INNOVATING NUCLEAR TECHNOLOGY

ANALYSIS AND MEASUREMENT SERVICES CORPORATION

Cable Condition Monitoring for Aging Management and Life Extension

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Presented at:

Polymers in Nuclear Applications 2024

March 19th, 2024

Development of Cable Aging Acceptance Criteria

Accelerated Aging

Condition Monitoring Tests

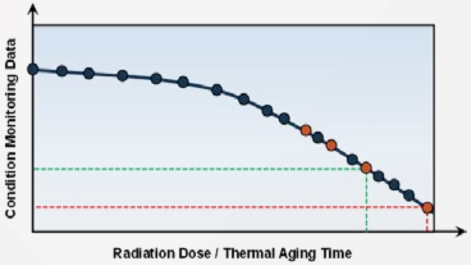
Laboratory

- Elongation at Break
- Oxidation Induction Time
- Thermogravimetric Analysis
- Density

In-Situ

- Frequency Domain Reflectometry
- Indenter Modulus
- Impedance Measurements
- Fourier Transform Infrared Spectroscopy

LOCA Exposure (Accident Scenario)



Cable Types and Accelerated Aging Conditions

Cable ID	Manufacturer	# of Cond.	Voltage (V)	Insulation Thickness (mils)	Gauge (AWG)	Shield Type	Insulation	Jacket	Year of Manufacture
A	Rockbestos	3	600	30	12	None	XLPE	CSPE	2007
B	Brand Rex	3	600	20	12	None	XPLE	CPE	1982
C	Rockbestos	3	600	25	16	Copper Foil w/ Drain Wires	XLPE	CSPE	1980
D	Eaton/Dekoron	4	600	20	16	Copper Foil w/ Drain Wires	XLPO	CSPE	1980
E	AIW	2	600	25	10	None	EPR	CSPE	1979
F	Rockbestos	2	600	30	14	Copper Foil w/ Drain Wires	SR	Thermoset Polyolefin	2016
G	Anaconda	2	600	25	14	None	EPR/CSPE Bonded	CSPE	unknown
H	Okonite	3	600	25	14	None	EPR/CSPE Bonded	CSPE	1985

Gamma radiation aging at PNNL

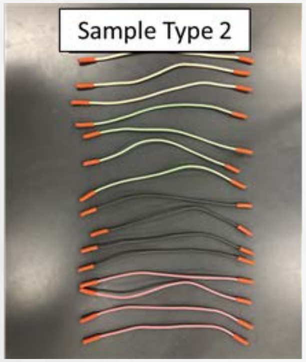
- Cobalt-60 source (High Exposure Facility)
- Dose rate: Approximately 250 Gy/hour
- Total dose: 300 kGy
- Duration: Approximately 50 days

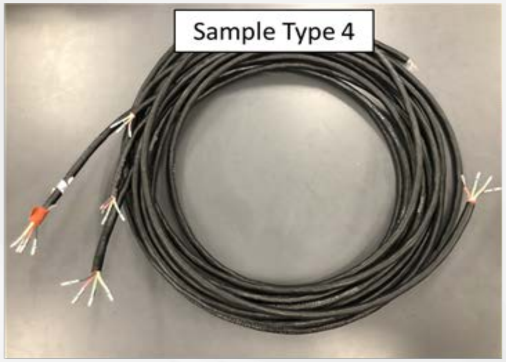
Thermal aging at AMS

- XLPE/O and EPR aged at 120 °C
- SR aged at 165 °C

CM Tests and Sample Types

- Elongation at Break (EAB)
- Oxidation Induction Time (OIT)
- Oxidation Induction Temperature (OITP)
- Thermo-gravimetric Analysis (TGA) in O_2 environment
- Relative Density
- Frequency Domain Reflectometry (FDR)
- Fourier Transform Infrared Spectroscopy (FTIR)
- Indenter Modulus (IM)
- Dielectric Frequency Response
- Electrical Permittivity
- Dissipation Factor (varying frequency, constant low voltage)
- AC Resistance/Reactance
- Capacitance
- Mass Spectroscopy (MS)



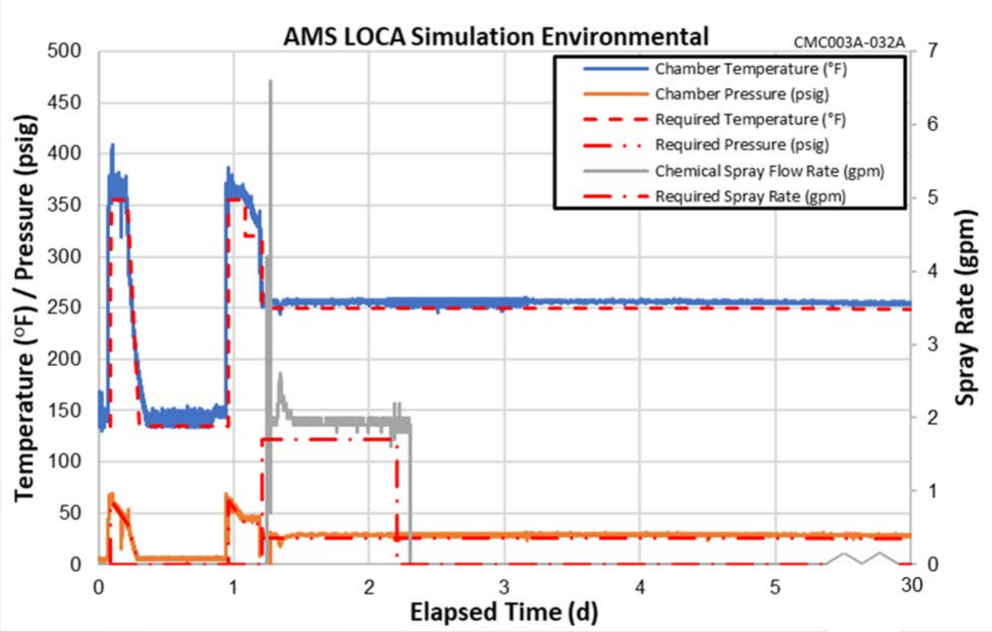


LOCA Exposure Conditions

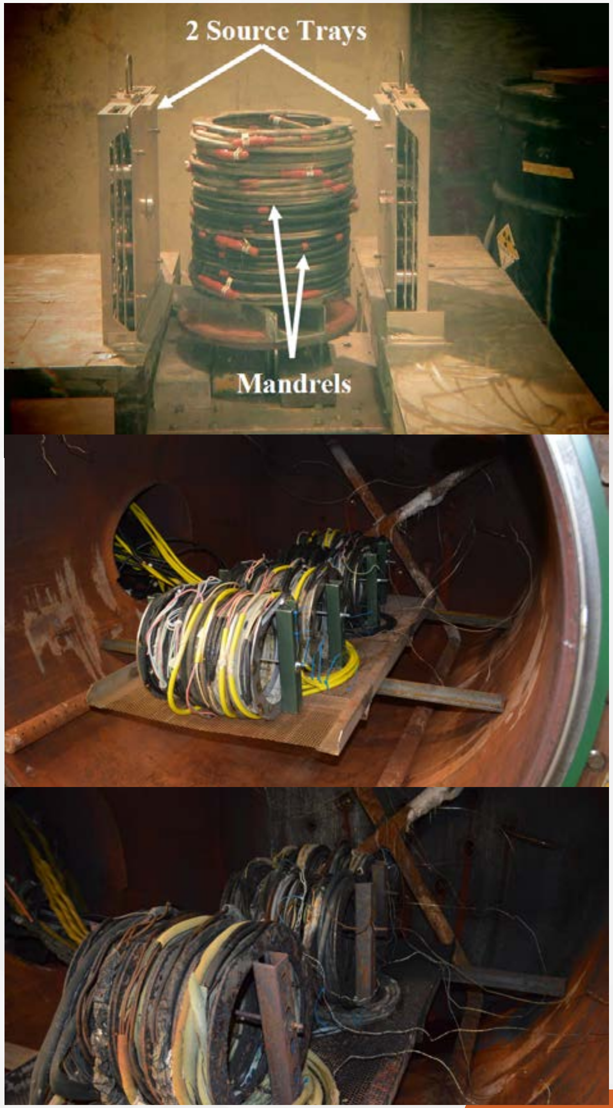
Aged cables of varying levels were subjected to a LOCA test

- Accident Dose Radiation: 1,500 kGy total dose with a 6 kGy/hr dose rate.

Combined thermal/pressure transients with chemical spray for 30 days

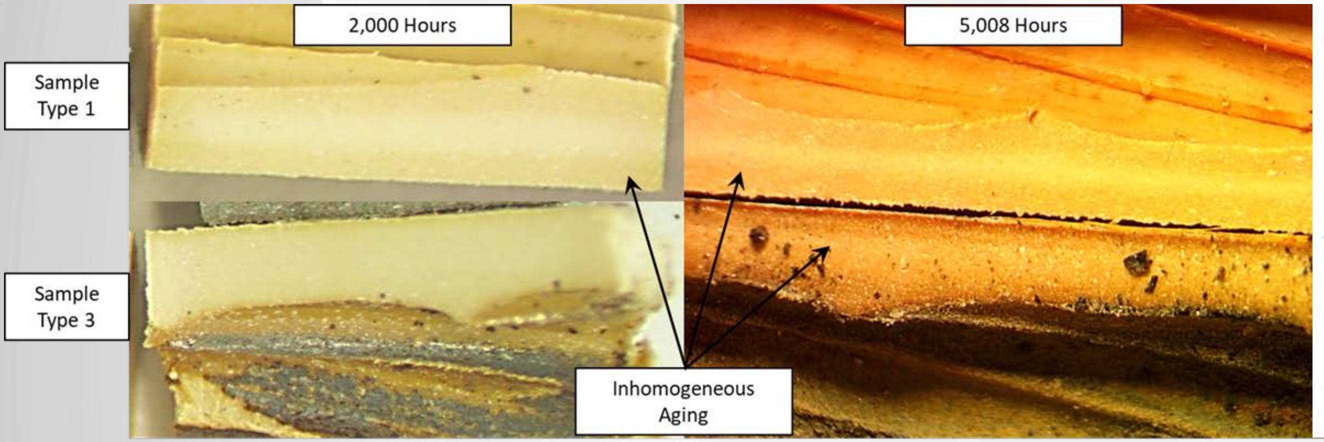


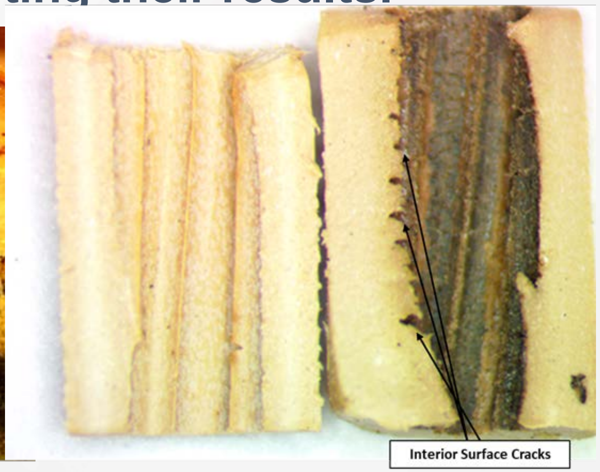
From the PWR/BWR LOCA Profile in IEEE 323-1974



Impact of Accelerated Aging Phenomena on Material Properties

NUREG/CR 7153 - Accelerated aging effects must be accounted for when, "performing condition monitoring tests and interpreting their results."



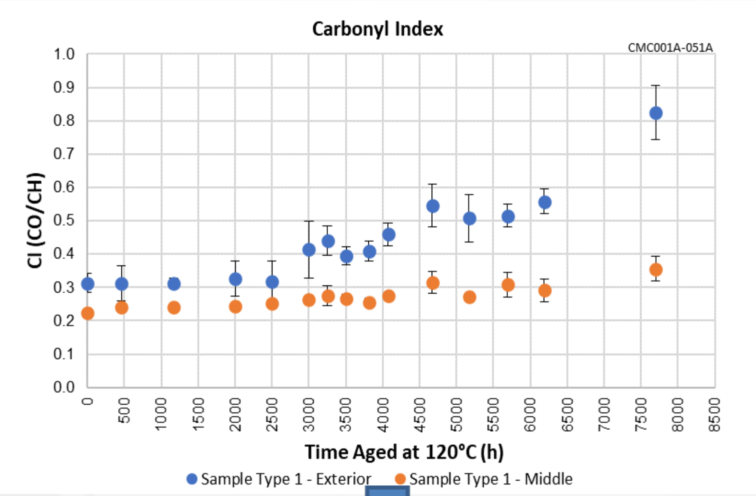


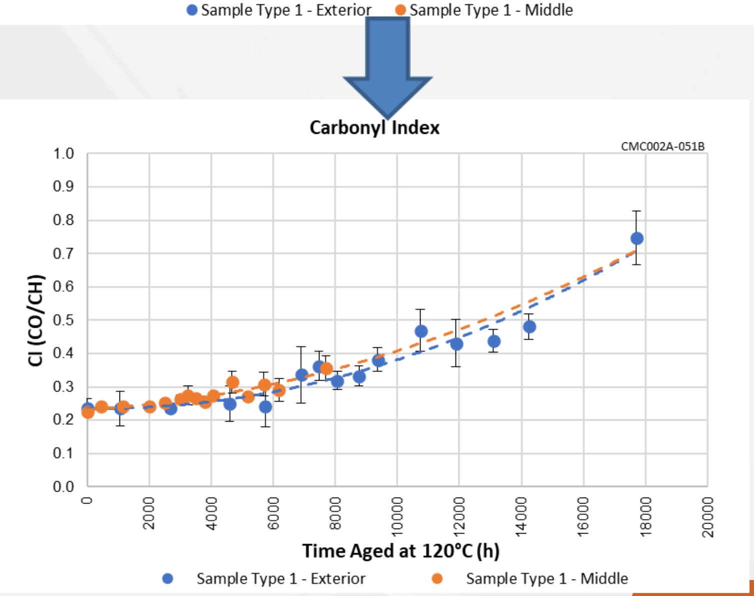
Material properties and CM results are impacted by these effects in different ways.

- "***Parameters that average across cross-section (OIT, OITP, density, TGA, etc.) are affected by DLO***." (Gillen, Polymer Vol. 33, Issue 20, pgs. 4358-4365, 1992).
- **"…in many such instances, tensile elongation measurements are unaffected by such DLO effects. This is due to the fact that cracks that originate at the hardened sample surface during elongation testing quickly propagate through the sample, implying that the surface chemistry reflected in the surface modulus values determines the elongation."**

Accounting for the Effects of Accelerated Aging

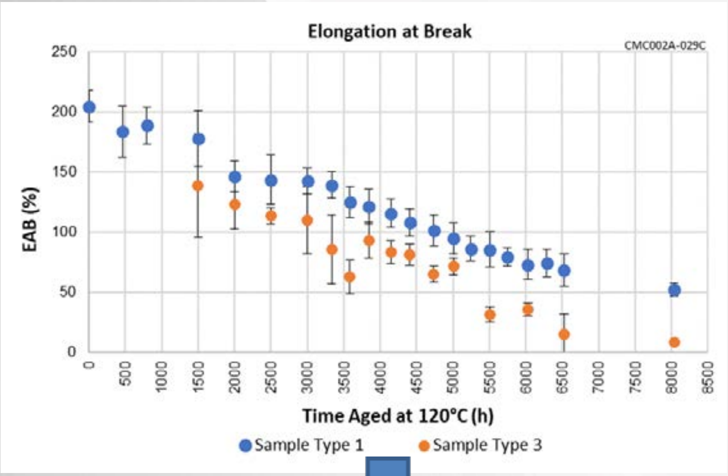
- **Trends in different CM measurement results generally dominated by one effect.**
- **Materials characterization testing results can be used to analyze the effects of individual phenomena.**
- **Use the materials testing results to determine time shift factors for different effects.**
  - Data presented here is FTIR-CI data acquired from 2 locations in Sample Type 1.
  - Differences observed in the CM data collected from the middle section and exterior surface are a direct result of DLO.
  - DLO slows down increase in FTIR-CI changes of middle section (orange trace) relative to the exterior surface (blue trace).
  - Results in the blue trace increasing at a rate 2.30 times faster.



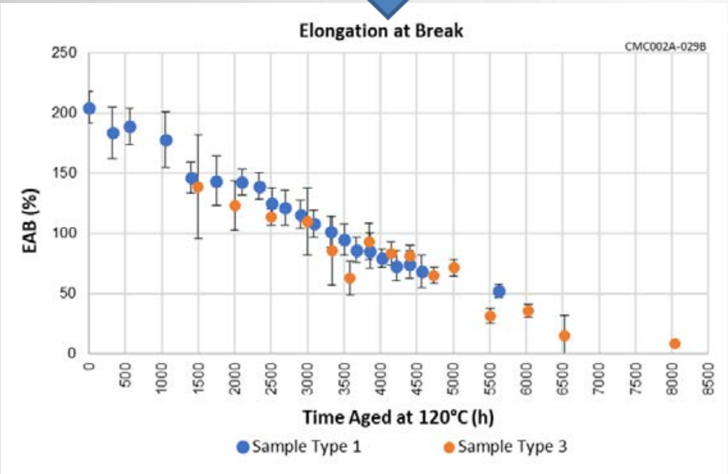


Effects on EAB Results Acquired for Different Polymer and Sample Types

Cable B (Brand Rex XLPE)



Time shift factor = 0.70

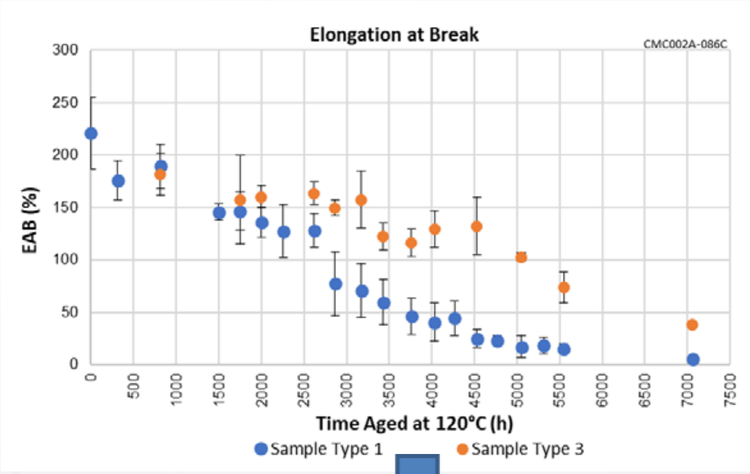


Interfacial Interactions dominate differences observed in Cable B XLPE.

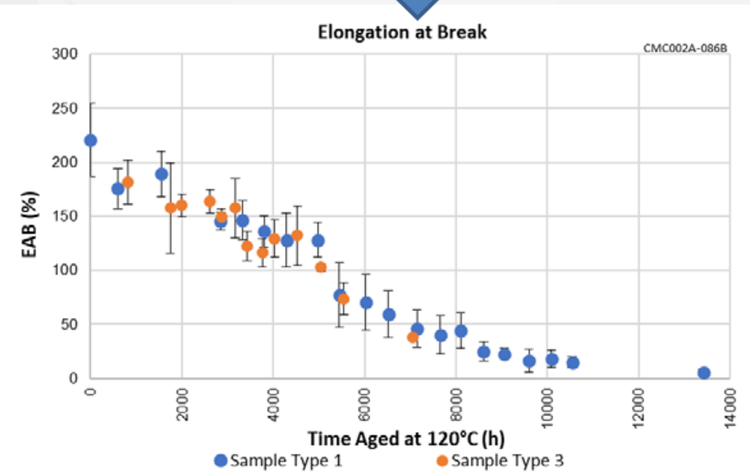
DLO dominates differences in Cable E EPR.

Type 3 data (orange traces) is most comparable to LOCA materials (Sample Type 4).

Cable E (AIW EPR)

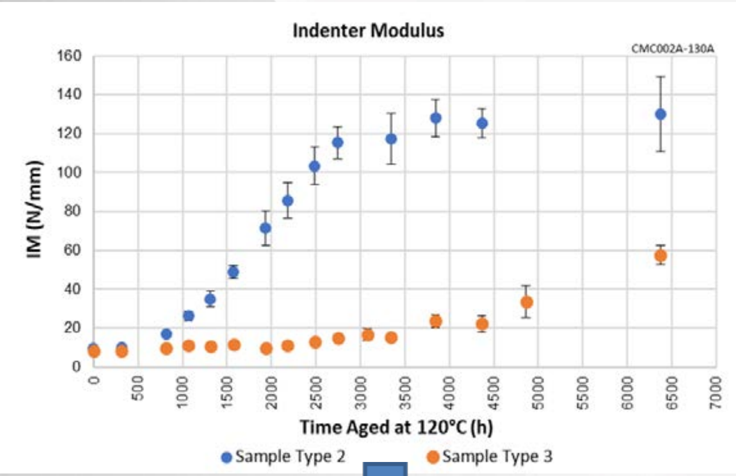


Time shift factor = 1.90

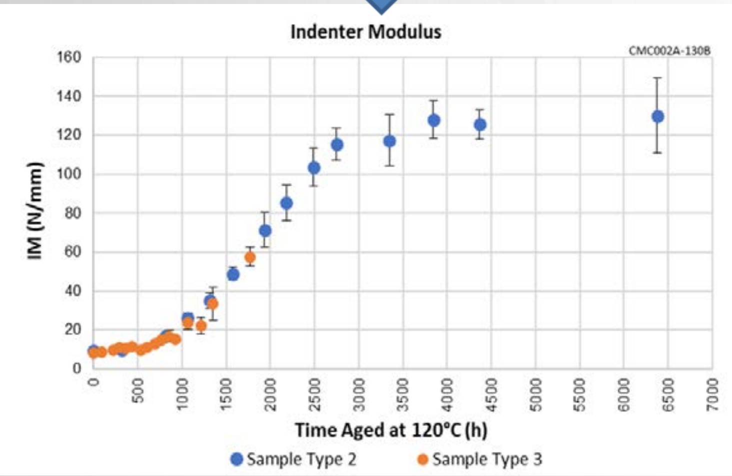


Application of Time Shift Factors to Different CM Measurements

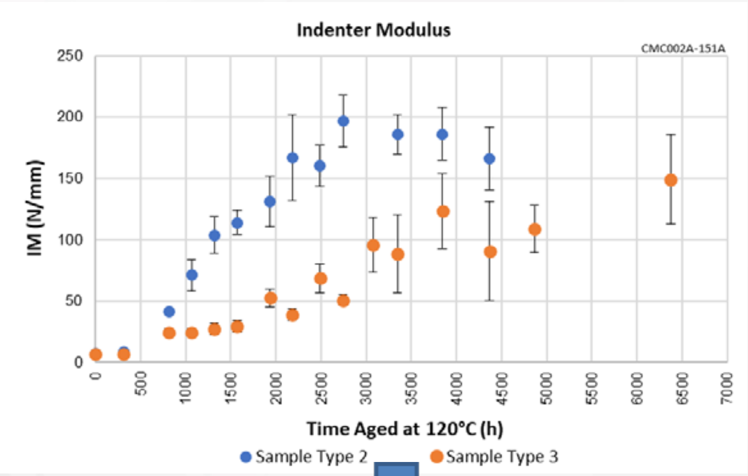
Cable G (Anaconda CSPE-EPR)



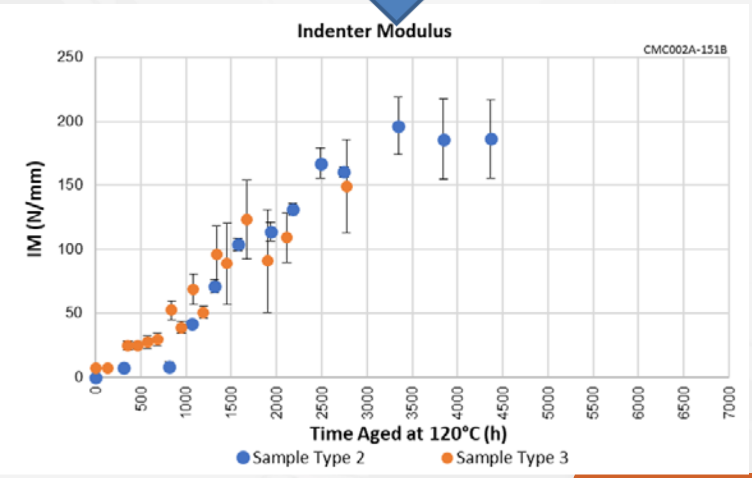
Time shift factor = 3.60



Cable H (Okonite CSPE-EPR)



Time shift factor = 2.30

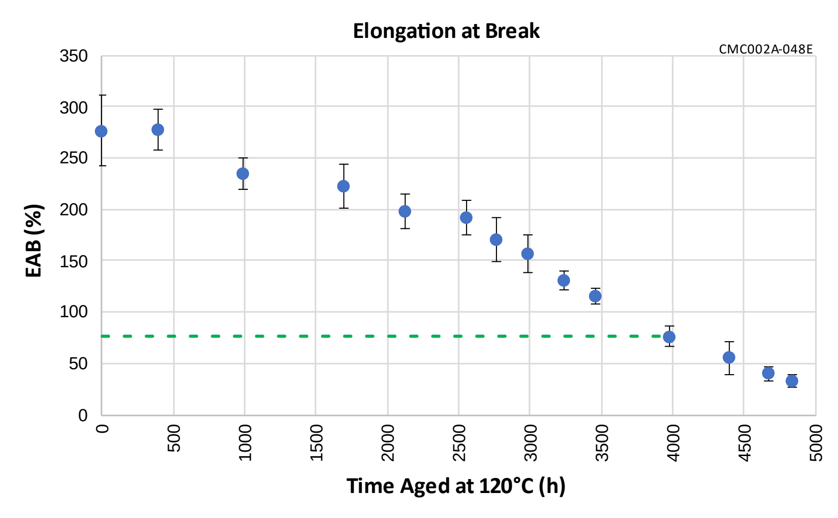


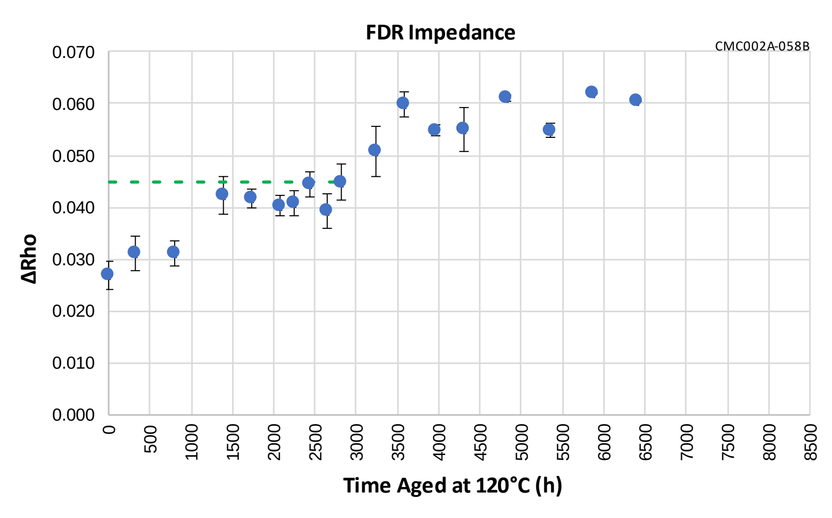
Time shift factors derived from one measurement can in some cases be applied to other test results.

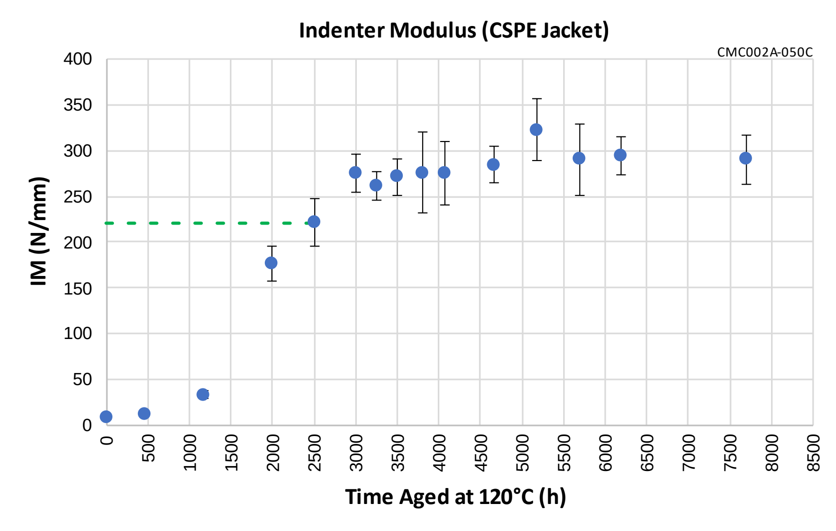
Examples here show application of time shift factors determined using FTIR-CI data acquired to IM results.

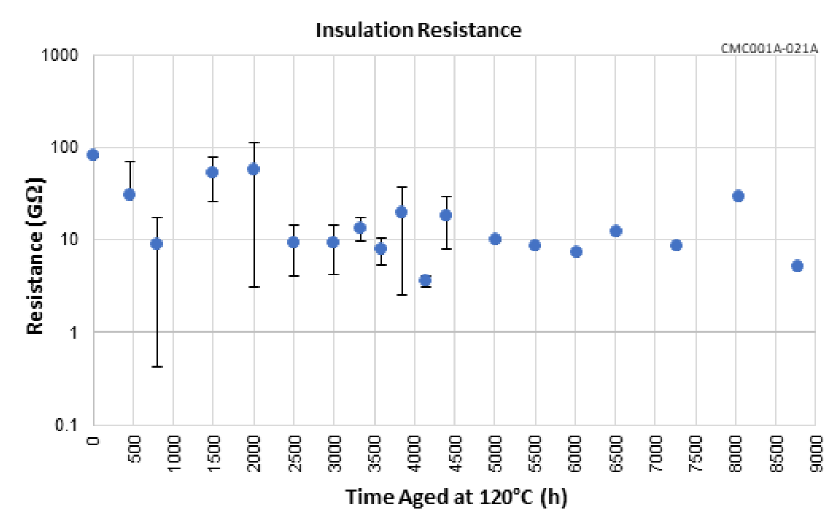
Differences observed here are caused by Jacket DLO.

Representative Research Results









Cable CM Tests and Materials with Aging Acceptance Criteria

Cable	Insulation Polymer Type	Jacket Polymer Type	CM Tests with Acceptance Criteria
Firewall III, circa 2007	XLPE	CSPE	EAB, IM (Jacket), FDR, LCR (20 Hz to 1 MHz), FTIR-CI, OIT, OITP
Brand Rex	XLPE	CPE	EAB, IM (Jacket), FDR, LCR (1 mHz to 1 MHz), FTIR-CI, OIT, OITP, TGA
Firewall III, circa 1980	XLPE	CSPE	EAB, IM (Jacket), FDR, LCR (20 Hz to 1 MHz), FTIR-CI, OIT, OITP, TGA
Eaton/Dekoron	XLPO	CSPE	EAB, IM (Jacket), FDR, LCR (20 Hz to 1 MHz), FTIR-CI, OIT, OITP, TGA
AIW	EPR	CSPE	EAB, IM (Jacket), FDR, LCR (20 Hz to 1 MHz), FTIR-CI, OIT, OITP
Rockbestos	SR	Thermoset Polyolefin	EAB, IM (Jacket), LCR (1 mHz to 1 kHz)
Anaconda	EPR/CSPE Bonded	CSPE	EAB, IM (Insulation and Jacket), FDR, LCR (1 mHz Hz to 1 kHz), FTIR-CI, OIT, TGA, Density
Okonite	EPR/CSPE Bonded	CSPE	EAB, IM (Jacket), FDR, LCR (1 kHz), FTIR-CI

New Developments in Cable Condition Monitoring and Aging Management

- Project to develop acceptance criteria for cable condition monitoring has been completed.

- The project was done with $3.5M in DOE funding and in partnership with PNNL and ORNL

- Topical Report to be submitted to NRC in Early 2024

Condition Monitoring techniques and acceptance criteria can be used today to satisfy GALL requirements and extend the life of EQ cables based on condition monitoring results

Contains four primary elements:

1. Defining the scope of plant cables that will be evaluated.
2. Selecting CM tests that effectively trend with age-related degradation of cable materials.
3. Establishing acceptance criteria for the CM tests that correlate the properties of the cable polymer(s) to the critical characteristic properties the cable(s) must retain to perform their design and safety function.
4. Performing initial CM tests to determine current condition and establish appropriate test interval/frequency for future evaluations.

How Do Condition-Based Evaluations Help The Industry?

- Extend cable life beyond reanalysis alone.
- Know the actual condition of installed cables.
- Avoid replacing healthy cables.
- Informed replacement schedules.
- Reduce uncertainties with lifetime estimates.

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Thank You

Questions?