



INNOVATING **NUCLEAR** TECHNOLOGY

Condition of 44-Year Naturally Aged Cable

Presented by:

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January 23, 2020

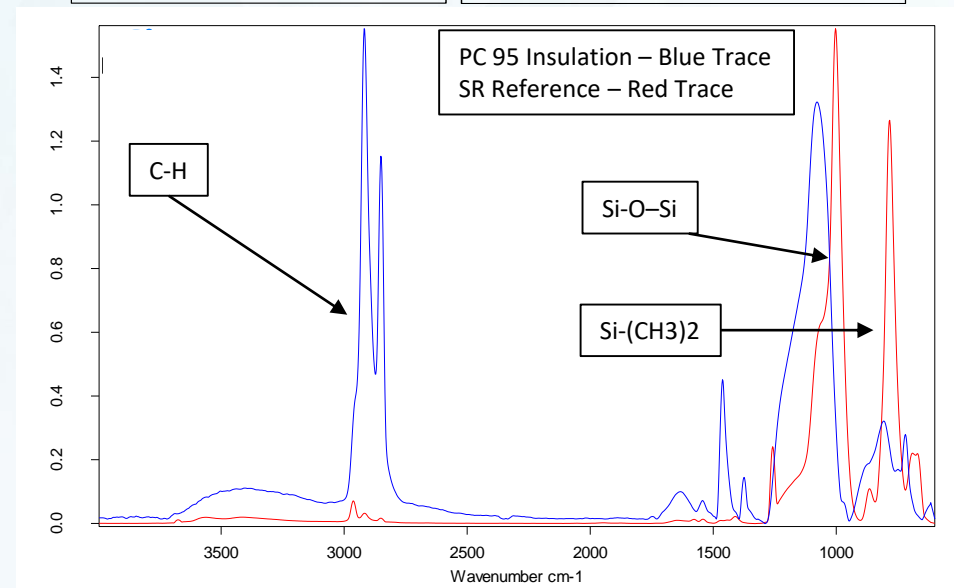
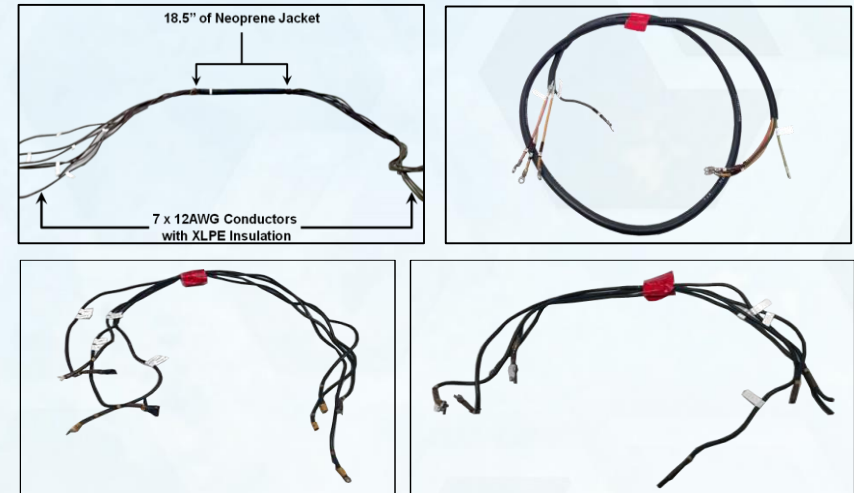


Cables Included in Cable Aging Assessments

Three (3) types of cable were sent to AMS from Cooper Nuclear Station for laboratory testing:

- 7.5' section of Rockbestos Pyrotrol III (PC113)
 - 7 conductors
 - Installed prior to plant startup in 1974
- Two 3.0' sections of Raychem Flamtrol (PC107 and PC95)
 - 4 conductors each
 - Installed prior to plant startup in 1974
- 7.5' section of Rockbestos Firewall III (PC101)
 - 5 conductors
 - Installed in 2001

These cables were removed from service in Cooper's steam tunnel





Summary of Cable Aging Assessments

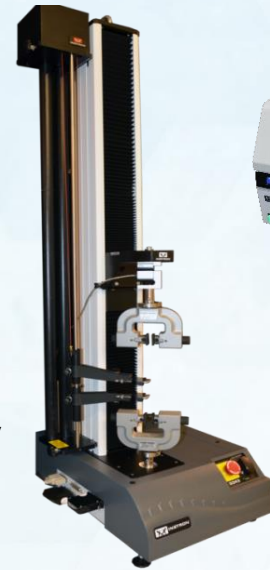
The testing includes:

- 1) *As-found cable condition assessments*
- 2) *Accelerated aging tests to determine the cables' remaining useful life (RUL)*

• The cables were evaluated using:

- Visual inspections
- Optical and scanning electron microscopy
- Insulation Resistance
- Indenter Modulus
- Elongation at Break
- Oxidation Induction Time
- Thermo-gravimetric Analysis
- Relative Density
- Fourier Transform Infrared Spectroscopy

• The key findings of the aging studies are summarized in this presentation



EAB



DSC/OIT
and TGA



FTIR



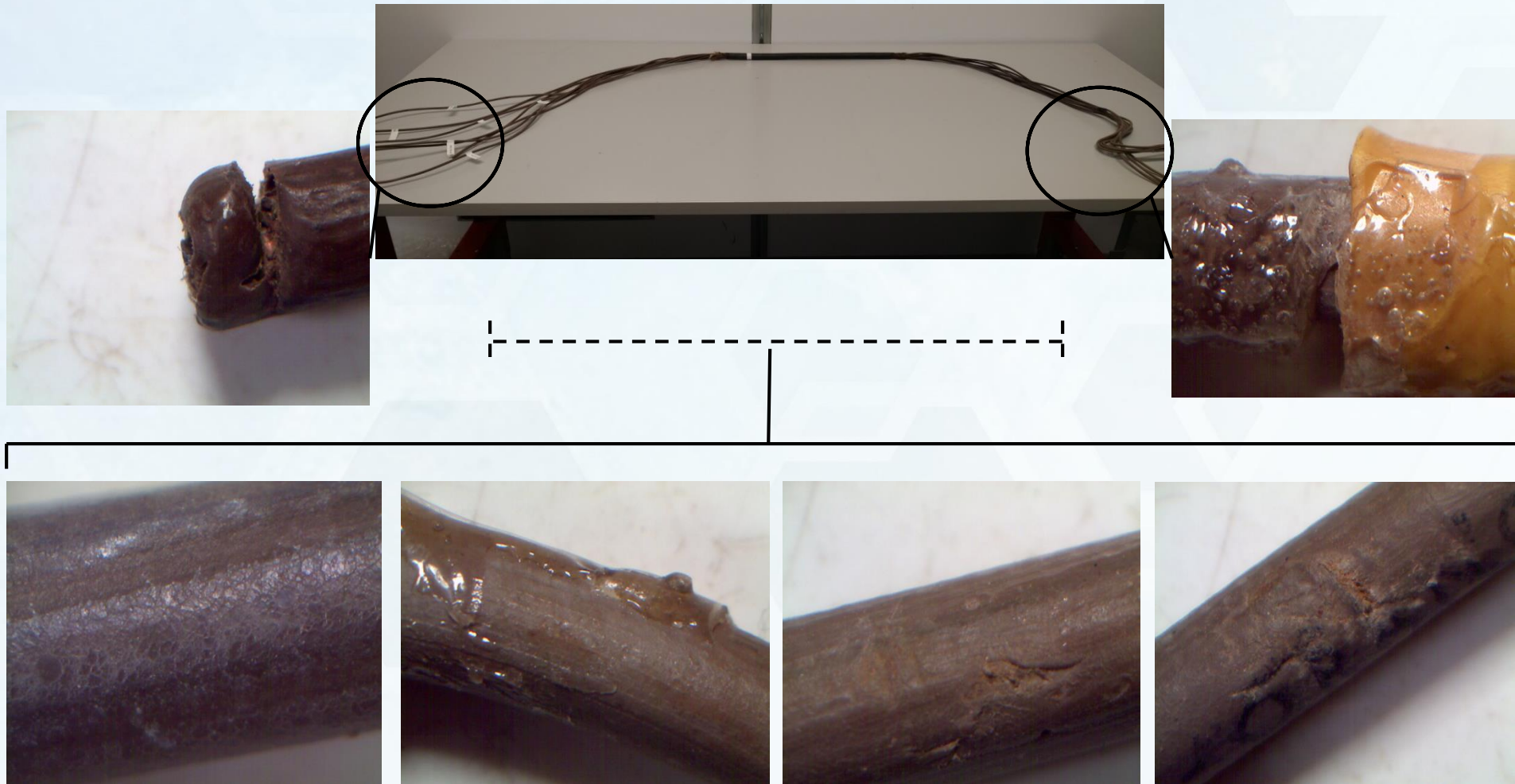


As-Found Test Results



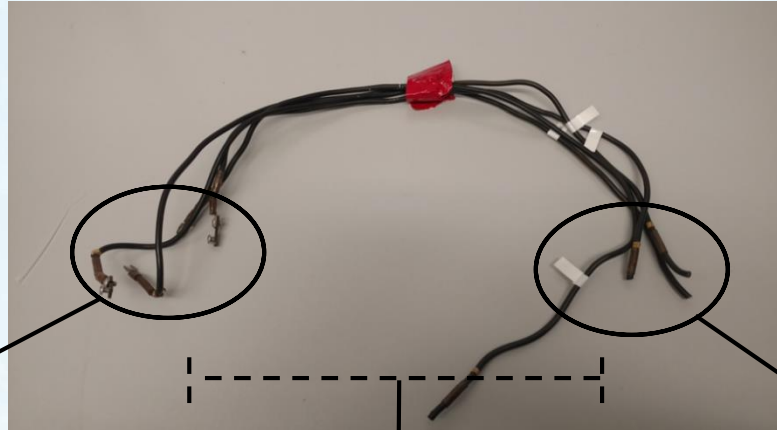
Results of Visual and Microscope Inspections (PC113)

PC113



Results of Visual and Microscope Inspections (PC95)

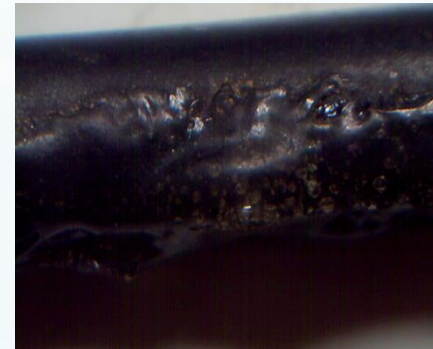
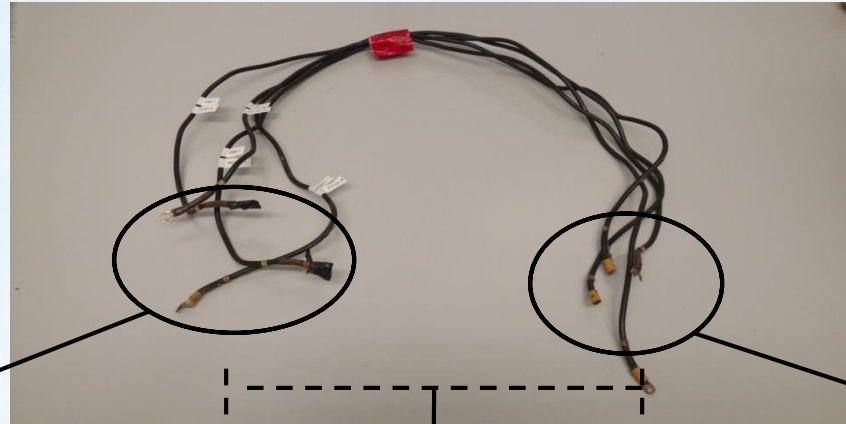
PC95





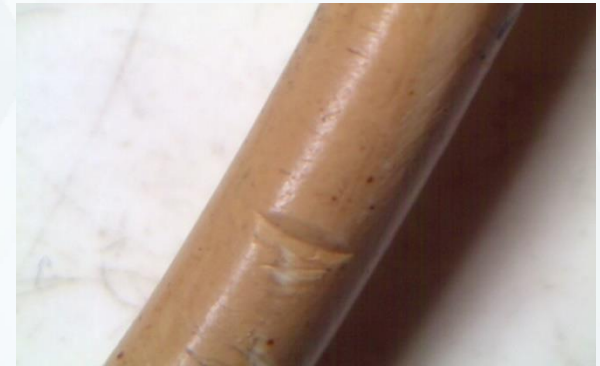
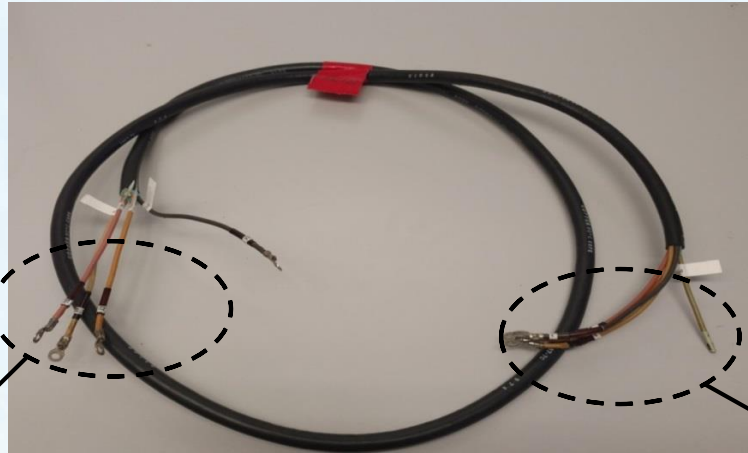
Results of Visual and Microscope Inspections (PC107)

PC107



Results of Visual and Microscope Inspections (PC107)

PC101

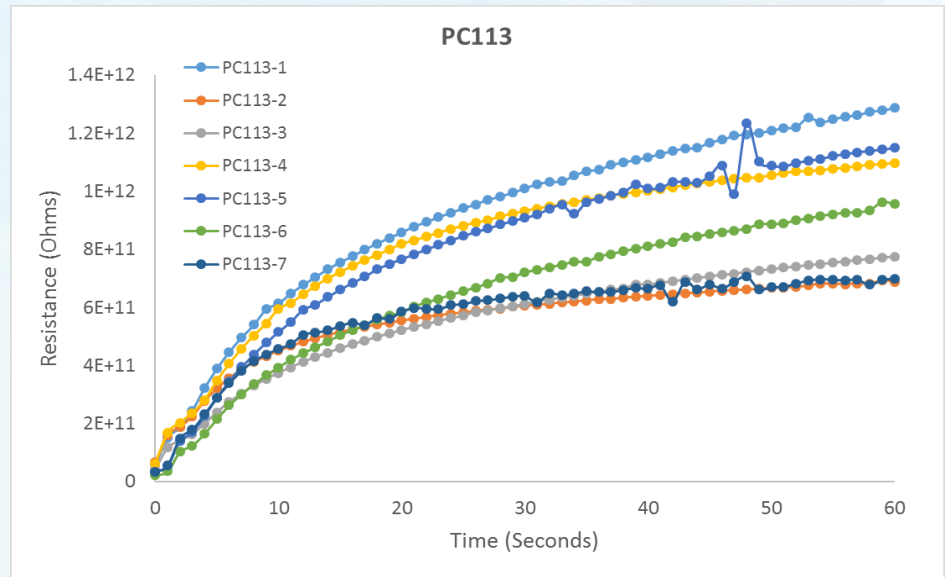




Insulation Resistance Measurements for each Conductor

One minute, 600 V insulation resistance (IR) measurements were performed for each conductor

IR results: Each of the PC95, PC107, PC101, and PC 113 conductors have IR values above 1 GOhm. No signs of insulation break down were present during the tests.



Cable ID	IR (Ohms)
PC113-1	1.29E+12
PC113-2	6.89E+11
PC113-3	7.76E+11
PC113-4	1.1E+12
PC113-5	1.15E+12
PC113-6	9.56E+11
PC113-7	7E+11

Cable ID	IR (Ohms)
PC101-1	1.02E+13
PC101-2	1.58E+11
PC101-3	7.16E+11
PC101-4	1.73E+13
PC101-5	8.17E+12

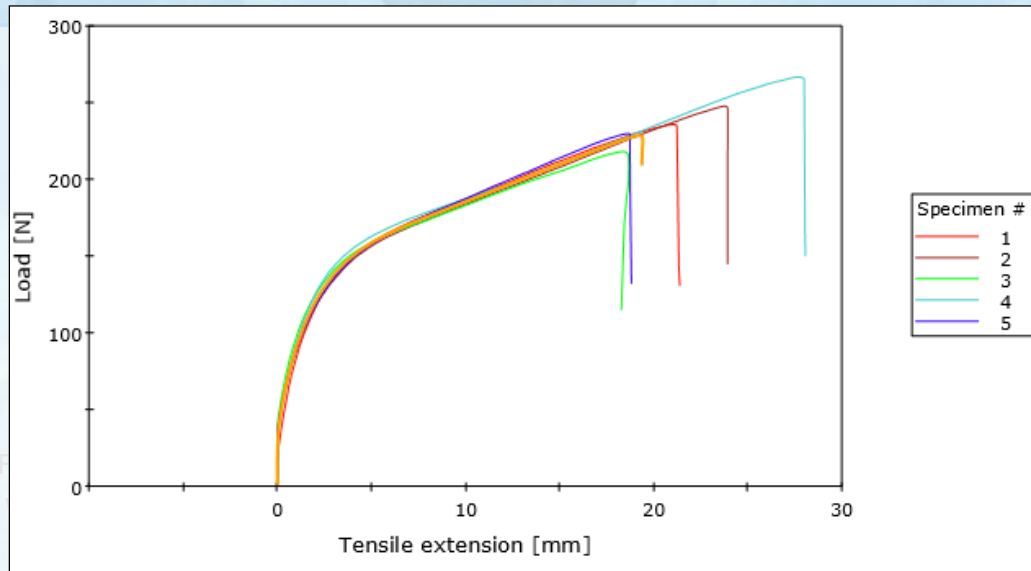
Cable ID	IR (Ohms)
PC107-1	3.33E+12
PC107-2	3.65E+11
PC107-3	2.6E+12
PC107-4	2.54E+12

Cable ID	IR (Ohms)
PC95-1	6.36E+12
PC95-2	5.99E+12
PC95-3	8.19E+12
PC95-4	7.36E+12

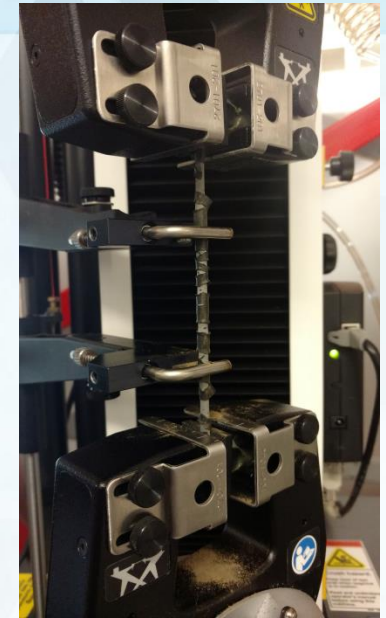


Elongation at Break Results for Each Cable

PC113



PC107



As-Found EAB results: The PC101 insulation shows no signs of degradation while PC95 and PC107 show signs of moderate insulation degradation. The PC113 insulation is approaching 50% EAB and exhibits signs of significant insulation material degradation.

Cable ID	Insulation EAB (%)
PC113	74
P95	174
PC107	188
PC101	199



As-Found Testing Results

The results of the As-Found testing indicate that:

1. PC113 has degraded significantly during operation
2. PC107 and PC95 show moderate signs of degradation
3. PC101 does not exhibit signs of insulation degradation

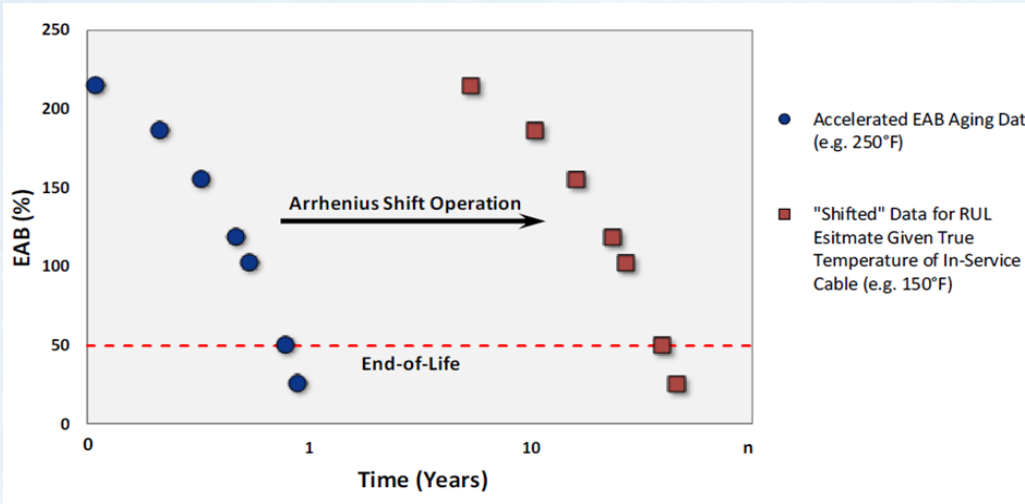
Cable ID	EAB (%)	Visual Inspections	OIT (Minutes)	Insulation Resistance
PC113	74	Insulation Surface Cracks	5.5	>100 G Ω
PC107 and PC95	181	Outer Layer Insulation Cracks	15.0	>100 G Ω
PC101	199	No Cracks	23.5	>100 G Ω



Accelerated Aging Test Results and RUL Estimations



Normalization of Aging Data to Environmental Service Temperatures Using Arrhenius Equation



$$t_1 = t_2 * e^{\left(\frac{E_a}{R}\right) * \left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

t_1 = service time

t_2 = laboratory aging time

E_a = activation energy (in kJ/mol)

R = gas constant (8.3114 J/mol*K)

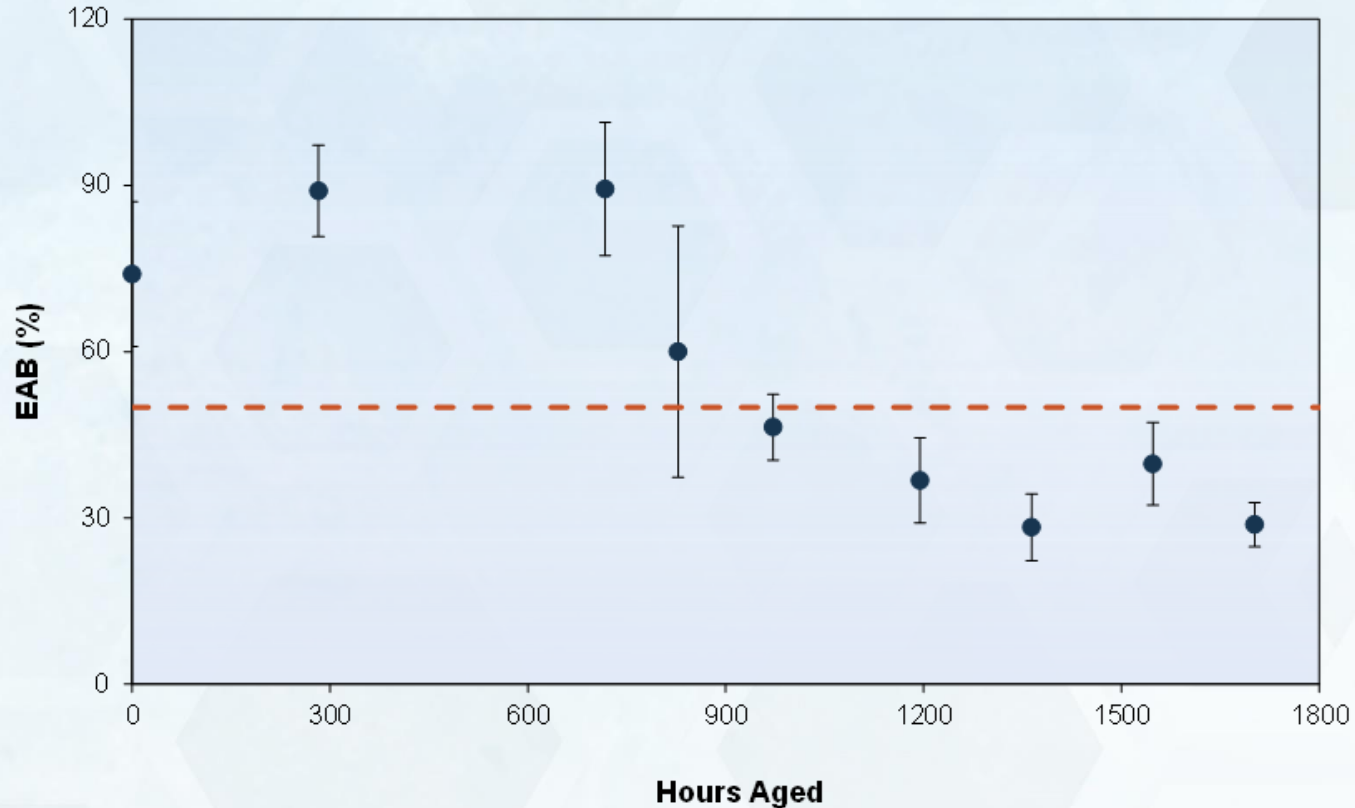
T_1 = service temperature (in Kelvin)

T_2 = lab aging temperature (in Kelvin)

Cable ID	Activation Energy (eV)	Service Temperature (°F/°C)	Aging Temperature (°F/°C)
PC113	Two values provided: 1.30 and 0.86 (0.86 is recommended by manufacturer). End of life estimations for both were provided in the report.	150/65	275/135
PC107 and PC95	0.90	140/60 and 150/65. End of life estimations for both are provided in the final report.	275/135
PC101	1.34	140/60 and 150/65	275/135



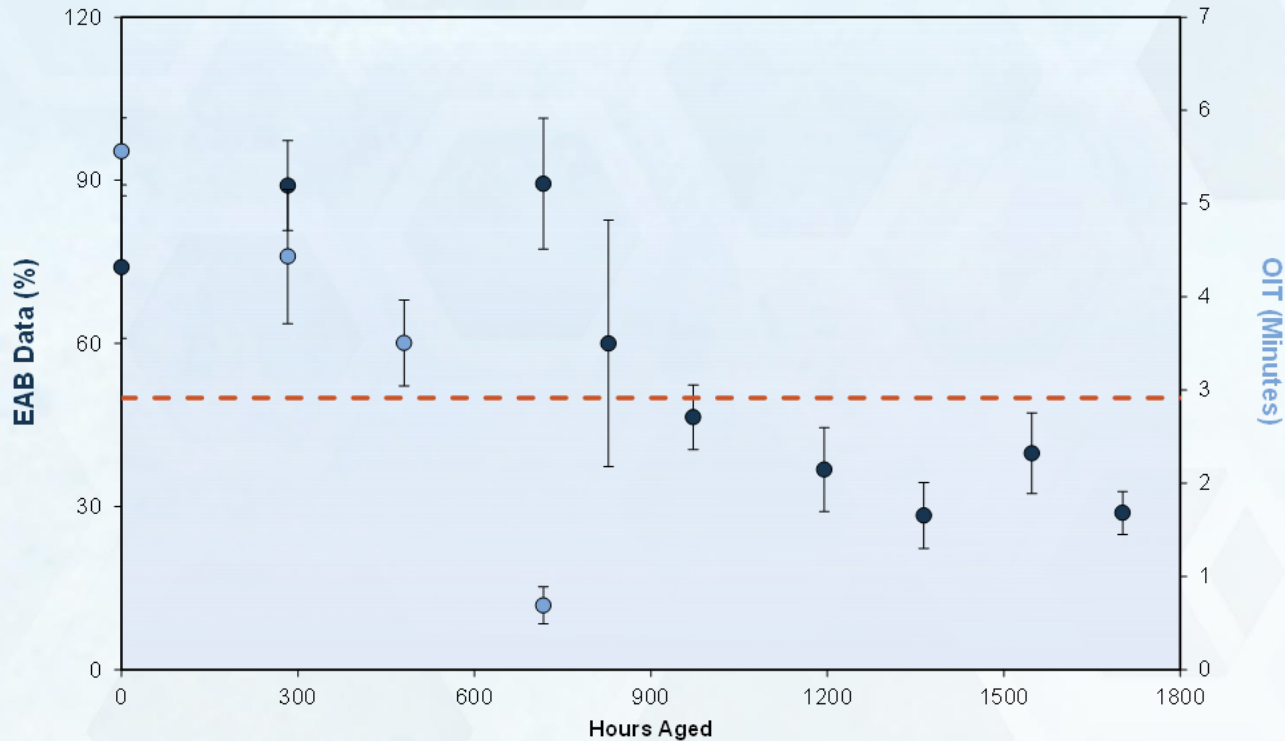
Aging Results for Pyrotrol III (PC113) Cable Insulation at 135°C (275°F)



- Each elongation at break (EAB (%)) data point is an average of three to five measurements
- The average standard deviation is +/- 10.4% EAB
- The red dashed line on the plot represents 50% EAB



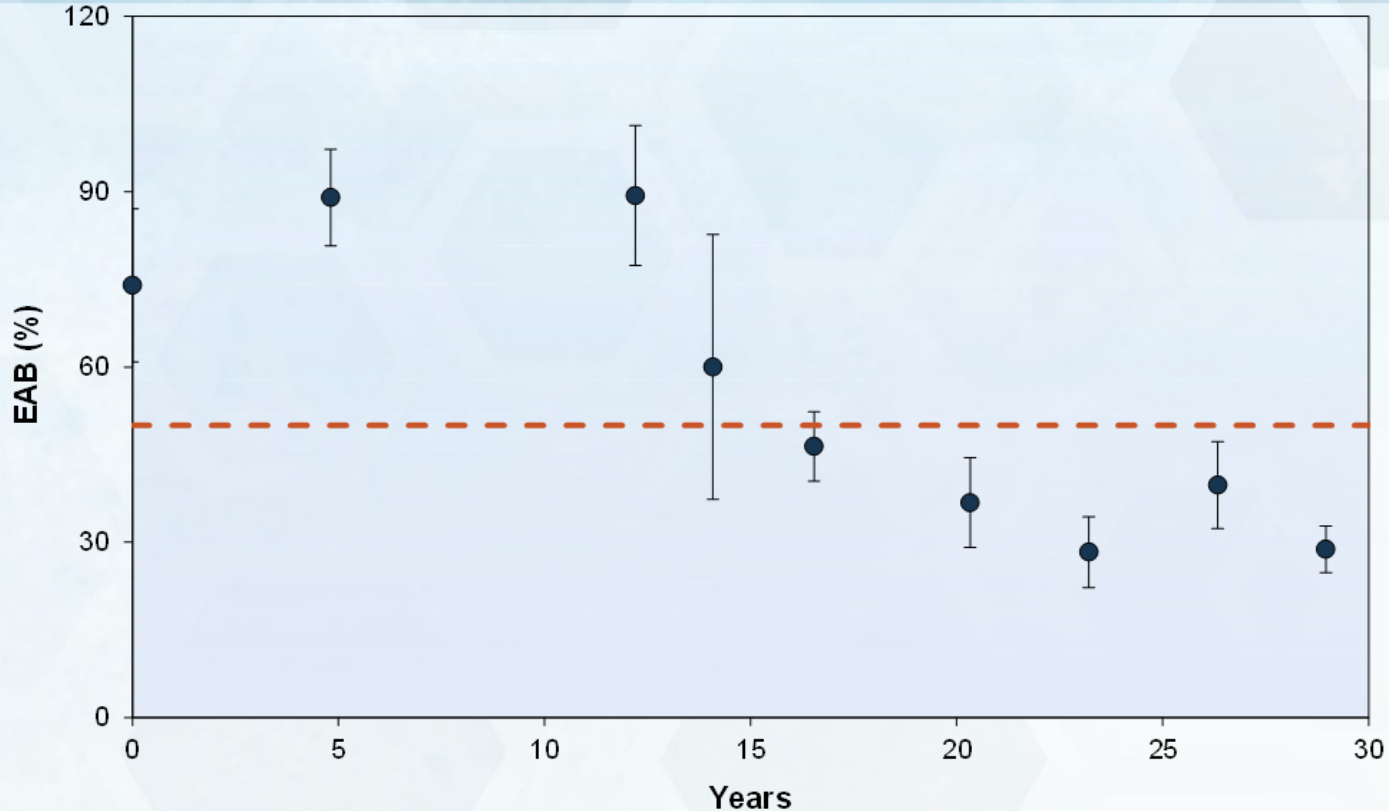
Pyrotrol III (PC113) EAB vs. OIT Cross Plot



- Oxidation Induction Time (OIT) measurements made for PC113 were conducted at 230°C
- Each OIT data point contains three measurements
- Six minute baseline OIT indicates degradation has occurred to PC 113 during operation (Unaged XLPE is typically above 40 minutes at 230°C)
- OIT for PC113 rapidly decreases during the first 800 hours of aging. Indicates early portions of aging process



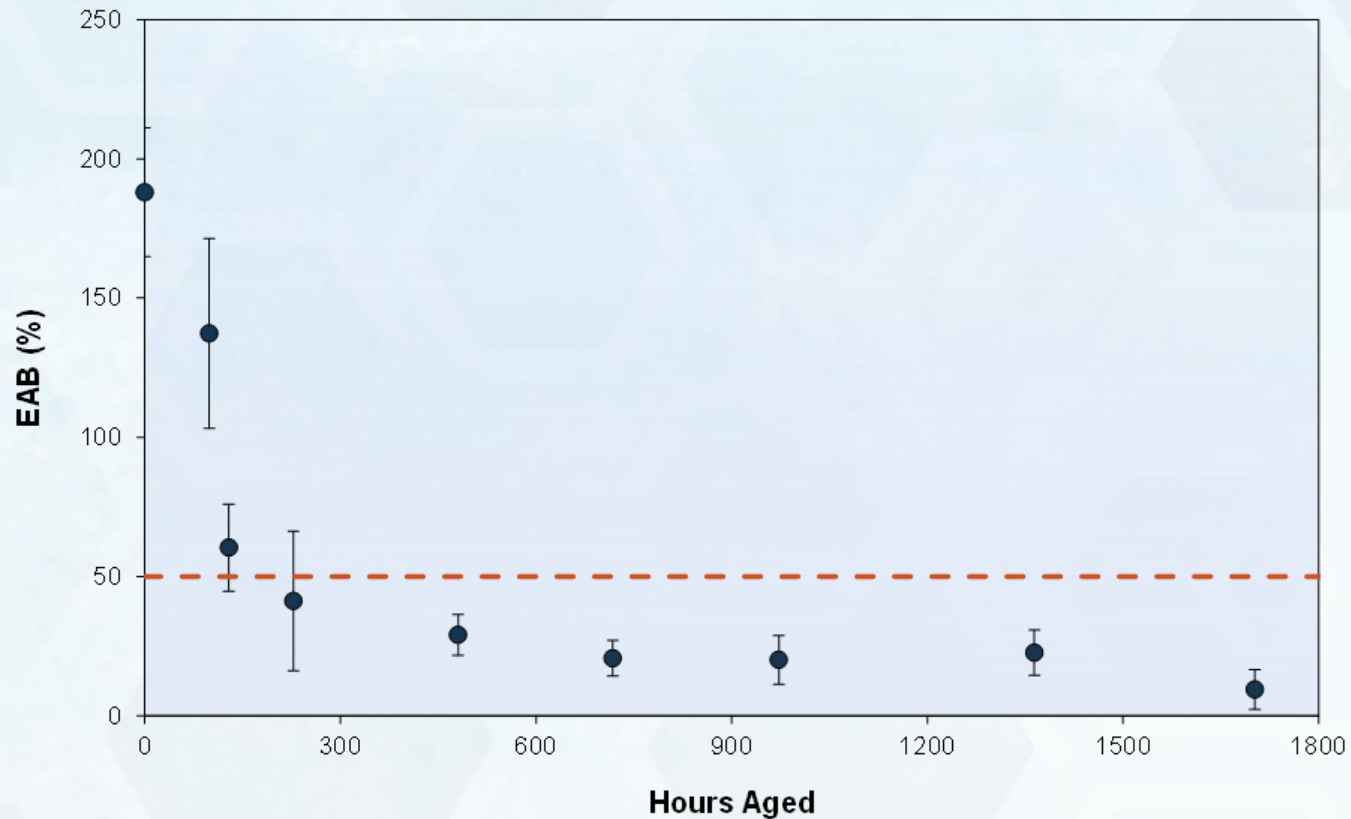
Pyrotrol (PC113) RUL (150°F and 0.86 eV Activation Energy)



- Arrhenius EAB data is determine using 150°F operating temperature and 0.86 eV activation energy
- Based on results, the PC113 cable insulation will be below the 50% EAB end of life condition in the next fifteen years, which is less than the extended operating life of a nuclear power plant.



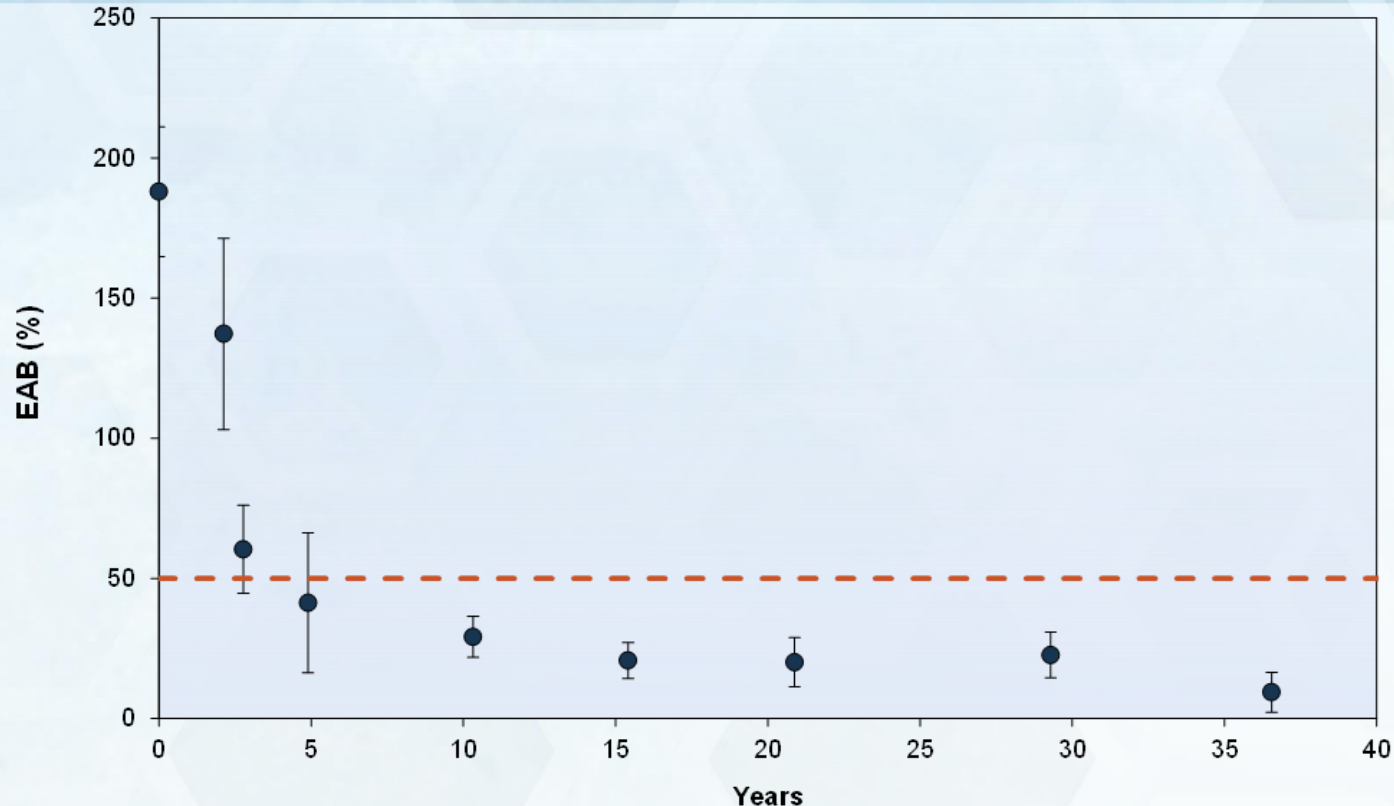
Aging Results for Flamtrol (PC95/PC107) Cable Insulation



- Each elongation at break (EAB (%)) data point is an average of three to five measurements
- The average standard deviation is +/- 12.3% EAB
- The orange dashed line on the plot represents 50% EAB



Flamtrol (PC107/PC95) RUL (150°F and 0.90 eV Activation Energy)

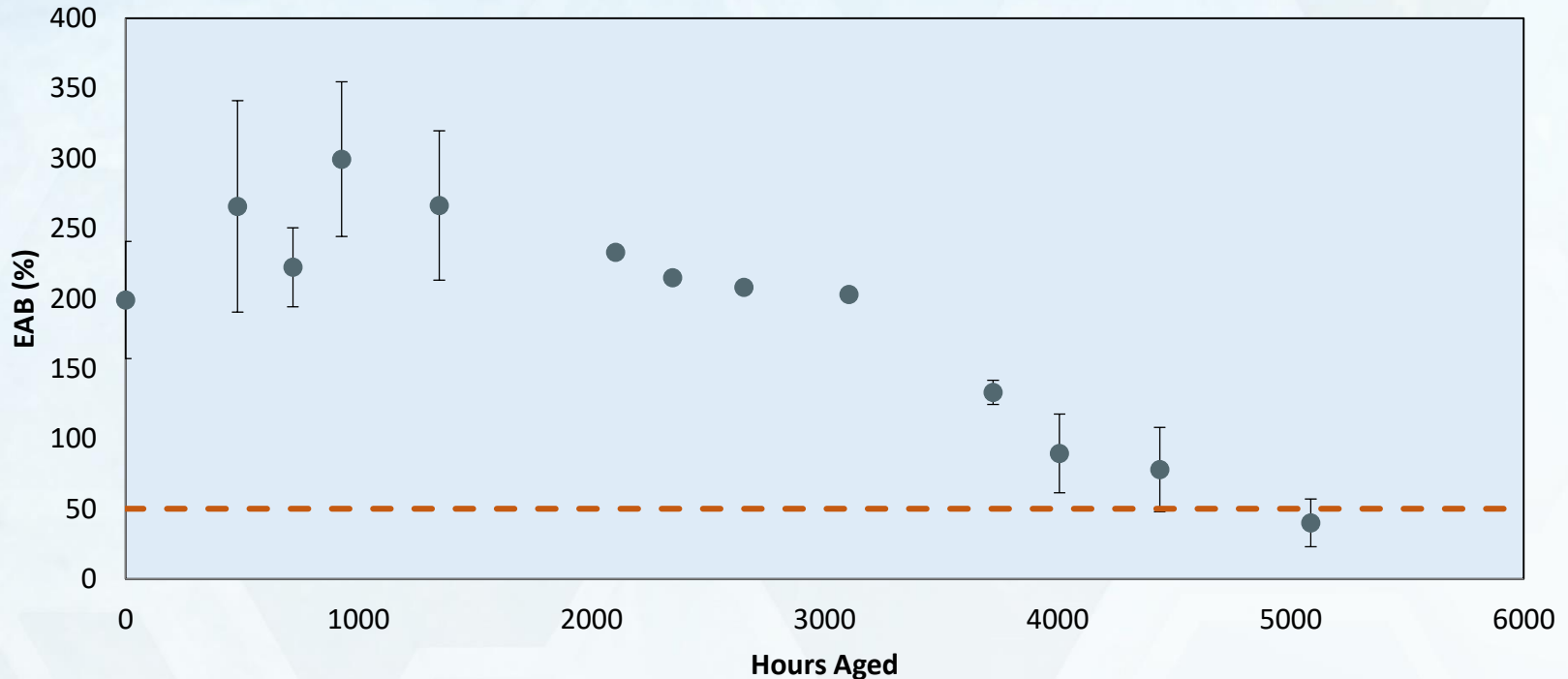


- Arrhenius EAB data is determine using 150°F operating temperature and 0.90 eV activation energy
- Based on results, the PC107/PC95 cable insulation will be below the 50% EAB end of life condition in the next five years, which is less than the extended operating life of a nuclear power plant



Aging Results for Rockbestos Firewall III (PC101) Cable Insulation

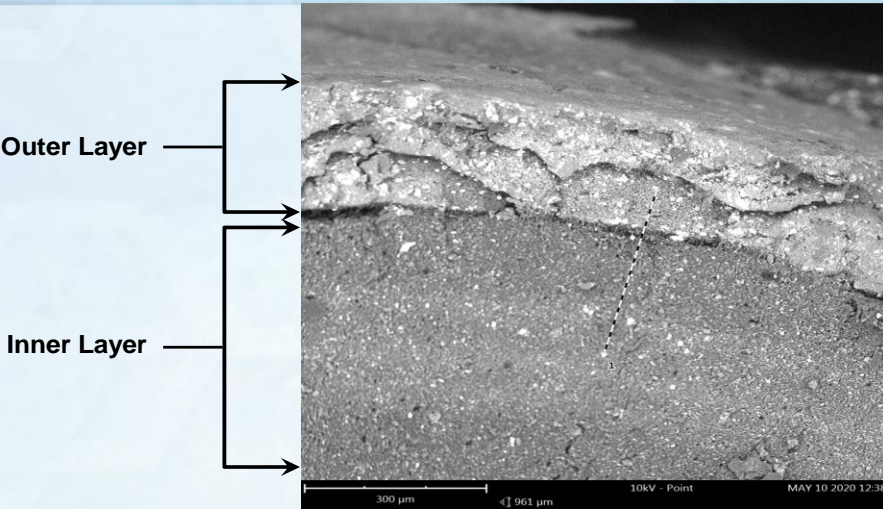
PC101 (Rockbestos Firewall III)



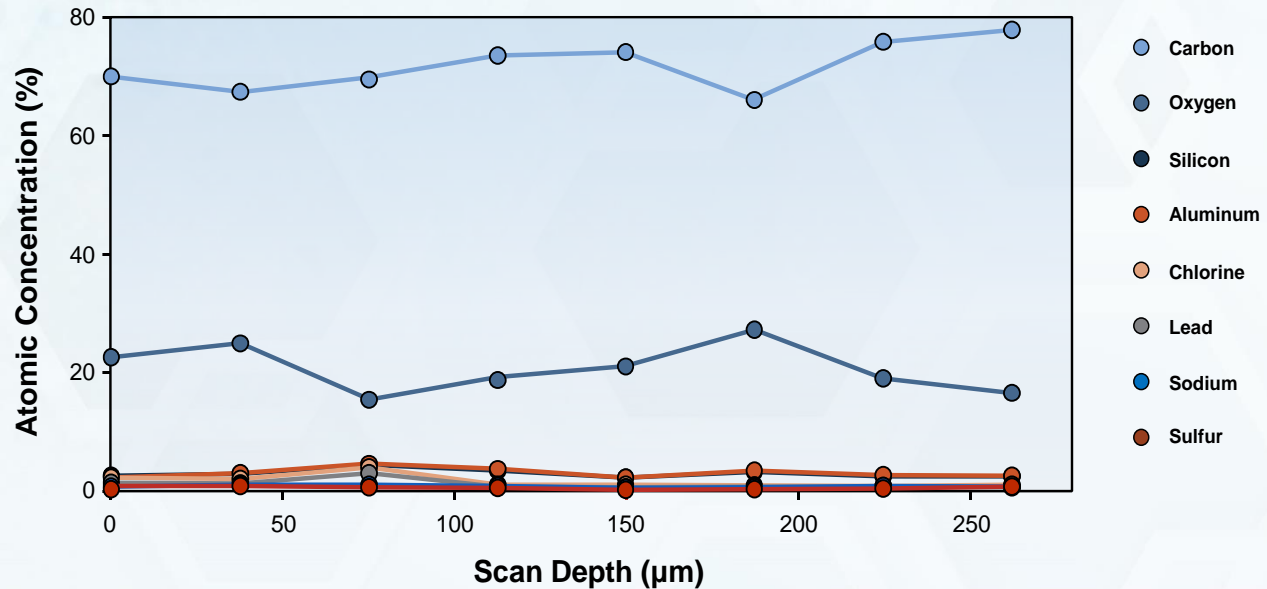
- Arrhenius extrapolation of this data to a 150°F operating temperature using a 1.34 eV activation energy showed that this cable insulation would not reach its end if life condition for an additional 50 years of service in the plant.



Flamtrol (PC107) SEM/EDS Baseline Results



Indicates that the material (based on plant information) is most likely Flamtrol
EDS shows no variation between layers





Summary of Test Results

		AS FOUND RESULTS			END OF LIFE ESTIMATIONS
Cable ID	EAB (%)	Visual Inspections	OIT (Minutes)	Insulation Resistance	Time Remaining Before Insulation Reaches End of Life Condition
PC113	74	Insulation Surface Cracks	5.5	>100 GΩ	15 years in 150°F (65°C) environment
PC107 and PC95	181	Outer Layer Insulation Cracks	15.0	>100 GΩ	5 years in 150°F (65°C) environment
PC101	199	No Cracks	23.5	>100 GΩ	50 years in 150°F (65°C) environment



Thank You
Questions?