INNOVATING NUCLEAR TECHNOLOGY

Development of Cable Aging Acceptance Criteria for Nuclear Facilities

Presented by:
Patrick Ward

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Polymers in Nuclear Applications
Ringhals Nuclear Power Plant, Väröbacka, Sweden

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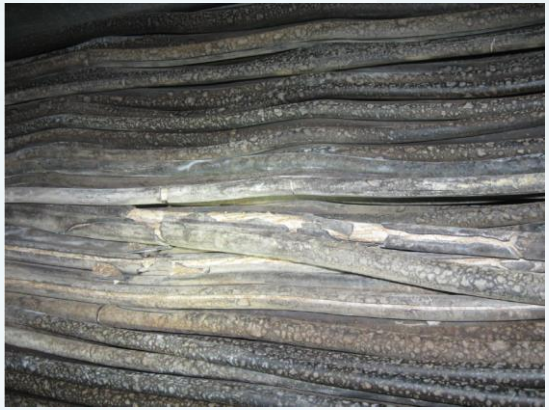
Project Goal

Project title: *Development of Cable Aging Acceptance Criteria for Nuclear Facilities*

Purpose of the project:

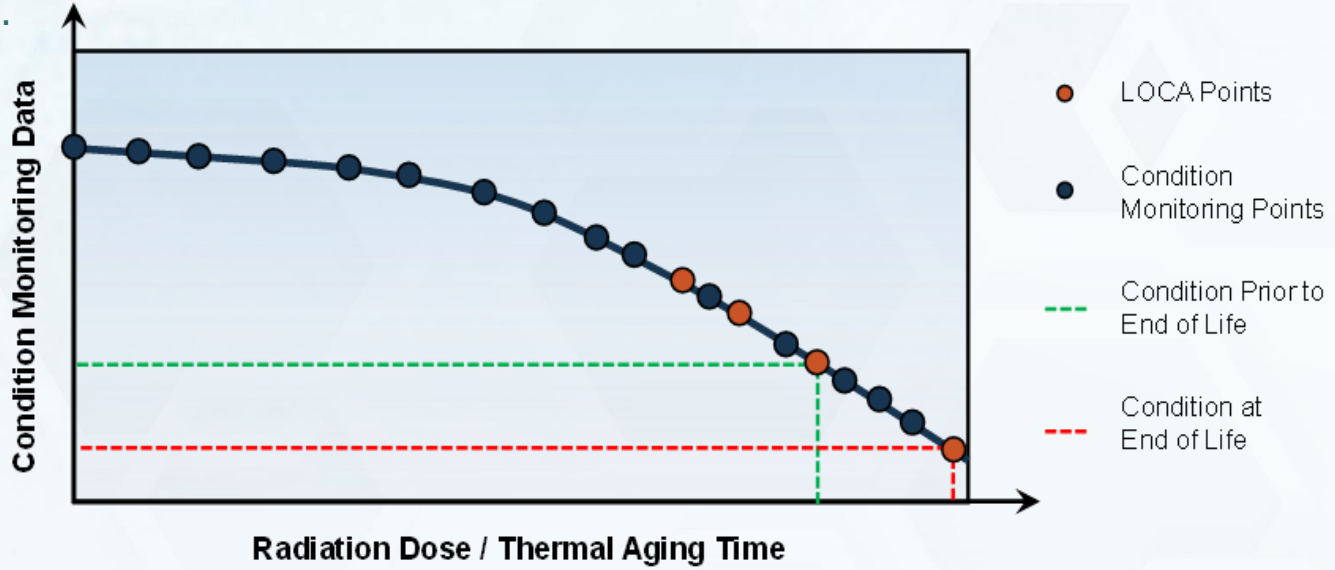
- Develop acceptance criteria for multiple condition monitoring techniques to quantify the level of aging in cable polymers.
- Provide means to perform condition based evaluations in support of qualification and aging management



Project Overview

The project involved:

- Accelerate the aging of low voltage cables (sequential radiation exposure followed by thermal exposure).
- Periodically perform condition monitoring tests throughout the aging process.
- Expose cables with varying degrees of aging to LOCA (per IEEE-323 and IEEE-383).
- Correlate the trend in CM data with the aging point where the cables will no longer pass a LOCA test.



Process similar to Condition-Based Qualification Process in NUREG/CR-7153 and IAEA NP-T-3.6

Description of Cables Evaluated in this Work

Three types of insulation materials were evaluated

- Three cables with Ethylene Propylene Rubber (EPR) insulation
- Four cables with Cross-Linked Polyethylene (XLPE/XLPO) insulation
- One cable with Silicone Rubber (SR) insulation

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

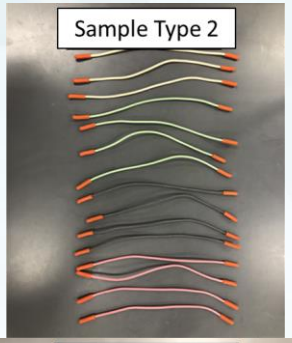
Sequential Aging Conditions

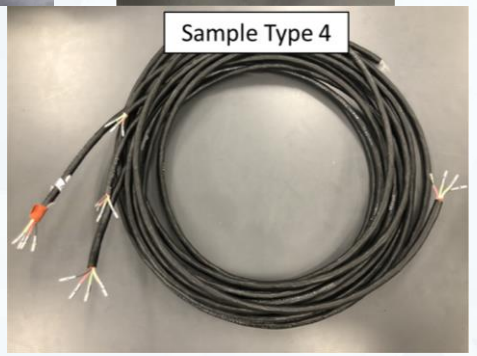
Gamma radiation aging at PNNL

- Cobalt-60 source (High Exposure Facility)
- Dose rate: Approximately 25 krads/hour (250 Gy/hour)
- Total dose: 30 Mrads (300 kGy)
- Duration: Approximately 50 days

Thermal aging at AMS

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



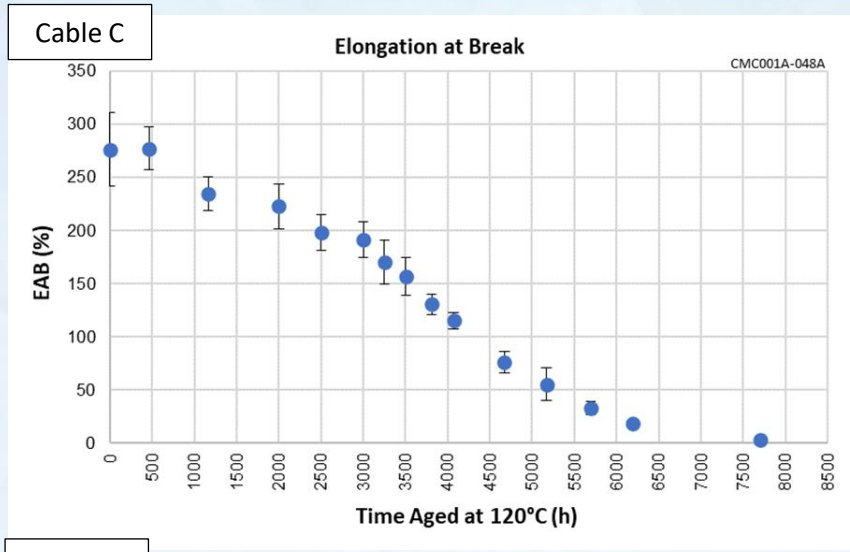


Cable Condition Monitoring Techniques

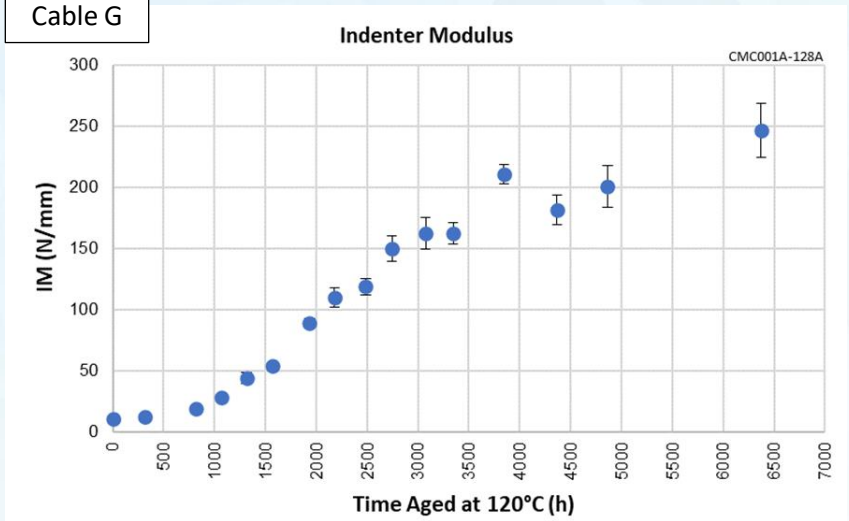
- Elongation at Break (EAB)
- Oxidation Induction Time (OIT)
- Oxidation Induction Temperature (OITP)
- Thermo-gravimetric Analysis (TGA) in O_2 environment
- Relative Density
- Frequency Domain Reflectometry (FDR)
- Fourier Transform Infrared Spectroscopy (FTIR)
- Indenter Modulus (IM)
- Dielectric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

Typical CM Data Collected During Aging

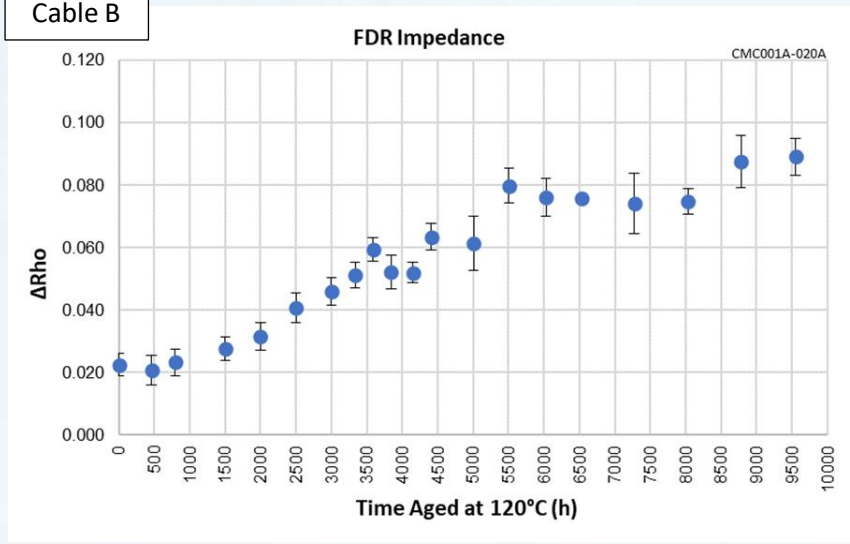
Cable C



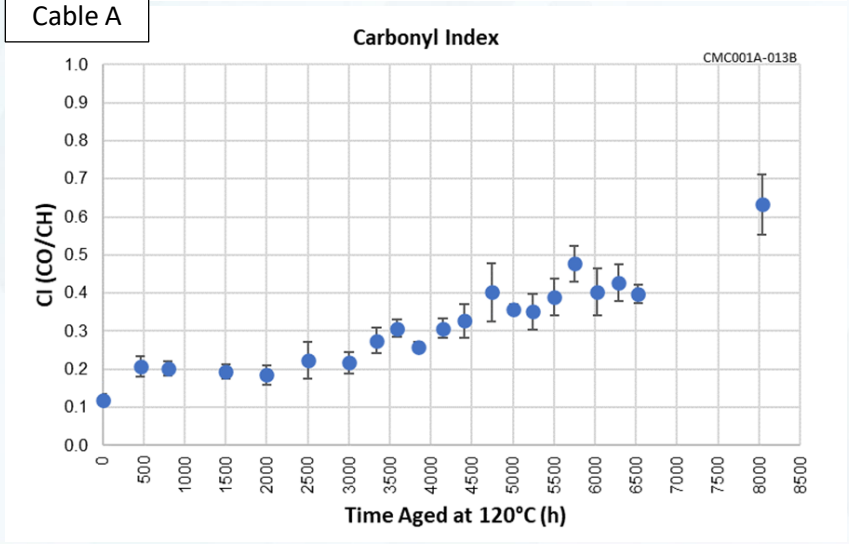
Cable G



Cable B

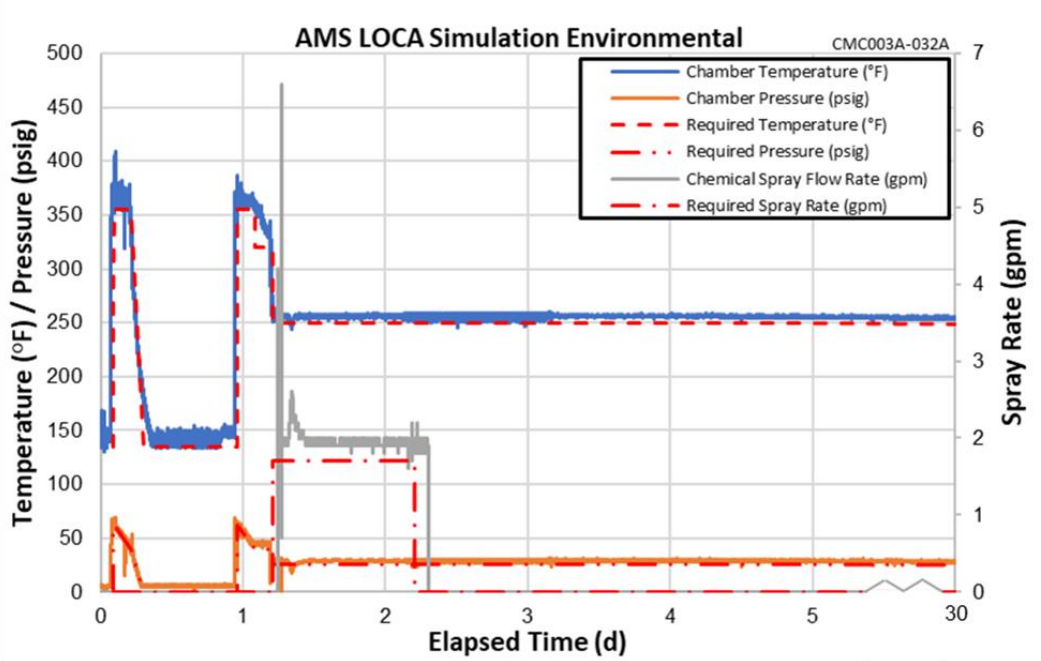


Cable A

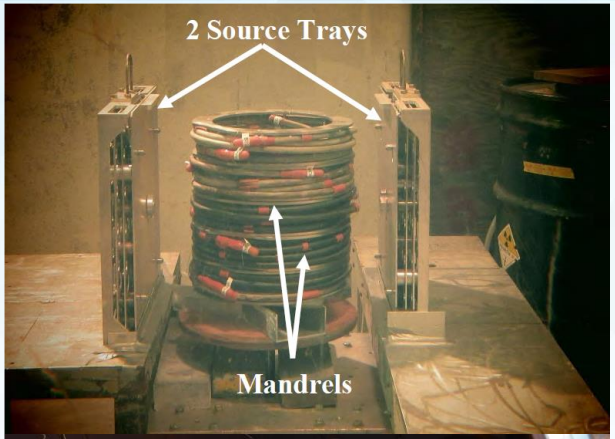


LOCA Exposure Conditions

- **Aged cables of varying levels were subjected to a LOCA test**
  - Accident Dose Radiation: 150 Mrad (1500 kGy) total dose with a 0.6 Mrad/hr (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

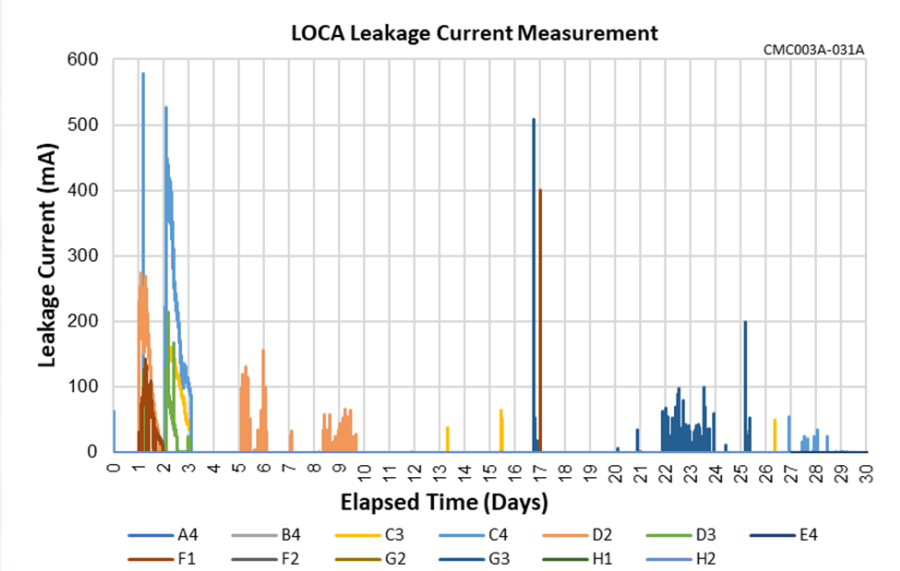


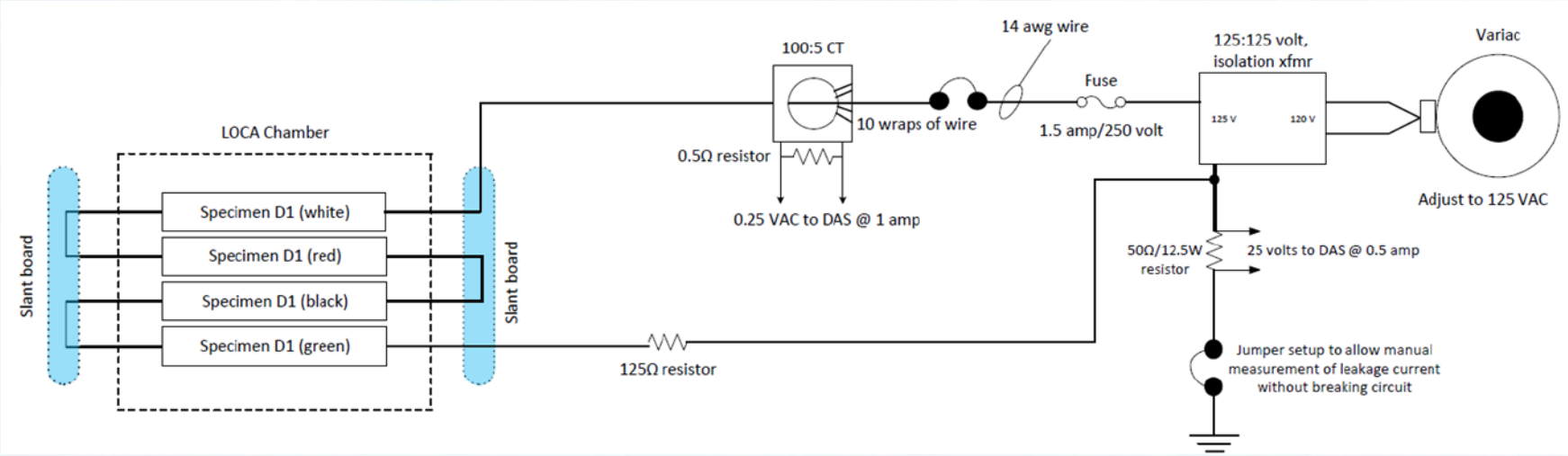
Electrical Monitoring During LOCA

Penetration Setup

Power Supply Setup

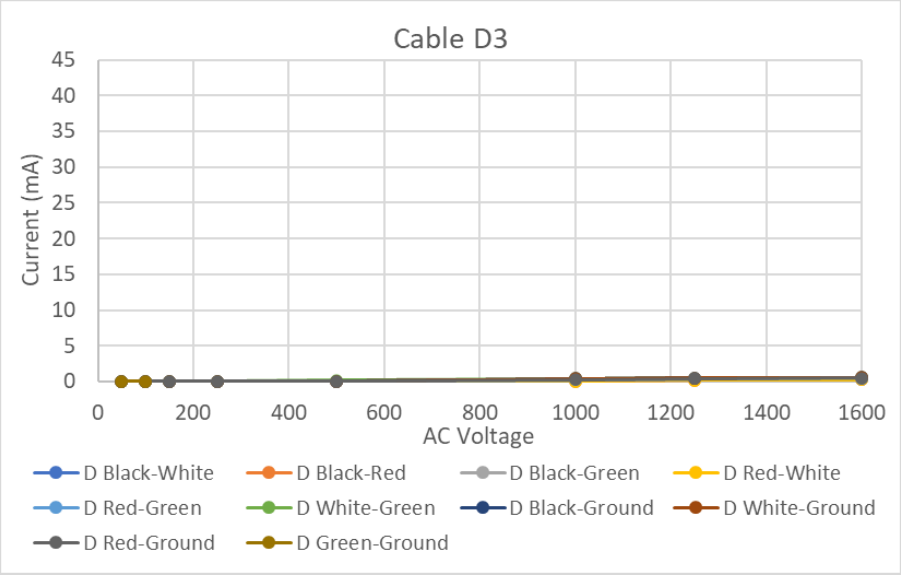
Circuit Load Setup

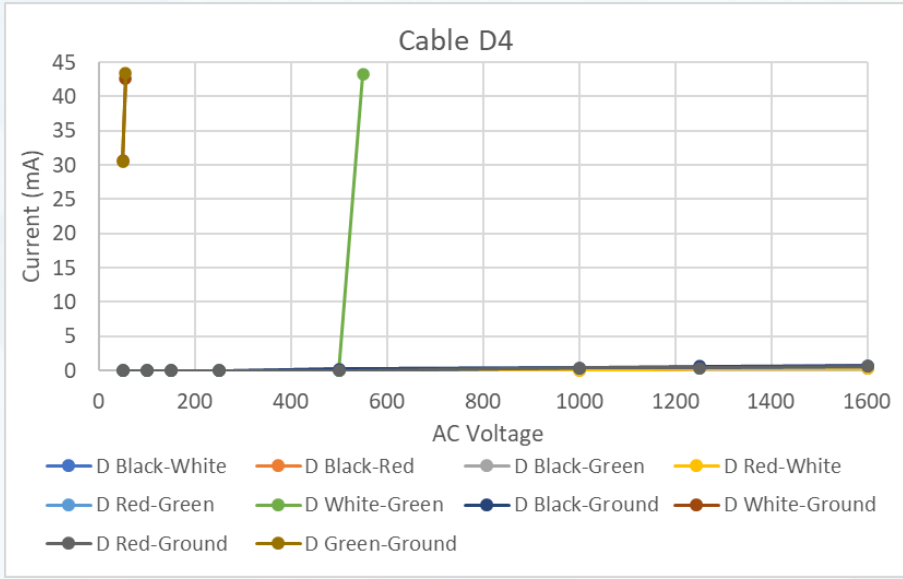




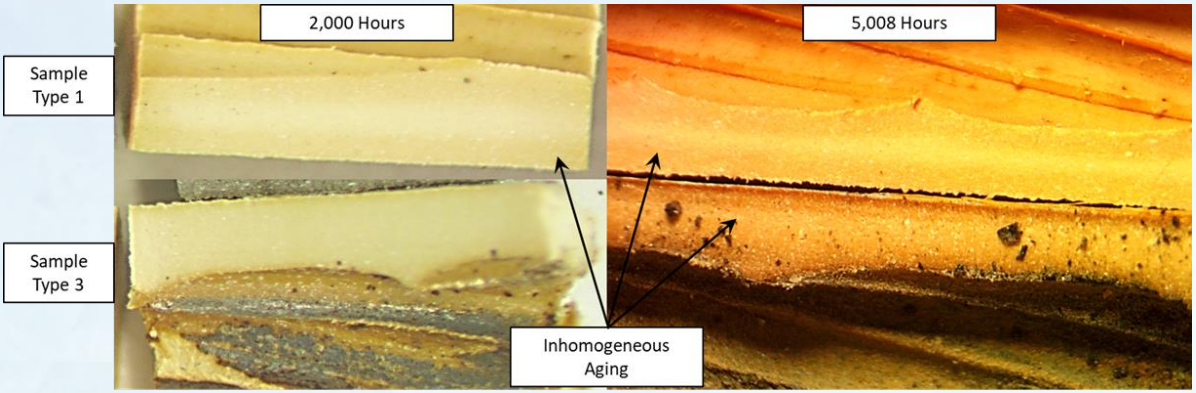
Post-LOCA Withstand Testing

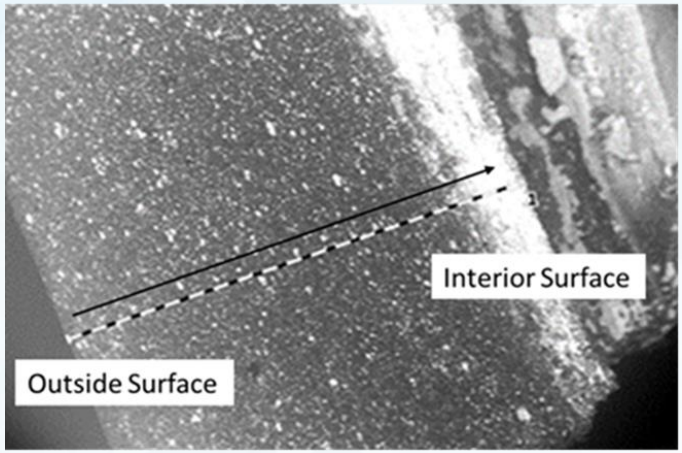
- Following guidance in IEEE 383-2003.
- Removed cables from 20X mandrels, straightened, installed on 40X mandrels, and submerged for 1 hour.
- Testing performed at 80 VAC/mil of insulation thickness, voltage applied for 5 minutes.

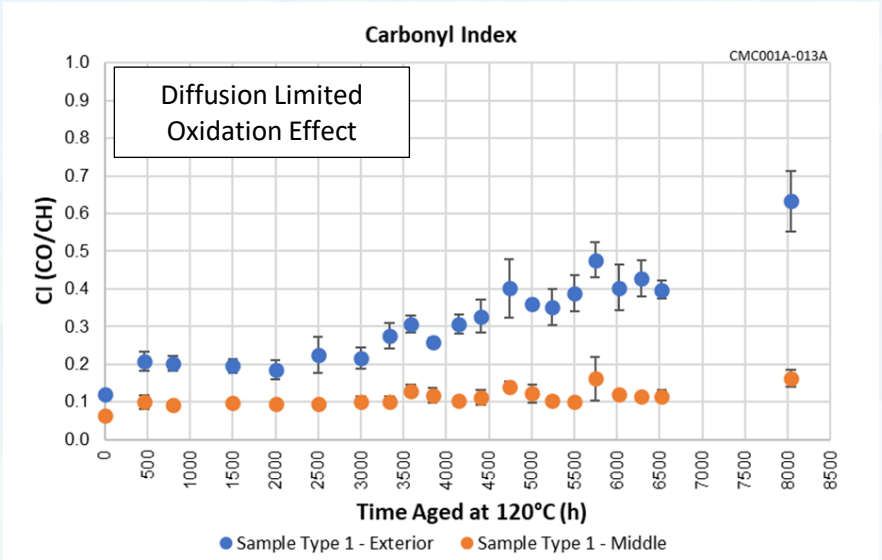


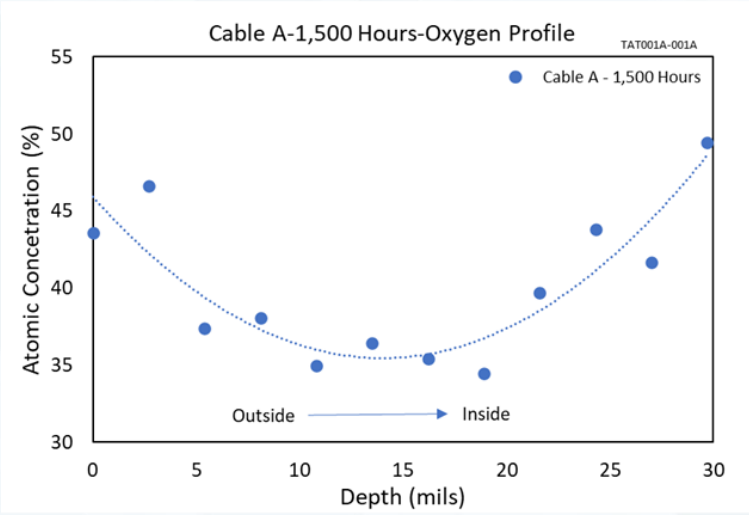


Effects of Inhomogeneous Aging – Diffusion Limited Oxidation

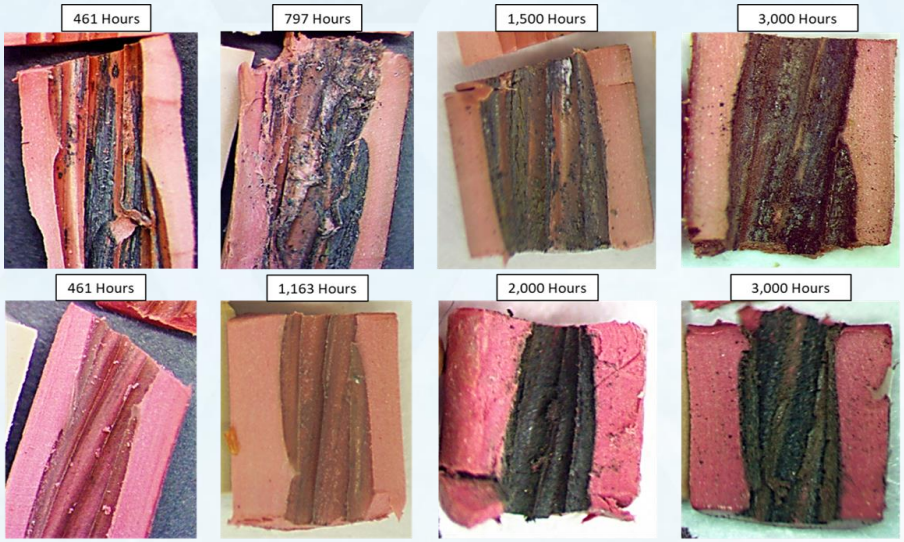


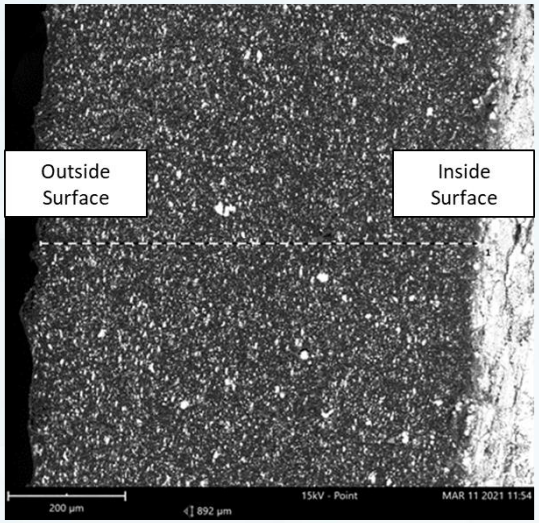


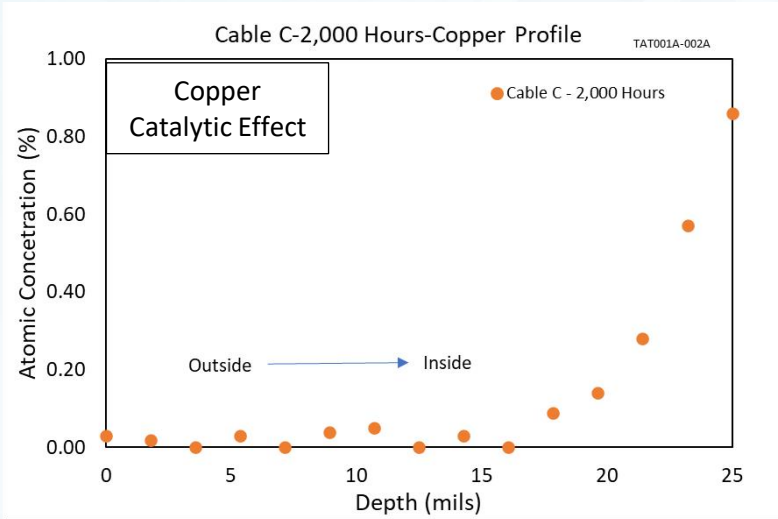




Effects of Inhomogeneous Aging – Copper Catalytic Effect

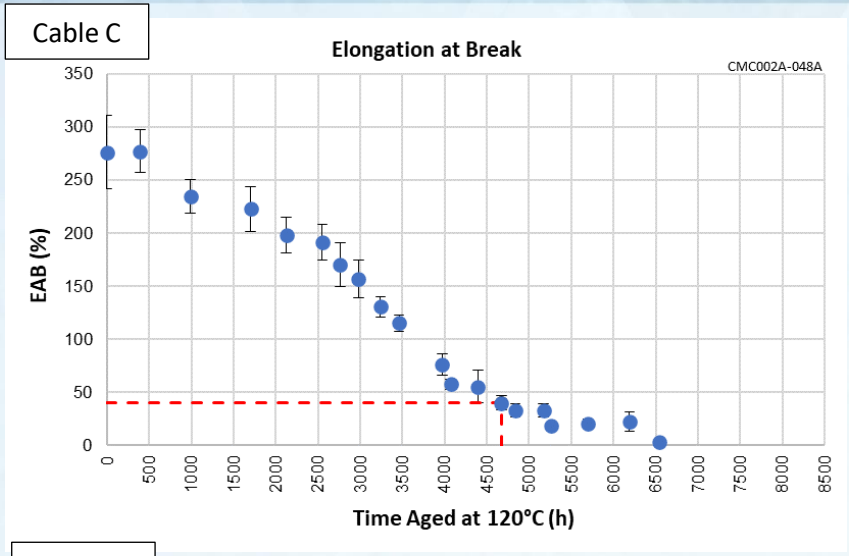




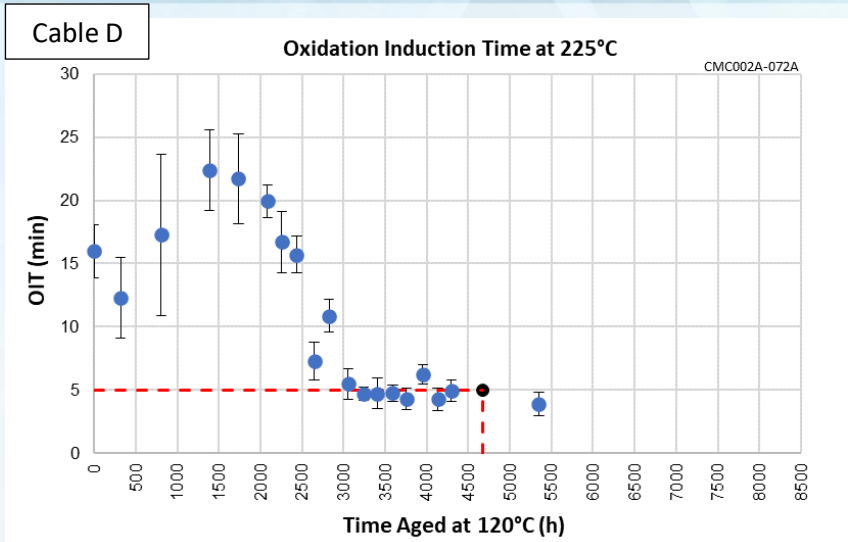


Aging Curves with LOCA Failure Point

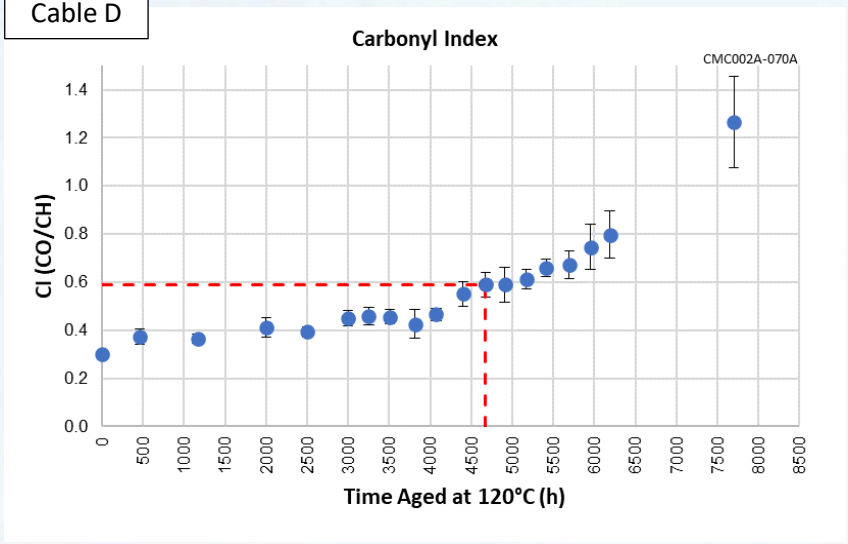
Cable C



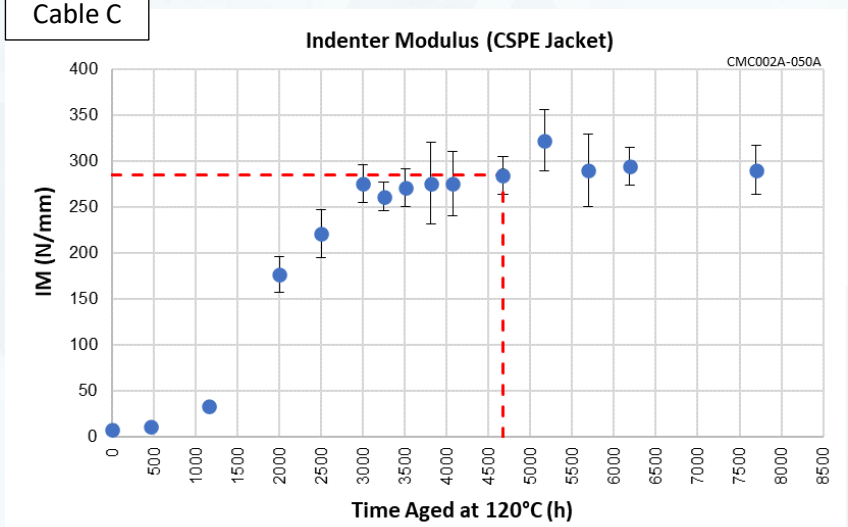
Cable D



Cable D

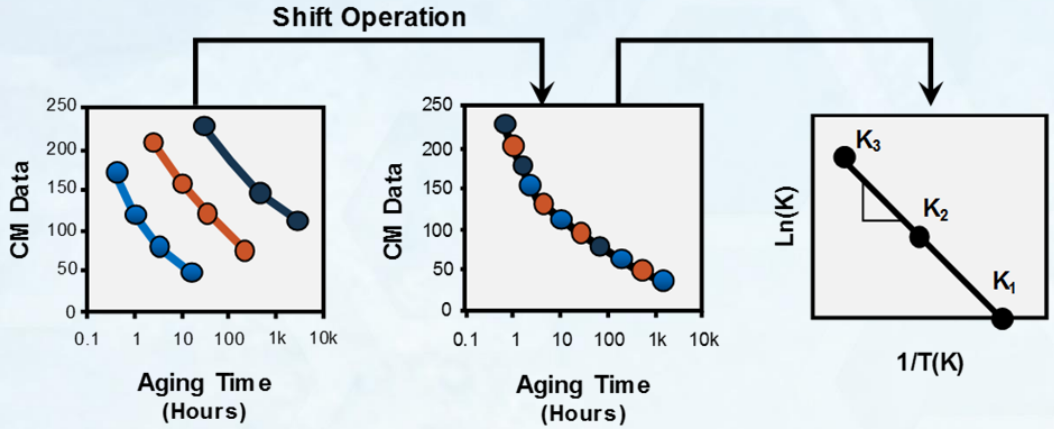


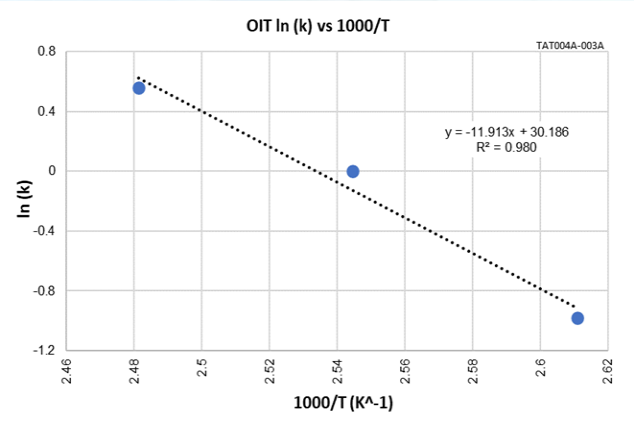
Cable C

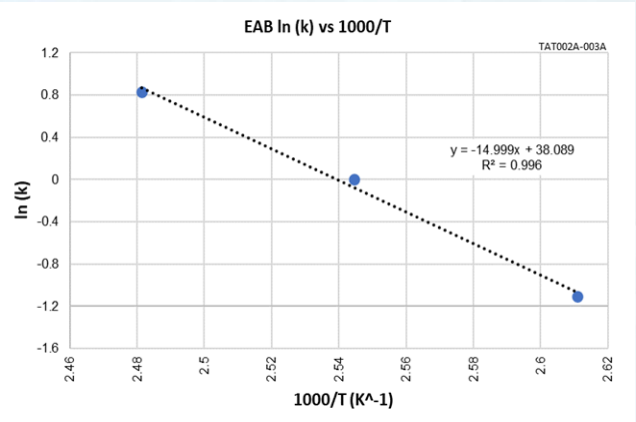


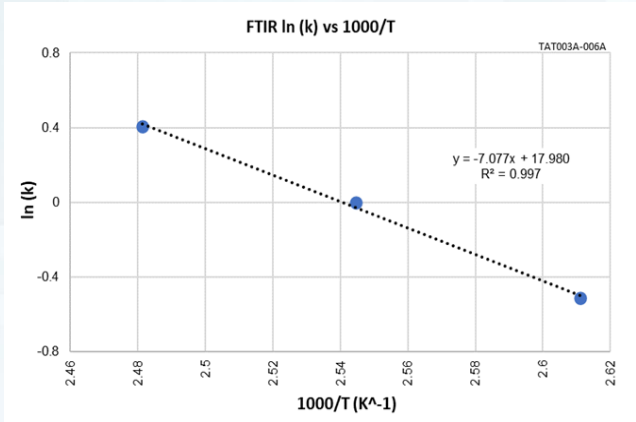
Application of Arrhenius Method to Various CM Data

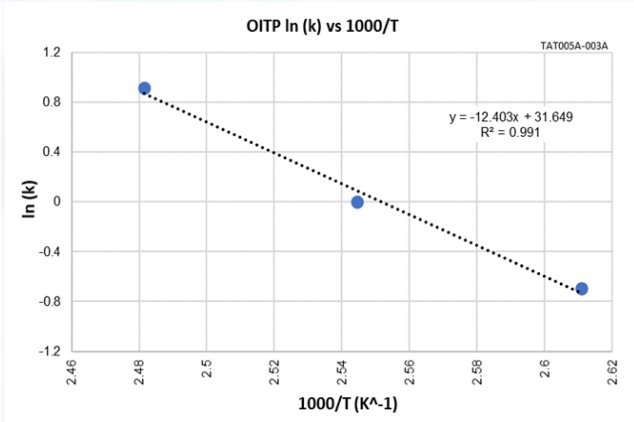
Cables were thermally aged at 110˚C, 120˚C, and 130˚C. Testing performed included EAB, OIT, OITP, and FTIR.











Project Outcomes

- **Developed acceptance criteria that reflect the properties of insulation materials at the point at which cables will no longer pass a LOCA test.**
- **This information will be used to provide the nuclear industry with an objective *condition based* assessment of cable aging.**
- **Demonstrated various CM methods for their use in determining activation energy for Arrhenius lifetime estimates.**
- **Evaluated and quantified inhomogeneous aging effects.**

INNOVATING NUCLEAR TECHNOLOGY

Questions