INNOVATING NUCLEAR TECHNOLOGY

ANALYSIS AND MEASUREMENT SERVICES CORPORATION

Development of Cable Insulation Materials for Advanced Reactors

Presented by:

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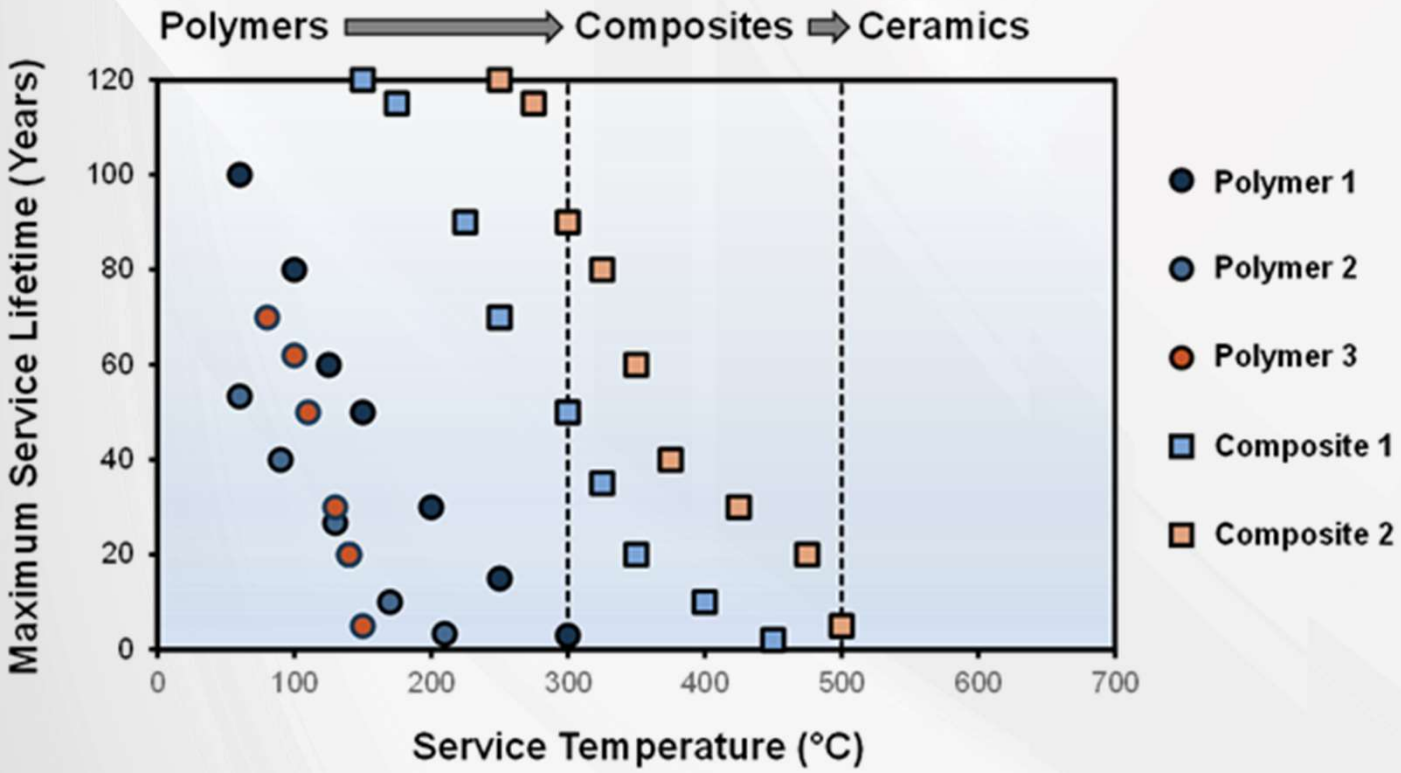
Presented to:

ASI Program Annual Review Webinar

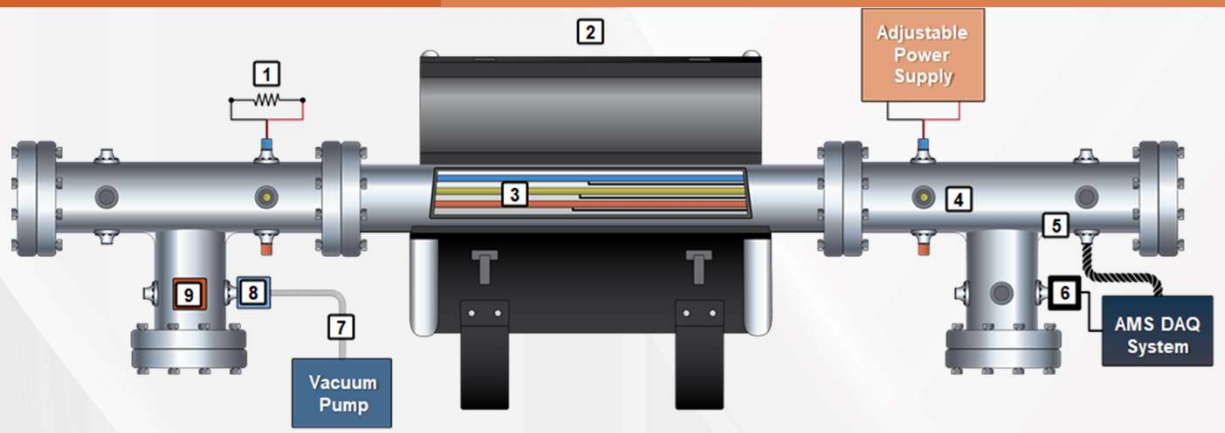
11/07/2024

R&D Overview

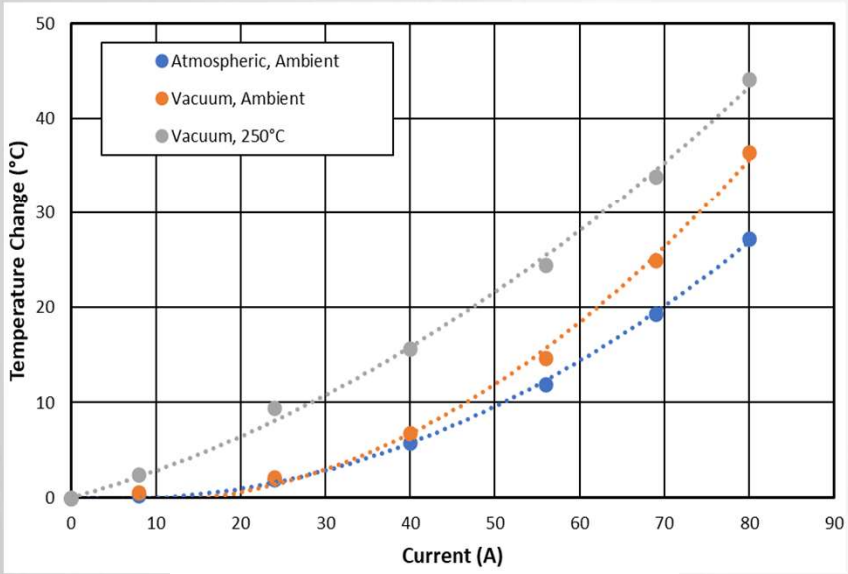
Purpose of the research: Develop guidance needed for advanced reactor developers to identify and select cable materials suitable for their operating environments.



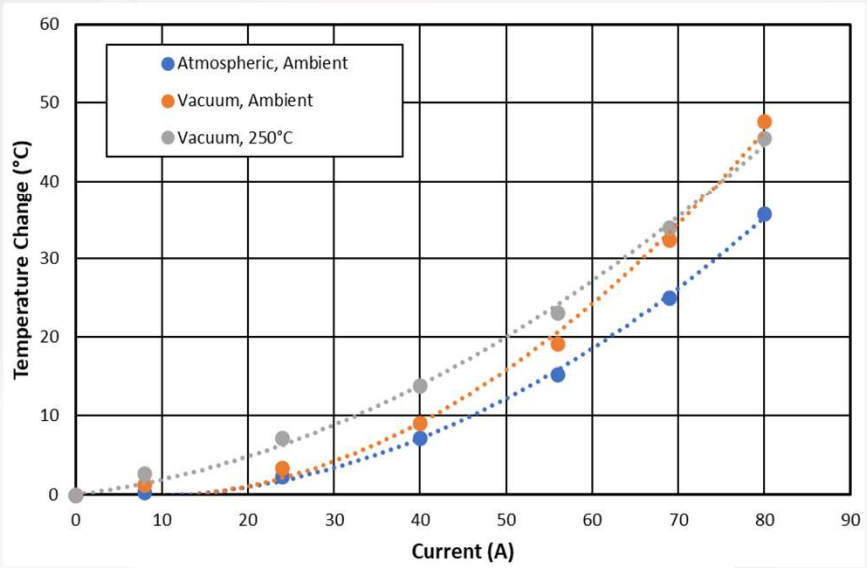
Derating Cables Under Vacuum



1 Load Resistor
2 Furnace
3 Cables Under Test
4 Cable Penetrations
5 Thermocouple Port
6 Pressure Sensor
7 Vacuum Hose
8 Solenoid Valve
9 Pressure Switch



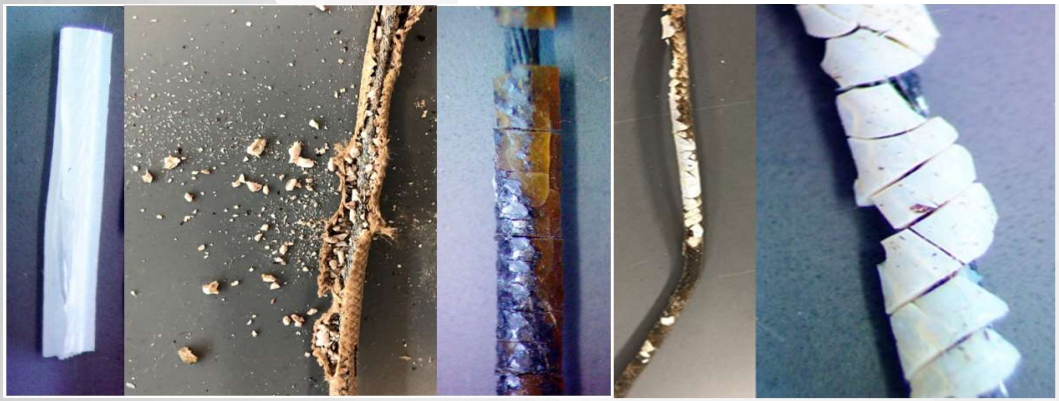
Current vs. Surface Temperature of Silicone Rubber Cable



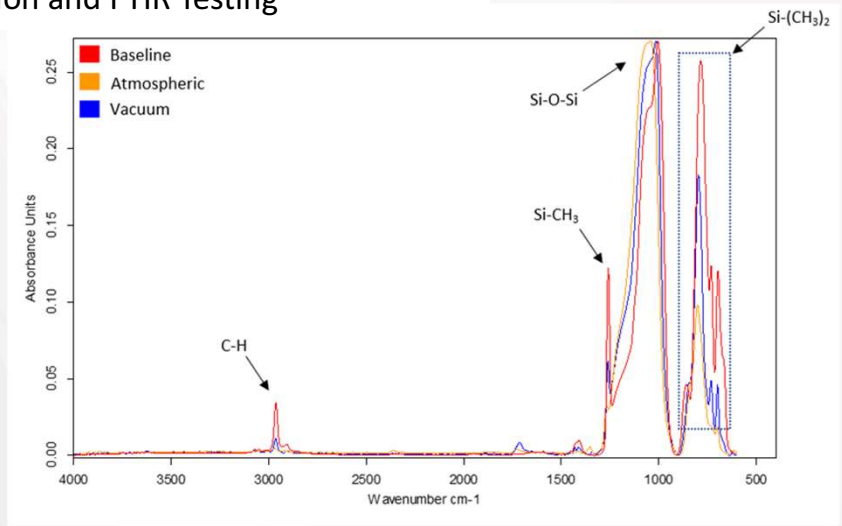
Current vs. Surface Temperature of Magnesium Oxide (MgO) Cable

Findings of Cable Derating R&D

Silicone Rubber Visual Inspection and FTIR Testing

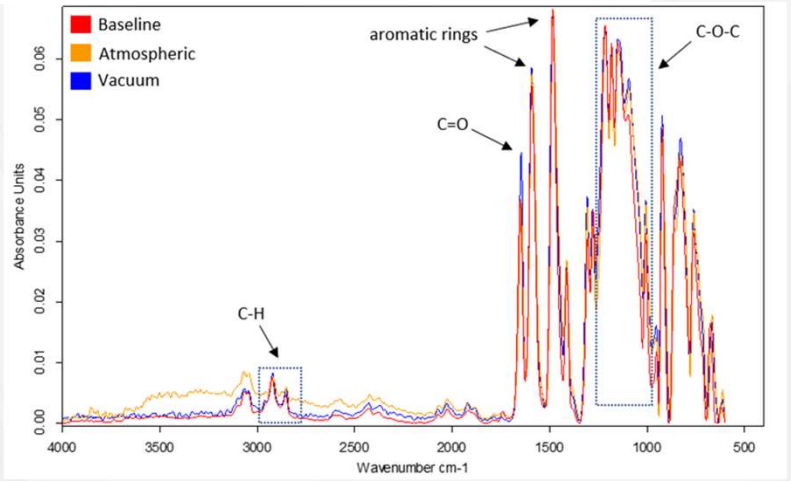


Baseline | 1,000 hours at 250°C, Atmospheric (No Vacuum) | 1,000 hours at 250°C, Vacuum



PEEK Visual Inspection and FTIR Testing

Baseline | 1,000 hours at 250°C, Atmospheric | 1,000 hours at 250°C, Vacuum



Polyimide and PEEK may be suitable for this environment.

Silicone Rubber material would need substantial changes in formulation.

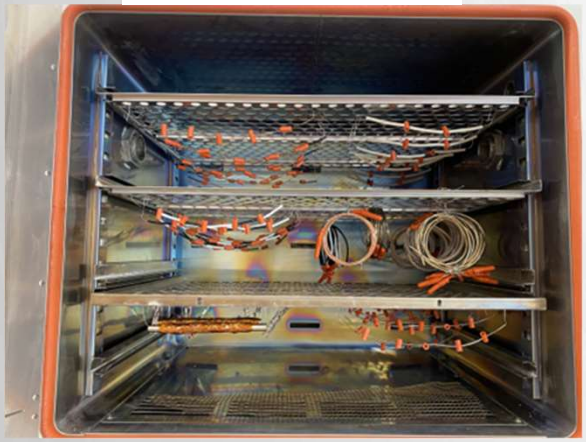
Cables in Simulated Environments of Different Advanced Reactors

Material ID	Manufacturer	Insulation	Thickness (mils)	Activation Energy (kJ/mol)	Accelerated Aging Duration at 190°C and 225°C (days)
1	A	PEEK	15	116	70
2	A	PEEK	13		
3	B	PEEK	7		
4	C	Polyimide	<5	180	
5	D	Kapton	<5		
6	E	Polycarbonate Alloy	5	N/A	98
7	A	ETFE	14	92	140

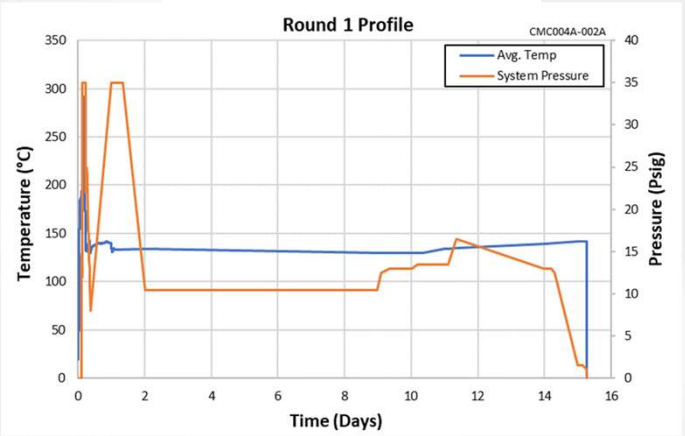
190°C - Simulated 60-years in service.

225°C - Simulated 20-years in service.

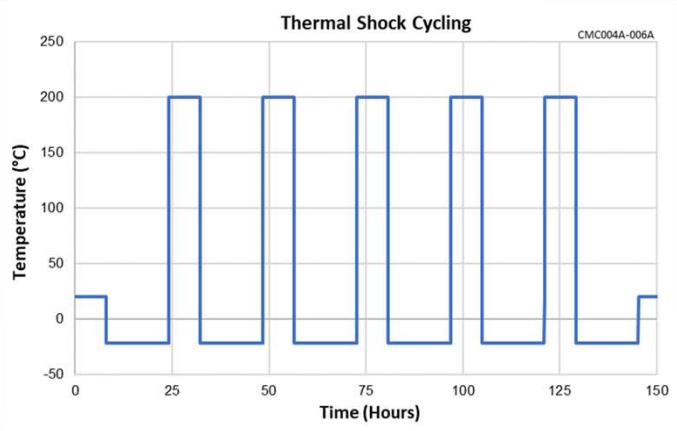
Aging Environment



DBE Simulation Profile

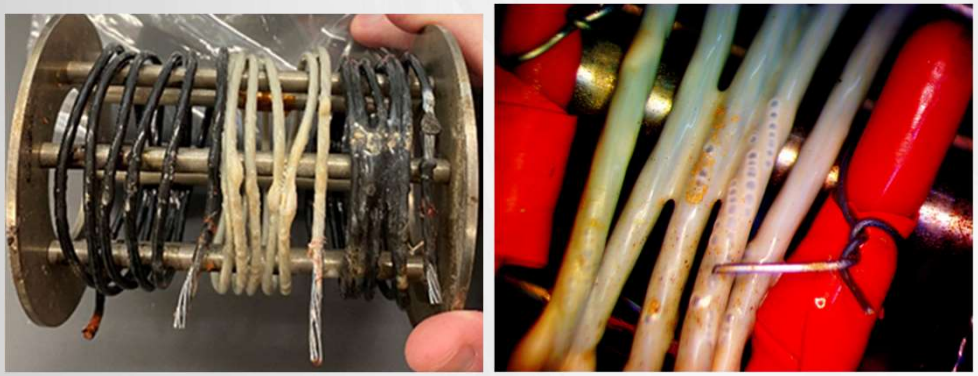


Thermal Shock Testing



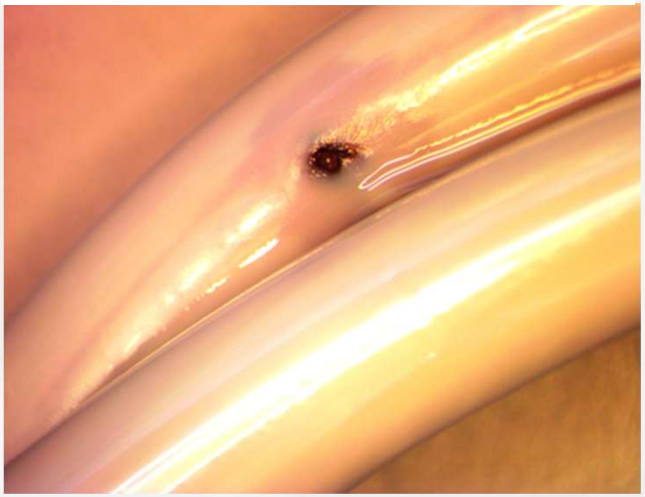
Findings of R&D

- PEEK exhibited the best performance.
  - Minimal changes in material/electrical properties during accelerated aging and DBE simulation.
- Polyimide/Kapton were minimally affected by thermal aging; however, further evaluation would be necessary due to its hydroscopic nature and DBE performance.
- The ETFE and PC alloy polymers could not withstand the simulated environments.



ETFE after 3,362 Aging Hours and DBE

PEEK after 10 thermal shock cycles



Ongoing Research

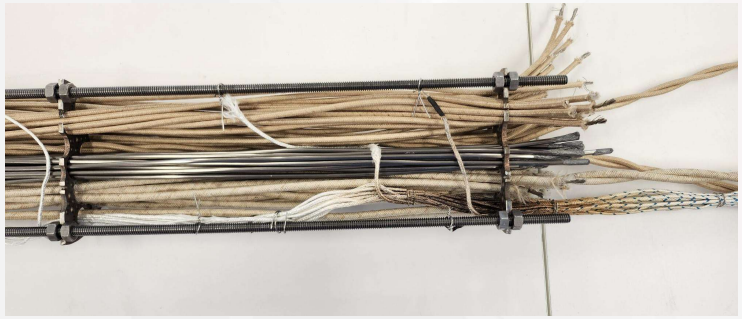
Environmental testing of composites and ceramics:

- Testing at temperatures ≥ 400ºC.
  - Materials characterization and property measurements.
  - DBE testing (steam, high pressure, elevated temperature exposure, etc.).
  - Gamma or neutron irradiation ≥ 300 MRads total dose, testing at multiple dose levels.
  - Will test samples exposed to thermal only, sequential thermal-radiation, and radiation only.
- **Testing of polymers is being performed following similar testing strategy at 250ºC.**

Material ID	Manufacturer	Insulation Type
1	F	Mica
2	F	Mica/Glass Composite
3	F	Mica
4	F	Silicone Rubber
5	G	Magnesium Oxide (MgO)
6	A	PEEK
7	E	Mica

Thermal Testing of Cable Insulations

Ceramic and Composite insulations at ≥ 400ºC



Polymers at 250°C

Material Characterization and Property Testing

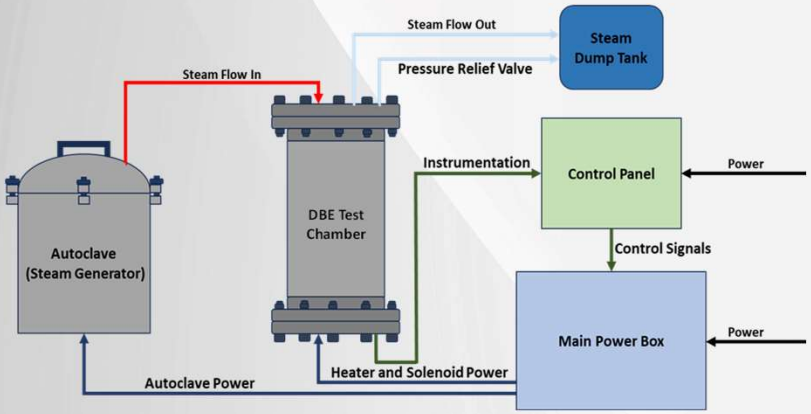
Testing performed on various sample types.

- Sample Type 1: insulation tubes
- Sample Type 2: wired insulation samples
- Sample Type 3: short (≤ 4-foot) cables in their normal configuration
- Sample Type 4: long (≥ 4-foot) cables in their normal configuration

Insulation Polymer	Number of Samples	Testing
Silicone Rubber	20 Samples of Type 2	- Tensile testing - TGA - DTA - FTIR - Density - SEM-EDS - Electrical Permittivity - Mass Spectroscopy
	9 Samples of Type 4	- DBE simulations and electrical withstand following IEEE 383 - Frequency Domain Reflectometry (FDR) - Dielectric Spectroscopy (DS) - Polarization-Depolarization (PDC)

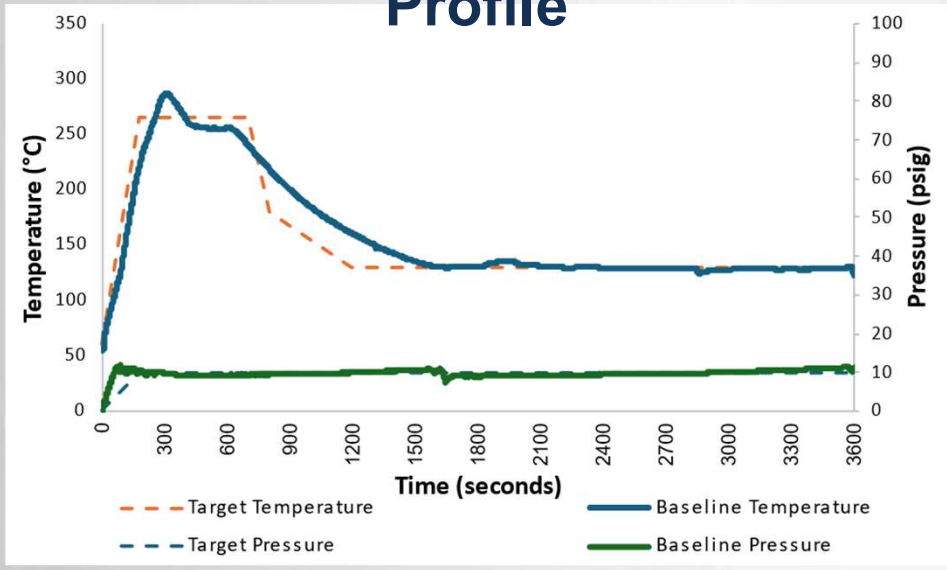
DBE Testing

Test Chamber



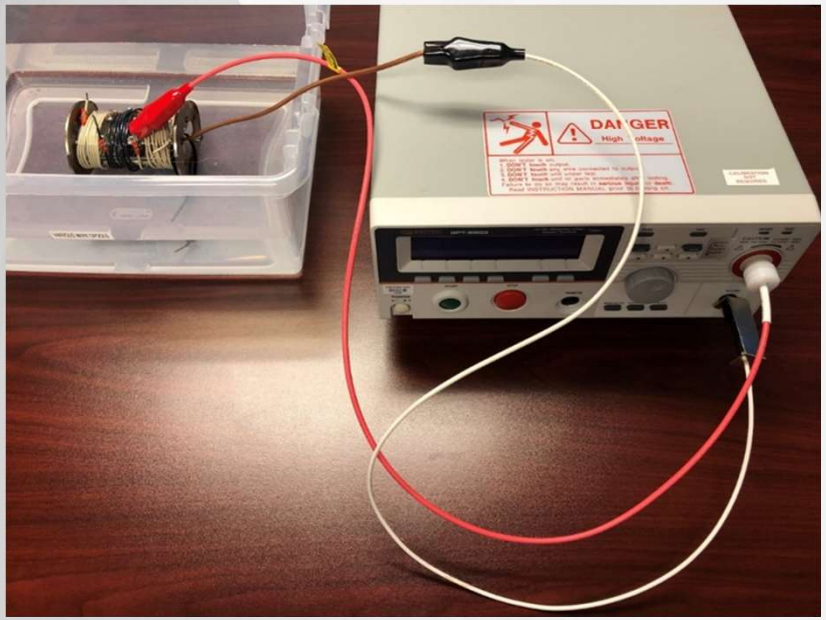
Testing performed following Standards used by the Nuclear Industry for Environmental Qualification

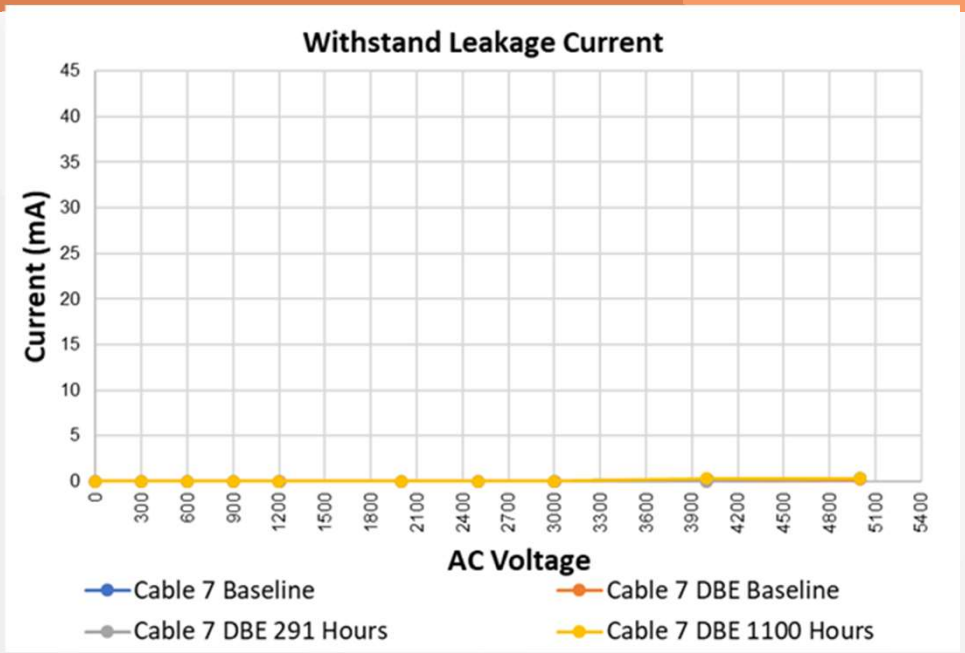
Profile



Samples

Post-DBE Withstand Testing





Material ID	Insulation Thickness (mils)	Maximum Test Voltage (VAC)
1	35	3000
2	43	3500
3	60	3500
4	83	5000*
5	15	1200
6	13	1200
7	20	1600

*Test equipment maximum voltage

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Thank You

Questions?