RSCC Nuclear Cable

A Berkshire Hathaway Company

# QUALIFICATION UPDATE

## *RSCC-Kerite Medium Voltage Cables*

Eric Rasmussen

Kerite®

Quality Cables Since 1854

# MEDIUM VOLTAGE

90°C · 60 year

Four successful qualifications to date:

- QR-1305: Kerite Shielded MV Power Cables for 60 Year Life at 90°C (LOCA)
- QR-1403: Kerite Shielded MV Power Cables for 60 Year Life at 90°C Normal Service Use and Raychem Splice and Termination Compatibility Testing
- QR-1501: Kerite Nonshielded MV Power Cables for 60 Year Life at 90°C (LOCA)

} IEEE 383-1974

- QR-1601: Kerite Shielded MV Power Cables for 60 Year Life at 90°C (LOCA)

} IEEE 383-2003

# Kerite® Shielded Cable Design

Conductor

Permashield® Conductor Shield

Kerite® Discharge Resistant EPR Insulation

Semicon Insulation Shield

Metallic Shield

Flexible LSZH Jacket

# Qualification IEEE 383-2003

Aging properties (section 6.4.1)

- “Aging data shall be used to establish the activation energy of the critical materials, including insulation, jacket (when cable jacketing may impact cable qualification), mastics (when used and credited as part of field splice qualification), and semiconducting material if used.”

- Kerite utilizes a nonconducting conductor shield and whereas typical medium voltage designs utilize semicon shields, it is considered as a critical material.

# Qualification IEEE 383-2003

Samples were thermally aging at 165°C for 685 hours

| Polymeric Layer | Activation Energy | Qualified Life |
|---|---|---|
| Permashield Conductor Shield | 1.232 eV | 66 years at 90°C |
| Kerite DR-EPR Insulation | 1.238 eV | 68 years at 90°C |
| Semicon Insulation Shield | 1.035 eV | 63 years at 79°C |
| Flexible LSZH Jacket | 1.342 eV | 463 years at 79°C |

# Qualification IEEE 383-2003

Sample selection criteria (section 6.1.1)

- “medium voltage cables shall only be tested as a completed cable, including jackets, shields, and stress control layers where applicable.”

- “Qualification of a type test sample cable shall qualify cable with the same insulation thickness and with heavier thickness without regard to voltage rating, within the same voltage class if and only if the applied peak voltage stress in V/mil during the test is equal to or greater than the peak voltage stress that a test sample or the higher voltage rating would require.”

# Qualification IEEE 383-2003

The equation for peak stress follows:

$$Vp = \frac{V}{r \cdot \ln \frac{D}{d}}$$

Where:

Vp = Peak voltage stress (Volts/mil)
V = Voltage across insulation to ground (Volts)
r = Radius of conductor over conductor shield (Inches)
D = Diameter over single conductor insulation (Inches)
d = Diameter over conductor shield (Inches)

# Qualification IEEE 383-2003

| Cable Type (Size, Rated Voltage) | 6 AWG 5 KV 133% | 6 AWG 8 KV 133% | 4/0 AWG 8 KV 100% | 4/0 AWG 15 KV 133% | 1000 KCMIL 15 KV 100% |
|---|---|---|---|---|---|
| Insulation thickness (mils) | 115 | 135 | 115 | 220 | 175 |
| Conductor OD (mils) | | | | | |
| Concentric | 183.6 | 183.6 | 527.5 | 527.5 | 1,152 |
| Compressed | 179.8 | 179.8 | 512 | 512 | 1,117 |
| Compact | 169 | 169 | 475 | 475 | 1,060 |
| Compressed conductor | | | | | |
| V (Volts) | 2,887 | 4,619 | 4,619 | 8,660 | 8,660 |
| r (mils) | 110 | 110 | 276 | 276 | 579 |
| D (mils) | 450 | 490 | 782 | 992 | 1,507 |
| d (mils) | 220 | 220 | 552 | 552 | 1,157 |
| Vp (Volts/mil) | 36.7 | 52.5 | 48.0 | 53.5 | 56.6 |
| Compact conductor | | | | | |
| V (Volts) | 2,887 | 4,619 | 4,619 | 8,660 | 8,660 |
| r (mils) | 105 | 105 | 258 | 258 | 550 |
| D (mils) | 439 | 479 | 745 | 955 | 1,450 |
| d (mils) | 209 | 209 | 515 | 515 | 1,100 |
| Vp (Volts/mil) | 37.2 | 53.3 | 48.6 | 54.5 | 57.0 |

# Qualification IEEE 383-2003

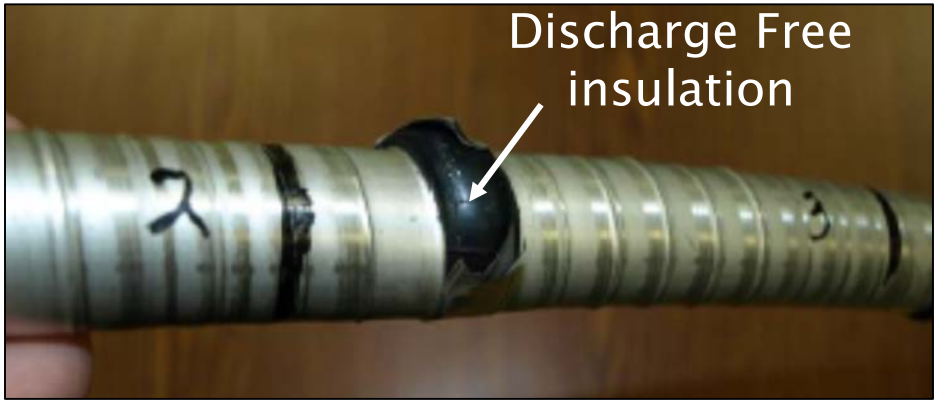
Qualification sample was 6 AWG 5 KV shielded cable and was energized at 4.5 KV AC during DBE simulation

| Cable Type (Size, Rated Voltage) | 6 AWG 5 KV 133% |
|---|---|
| V (Volts) | 4,486 |
| r (mils) | 110 |
| D (mils) | 450 |
| d (mils) | 220 |
| Vp (Volts) | 57.0 |
| Insulation thickness (mils) | 115 |
| Conductor OD (mils) | |
| Compressed | 179.8 |

# Qualification IEEE 383-2003

Helically applied metallic tape shield was chosen for the qualification sample.

- Adverse interaction between shield and insulation exists for some discharge free insulations due to high coefficients of thermal expansion.
- Helically applied metallic tape shields qualify longitudinally corrugated tape shields (LCS) and not visa versa.
- LCS shields open and close as insulations expand and contract during thermal excursions. (i.e. short circuit events)



# Qualification IEEE 383-2003

Thermal and radiation exposure was performed in both sequences.

Normal Service Test Samples

- Set #1: Unaged and 50 Mrads
- Set #2: 60 years aged and 50 Mrads (T->R)
- Set #3: 60 years aged and 50 Mrads (R->T)

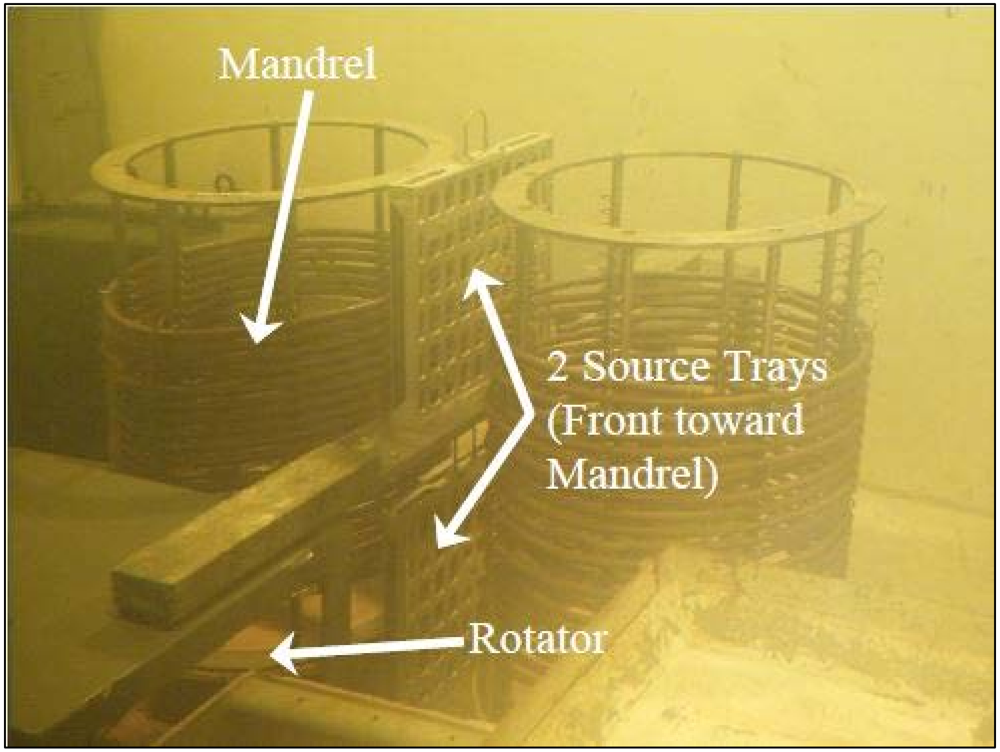
DBE Test Samples

- Set #4: Unaged and 220 Mrads
- Set #5: 60 years aged and 220 Mrads (T->R)
- Set #6: 60 years aged and 220 Mrads (R->T)

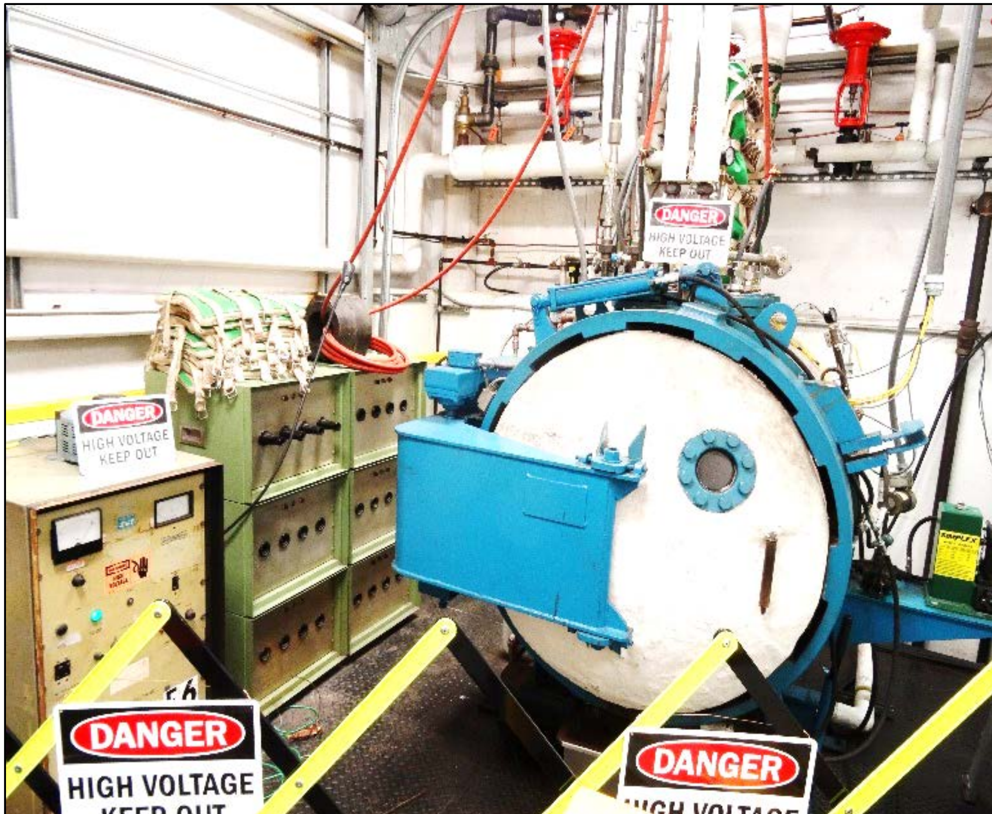
*Since thermal aging was based on the conductor shield, then the flexible LSZH jacket was significantly over aged ~463 years.

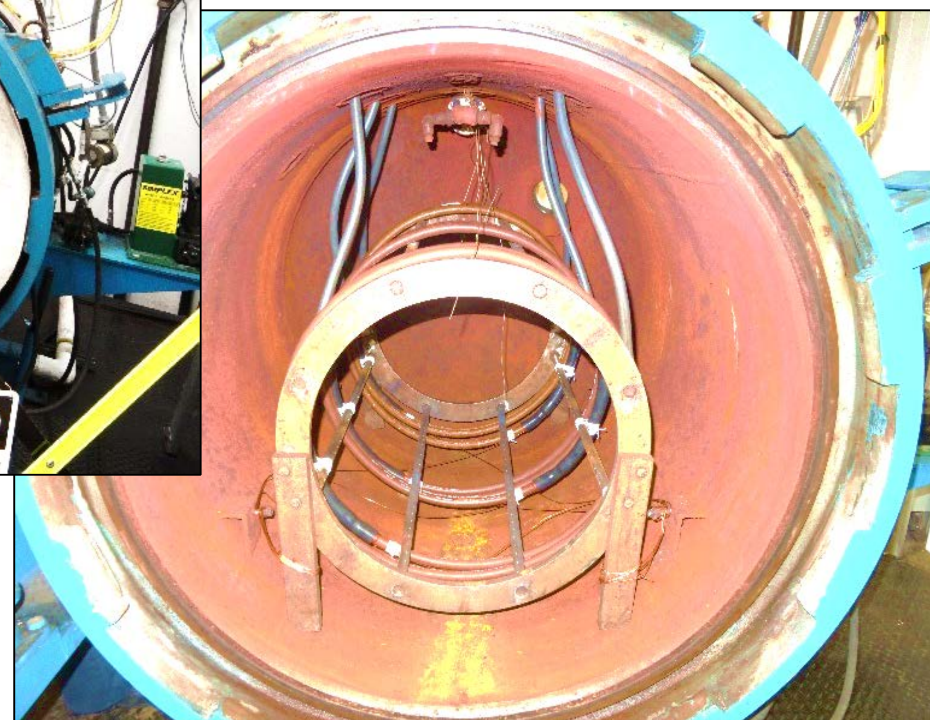
# Qualification IEEE 383-2003

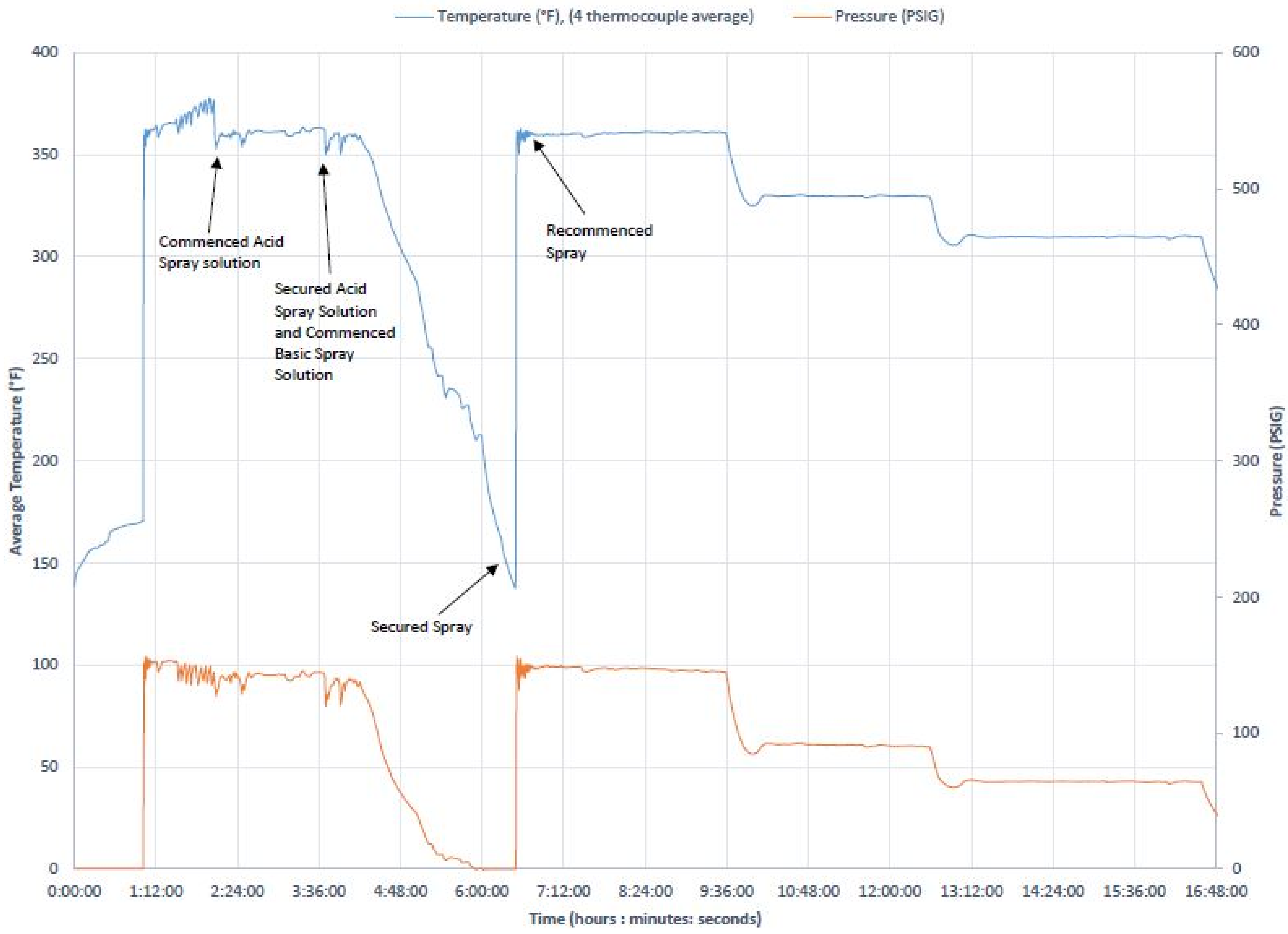
Total integrated dosage was based on 2σ confidence level



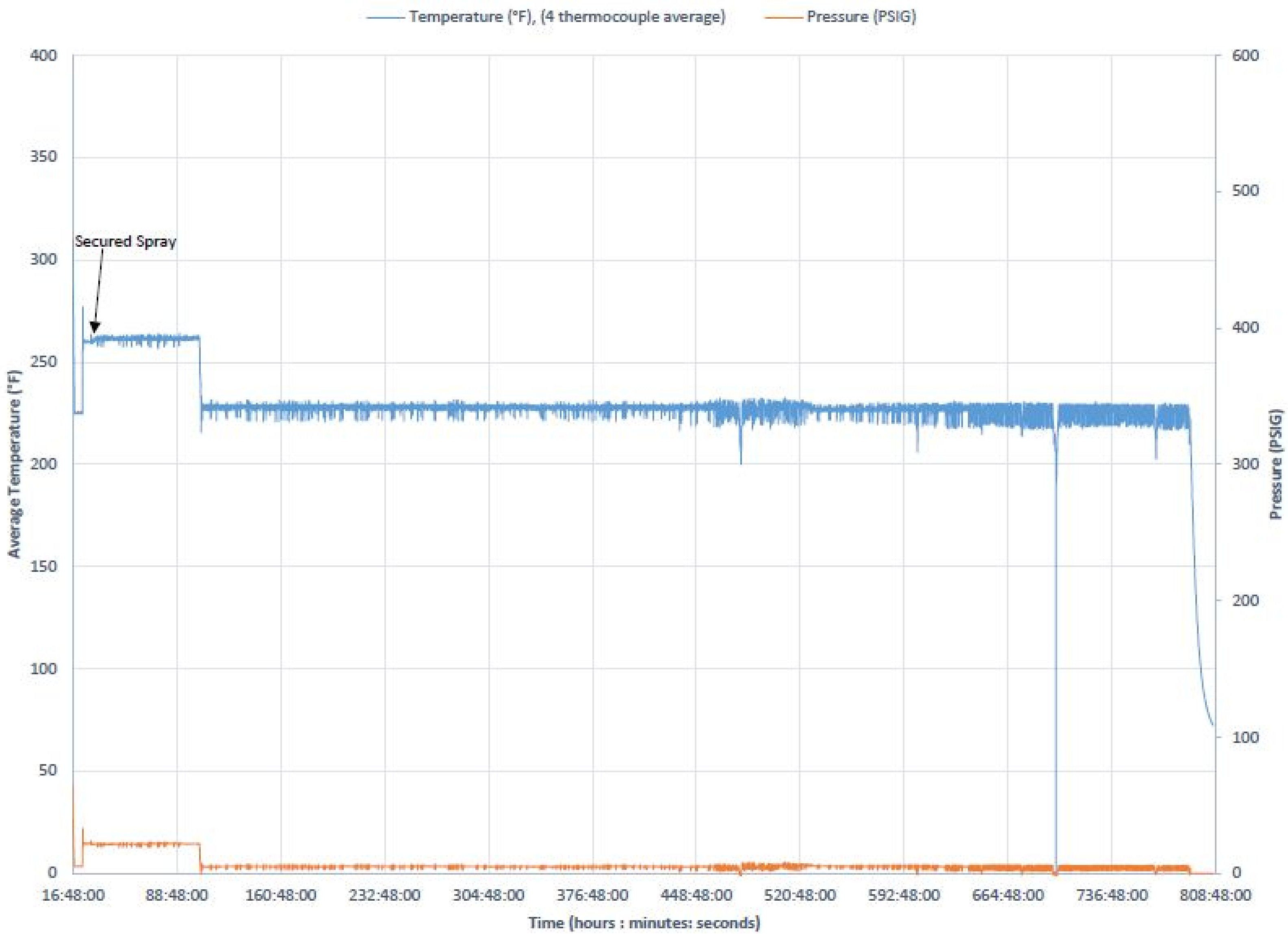
# Qualification IEEE 383-2003





Temperature (°F), (4 thermocouple average)
Pressure (PSIG)
Average Temperature (°F)
Pressure (PSIG)
Time (hours : minutes: seconds)
400
350
300
250
200
150
100
50
0
600
500
400
300
200
100
0
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
7:12:00
8:24:00
9:36:00
10:48:00
12:00:00
13:12:00
14:24:00
15:36:00
16:48:00
Commenced Acid Spray solution
Secured Acid Spray Solution and Commenced Basic Spray Solution
Recommenced Spray
Secured Spray



Temperature (°F), (4 thermocouple average)
Pressure (PSIG)
Secured Spray
Average Temperature (°F)
Pressure (PSIG)
400
350
300
250
200
150
100
50
0
600
500
400
300
200
100
0
16:48:00
88:48:00
160:48:00
232:48:00
304:48:00
376:48:00
448:48:00
520:48:00
592:48:00
664:48:00
736:48:00
808:48:00
Time (hours : minutes: seconds)

# Test Results

Normal Service Test

- Following thermal and radiation aging, samples were straightened, bent around 20x mandrel, and submerged voltage withstand tested after 1 hour submergence

DBE Test

- IR measured prior to DBE, at each plateau, and post DBE
- Samples maintained rated voltage and current throughout DBE
- After removal from chamber, samples were straightened, bent around 40x mandrel, and submerged voltage withstand tested after 1 hour submergence

# Flame Testing

IEEE 1202-2006 as modified by NRC Reg. Guide 1.211

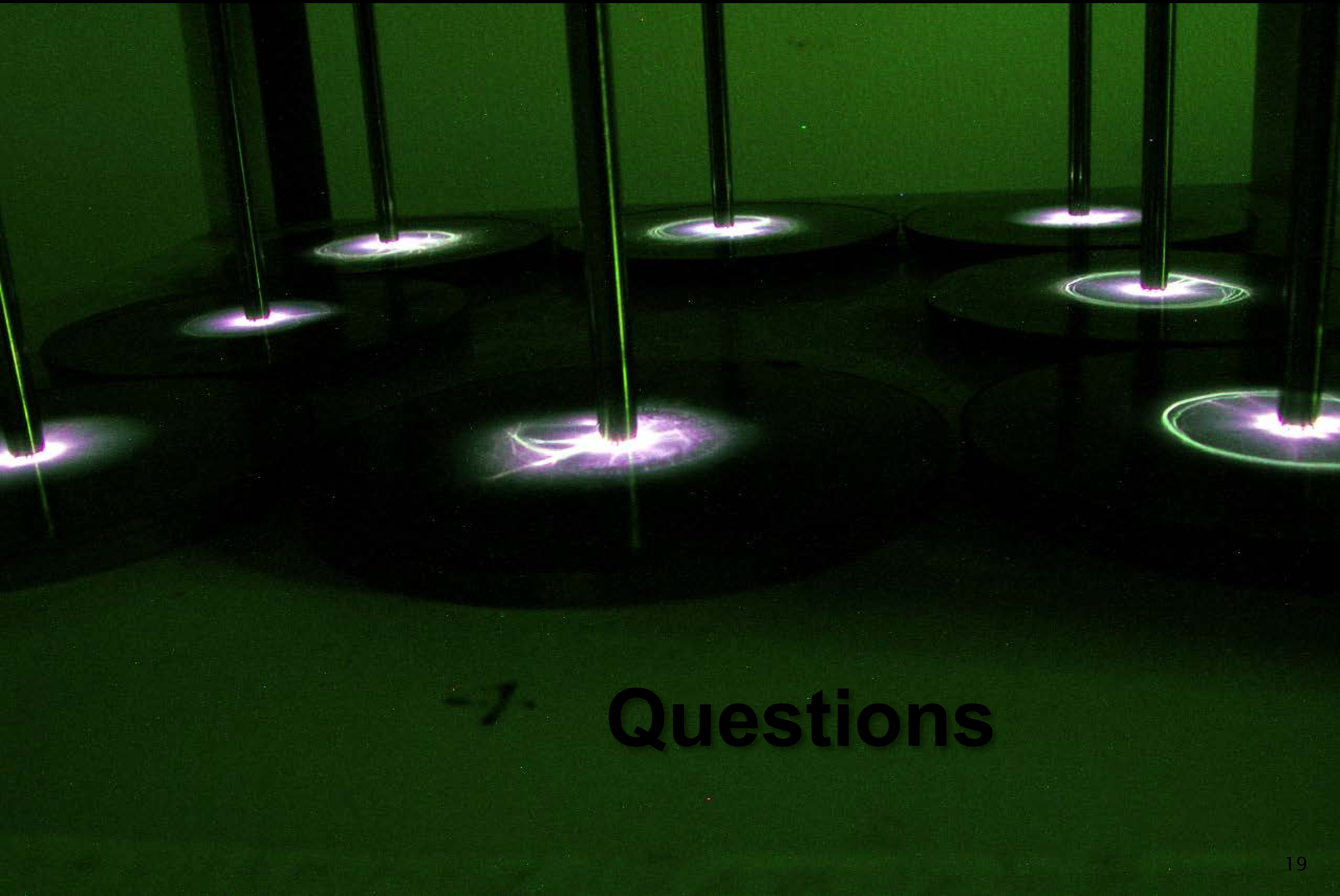
- Samples passed

# Anomalies

Total of 9 anomalies:

- 2 due to thermal aging oven falling below the required temperature
- 2 due to the voltage falling below the required operating voltage during DBE simulation
- 5 due to temperature within the chamber falling below the required DBE profile

In each instance the qualification was extended in order to envelop the time outside the required conditions.



# Questions

# Two Design Concepts Allowed

**"Discharge Resistant"**

- Falls in accordance with ICEA S-93-639 Section 4.3.2.2
- Point Probe Test for Discharge Resistance per ASTM D2275
- Partial Discharge Testing is never performed.
- Formulated to prevent the degradation that occurs as a result of partial discharge.

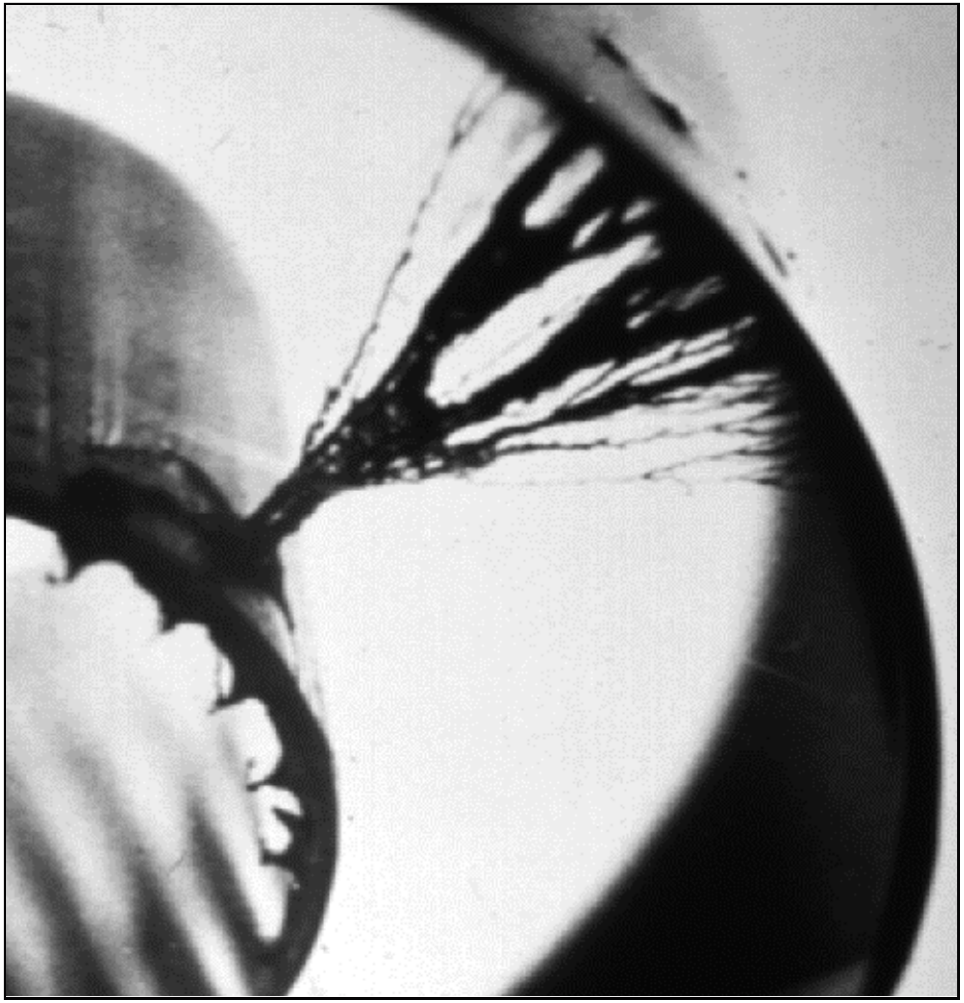
**"Discharge Free"**

- Falls in accordance with ICEA S-93-639 Section 4.3.2.1
- Partial Discharge Test is required and shall not exceed 5 pC for any continuous length.
- Designed to minimize partial discharge.
- Extruded dielectric cables cannot be made 100% partial discharge free.

# “Discharge Free” vs. “Discharge Resistant”

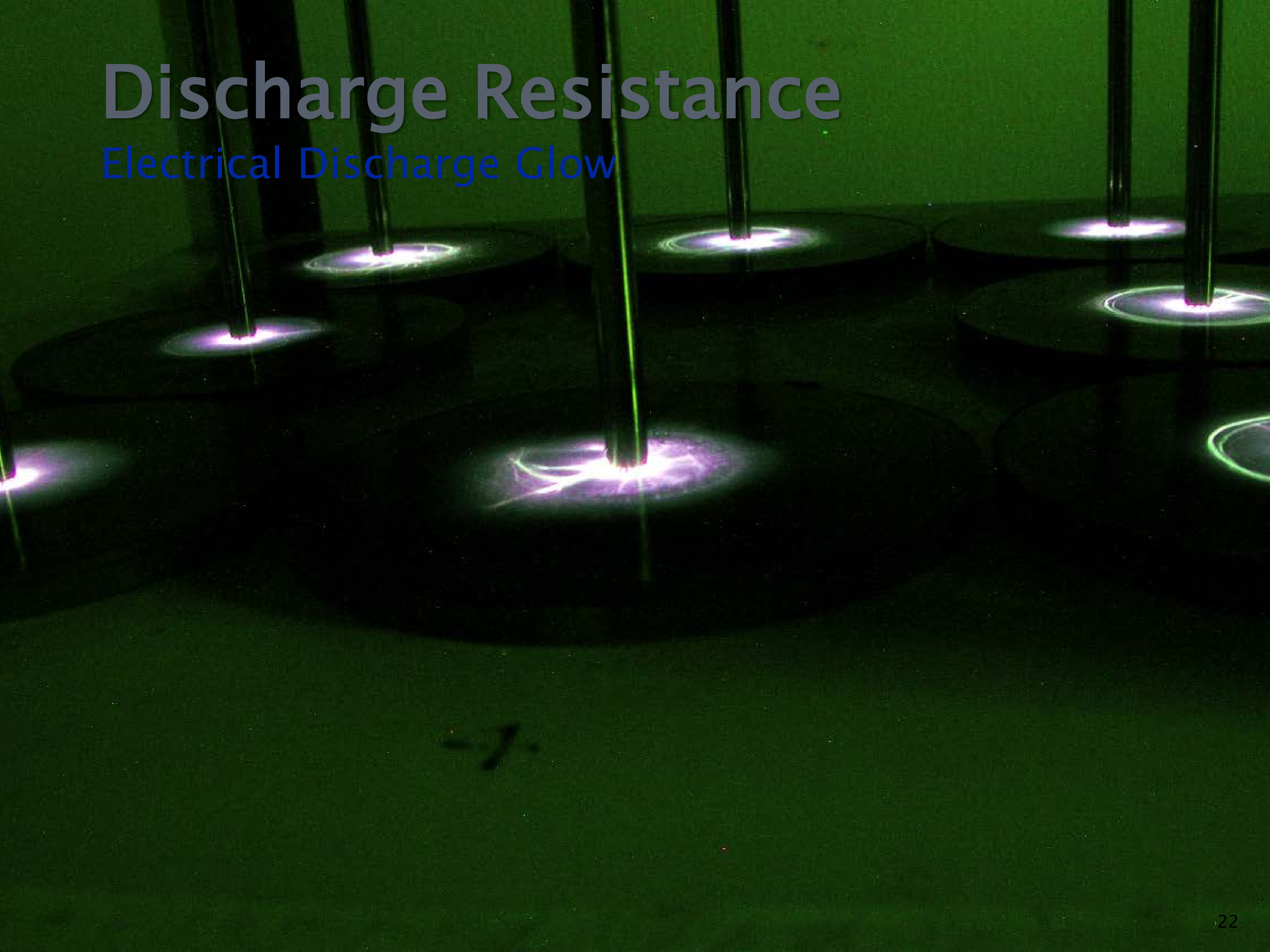
- The major difference between Kerite and all other MV cable insulation is  Discharge Resistance.

- Discharge, or corona, electrically ages MV cable:
  - Voids and contaminants are sites for the initiation of this deterioration
  - Electrical breakdown pulses occurring in microscopic voids/contaminants
  - Causes fracturing of the insulation resulting in points of high stress
  - Results in “treeing”



# Discharge Resistance

## Electrical Discharge Glow

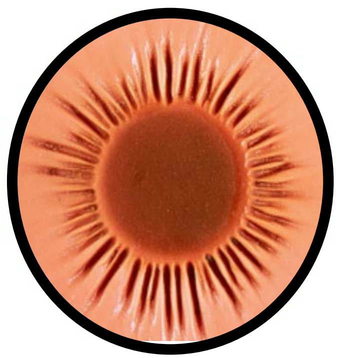


# Discharge Resistance

Insulation Surface Degradation Results

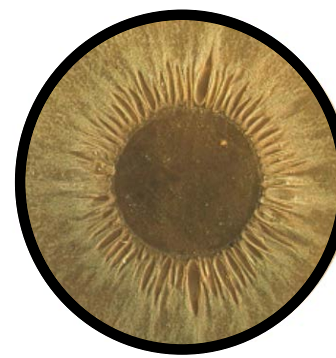
| | | | |
|---|---|---|---|
| TIME TO INCEPTION OF EROSION (HOURS) | | | |
| >250 | 48 | Immediate | Immediate |
| TIME TO DIELECTRIC FAILURE (HOURS) | | | |
| >250 | 120 | 80 | 45 |
| AVERAGE EROSION RATE (MIL/HOURS) | | | |
| 0 | .15 | .10 | .5 |

Discharge Resistant EPR



Discharge Free EPR

TR-XLPE



XLPE

# Life Expectancy

## Kerite Cable Case Study

- Directly Buried in Syracuse, NY 1977
- Continuous Operation for 28 Years (Tested July 2005)
- Cable Description
  - Conductor: #2 AWG Stranded Aluminum
  - Conductor Shield: Permashield
  - Insulation: 175 mils Kerite EPR (15kV)
  - Insulation Shield: Semiconducting
  - Concentric Shield: 10 #14 AWG Copper Concentrics
  - Jacket: None
- Testing
  - Physical Test
  - AC Breakdown Test
  - Impulse Test
  - Discharge Resistance Test (U-Bend)

# Life Expectancy

## Kerite Cable Case Study

| Physical Tests | | | |
|---|---|---|---|
| | 28 Year Old Cable | New Cable | |
| | | Minimum | Range |
| Tensile (PSI) | 1019 | 650 | 700-900 |
| Elongation (%) | 478 | 350 | 400-525 |
| Voids | None | 4 mil Max | |
| Contaminants | None | 10 mil Max. | |
| Trees | None | N/A | |
| | | | |

| AC Breakdown (1-3) and Impulse (4-7) Tests | | |
|---|---|---|
| | 28 Year Old Cable | New Cable |
| Sample 1 | 63kV | 54kV |
| Sample 2 | 60kV | |
| Sample 3 | 74kV | |
| Sample 4 | 194kV@RT | 160kV |
| Sample 5 | 195kV@RT | |
| Sample 6 | 197kV@RT | |
| Sample 7 | 220kV@130C | |

- Passed u-bend plate test: 1,000 hours.
- No deterioration of performance characteristics.
- Parameters measured still within range expected for new cable.
- Since there is no aged related degradation, then an extrapolation to end-of-life can not be made.
- Cable should last another 28 years, or even more.

# NEI 06-05 – US Nuclear MV History

- NEI 06-05, *Medium Voltage Underground Cable White Paper*, April 2006, Details a Study Performed Across a Variety of Medium Voltage Cables Installed in US Nuclear Power Plants
- 81/104 US Nuclear Units Reported and the 20 Units Having Brown EPR (Kerite) Reported <u>Zero</u> Failures
  - Still Only Cable With <u>Zero</u> Failures of the Insulation System
- Concluded that "*at a minimum, a proven, modern cable design should be used for replacements. Based upon successful performance ... brown EPR (Kerite) is the current material of industry preference.*"

# Submerged/Wet Performance

- EPRI Plant Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants, Revision 1 concluded that:

  - "brown EPR insulation, while being available to the early nuclear plants, continues to be produced. Approximately 20% of plants report its use. No water related failures have been reported in the nuclear industry to date. There have been a few cases where defective splices have been replaced, and, in some cases, new cable sections have been installed due to zinc shield deterioration."

- NEI 06-05 Medium Voltage Underground Cable White Paper concluded that:

  - "81 units provided information on the number of circuits in wet and dry applications" and "of the 20 units having brown EPR (Kerite HTK), none had a failure of wet underground cable." It further went on to state that "no wet failures of brown EPR have been identified to-date. (The one failure on a brown EPR circuit was related to a poorly made splice rather than failure of the insulation)."