

Kinectrics Inc.

*Life Cycle Management
Solutions*

*Medium Voltage Cable
Condition Monitoring and
Qualification Considerations
(Nuclear Focus)*

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KINECTRICS

Topical Outline

Medium Voltage Cable Failures and Testing

- Nuclear Background
- Typical degradation forms
- Testing methods and results
 - *Field*
 - *Qualification/Lab*
- *Qualification Considerations*
 - IEEE 383 Elements
 - Condition Monitoring
 - Submergence

Why Do Nuclear Cables Fail?

Installation Issues:

- Misalignment
- Contamination
- Incorrect components

Aging Stresses

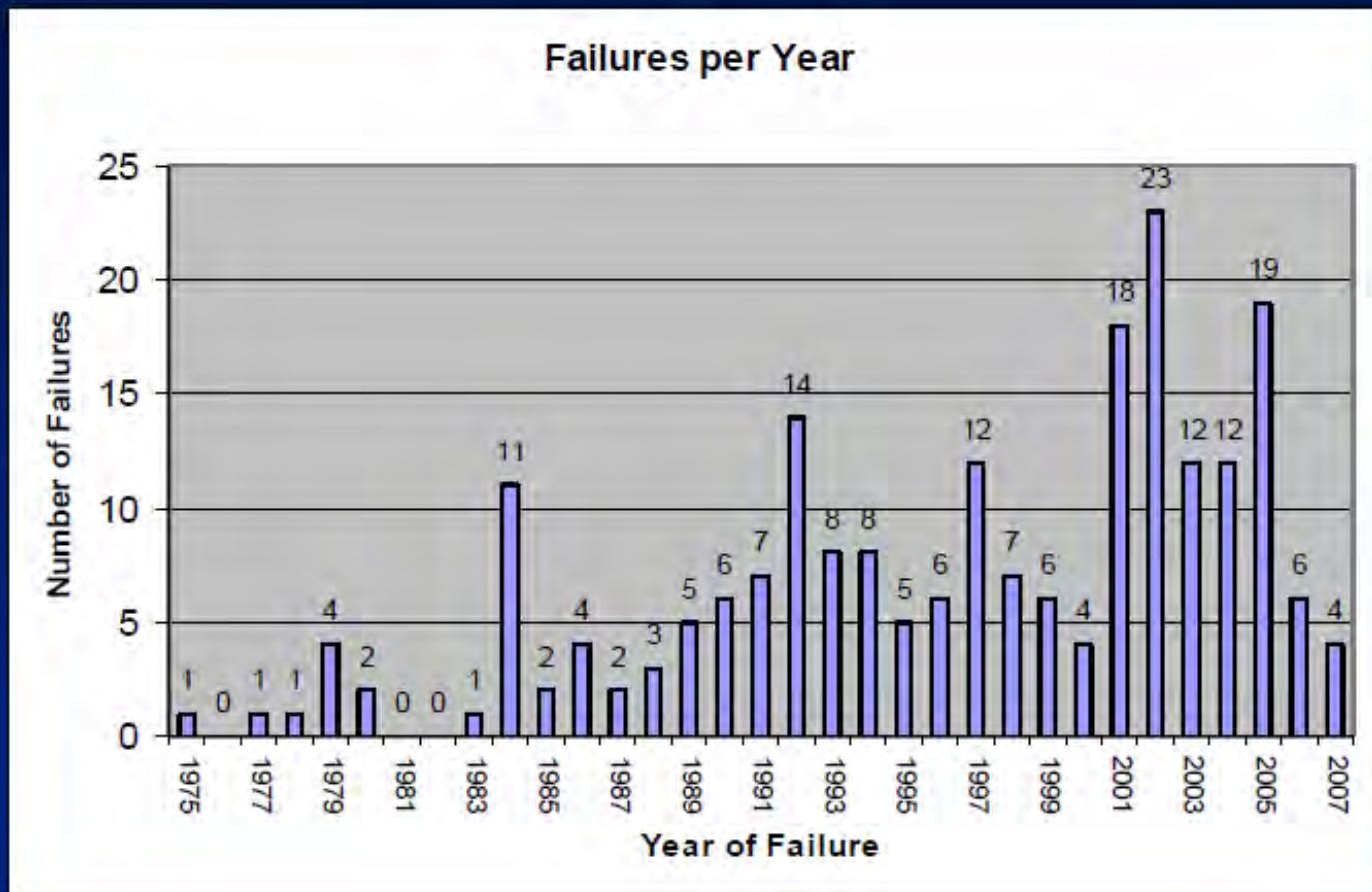
- **Electrical**
- **Thermal**
- Mechanical
- **Chemical**
- **Radiation**

⇒ Present all the time during normal operation

Failure Mechanisms

- **Electrical treeing**
- **Water Treeing**
- **Thermal Issues**
- **Radiation Aging**
- **Chemical Exposure**
- Installation Issues

NRC Eval of 2007 Data Reflects Negative Trend



NRC Summary Conclusions



Summary of Staff Review

- 269 Cable failures
- 60 % of the sites reported cable failures
- Increasing trend in cable failures
- Cables are failing within the plants' 40-year license term
- No manufacturer or insulation type is immune from failure
- Both de-energized and energized cable failures identified
- Both low voltage and medium voltage cable failures identified

NRC Summary Conclusions



Summary of Staff Review – Cont.

- Predominant factor contributing to cable failures - water/moisture or exposed to submerged conditions
- Cable failures resulted in plant transients and shutdowns and loss of safety redundancy
- Only a very few licensees have implemented a combination of diagnostic cable testing methods to identify the cable degradation at power plants

5kV and 8 kV Installed Nuclear Cables- 2006 NEI Survey

(from EPRI Cable Users Group)

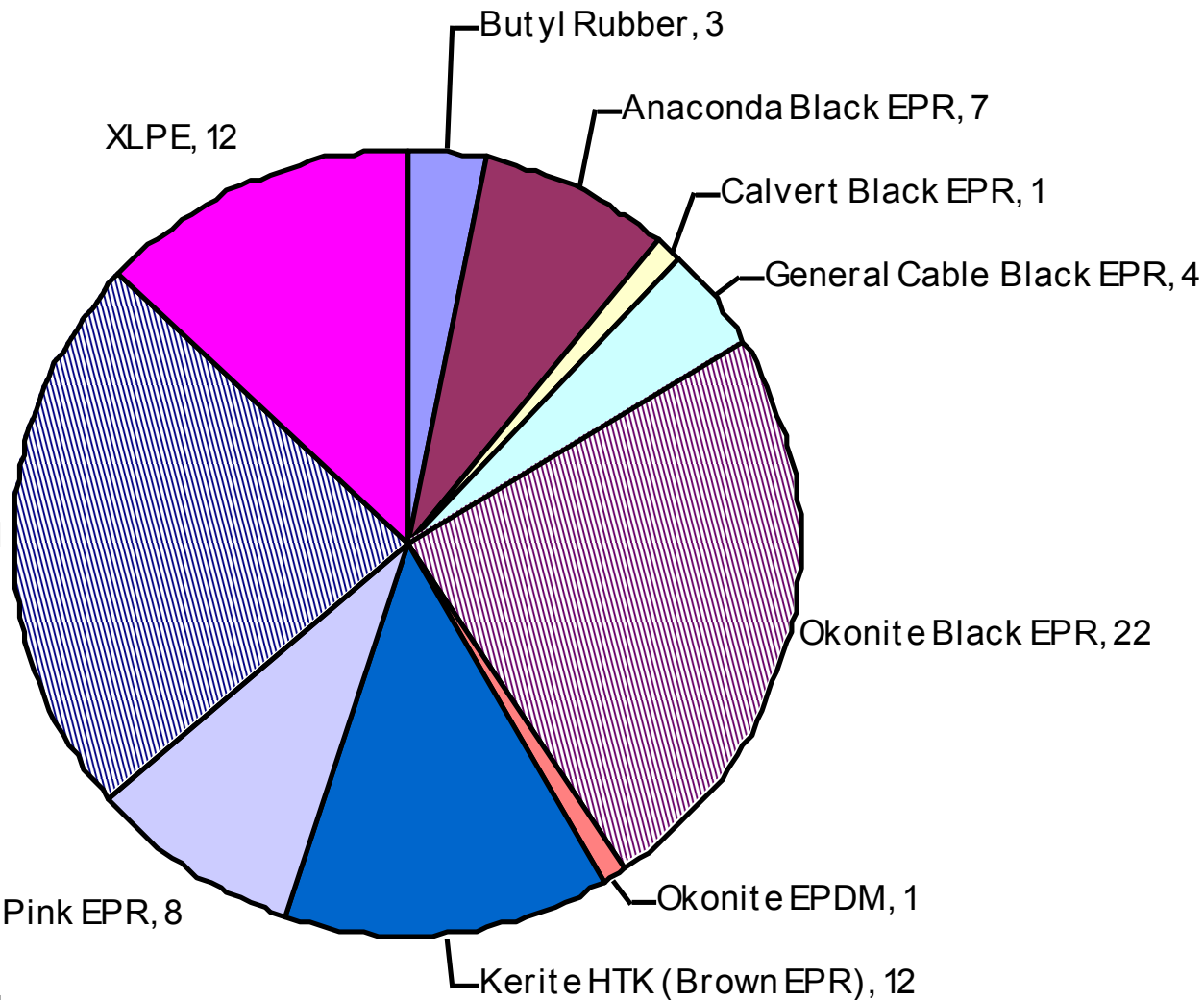
Dominant Insulation Types

XLPE – 12 Units

EPR Black – 35

EPR Brown – 12

EPR Pink -- 29



Shielded = ~80%

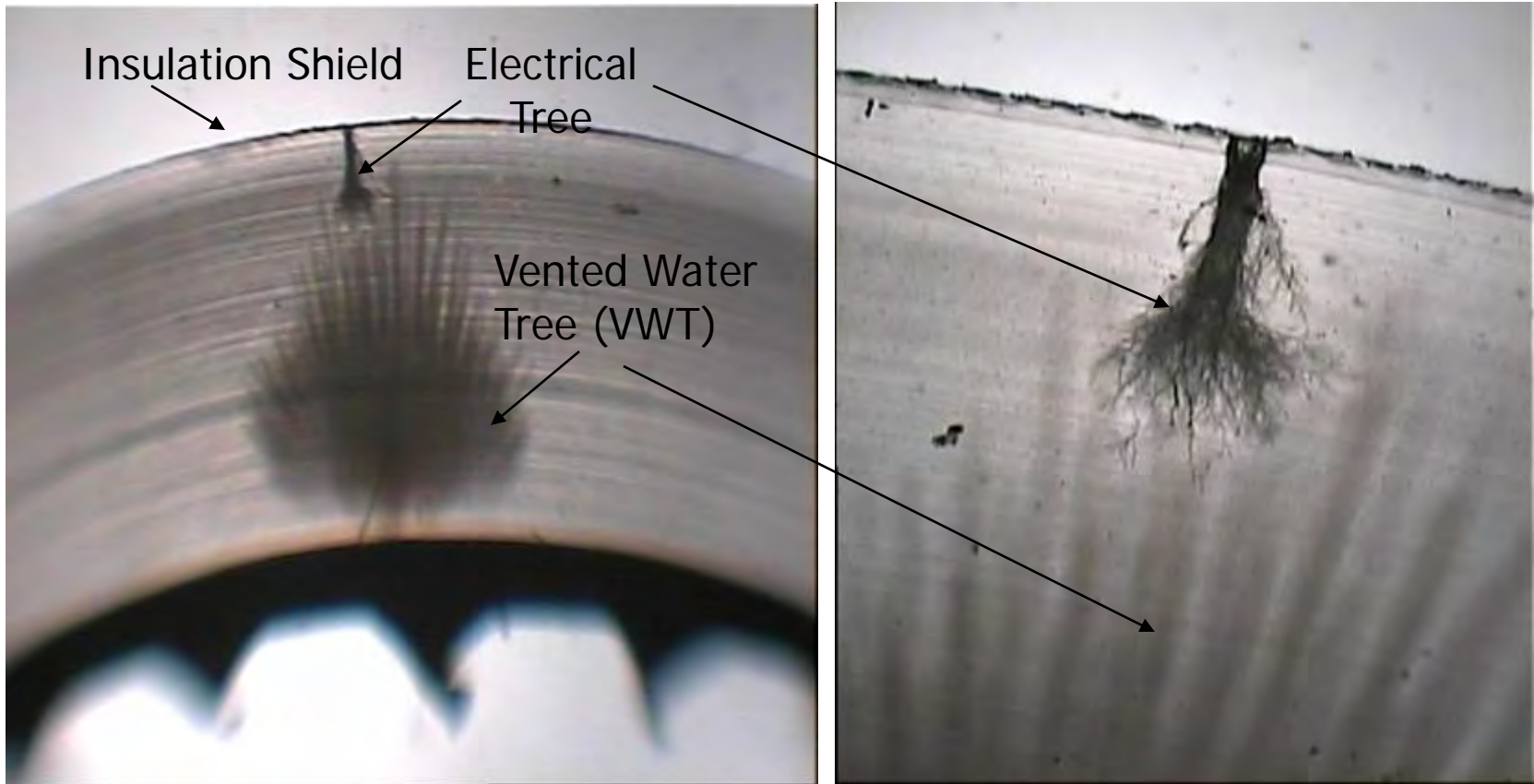
Un shielded = ~20%

Unshielded not considered testable

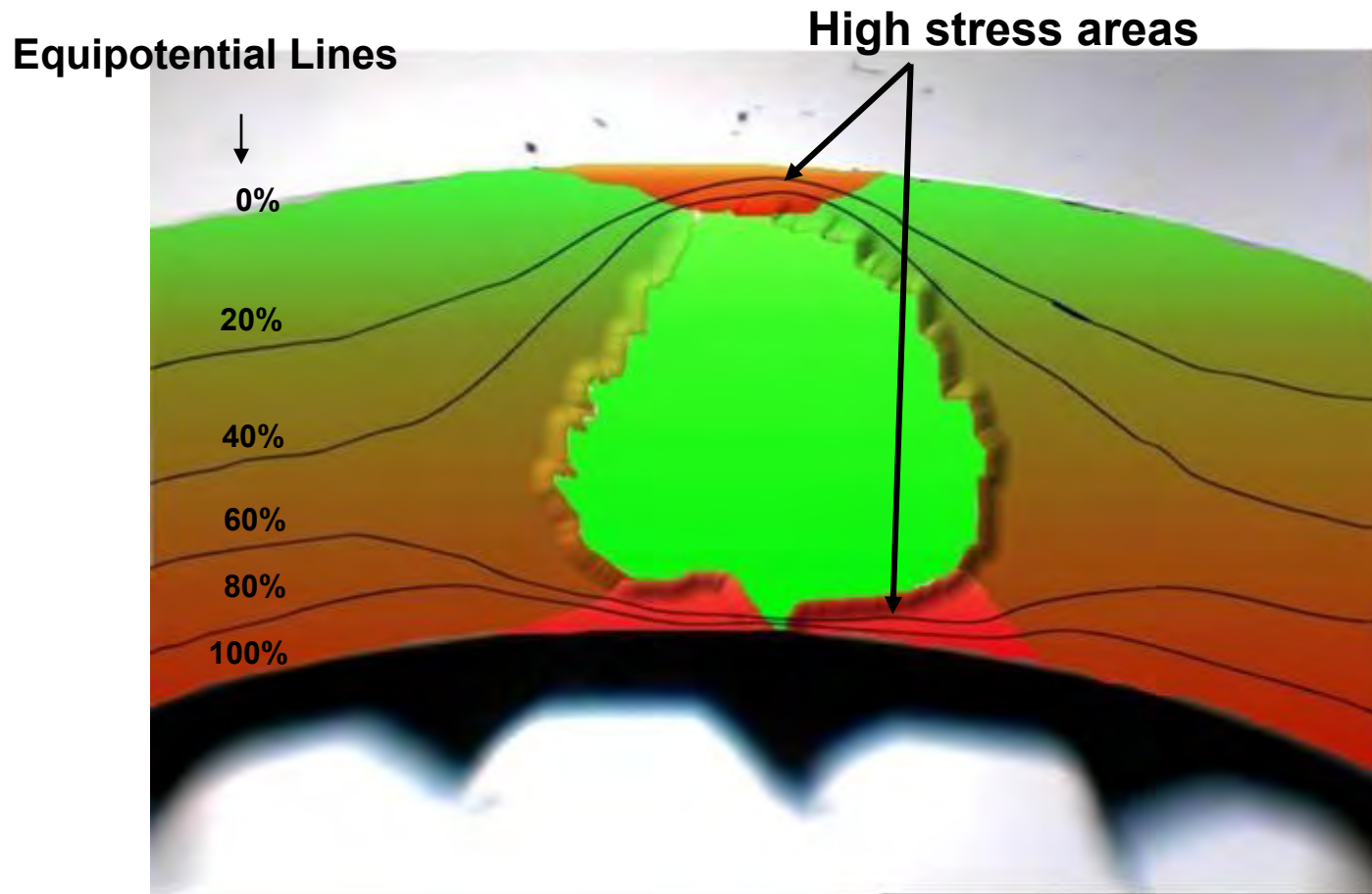
Water Trees

- A diffuse tree-line structure of water-filled microcavities 0.01 – 5mm long
- Two types of water trees:
 - *Bowtie Trees*
 - *Vented or Streamer Trees*
- The former typically originates either at a cavity, contaminant or imperfection within the insulation
- The latter typically originates at the insulation and semiconductive interfaces
- Become invisible when the insulation heats up but reappear when the insulation is soaked in warm water. Can also be dyed
- Formation requirements
 - *Moisture is present in the insulation*
 - *An electrical field is required for water trees to form and grow. However, water trees may form and grow at much lower field strengths than electrical trees*

Water Trees (XLPE)

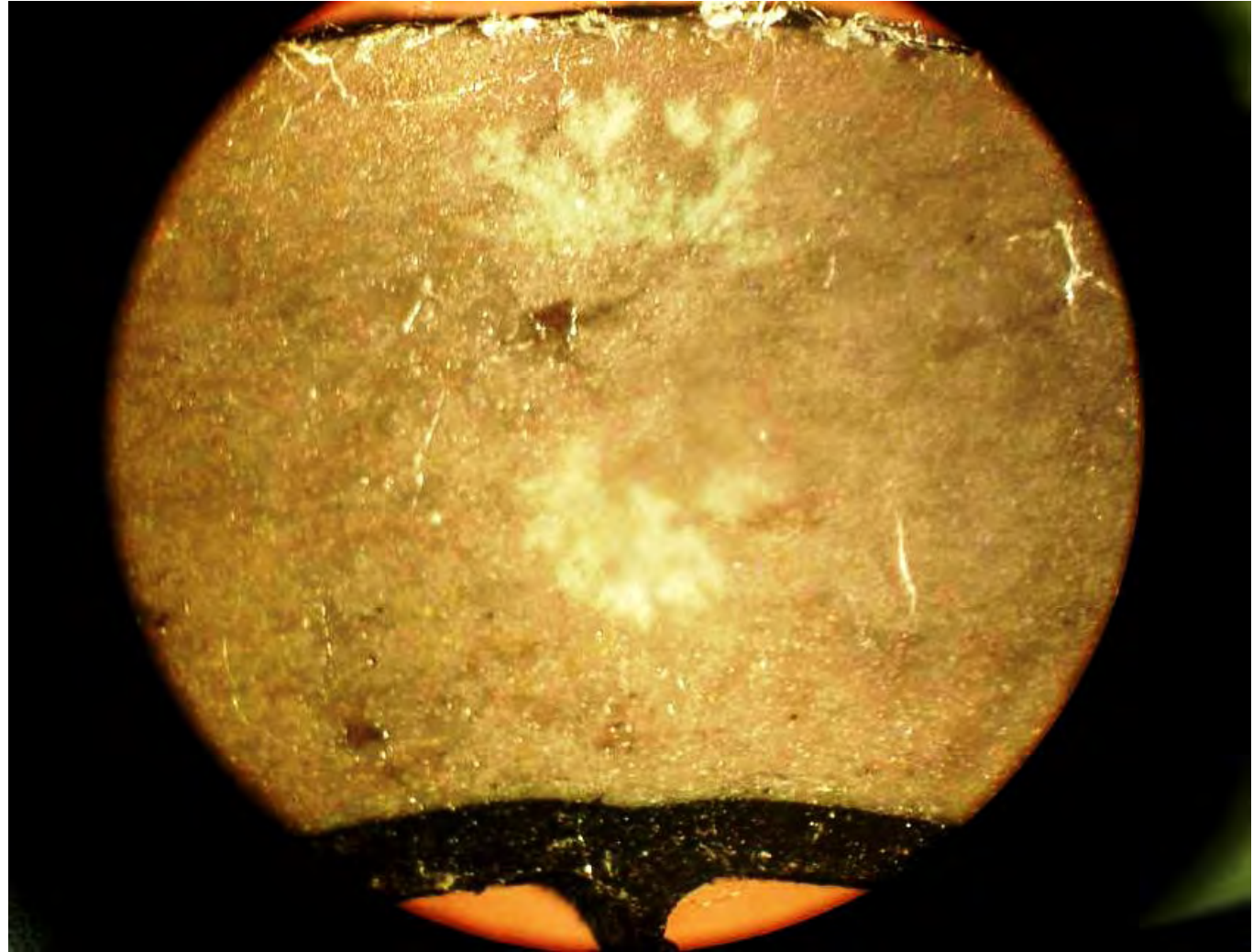


Water Trees: Field Distortion



Water Trees in Pink EPR- Bow Tie Pattern

Insulation Thickness
0.175 in



Forensic Evaluation of Failed Cable Splice

(Analysis Performed by Kinectrics)



Failed MV Cable Splice from Nuclear Station

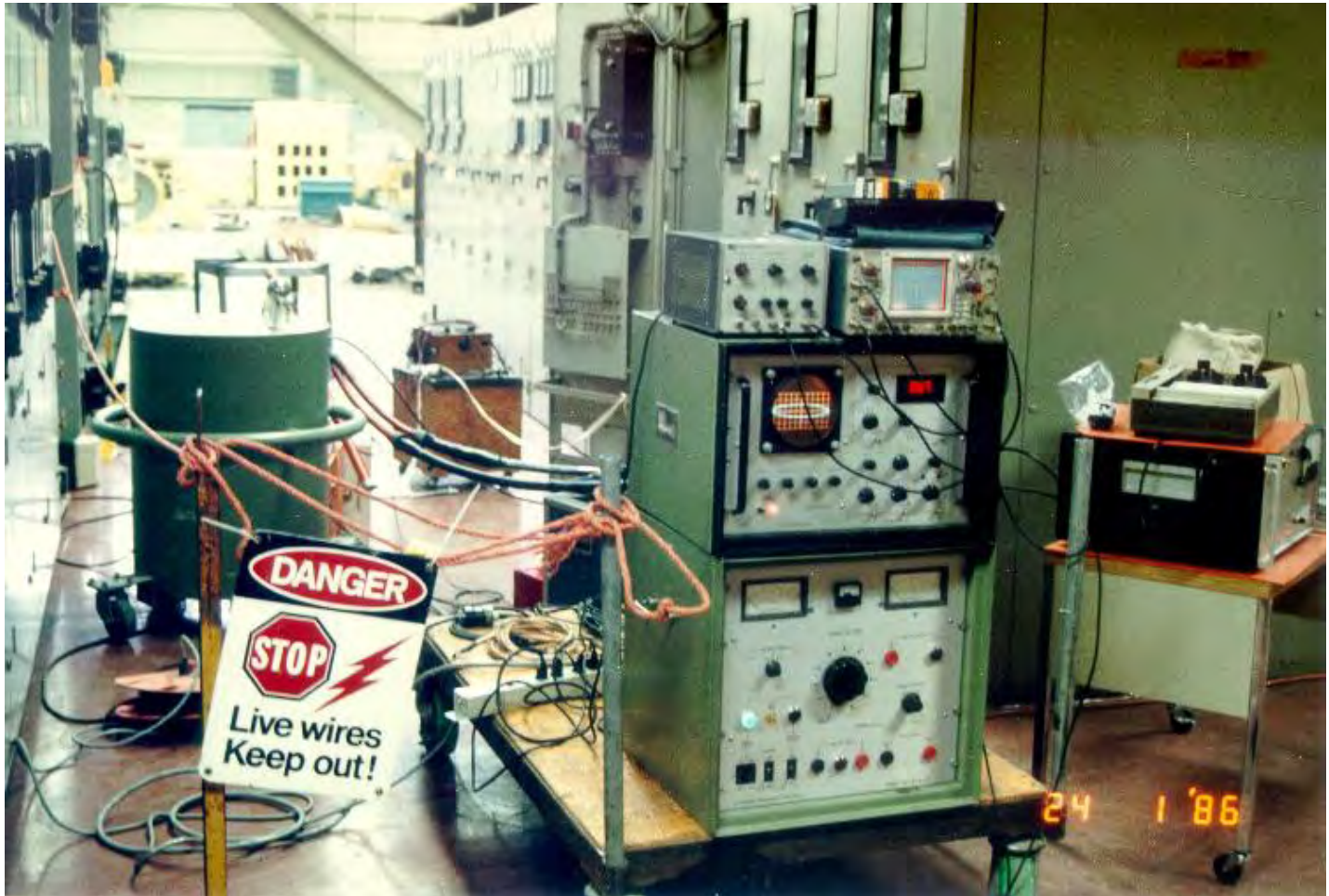
Available Tests

- DC or AC HiPot (potentially destructive)
- Insulation resistance
- Partial discharge (on- or off-line)
- Dielectric loss measurements ($\tan \delta$ or dissipation factor measured at single (0.1 Hz or 60 Hz) frequencies or multiple frequencies (dielectric spectroscopy))
- Indenter Modulus
- Near infra-red spectroscopy (NIR)
- Other technologies in development

AC HiPot and Partial Discharge Test

- Potentially destructive test
- Subjecting insulation to over potential for a given period of time
- Recommended high potential test level ranges from $1.7U_0$ and upwards
- Finds installation defects
- Can find weak points in aged cables (including splice)
- High potential voltage applied from 5 minutes to 60 minutes
- Often followed by an off-line partial discharge test

AC HiPot & PD Test Equipment



Dielectric Loss Measurements

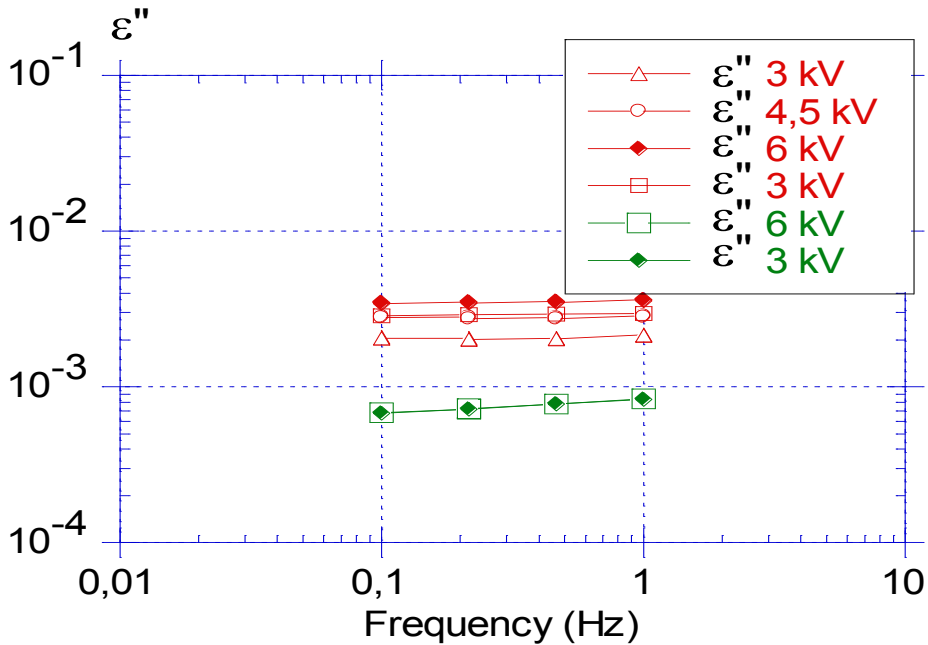
- Measurement of dielectric loss can provide quantitative assessment of void content similar to PD testing
- However, the dielectric loss also provides information on bulk effects due to thermal ageing and water treeing that are not amenable to PD measurements
- Dielectric loss measurement techniques include,
power frequency dissipation factor ($\tan \delta$)
dielectric spectroscopy (multi-frequency dissipation factor)
polarization/depolarization methods, e.g., recovery voltage

Dielectric Spectroscopy

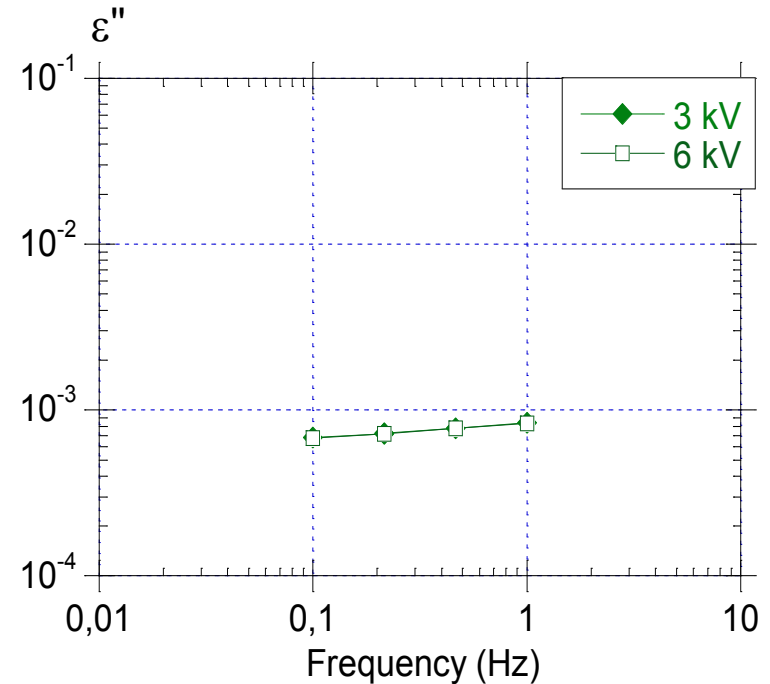


Dielectric Spectroscopy: Two Examples

Degraded Cable



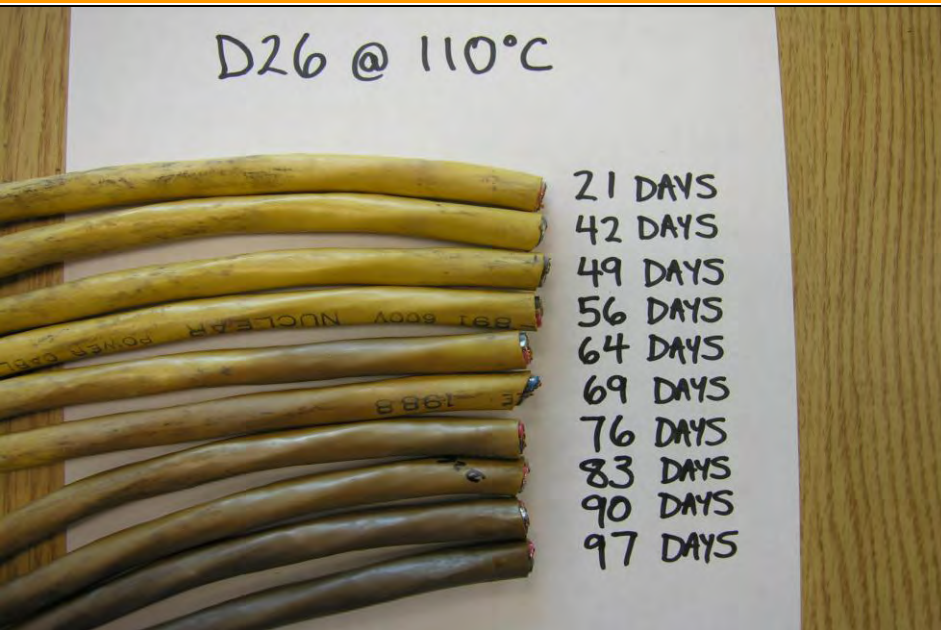
No Degradation



Visual Inspection

and

NIR Spectroscopy



	Jacket Condition	Insulation Condition	Comments
Outside Vault	No Discoloration	Minimal or No Insulation aging	None
	Mild Discoloration	Same as above	None
	Blackened	Require monitoring of Insulation condition	None
Inside Vault	No Discoloration	Minimal or No Insulation aging	Require monitoring of radiation aging
	Discoloration	Require monitoring of Insulation condition	

- Materials absorb IR at characteristic frequencies
- Capable of discriminating between formulations
- Flexible, fiber-optic probe for easy access to cables
- Used on > 10,000 cables samples in CANDU plants
- Non-destructive: Light colored cables only

Indenter Modulus



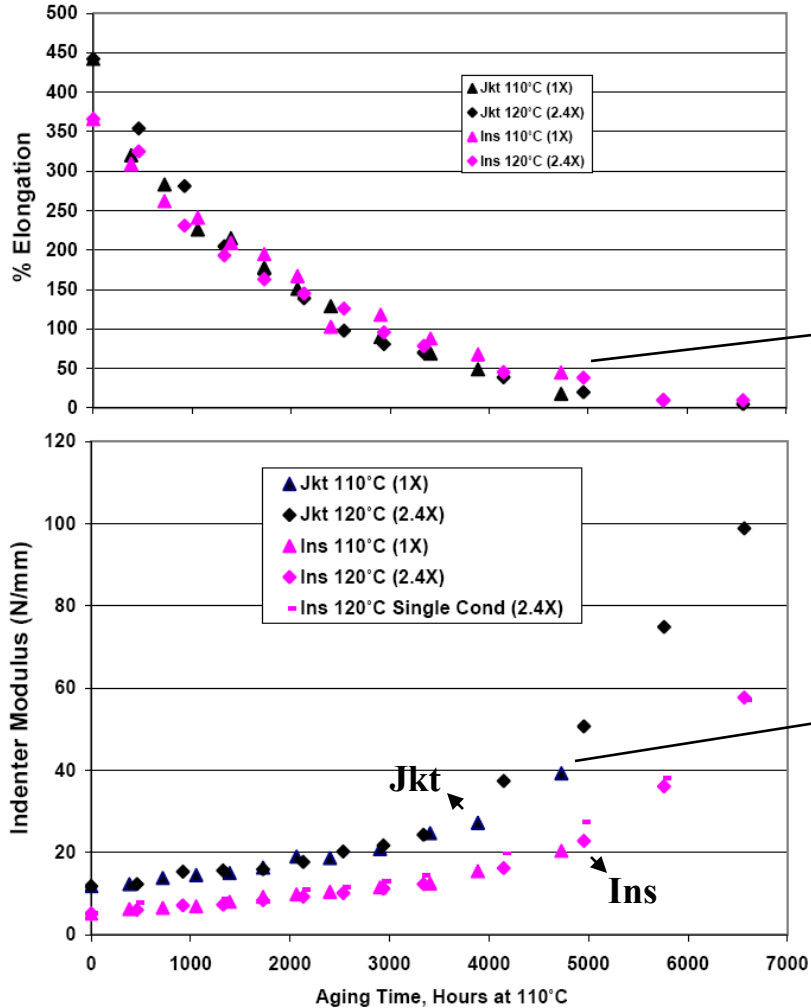
The Indenter Tool as used in the lab



The Indenter Tool in a cable tray as used in the field

Indenter Results for CSPE Outer Jacket and EPR/CSPE Composite Insulation

Cable US#10



50% absolute elongation reached ~ 5000 hours

Jacket Modulus increased to 40 N/mm at 50% elongation

Class 1E Qualification Theory

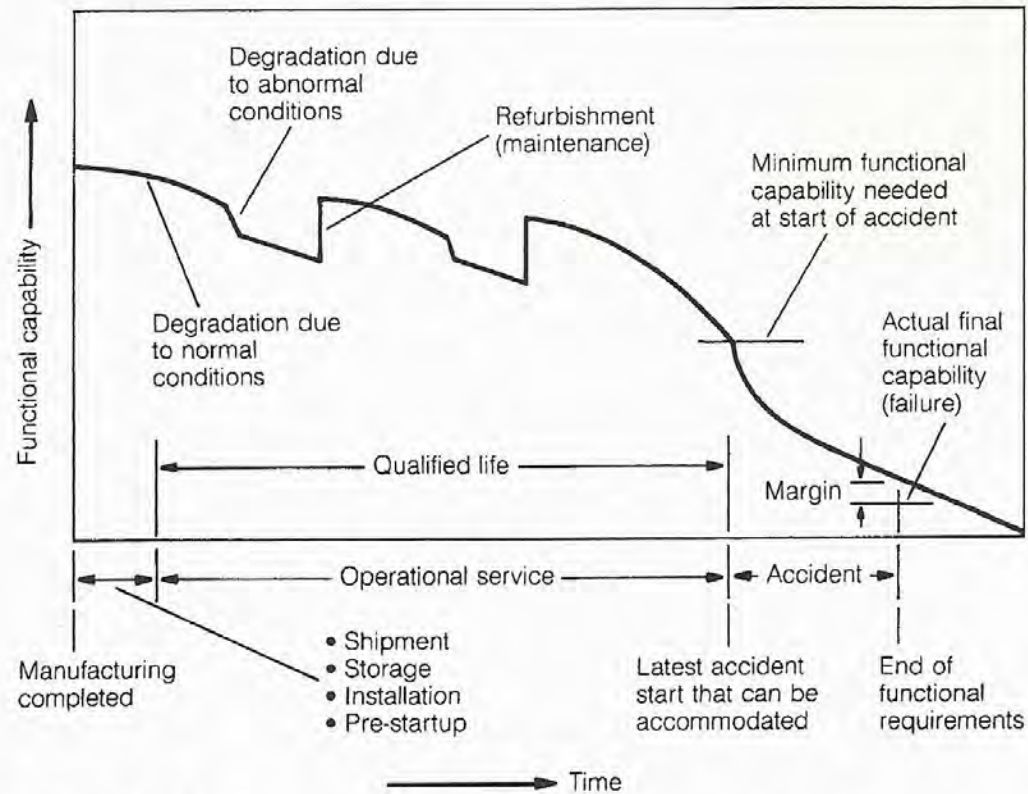


FIGURE 4.13 Relationship of functional capability to qualified life

From EPRI EQ Reference Manual- TR-100516, 1992

Cable IEEE-383 Qualification Elements

- Initial Inspection
- Baseline Function Test
- Radiation Aging of 60 Mrads (60 years)
- Post-Radiation Function Tests
- Thermal Aging 60 years equivalent aging at 90°C
- Post-Thermal Aging Function Tests
- Accident Radiation Aging of 176 Mrads,
- Post-Radiation Function Tests (electrical)
- Harsh Environment - combined LOCA /HELB Test
- Post-DBE Function Tests
- Final Visual Inspection

- Expected adds to consider:
 - *Condition monitoring*
 - *Submergence*

Condition Monitoring- Class 1E Cable Qualification

- Condition monitoring to be addressed in product design and qualification for new nuclear plants
 - *Primarily to be used in aging management programs*
 - Better predict and trend cable life/remaining life
 - Help to address differences in design and operating environments
 - *May help remove some of the built in conservatisms of Arrhenius testing, especially at high temperatures*
- Qualification should use field proven test methods on artificially aged specimens to establish baseline data, performance characteristics, and develop aging models
- Pending IEEE 383 revision expected to address condition monitoring

MV Cable Submergence Considerations

- **Containment/Harsh Environment Addressed in Typical EQ Program**
- **Submergence Addresses “Normal” Conditions**
 - *Address safety system cable (Service Water)*
 - *Relatively mild environment*
 - Underground, below grade, outdoor
 - Rainwater, low temp, mild chemicals
- **IEEE 383-2003 does not reference means of qualifying for submergence**
 - *May be part of standard rewrite*
 - *May incorporate other standards*
 - *May look for other means/methods to address submergence*



Manhole MHE1B As Found

Possible Condition Monitoring Techniques to Introduce During Qualification/Aging

- Indenter modulus
- Elongation at break
- Dielectric loss measurements (especially valuable in submergence)
- NIR
- Dielectric withstand (to failure)
- Emergent technologies (for data only)

We transform

ideas

INTO ENERGY