pulses (1-15 kV) are launched down cable
  - Electrical breakdown results in impedance discontinuity
  - High Bandwidth, Improved sensitivity, addresses attenuation issues
  - High power (kW), but low energy (mJ)



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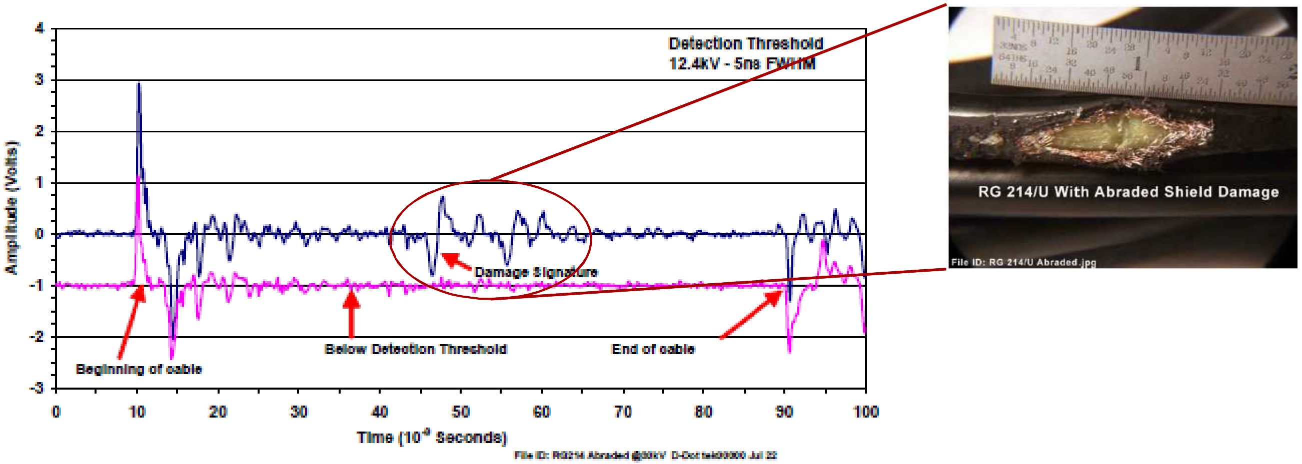
Mechanical damage



[1] **SANDIA REPORT SAND2005-2638,** “Final Report on Development of Pulse Arrested Spark Discharge (PASD) for Aging Aircraft Wiring Application,” R. Kevin Howard, Steven F. Glover, Gary E. Pena, Matthew B. Higgins, Larry X. Schneider and Thomas R. Lockner, September 2006.

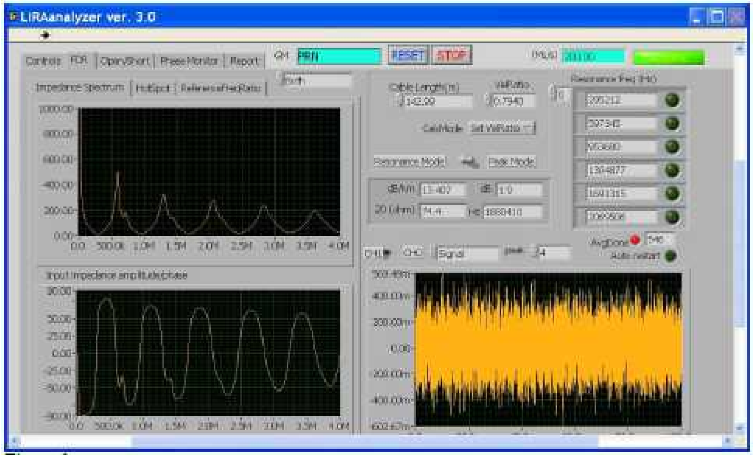
Line Resonance Analysis (LIRA)

Reprinted from [1]

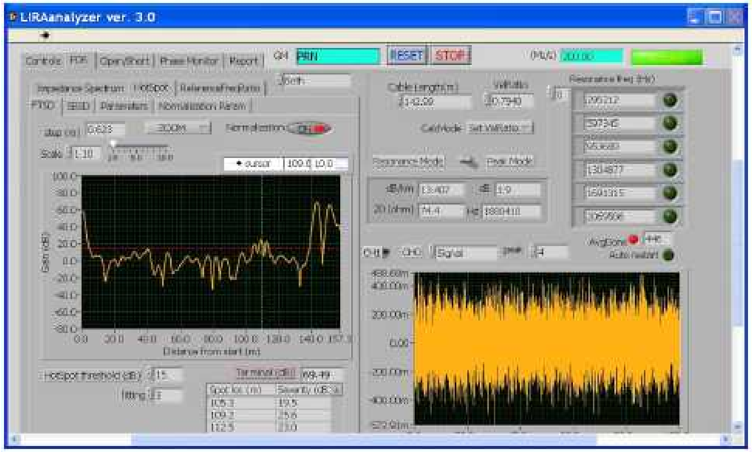
- Proprietary method that evaluates line impedance spectrum from noise measurements [1-2]
- Originally indicated/demonstrated for detecting gross mechanical damage, thermal and radiation degradation of low voltage cables [1-2]
- Demonstrated in laboratory and in situ
- Reported detection of water tree degradation in 5kV XLPE submerged cable [3]

$$|F(\omega)|$$

$$\angle F(\omega)$$



$$|f(d)|$$



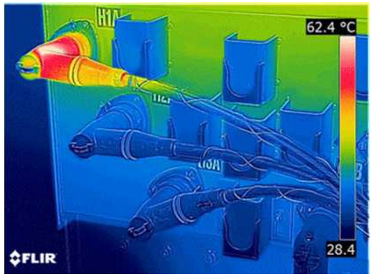
[1] **NKS-157,** “Wire System Aging Assessment and Condition Monitoring (WASCO)”; Paolo F. Fantoni, Nordic nuclear safety research, ISBN 978-87-7893-221-1; 2007.

[2] **1015209,** “Plant Support Engineering: Line Impedance Resonance Analysis for the Detection of Cable Damage and Degradation,” EPRI, Palo Alto, CA, 2007.

[3] Fantoni,P.;Juvik,J.I.;”Condition Monitoring of Electrical Cables using Line Resonance Analysis (LIRA)”; Insulated Power Cales, 8th International Conference on; JiCable; Versailles, France; 2008.

Example of Speculative CM - Infrared Thermography

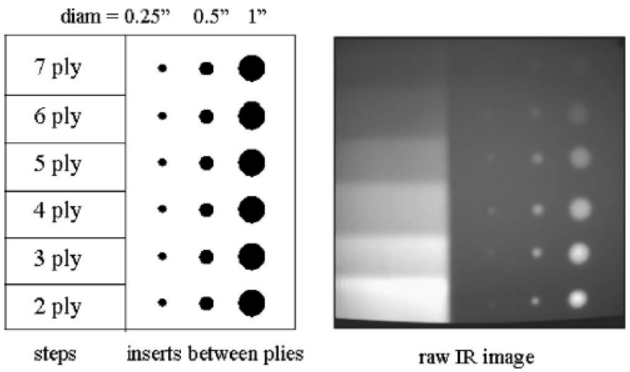
- Classical IR Thermography
  - Anomalous heating may indicate damage
  - Typically requires line-of-site or view port
  - Advanced image processing may resolve thermogram through walls
- Flash Infrared Thermography/Videography
  - Test surface is heated with a flash lamp
  - Asymmetrical cooling reveals subsurface defects



Thermal imaging being used to identify a potentially faulty connection. [Flir.com]

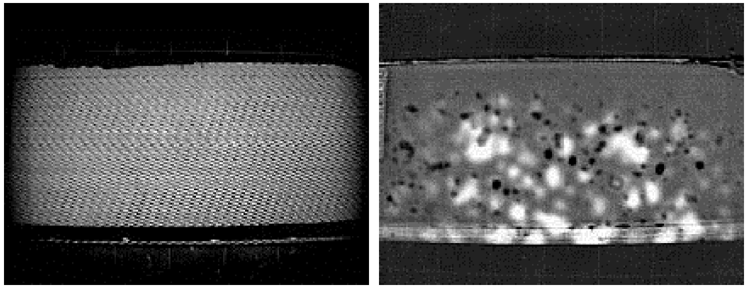
Thermal imaging of a cable fault inside a concrete structure [1]

Graphite epoxy sample [2]



Carbon epoxy composite

Thermal Image   Thermal Image after flash



[Courtesy of Thermal Wave Imaging ThermaLogix.com]

[1] M. S. Jadin, S. Taib, S. Kabir;"Infrared Thermography for Assessing and Monitoring Electrical Components within Concrete Structures," *Progress in Electromagnetics Research Symposium (PIERS), Proceedings of the,* Marrakesh, Morocco, March 2011.

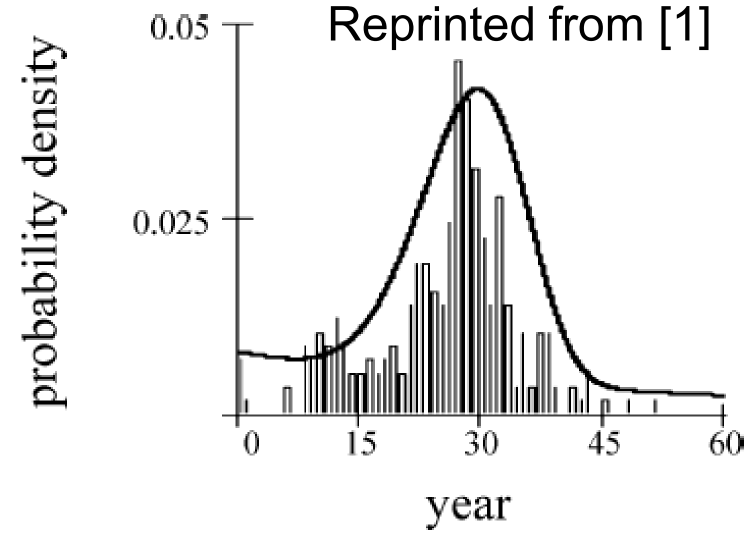
[2] S. Shepard, J. Hou, J. Lhota, J. Golden; "Automated Processing of Thermographic Derivatives for Quality Assurance," *Optical Engineering*, Vol 45, No 5, May 2007.

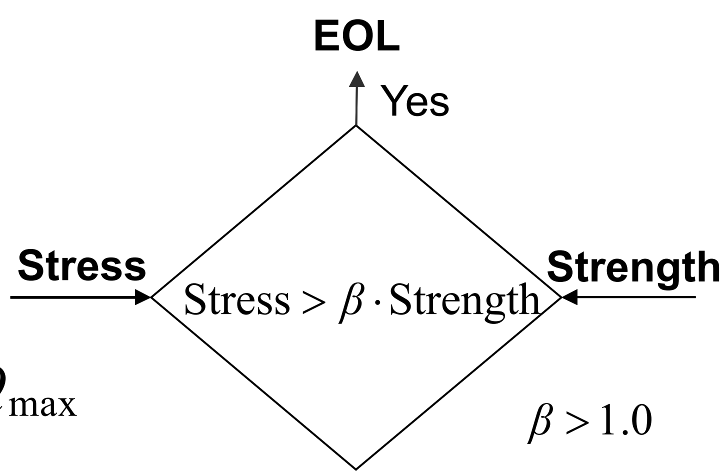
Condition Monitoring as an Assessment of *Reliability*

- What is the probability of failure?

$$P(\text{Failure} \mid \text{some time period}) < P_{\min}$$

- Failure vs *End-of-Life*
- *Remaining Useful Life* (RUL) defined as the time before the cable has reached *End-of-Life* (EOL)
  - Cable condition may be quantified by considering its likelihood to reach *End-of-Life* within a specified time [2]



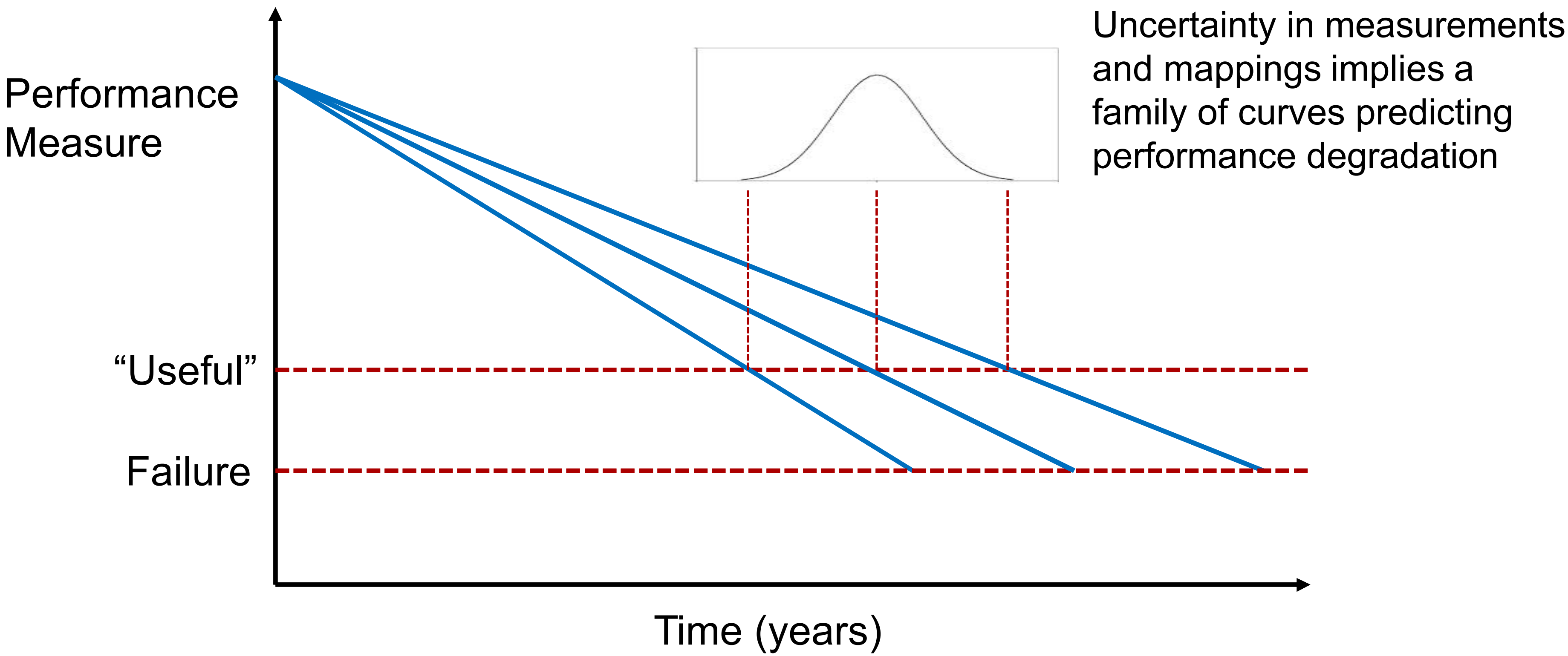


$$E(RUL(t_k)) \leq RUL_{\min} \quad \text{or} \quad P(RUL(t_k) < T_{\min}) > Q_{\max}$$

[1] Zhang, X.; Gockenbach, E., "Assessment of the actual condition of the electrical components in medium-voltage networks," *Reliability, IEEE Transactions on*, vol.55, no.2, pp.361-368, June 2006.
[2] K. Le Son, M. Fouladirad, and A. Barros. "Prognostic maintenance policy based on remaining useful life estimation," *ESREL (European Safety and Reliability Conference) PSAM11,* p.10, Helsinki, 25 June 2012.

Remaining Useful Life (RUL) Estimation

- By trending the results of condition monitoring methods while considering the error



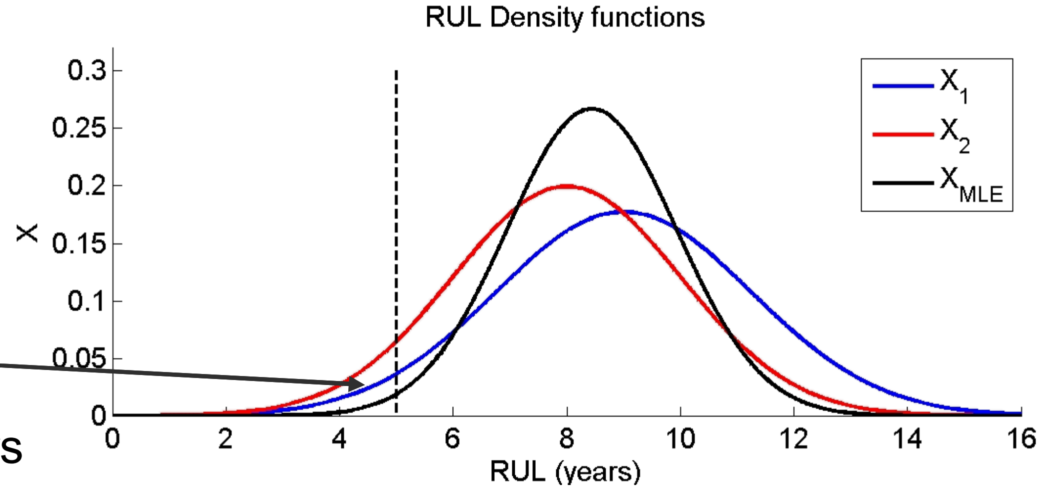
Remaining Useful Life (RUL) Estimation

- Field of *Reliability Engineering* deals with the prediction and prevention of system failures
- Maximum Likelihood Estimation (MLE) of remaining useful life gives a quantifiable measure of reliability
  - Combine Life Models and trendable tests to improve RUL estimate
  - Established test results need to be mapped to RUL estimates
  - Using Lifetime models, the effect of mitigation strategies may be assessed

$$X_{MLE} = \hat{\sigma}^2 \left(\frac{X_1}{\sigma_1^2} + \frac{X_2}{\sigma_2^2} \right)$$

$$P\big(RUL(t_k) < 5\text{yrs}\big) > Q_{\max}$$

Area under the curve for $T_{\min}$ = 5 years



In Summary

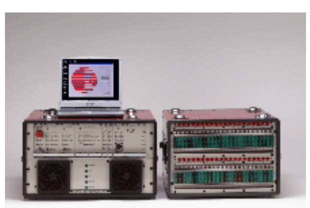
- R&D Path Forward
  - Chemical reaction processes associated with degradation are largely unknown
    - Isotopic Labeling will be utilized to explore organic degradation chemistry
  - Quantitative comparisons between laboratory and field aged samples are needed
    - A candidate test matrix is in development to explore stressors and stress synergisms
  - Improved Condition Monitoring schemes for identifying local degradation
    - Four candidate methods have been identified for investigation
  - Quantitative estimates of cable life are lacking
    - Community-accepted definition for End of Life (EOL)
    - Incorporation of Reliability Metrics into bulk CM methods (test matrix)

Examples of Aging Mechanisms Linked to Detectable Markers

Number	Category of Degradation	Marker	Test(s)
1	Thermo-oxidative aging jacket	Material hardening	Indenter test
	Thermo-oxidative aging dielectric	Low frequency dielectric loss	Dissipative methods
	Thermo-oxidative aging dielectric	Changes in capacitance	LIRA
	Thermo-oxidative aging dielectric	PD activity in response to voltage application	Partial Discharge
2	Mechanical Damage	Crack, break in dielectric	Resistance, TDR, PASD
3	Water tree growth	Low frequency Dielectric loss	Dissipative methods
		High frequency dielectric loss	DTDR, PASD
		Increased conduction currents	Resistance, VLF tan δ
4	Corrosion	Increased resistive loss (heat)	Infrared emission (IRT)

Wiring Test Bed Will Be Necessary to Evaluate CM Methods 'Side by Side'

Example wiring test bed developed for the evaluation of wiring diagnostics for commercial aircraft



Visual Inspection Methods

- Background
  - Regarded as the simplest and most common method of inspection [1]
  - Walkthrough procedures have been documented [2-3]
  - NESCC noted that "…universal procedures for walk downs of cable installations are needed to help pinpoint the locations of trouble."[4]
  - No academic literature was identified quantifying the efficacy of visual inspection methods
- Applicability to Submerged Cable
  - 'Unaided' inspection plausible in manways
  - Illuminated borescope allows visual access to submerged ducts

Reproduced from [1]

[1] Shumaker,B.D.; Campbell,C.J.; Sexton, C.D.;Morton, G.W.; "Cable Condition Monitoring for Nuclear Power Plants," *Future of Instrumentation International Workshop (FIIW),) 2012*, pp.1-4, Oct. 2012.
[2] **IAEA Nuclear Energy Series No. NP-T-3.6, "**Assessing and Managing Cable Ageing in Nuclear Power Plants," International Atomic Energy Agency, May 2012
[3] **1011223,** "Aging Identification and Assessment Checklist: Electrical Components,," EPRI, Palo Alto, CA and Altran Corporation, Boston, MA, 2005.
[4] **Nuclear Energy Standards Coordination Collaborative (NESCC),** "Electrical Cable Aging and Condition Monitoring Codes and Standards for Nuclear Power Plants: Current Status and Recommendations for Future Development," January 2014.

Environmental Conditions Need to Be Reproduced in the Laboratory

- Selection of the most significant stressors must be performed
  - Moisture level and content
    - Ions
    - Salts
    - Other contaminants
- Mechanical stressors
  - Tension
  - Torsion
  - Compression
- Electrical Stressors
  - Magnitude of the electric field
  - Derivative of the electric field
  - Frequency of the electric field
- Creating independent stressors will be critical for linking to aging processes

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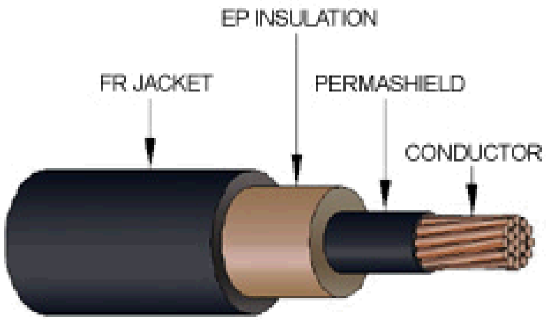
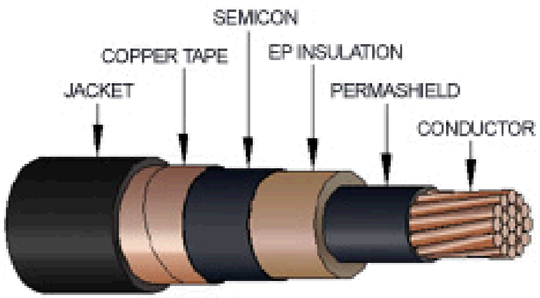
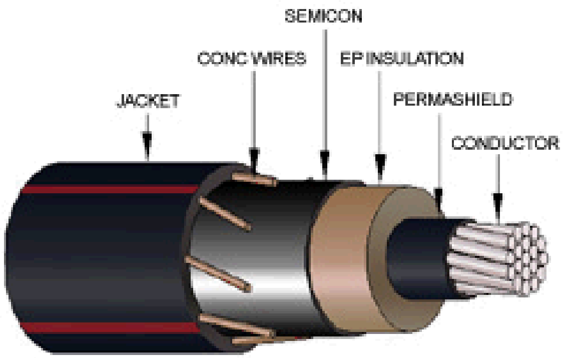
- Flow diagram/road map
    - Schedule
- Skill sets and expertise
- Pilot testing to larger parameter space
- Down select of stressors
    - Identify all stressors we want to address
    - Decision Points on which stressors will be emphasized
- Deliverables

Cables to Be Considered

- This study included shielded and unshielded submerged medium voltage cable with extruded insulation
  - EPR (e.g., black, pink, brown, old, new)
  - XLPE
- Most cables at nuclear power plants are shielded (~80%)
- All medium voltage (MV) cable (5 kV – 35 kV) in nuclear power plants is jacketed [1]
- Majority of cable shields are made with copper tape shield [1]







[Used by permission from Kerite]

[1] **3002000557, "**Plant Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants (Revision 1)," EPRI, Palo Alto, CA, June 2013.

Determine Signatures of Mechanistic Aging

- Determine signatures of mechanistic aging
  - Must consider different insulation types
  - Utilize multi-factor approach
  - Multi-factor approach must consider impacts of
- Accelerated Aging for Multi-factored Lifetime Models
  - Multiple experimental configuration (small and intermediate scale)
- Fundamental Understanding of breakdown mechanisms
- Scoping studies to evaluate impact of variables in mechanistic aging

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Map Diagnostic Results to RUL Estimations

- Bulk (trendable) CM methods for shielded cables
  - Polarization/depolarization current
  - tan δ, Delta tan δ, Dielectric spectroscopy
  - Withstand test to failure and microscopy
- Localized assessment of shielded cables
  - Differential TDR
  - LIRA
  - PASD
  - Microscopy
- Localized assessment of unshielded cables
  - Flash thermography
  - LIRA
  - PASD
  - Microscopy
- Reliability assessment and confidence in integration of different CM methods
- End-of-life criteria

Necessary Materials and Collaborations

- Materials
  - Long lengths of cable
  - Short lengths of cable
  - CM data from plants
- Collaborations
  - Consensus on end-of-life criteria and remaining useful life
  - Feedback

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Proposed Future Work

- Intermediate Cable Testing
  - Cables instead of plaques
  - ~ 3-5 feet length (~1-2 feet inside of 'vessel' and ~1-2 feet on each side)
- Ability to vary:
  - Electric parameters (frequency, voltage, 'voltage spikes')
  - Temperature
  - Water content (ion type, ion concentration)
  - Atmosphere
- Must be able to perform <u>multiple</u> tests in parallel to search for new methodology for acceleration/understand aging 'stressors'
- New investigations will require custom equipment

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