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October 8, 2010

To: Cable Users Group Attendees
Personnel with Interest in Cable Issues

Subject: Minutes from September 21 to 23, 2010 Cable Users Group Meeting

The September 2010 Cable Users Group Meeting was held in Windsor, CT. The attendees list is contained in Attachment 1. The agenda is contained in Attachment 2. The meeting opened with introductions of the attendees followed by a Round Table discussion of attendee interest and problem areas. The following table lists the presentations that occurred on September 21 and 22 and the associated presenters.

| Topic | Presenter | Attachment No. |
|---|---|---|
| EPRI Cable Aging Management Program Guidance Implementation | Gary Toman<br>EPRI | 3 |
| Status of CSPE Replacement | Robert Konnick<br>Marmon Innovation and Technology Group | 4 |
| Medium Voltage Aging Management Guide Update to EPRI Report 1016689 | Gary Toman<br>EPRI | 5 |
| Implementation Issue Discussion | Group | 6 |
| Accelerated Aging of EPR Cables | Howard Sedding<br>Kinectrics | 7 |
| New Products from RCC-Suprenant | Robert Konnick<br>Marmon | 8 |
| H.B. Robinson Electrical Event | Donna Young<br>Progress Energy | 9a |
| NPP Leibstadt (Switzerland) Results of VLF dissipation factor measurement | Valentin Noser<br>Kemkraftwerk Liebstadt | 9b |
| Remote and Automated Level Monitoring in Cable Manholes | Gregory Quist<br>Smartcover | 9c |
| Limerick Manual Scram Initiated by Cable Failure | Denise Thomas<br>Exelon | 9d |
| Low Voltage Cable Testing at Liebstadt with Line Resonance Analysis | Valentin Noser<br>Kemkraftwerk Liebstadt | 9e |
| Practical Testing Considerations When Performing Diagnostics on MV Cable | Craig Goodwin<br>HV Diagnostics Inc | 10 |
| Laboratory Testing of MV Cables from Nuclear Plants: Further Developments | Bogdan Fryszczyn<br>Cable Technology Laboratories | 11 |



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| Topic | Presenter | Attachment No. |
|---|---|---|
| INPO Perspective on Cable Aging Management | Wes Frewin<br>INPO | 12 |
| Medium Voltage Cable | Robert Fleming<br>Kerite | 13 |

A tour of the Kerite Cable manufacturing and test facilities occurred on the third day of the meeting.

I would like to thank all of the presenters and attendees for making the meeting a success. If you need further information, please do not hesitate to contact me at 704-595-2573 or gtoman@epri.com.

Yours truly,

Gary J. Toman
Senior Project Manager
Plant Support Engineering

Attachment 1: Attendees
Attachment 2: Agenda
Attachments 3 to 13: Per table above.

# Cable Users Group Meeting

**Hartford, Connecticut** **September 21-23, 2010**

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# Cable Users Group Meeting

**Hartford, Connecticut** **September 21-23, 2010**

| First Name | Last Name | Company | Email Address | Work Phone |
|---|---|---|---|---|
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**EPRI Plant Support Engineering**
**CABLE USERS GROUP MEETING**
**September 21 through 23, 2010**
**Hartford, CT**

## Agenda

| **Tuesday, September 21, 2010** | |
|---|---|
| **Time** | **Topic** |
| **8:00 a.m.** | **Introductions/Review of Agenda** |
| **8:15 a.m.** | **Round Table – Issues and Events of Interest to Cable Personnel with Focus on NRC and INPO Interactions on Cable and Cable Systems**<br>*Group* |
| **9:00 a.m.** | **Cable Aging Management Program Guidance Implementation**<br>*Gary Toman, EPRI* |
| **9:45 a.m.** | **Break** |
| **10:00 a.m.** | **Status of a Replacement CSPE**<br>*Robert Konnik, Rockbestos* |
| **11:00 a.m.** | **Update of MV Aging Management Report**<br>*Toman/Mantey* |
| **12:00 Noon** | **Lunch** |
| **1:00 p.m.** | **Cable Program Implementation Round Table**<br>A discussion of known and potential issues concerning implementation of cable aging management programs<br>*Group* |
| **2:45 p.m.** | **Break** |
| **3:00 p.m.** | **Cable Program Implementation Round Table (continued)** |
| **3:45 p.m.** | **EPR Accelerated Aging Research**<br>*Kinectrics* |
| **4:30 p.m.** | **Cable Discussion**<br>*Rockbestos* |
| **5:00 p.m.** | **Adjourn** |

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## Agenda

**Wednesday, September 22, 2010**

| Time | Topic |
|---|---|
| **8:00 a.m.** | **Plant Event Discussions**<br>*Robinson, Limerick, Peach Bottom telemetering* |
| **9:45 a.m.** | **Break** |
| **10:00 a.m.** | **Laboratory Testing of MV Cables from Nuclear Plants, Further Developments**<br>*Bogdan Fryszczyn, Cable Technologies Laboratory* |
| **11:00 a.m.** | **Practical Test Issues**<br>*Craig Goodwin, High Voltage Diagnostics, Inc.* |
| **12:00 Noon** | **Lunch** |
| **1:00 p.m.** | **INPO Perspective on Cable Aging Management** |
| **1:45 p.m.** | **Separable Connector Qualification**<br>*Andrew Mantey, EPRI* |
| **2:30 p.m.** | **Break** |
| **3:00 p.m.** | **Kerite-Rockbestos MV Power Cable**<br>*Robert Fleming, Kerite* |
| **4:30 p.m.** | **Proposed Fiber Optic Cable Aging**<br>*Gary Toman, EPRI* |
| **4:40 p.m.** | **Discussion of Topics for Spring Meeting**<br>*Group* |
| **5:00 p.m.** | **Adjourn** |

**EPRI Plant Support Engineering**
**CABLE USERS GROUP MEETING**
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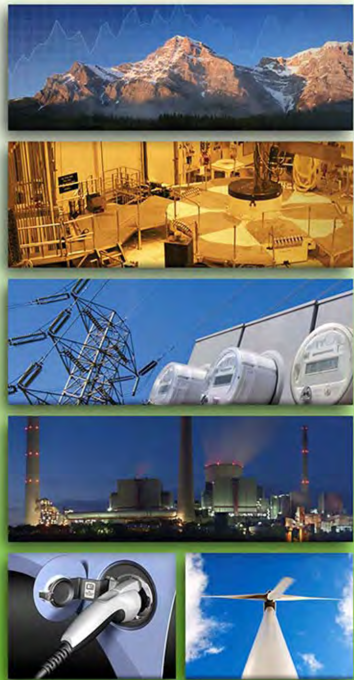
## Agenda

**Thursday, September 23, 2010**

| Time | Topic |
|---|---|
| 7:30 a.m. | Continental Breakfast |
| 8:30 a.m. | Travel to Kerite Cable Plant for Tour (Transportation supplied courtesy of Rockbestos Suprenant/Kerite) |
| 9:30 a.m. | Kerite Cable Plant Tour |
| 3:30 p.m. | Arrive at Hartford Marriott (Meeting Activities End). Earlier times possible. |



# EPRI Cable Aging Management Program Guidance Implementation

## Cable Users Group Meeting September 2010

**Gary Toman**
**Plant Support Engineering**
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## Topics

- Impetus for Cable Aging Management Programs
  - NRC push
  - Industry management push
- Industry – NRC Regulatory Issue Resolution Protocol on Cable
  - Linkage to Maintenance Rule scope and interaction with Maintenance Rule activities
  - Expected resolution path
- EPRI Cable Aging Management Program Guides

## Impetus for Cable Aging Management Programs

- From 2008 through 2010, approximately 29 plants received NRC violations related to having submerged medium voltage cable
- In 2010, at least 3 plants received violations for having submerged low voltage cable
- Even though these cables were purchased for wet conditions, the NRC has not accepted that the cables were designed for wet conditions and utilities have not been successful in staving off violations
- The NRC Inspection Manual requires Resident Inspectors to inspect three cable vaults and manholes twice a year for water and directs the inspector to give a violation if cables are water covered




## Impetus for Cable Aging Management Programs

- In the EPRI Nuclear Power Council (the highest level EPRI advisory committee), January 2009, utility chief nuclear officers directed EPRI to create the guidance needed to resolve cable aging issues including guidance on setting up programs
  - A three week outage had occurred at one plant due to loss of off-site feed cables
  - A two week outage occurred at another plant when a component cooling water pump cable failed
  - CNOs indicated that they did not want extended outages nor did they want a cable failure to embarrass the industry
- EPRI began work with utility members to develop cable aging management program guidance

## Regulatory Issue Resolution Protocol on Cable

- In early 2009, NRC and NEI management agreed to a Regulatory Issue Resolution Protocol that was would help manage significant NRC-Industry issues to resolve them more quickly in a manner acceptable to both and to provide durable regulatory guidance
- In mid 2009, NEI and the NRC agreed that cable issues would be the topic of the first RIRP effort
- Periodic open meetings began in mid 2009 and ran through July 2010
- The title of the cable RIRP became "Inaccessible or Underground Cable Circuit Performance Issues at Nuclear Power Plants"




## Regulatory Issue Resolution Protocol on Cable

- The scope became the same as that of Generic Letter 2007-01: Inaccessible or Underground Power Cable Failures that Disable Accident Mitigation Systems or Cause Plant Transients
  - The scope of the Generic Letter was those cables that support Maintenance Rule function
  - The main concern was submergence
  - Medium voltage cable (essentially 5 to 35 kV rated cable) and low voltage power cable (generally 600 V rated ac and dc power cable)

## RIRP and Continued Issuance of Violations

- The NRC stated in the initial meetings that, during the course of the RIRP, the dictate to issue violations upon finding submerged cables would continue. Entering the RIRP did not constitute a reason for the NRC to change its policies
- The NRC also stated that the development of a NUREG/CR on cable condition monitoring and a Regulatory Guide on the same topic would continue during the cable RIRP




## RIRP Outcomes

- Meetings helped both sides understand differences of opinions and differences in understanding of key words including wetting, submergence, and qualification
- The NRC working level staff considered this a mature issue and had strong positions regarding its resolution (essentially, make the cable dry and determine its condition)
- The staff rejected the industry information provided on both submergence capability of cable and what the industry thought were the applicable regulations

## RIRP Outcome January 2010 Meeting

**Agreed Upon Problem Statement:**

- The environment of inaccessible or underground power cable circuits within the scope of the Generic Letter (GL) 2007-01 may cause them not to perform their design function.

**Industry Proposed Solution:**

- Implementation of Cable Aging Management Programs by Nuclear Power Plants
  - Industry described the elements of a Program
  - NRC management agreed to review the EPRI guides that were being developed and endorse them through a document such as a Regulatory Guide or a Regulatory Issue Summary




## July 28 RIRP Meeting

- Totally different group of upper NRC managers
- Staff rejection of the agreed upon problem statement
- Return to July 2009 position by the Staff
- Industry still requesting endorsement of 1020804 and 1020805
- Suggestion was made that the two EPRI reports be used instead of DG-1240
  - Discussion of DG-1240 status is at the end of this presentation

## Industry Resolution Path Determined September 1, 2011

- The industry decided to:
  - Conclude the RIRP on cable with no further request for endorsement by the NRC staff of the EPRI Guides
  - The industry closure letter will state that the industry will follow the EPRI Guides
  - The closure letter will also state that INPO will include cable aging management in their assessments and issue areas for improvement as appropriate




## EPRI Cable Aging Management Guides

Two Guides were issued in June 2010:

- 1020804: *Aging Management Program Development Guidance for AC and DC Low-Voltage Power Cable Systems for Nuclear Power Plants*
- 1020805: *Aging Management Program Guidance for Medium Voltage Cable Systems for Nuclear Power Plants*

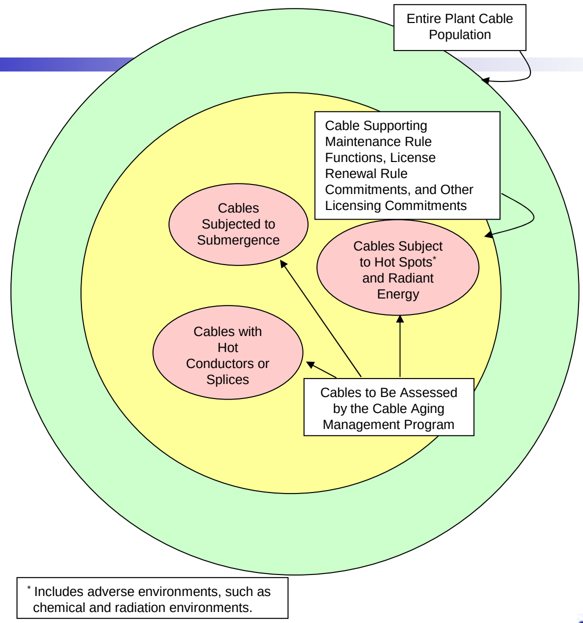
## Basic Guide Concepts

- Both Guides start with the concept that the overall scope of cables that could be considered is that set that supports Maintenance Rule functions
- Additional scope cables include any additional cables from License Renewal (brings in a few more) and any cables that come from commitments in other licensing actions
- Operationally important cables not covered by Maintenance Rule scope can be added at management option




## Basic Guide Concepts

- The cables to be assessed are those cables subject adverse environments or service conditions
  - Adverse environments:
    - Elevated temperature
    - Elevated radiation
    - Oil, chemical, hydraulic fluid exposure
  - Adverse service conditions
    - Wet/submerged
    - High ohmic heating
    - High resistance connections








## Relationship to Maintenance Rule

- Original Statements of Consideration for 10CFR50.65 gave cable as an example of a component that was "inherently reliable"
- Most plants do not have cables explicitly in their Maintenance Rule considerations
  - If a cable failed and affected a Maintenance Rule function, it would have to be assessed
  - However, the Maintenance Rule does not call for pro-active cable condition monitoring.
- For most plants, cable failure has not significantly affected Maintenance Rule function
- Adding cable assessment for adverse environment/ service condition cables (up to and including condition monitoring) is proactive in most cases
- Given that benign environment/service condition cables have a very low expected failure rate, there is no need to monitor under Maintenance Rule
- If an unexpected failure mechanism occurs in the future for the "benign" population of cables, the Maintenance Rule would require action to control that failure mechanism

## Cable Program Development Guides

- Each nuclear power plant should have an aging management program for medium-voltage cable systems.
- The program will assess the condition of cables
- Plants will test wetted shielded MV cables and wetted LV cables that support Maintenance Rule functions
- MV cable tests will require separation from loads and circuit breaker back planes
  - Cable replacement may be necessary for a few MV circuits that have been wetted for extended periods (entire population will not be degraded)
- For dry low and medium voltage cables, adverse localized environments (high temperature, high radiation, or chemical exposure) will be identified and the effects on cables determined
  - Some thermal damage may be identified that requires repair or replacement of cable




## Benign Environment Cables

- Much of the cable system is subjected to benign conditions (dry, low temperature (<104°F) and radiation, no chemicals)
- Under these conditions, the cables barely age leading to very long lives (>>60 years)

  The Cable Aging Management Programs will not evaluate these cables
- If some unexpected failure mechanism exists for benign environment cable, we will rely on the Maintenance Rule and corrective action programs for identification and requiring the issue to be addressed

## Draft Regulatory Guide 1240 – *Condition Monitoring Program for Electrical Cables Used in Nuclear Power Plants*

- This guide describes a method that the NRC staff considers acceptable for condition monitoring of electric cables to meet the requirements of 10CFR50.65, the Maintenance Rule
- The NRC developed this Regulatory Guide in parallel with and independently of EPRI Cable Aging Management Guides




## Summary of Comments on Draft Regulatory Guide 1240

- Section B, *Discussion*, contains many technical errors that could mislead utility and regulatory personnel. Examples are:
  - Medium voltage and low voltage condition monitoring techniques for wet and dry conditions are discussed as if they apply to all cables. The reader will likely misunderstand what tests to use and the types of degradation they can detect
  - The text while trying to encourage condition monitoring, disparages practical methods and reads as if getting useful results will be very difficult
  - Dc tests that IEEE standards state should not be applied to polymer insulated medium voltage cables are recommended
  - Nearly all of the 11 test methods listed in the RG are mischaracterized with respect to what they can detect or what cables they apply to

## Summary of Comments on Draft Regulatory Guide 1240

- Section C.1, *Implementation* has elements that are similar to those in the EPRI Cable Aging Management Guides (1020804 and 1020805) with the following exceptions:
  - The Reg Guide infers all cables must be monitored rather than concentrating on cables subject to adverse environments
  - The Reg Guide assumes that data will be tracked on a per circuit basis rather than from a local hot spot basis, which is a key alternative that will be used
  - The Reg Guide assumes that all cable environments should be monitored and documented.
  - Section A lists the Maintenance Rule as the main requirement for implementing cable condition monitoring. However, the Maintenance Rule allows other alternatives and does not demand a large cable condition monitoring program




## Current NEI-NRC Status of DG-1240

- Comments closure occurred on August 13
- NEI issued a formal letter to the NRC requesting withdrawal from further consideration of the Draft Regulatory Guide based on DG-1240 being "Unnecessary and Inconsistent with 10 CFR 50.65 (Maintenance Rule)"
  - Letter suggests that "the industry guidance documents" (1020804 and 1020805) should be used instead

    (Copy of Letter will be with meeting minutes)
- NEI also issued technical comments on DG-1240

## Potential DG-1240 Outcomes

- NRC may decide to go no further
- NRC may decide to revise the DG
  - If a revision is made, the revisions are expected to be substantial and a new comment period is expected to be necessary




## Conclusions

- Implementation of a Cable Aging Management Program is necessary for each plant
- EPRI 1020804 and 1020805 should be used as a basis
- EPRI 1021629 on I & C cable (very similar to LV Power guide) is expected by the end of 2010
- Development of a Cable Aging Management Plan in the very near term is highly recommended
- Determining scope and identifying assessment strategy is needed in the short term
- Full implementation of initial inspections and tests is recognized as taking a 2 to 3 operating cycles


Questions
?
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# Status of CSPE Replacement

Robert Konnik
Chief Technology Officer

MARMON
Innovation & Technology Group

# Agenda

- Review of Situation
- Review of Test Approach
- Review of Test Results
- Conclusions

## Review of Situation

- DuPont Ceased Supply of CSPE (Hypalon)
  - April 2010
- RSCC Reviewed Like for Like Test Plan With Select People & Groups
  - Kent Brown of TVA
  - NUGEG Group
- RSCC Test Report For Comments June

## Review of Situation

- RSCC Final Report Released in August
- Report Accepted By Many
  - TVA
  - MOX
- Stock Changed To New Resin
- Supply Of DuPont Material Limited

## Review of Test Approach

- Drop in Equivalent Polymer Was Evaluated
  – Polymer Was Tested To Be The Same
- No Other Change In Formulation
  – For Conservatism Both Old and New Polymer Tested to Confirm Resultant Compound Same in Form, Fit and Function
- Report on Equivalency Issued

## Source

- Initial Source Reviewed From China
  – Not Ready: Still Scaling Up Plant
- Present Source Tosoh From Japan
  – Supplying Material to US for 40 Yrs
  – Increased Capacity

# Jacket Function

- Environmental Qualification Testing Done on Insulation Without Need for Jacket
  - Checked Flame Test, Mechanical, Aging, Radiation, Chemical Spray Exposure, etc
- Polymer Drop in Equivalent
  - Compatibility with Insulation System Same
    - No Synergistic Effects Expected with Respect to Electrical, Chemical, and Mechanical Performance With Materials in RSCC EQ Reports

# Review of Test Results

- TEST REPORT
  - CSPE LIKE FOR LIKE REPLACEMENT
    - TR-1008 R0, 8/30/10
- Polymer Testing
  - Chlorine Content: 36 ± 1.5
  - Sulfur Content: 1 ± 0.12
  - Mooney Viscosity: 85 -103
  - FTIR: Compare Old & New

# Polymer Testing

- Literature Same
- FTIR Same
- Testing Also Done on Completed Formula
  - Results All Comparable

| | | | | | |
|---|---|---|---|---|---|
| FTIR, Resin & Finished Compound | Compound | RSCC | Report | Comparable to KH-131 Dupont | Comparable to KH-131 Tosoh |
| Mooney Viscosity | Compound | RSCC | Report | Comparable to KH-131 Dupont | Comparable to KH-131 Tosoh |
| Chlorine Contain | Compound | LECO Method | Report | 12.4% | 13.2% |
| Sulfur Contain | Compound | ASTM D3566/D512 | Report | 0.83% | 0.77% |
| Specific Gravity | Compound | RSCC | 1.60+/- 0.03 | 1.63 | 1.62 |

# Compound Testing

- Completed Compound Mixed Using Same Formula and Procedures
  - Both New and Old Polymer Mixed
- The Following Tests Performed:
  - ICEA Properties
  - Aging for a 90°C CP Jacket Per UL
  - Radiation Aging – 50 and 220 Mrads
  - Borated Spray Exposure 24 Hours

## Other Testing

- Limited Oxygen Index per ASTM D2863
- Acid Gas Per CSA C22.2 No 0.3
- Low Temperature Brittleness ASTM D746
- Gravimetric Moisture Absorption
- Compatibility With Pulling Lubricants

## Results

- Initial Tensile and Elongation Can Vary
  - Based on Preparation of Samples, Test Variation, Extrusion Variation and Mixing
  - Requirement: 1800 PSI & 300%
    - New: 2200 PSI & 432%
    - Old: 1882 PSI & 332%
- New Slightly Better
  - May Not Be Statistically Significant
- As Good as or Better in Initial Physicals

# Results (Continued)

- Tensile Stress at 200% and Set
  - Measure of Cure State
  - Requirement 500 PSI & 30%
    - New: 1316 PSI & 10%
    - Old:   1466 PSI & 10%
  - Show Equal Cure State

# Results (Continued)

- Gravimetric Moisture Absorption
  - Requirement 40 mg/sq in
    - New: 17 mg/sq in
    - Old:     8 mg/sq in
  - Meets Requirement for Both Materials
  - Not Significantly Different for a Jacket

# Results (Continued)

- Oil Immersion: 18 Hr @ 121C, ASTM #2
  - Requirement: 60% T & E Retention
    - New: 88%/82%
    - Old: 105%/85%
  - Equivalent for Both Materials

# Results (Continued)

- Surface Resistivity
  - Requirement: 200,000 Megohm Min.
    - New: 5,621,000 Megohms
    - Old: 6,548,000 Megohms
  - Equivalent for Both Materials
  - Values Very High and Subject to Variability

## Results (Continued)

- Aging Values: 7 Day @ 100°C
  - Requirement: 85% T & 65% E Retention
    - New: 2439 PSI & 357% (111%/83%)
    - Old: 2366 PSI & 300% (126%/93%)
- Aging Values: 7 Day @ 121°C
  - Requirement: 85% T & 50% E Retention
    - New: 1969 PSI & 288% (90%/67%)
    - Old: 1843 PSI & 212% (98%/66%)
  - Equivalent

## Results (Continued)

- LOCA Spray Solution: 90°C for 24 Hours
    - New: 2527 PSI & 407% (115%/94%)
    - Old: 2546 PSI & 340% (135%/106%)
  - No Effect
- LOCA Spray Solution & 50 MR: 90°C for 24 Hours
    - New: 2084 PSI & 173% (91%/124%)
    - Old: 2015 PSI & 105% (88%/98%)
  - No Effect Vs 50 MR

# Results (Continued)

- Effect of Radiation: 50 MR
    - New: 2286 PSI & 140% (104%/32%)
    - Old: 2300 PSI & 107% (122%/33%)
  - – Equivalent
- Effect of Radiation: 220 MR
    - New: 1656 PSI & 23% (75%/5.3%)
    - Old: 1577 PSI & 15% (84%/4.7%)
  - – Equivalent

# Results (Continued)

- Tray Flame Testing Most Important Feature
  - – Tested to IEEE 383-1974 and IEEE 1202-2006
  - – IEEE 383: 2/C 16 AWG Firewall III
    - New: 45 inch
    - Old: 44 inch
  - – IEEE 1202: 2/C 16 AWG
    - New: 40 inch
    - Old: 38 inch
- Passed Easily With Equivalent Results

# Results (Continued)

- Sunlight Resistance
  - Requirement: 85% T & E Retention
    - New: 2404 PSI & 418% (109%/97%)
    - Old: 2149 PSI & 320% (114%/99%)
  - Equivalent
  - Not a Concern for Black Jackets

# Results (Continued)

- Limited Oxygen Index (LOI)
    - New: 37
    - Old: 37
  - Measure of Flame Resistance
  - Equivalent for Both Materials

# Results (Continued)

- Acid Gas
    - New: 7.4%
    - Old: 7.7%
  - Samples Easily Met 14% Requirement
  - Equivalent Values

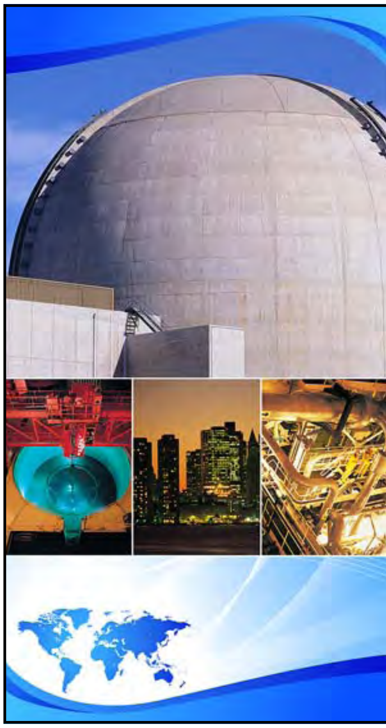
# Results (Continued)

- Low Temperature Brittleness
    - New: -40C
    - Old: -39C
  - Both Show Equivalent Performance
- Pulling Lubricant IEEE 1210 Testing Done on Grades Suggested by Polywater
  - All Had Similar Performance

## Conclusions

- All Testing Performed Indicates The Polymer is a Like for Like Equivalent, and When Used in the Same Formulation Provides Equivalent Performance
- The Resulting Material is the Same in Form, Fit and Function and the Change Has no Effect on the Qualification

# Questions



# Medium Voltage Aging Management Guide Update to EPRI Report 1016689

**2010 Fall Cable User Group Meeting**
September 21, 2010
**Gary Toman and Andrew Mantey**
Senior Project Managers

## 1016689 *Medium Voltage Cable Aging Management Guide*

- Issued in December 2009 as a Technical Update (less formal final editing process)
- Contains in formation beyond assessment of aging necessary for replacement and operation of cable
- Some sections were less detailed than they should be
- Continued medium voltage research and additional operating experience can be added to strengthen the report

## Upgrades and Improvements

- Provide reference where appropriate to the “Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants”, 1020805.
- Provide alignment between 1016689 and 1020805
- Add introduction to each section identifying the material to presented and relevance to the reader
- Reorganize presentation to improve information flow
- Major rewrite of Testing Section to align with 1020805 recommendations




## Upgrades and Improvements (continued)

- Additional degradation causes will be included (corona, partial discharge)
- Deleted inconsequential information or corrected some technical errors missed in original document
- Tightened language where too informal
- Re-formatted to EPRI Technical Report Format
- Update to Appendices

## Issuance

- Revision will be issued late December 2010




## Together…Shaping the Future of Electricity

**Implementation Process Questions for Discussion**

**Program Degree and Scope of Implementation**

- How many utilities are here?
- How many have begun implementation of cable aging management?
- How long before the program documents are ready?
- How long do you expect to take for full implementation?
- What is considered under your program?
  - Pumping
  - Testing
  - Preemptive replacement
  - Walkdowns
- What scope is being implemented? LV, MV, I&C?

**What does one do for manholes that can't be drained? How is this issue addressed?**

**How often does one have to checkup on natural and auto pumping?**

**If rewetting occurs, how soon must a dry state be re-established?**

See discussion at end of section

**How does one (prioritize) risk rank cable? LV? MV?**

MV Cable Ranking Potential Items

- AP-913 ranking
- Consequence of Loss (Limiting Condition for Operation)
- Application (diesel cable, bus tie cable, off-site feed, ECCS motor, MCC/load center feeder)
- Adverse Condition Severity or significance
- Insulating material type and vintage
- Insulation Level (100%, 133%, 177%)
- Cable design (shield type, non-shielded, specialty design (UniShield)
- Testability
- Age of circuit
- Duct versus direct buried
- Duration of submergence
- Severity of ambient temperature, radiant energy, ohmic heating
- Failures on like circuits
- Industry operating experience
- PRA importance

LV Cable Ranking Potential Items

- AP-913 ranking
- Consequence of Loss (Limiting Condition for Operation)
- Application (Supports diesel start and operation, controls power to ECCS motor, controls critical plant circuit breakers, etc)
- Adverse condition severity or significance
- Insulating material type and vintage
- Age of circuit
- Duration of submergence
- Severity of ambient temperature, radiant energy, ohmic heating
- Failures on like circuits
- Industry operating experience
- PRA importance

**What are the training requirements for workers in the cable aging management program?**

- Industry training courses
- Cable program implementing procedures
- Know electrical system layout and design criteria
- Know FSAR statements related to cable and cable system design

**Electrical systems are designed to accommodate a failure of a single cable. What should be done to confirm that bus transfers will occur and that faulted cables will clear properly?**

<u>Recent Problems</u>:
Robinson breaker control fuse failure. Cable failure caused severe damage to three buses.
Limerick cable failed tripping bus source. Undervoltage circuit failed to cause bus transfer to another source. Plant tripped due to lack of generator cooling.

- Verify control power to all MV breakers
- Verify bus transfer circuitry
- For low criticality circuits (run to failure)
    - Are protective circuits (devices that would trip the associated breaker) run to failure as well? If so, is failure announce when it occurs and do responsible parties recognize that repair must be completed to preclude a failure that could remove a bus from service.

## Topic: Manhole/Vault Pumping

## Question: If rewetting occurs, how soon must a dry state be re-established?

**Assumption:** Manual pumping of manholes and vaults has been established. Assuming either a large storm or period of heavy rains (e.g., normal yearly rainy period or a period of unusual rain), how soon must the cable system be pumped dry to preclude an increased concern?

**Discussion:** The importance of returning a cable to a dry state after immersion from a period of rain or other source of in-leakage depends on many factors including past history, cable type and materials, and knowledge of condition through periodic testing. Electro-chemical degradation that causes water related degradation requires water ingress within the cable. Nuclear plant cables have jackets, commonly made of neoprene, CSPE, and CPE that slow the ingress of water such that when immersed, the water takes weeks to months to permeate to the shield and insulation depending on the jacket material and service conditions. Once the water is through to the insulation, the very slow process of electro-chemical degradation begins, which takes decades to result in deterioration that could lead to failure. In the absence of condition monitoring data, the longer the cable was previously exposed to water, the more important keeping the cable dry would be to reduce the likelihood of additional degradation. However, the effect of wetting on the process of degradation obviously is not instantaneous.

**Medium Voltage Cable:**
The following criteria are based on previous history of the circuit with respect to wetting and whether recent condition monitoring data are available. For example, if a circuit was always dry in the past, a short period of wetting will have no real effect. If a cable was wet for a long period in the past, it may have some degradation and wetting it again for a significant period could cause additional degradation to occur. However, if cable test data indicate that the cable is in "good" condition following its long term wetting, there would be less concern for period of rewetting.

### Pumping Criteria – Medium Voltage Cable

Table Q1-1 provides a summary of the criteria described below.

### No Condition Monitoring Data Exist:

*Always Previously Dry*[1]: Wetting for a few weeks to 2 months before drying will have no effect.

---

[1] Cable was rarely wet and only for short periods (days)

*Wet Occasionally during Life* (Wet for short periods (week or two) occasionally during a year): Wetting for a few weeks to 2 months before drying will have no significant effect.

*Long History of Wet Service Conditions* (e.g., 15 or more years): Some long-term deterioration may have occurred. An additional period of wetting may lead to additional long-term deterioration. If cable is rewet, return to dry state within 3 weeks.

**"Good" Condition Monitoring Results within the Last 6 Years:**

*Always Previously Dry*: Same as above

*Wet Occasionally during Life*: Same as above

*Long History of West Service Prior to Drying*: Given "good" test, the effects of long-term wetting have been minimal to date. If rewet, return to dry within 1 to 2 months.

**With "Further Study Required" Result from a Credible MV Cable Test**

Cable appears to have suffered some water related degradation. Dry cable as soon as practical (e.g., within a week) following the termination of cause of immersion (e.g., end of storm or flood). If a longer duration occurs, test at or before the next refueling outage to verify stability of condition.

**Other Considerations:**

If the cable supports a run to failure component, or one that is non-critical and has no significant effect on the plant should it fail, the criticality of maintaining a dry condition is reduced. If the cable is normally de-energized, electro-chemical degradation will not occur and the criticality of maintaining the cable in dry condition is reduced.

**Pumping Criteria – Low-Voltage Cable**

Unlike medium voltage cable insulation where electro-chemical degradation (e.g., water-trees in XLPE insulation) is a known degradation mechanism, there are no established failure mechanisms for low-voltage insulation. It is likely that manufacturing flaws or installation damage coupled with long term wetting leads to failure. However, electro-chemical degradation is not expected because the voltage stress in the insulation is very low (>20 V/mil (>0.5kV/mm)). The remaining concern with respect to the insulation is stability of the insulating polymer in water. Manufacturers' water stability tests have been performed indicating that long-term stability should not be a problem. However, where no obvious indication of the cause of a low-voltage cable failure exists, more detailed forensics is recommended.

Use of the medium voltage pumping criteria is recommended as a conservative approach for low-voltage cables.

**Instrumentation Cable**

While the insulation of low-voltage cable is not expected to deteriorate, jackets will allow water to permeate to the shields of instrumentation cable and may cause multiple grounds to occur. If multiple grounds have been experienced due to wetting of an instrument cable, the above pumping criteria should be modified to be consistent with maintaining the operability of the associated instrument circuits.

**Table Q1- 1. Pumping Criteria Summary Medium and Low-Voltage Cable**

| Condition Prior to Pumping | No Previous Test Results Available | | | "Good" Condition Monitoring Result in Last 6 Years | "Further Study Required" Test Result |
|---|---|---|---|---|---|
| Acceptable Action | Drain Within 3 Weeks | Drain within 1 to 2 Months | Drain within 4 Months | See Text in Box | Drain within a Week |
| Always Previously Dry | Ok | Ok | Ok | Drain within 4 Months | Ok |
| Wet Occasionally During Life | Ok | Ok | Not Recommended | Draining within 4 Months Allowed | Ok |
| Wet Most of Long Service Period prior to Drying | Ok | Not Recommended | Not Recommended | Draining within 1 to 2 Months Allowed | Ok |

# Accelerated Aging of EPR Cables

Howard Sedding - Kinectrics Inc.
Rick Easterling - Kinectrics Inc.

Rochelle Graham - Prysmian

## About Your Contractors

**Kinectrics:**

An established independent company

- *Formerly the Technical Division of Ontario Hydro, one of North America's largest, most reliable utilities*
- *Comprehensive facilities & advanced specialized laboratories near Toronto, ON Canada*
- *Almost 100 years of advanced technical expertise & experience*
- *In business as Kinectrics since 2001*
- *Over 400 scientists, engineers & professional staff*
- *New US Office (Cincinnati, OH)*

**Prysmian Cables and Systems:**

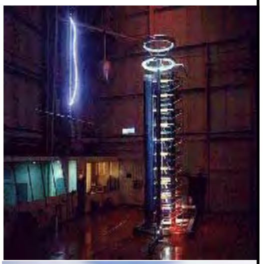
A global company

- Prysmian (formerly Pirelli Cable) has been producing wire & cable for electrical applications since 1879
- Seven research centers world wide
- Over 100 years experience in rubber and polymer design and application
- Established as Prysmian in 2005
- Over 12,000 employees
- Project performed out of Lexington, SC research center

## Background

- **Limited field data on aging of EPR cables**
- **Limited predictive lab aging studies for comparative purposes due to non-standardized test methods**
  - o **IEEE 1407-07 – *"IEEE Guide for Accelerated Aging Tests for Medium-Voltage (5 kV-35 kV) Extruded Electric Power Cables Using Water-Filled Tanks"***
- **Small body of specimens exist to fully evaluate existing and advanced test techniques**
- **Better understanding of degradation mechanism and cable response**
  - o ***Appropriateness of test methods***
  - o ***Development of acceptance criteria***
  - o ***Margin considerations***

## Accelerating Factors



Modified Accelerated Cable Life Test (ACLT)

- High voltage stress (4x Voltage to ground)
- Wet conditions
- High conductivity water (sea water at conductors)
- Lower conductor temperature
- Jacketless cable to promote aging acceleration

## ACLT Cable Core

| | |
|---|---|
| **Conductor Size** | #1/0 AWG 19/W Aluminum |
| **Filled Strand** | No |
| **Insulation Thickness (minimum average requirement)** | 4.45 mm (175 mil) |
| **Average Stress** | 7.7 kV/mm (196 V/mil) |
| **Concentric Neutral Wires** | 6# 14 AWG Cu |

## ACLT Cable Core Summary

- Single conductor, 1/0 AWG, 15 kV cable
- Commercially Available EPR Insulation
- Shielded cable
- Non-jacketed

## Pre-Aging Electrical Tests

- AC breakdowns on conditioned cables
- Partial discharge testing (off line)
- Tan delta
- Dielectric spectroscopy
- Insulation resistance

## Laboratory ACLT Aging Model

## ACLT Aging Conditions

| | |
|---|---|
| **Cable Preconditioning** | Yes<br>100 hours at 90ºC |
| **Media in Conductor** | Yes<br>Salt Water (Instant Ocean® ) |
| **Conductor Aging Temperature (Stress Cone)** | 45±3ºC |
| **Bath Media** | De-ionized Water |
| **Bath Temperature** | 35±5ºC |
| **Aging Voltage** | 4 Vg (34.4 kV) |
| **Load Cycling** | Yes<br>8 hours on & 16 hours off per day |
| **Aging Period (Maximum if no failures)** | 150 days |

## Aging Plan Overview

| # Specimens | Purpose | Conductor Temperature |
|---|---|---|
| 2 | Temperature monitoring | 45ºC |
| 13 | Aging test samples | |

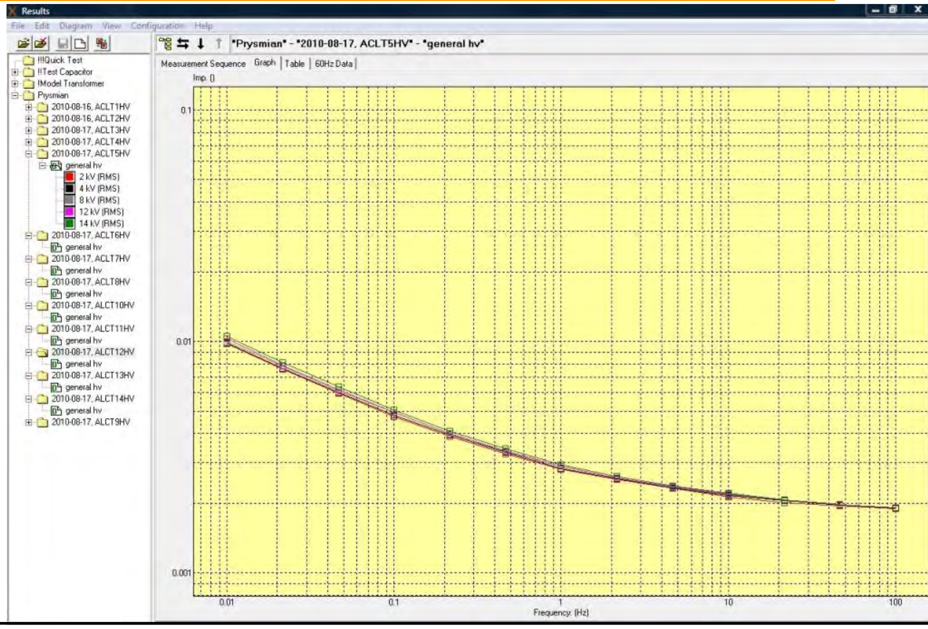
- Age 7 samples to failure, if possible
  - Examine for water treeing and failure mechanism
- Perform AC breakdown tests on samples that do not fail

**Note:** All cables will be subject to final electrical tests and destructive examination

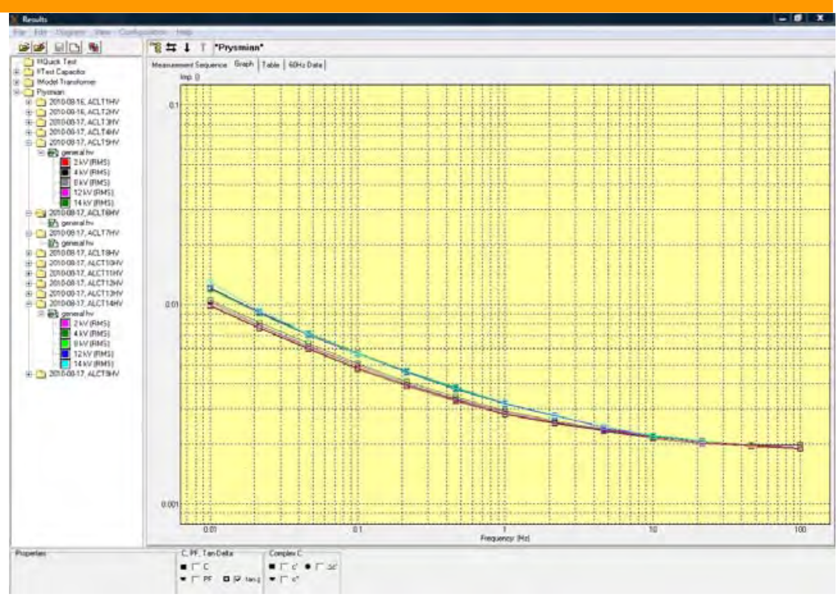
## Dielectric Spectroscopy Equipment

## Basic Test Set Up

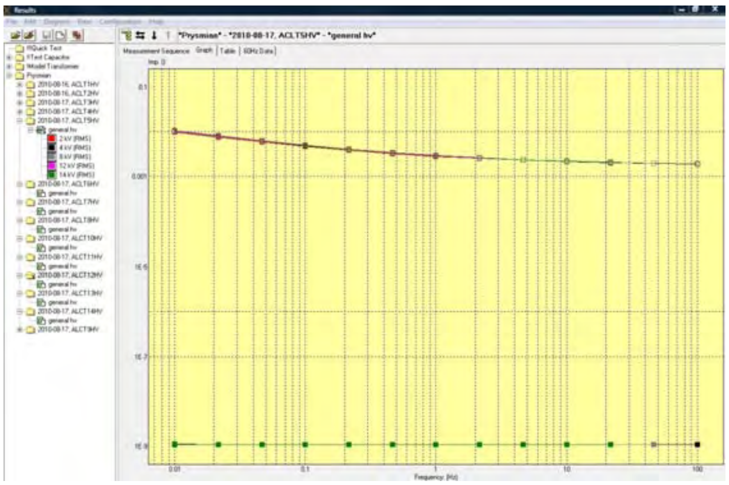
## Baseline Test Results




## Baseline Test Results



## Baseline Test Results



## Post-Aging Electrical and Destructive Evaluation Plan

- Remove cables as failures occur
- Perform partial discharge, tan delta, dielectric spectroscopy and insulation resistance testing on:
  - Failed cables
  - Cables that have not failed
- Perform AC breakdowns of test cables that have not failed
- Destructively evaluate failure sites for identification of water treeing or other failure mechanisms

# Project Status and Remaining Schedule

- Completed tasks:
    - Cable fabrication
    - Sectioning
    - Baseline (pre-aging) cable electrical testing
    - Aging program started September 14, 2010
- Aging nominally completed by February 11, 2011
- Post-aging electrical evaluation completed by beginning of March 2011
- Destructive examination completed by March 2011
- Final report submitted by April 2011

# New Products

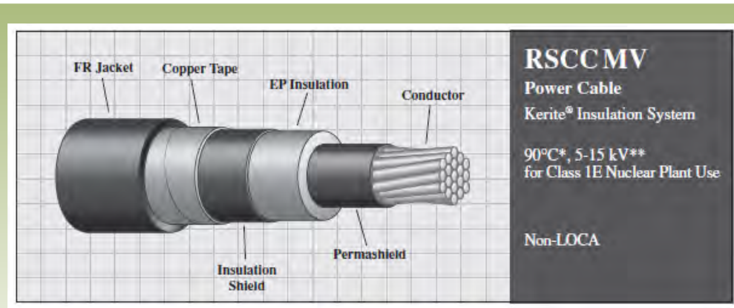
Robert Konnik, Rob Schmidt, & Robert Gehm

# The Marmon Group

# Agenda

- MV Cable
- Fiber Optic Cable
- 3 Hr Fire Rated Cable
- Field Bus
- Data Cable
- Motor Lead Update

# MV Cable




- Sizes Up to 2000 Kcmil
- 1/C and M/C
- Shield & Armor Options

# MV Cable

## Scope

RSCC MV is a jacketed, one conductor power cable designed for applications in Utility generating plants and substations. It is intended for use in harsh and demanding environments, including Class 1E nuclear plant (Non-LOCA) applications. It may be installed indoors or outdoors in trays, ducts, conduits, direct burial or arial applications to perform a variety of power functions.

### Features

- Kerite unique Permashield® conductor shield for enhanced performance
- Kerite discharge resistant insulation
- Thermoset insulation for enhanced thermal stability
- Specially formulated insulation for superior long term water resistance
- Nuclear qualified with a minimum 40-year thermal life expectancy at 90°C
- Radiation resistant (up to 220 megarads)
- Full traceability

### Performance Standards

- Insulation system in accordance with ICEA standard S-97-682 and CS-8
- Jackets in accordance with ICEA standard S-97-682 for heavy-duty chloro - sulfonated polyethylene (CSPE)
- Class 1E qualified in accordance with IEEE-383 and IEEE-323
- Cable passes IEEE-383 (1974) 70,000 BTU/hr vertical tray flame test
- Cable passes IEEE 1202 vertical tray flame test
- Quality Assurance program in accor - dance with 10 CFR 50Appendix B

### Construction

**Conductor:**
Copper, Class "B" compressed strand

**Conductor Shield:**
Unique Permashield® design

**Insulation:**
Proprietary heat, moisture, radiation resistant, and discharge resistant Kerite insulation system

**Insulation Shield:**
Thermoset semiconducting layer

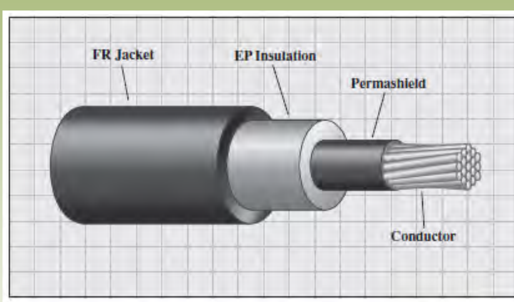
**Metallic Shield:**
Bare or coated 5 mil helically applied copper tape with 20% minimum overlap (optional longitudinally corrugated copper shield available)

**Barrier Tape:** Optional

**Jacket:**
Black heavy duty chlorosulfonated polyethylene, optional black thermoset low smoke zero halogen

**Note:** Special designs are available on request

# MV Cable NS




**RSCC MV-NS**

**Power Cable**

Kerite® Insulation System

90°C*, 5000 Volt**
for Class 1E Nuclear Plant Use

Non-LOCA

- Sizes Up to 2000 Kcmil
- 1/C and M/C
- Armor Options

# MV Cable NS

## Scope

RSCC MV-NS is a jacketed, one conductor power cable designed for applications in Utility generating plants and substations. It is intended for use in harsh and demanding environments, including Class 1E nuclear (non-LOCA) plant applications. It may be installed indoors or outdoors in trays, ducts, conduits, direct burial or arial applications to perform a variety of power functions.

### Features

- Kerite unique Permashield® conductor shield for enhanced performance
- Kerite discharge resistant insulation
- Thermoset insulation for enhanced thermal stability
- Specially formulated insulation for superior long term water resistance
- Nuclear qualified with a minimum 40-year thermal life expectancy at 90°C
- Radiation resistant (up to 220 megarads)
- Full traceability
- All cables pass a wet dielectric (tank) test prior to jacket to verify insulation integrity
- Easy strippability for installation ease

### Performance Standards

- Insulation system in accordance with ICEA standard S-96-659
- Jackets in accordance with ICEA standard S-96-659 for heavy-duty chlorosulfonated polyethylene (CSPE)
- Class 1E qualified in accordance with IEEE-383 and IEEE-323
- Cable passes IEEE-383 (1974) 70,000 BTU/hr vertical tray flame test
- Cable passes IEEE 1202 vertical tray flame test
- Quality Assurance program in accordance with 10 CFR 50 Appendix B

### Construction

**Conductor:**
Copper, Class "B" compressed strand

**Conductor Shield:**
Unique Permashield® design

**Insulation:**
Proprietary heat, moisture, radiation resistant, and discharge resistant Kerite insulation system

**Jacket:**
Black heavy-duty chlorosulfonated polyethylene

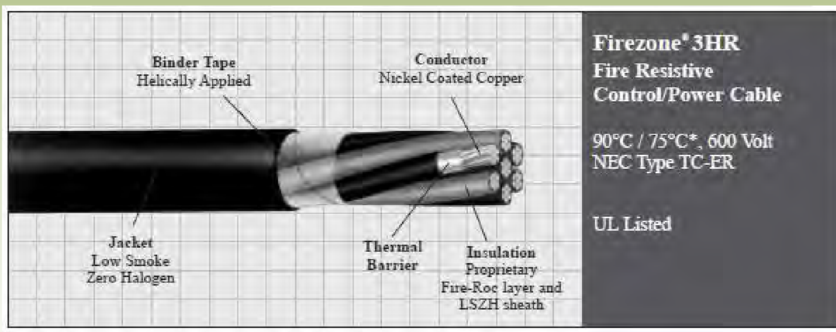
**Note:** Special designs are available on request.

# Fiber Optic Cable

RSCC AFL
Nuclear Fiber Cable Solutions

- Rockbestos-AFL Developments
- Standard Fiber to Super Radiation Hard
- Metal Armor Options
- Thermoset Jackets

# 3 Hr Fire Rated Cable




# 3 Hr Fire Rated Cable

## Scope

Firezone® 3HR is a unique cable which offers superior fire endurance capabilities along with the well-established benefits and features associated with NEC Type TC cable designs. This cable is suitable for use in circuits where the maintenance of circuit integrity is an absolute necessity to allow the operation of systems or equipment vital to life or safety under emergency conditions. It has applications in the nuclear industry to address Appendix R (Code of Federal Regulations: Titlle 10, Part 50.48) requirements.

## Features

- Fire Rated
- Moisture Resistant
- Installs in steel raceway with steel fittings
- Low Smoke, Halogen free design
- Flexible for installation ease
- Easy stripability
- Available in long lengths
- No special tools, connectors, or procedures
- Easily pulled (low friction jacket)
- Radiation resistant (up to 50 megarads)

* 90°C dry, 75°C wet per NEC

## Performance Standards

- Minimum three hour fire rating at 1925°F as defined by the ASTM standard E-119 and UL 2196
- UL Listed, NEC Type TC in accordnace with UL Standard No. 1277
- Approved and marked with the "Sunlight Resistant" designation
- Singles UL Type RHW suitable for wet locations
- Cable passed the IEEE-383 1974 70,000 BTU/hr vertical tray flame test
- Passes IEEE 1202 Flame Test and approved and marked with "FT-4" flame test designation
- -ER meets the crush and impact requirement of Type MC cable and can be used per NEC 336.10 (7) for extended runs

## Construction

**Conductor:**
Stranded, nickel coated copper

**Thermal Barrier:**
Inorganic layer

**Insulation System:**
Proprietary Low Smoke Zero Halogen thermoset Fire-Roc layer and thermoset low smoke zero halogen covering

**Color Code:**
ICEA Methd 3: Black single conductors with printed numbers and color name, following K-2 sequence

**Binder Tape:**
Helically applied

**Jacket:**
Black Low-Smoke Zero Halogen Polyolefin (other colors available on request)

# Browns Ferry

- March 22, 1975 – Near Miss!
- Fire Lasted More Than 7 Hours
- Over 1,600 Cables Damaged
- Unit 1 - Emergency Core Cooling Systems Inoperable!
- Unit 2 - Emergency Core Cooling Systems Damaged
- NRC Response to Fire: Issuance of Appendix R to 10 CFR 50

# Appendix R

Fire Protection Program for Nuclear Power Facilities

- Prevent Fires From Starting
- Detect Rapidly, Control & Extinguish Promptly Those Fires That Do Occur
- Provide Protection For Structures, Systems & Components Important To Safety So That A Fire That Is Not Promptly Extinguished By Fire Suppression Activities Will Not Prevent Safe Shutdown Of The Plant

# Appendix R

Section III.G.2

**Ensure One Redundant Train Is Free From Fire Damage**

- **Separation Greater Than 20 Feet With No Intervening Combustibles?**
- 3-Hour Fire Rated Barrier
- 1-Hour Fire Rating, Detection & Suppression

# NEI Seminar

- Fire Protection Information Forum September 12-16, 2010
- NFPA 805 Transition

# Circuit Integrity

## What Does Circuit Integrity Mean?

The ability of a cable to maintain its electrical function during a fire event

## Significance

It allows systems important to the safety of people to operate as intended while the fire is being suppressed

# Systems Used

## Fire Barrier

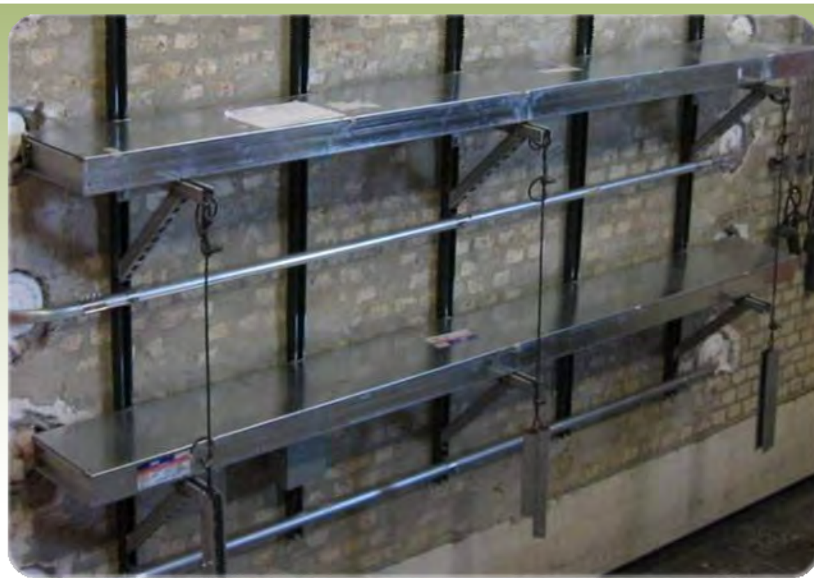
A continuous assembly designed and constructed to limit the spread of heat and fire and restrict the movement of smoke

## Fire Rated Cable

Acceptance criteria for cables are per UL 2196

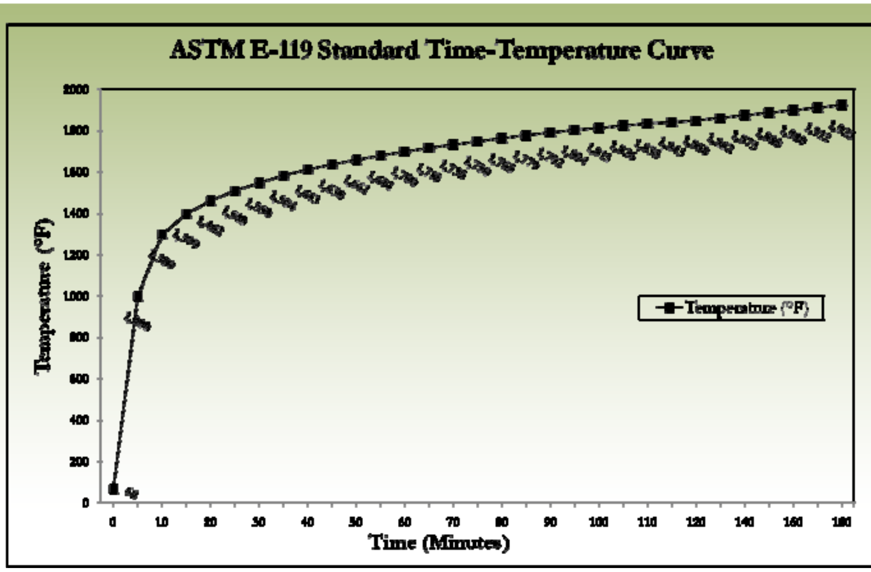
# Electrical Raceway Fire Barrier System

# Firezone® 3HR



# ASTM E-119

Standard Methods of Fire tests of building construction and materials




# UL 2196

Setup

Front

Back

## UL 2196

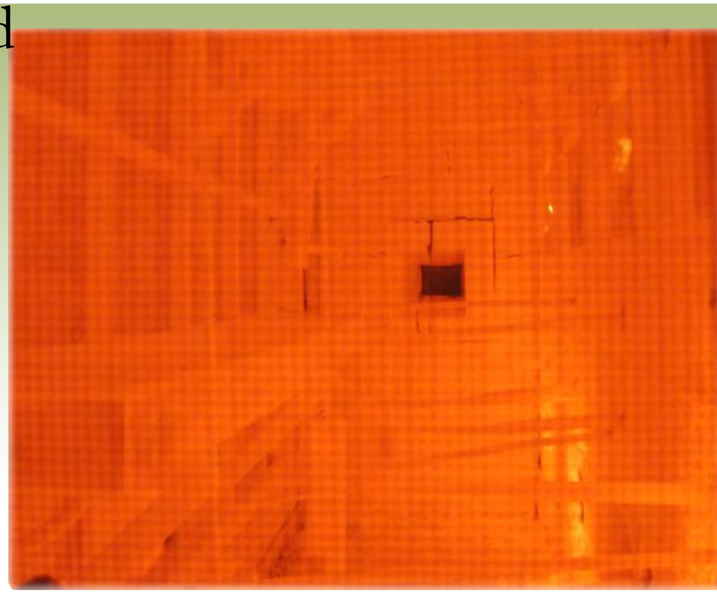
Fire Test

Beginning

## UL 2196

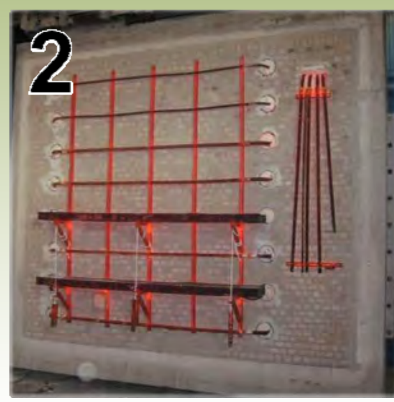
Fire Test

End



# UL 2196

## Hose Test

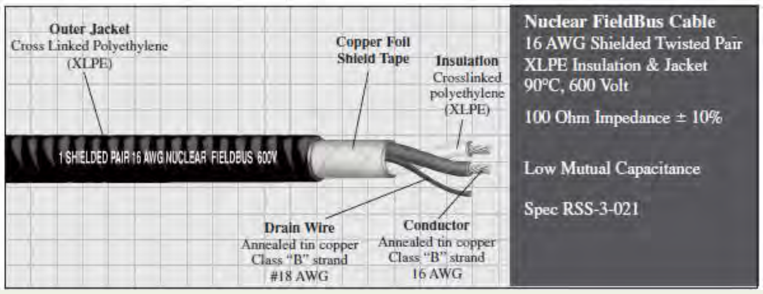






# Benefits

- 3 Hour UL Fire Rating
- Easy Install
- Passes IEEE 383 & IEEE 1202 Flame Tests
- Flexible

# Field Bus




# Field Bus

## Scope

Nuclear FieldBus is a high-performance Nuclear Grade cable rated for use in utility power plants. The low capacitances and high velocity characteristics allow the cable to be installed in long runs between fieldbus devices. Optional features can include jacketed pairs, inner jacket and overall shield. Nuclear FieldBus may be installed in tray, duct, or conduit and is suitable for direct burial. Products are available as single, multi-pair and composite constructions.

### FieldBus Standards

- Meets FieldBus Foundation FF-844 Specification, marked as Type A H1 FieldBus Cable
- Meets ISA 50.02 Part 2 FieldBus standard for use in industrial control systems
- Meets IEC 61158-2 requirements for industrial FieldBus cable

### Features

- 100 Ohms impedance (± 10 ohms)
- 20 pF/FT Mutual Capacitance (± 5%)
- Thermoset insulation & jacket (Nuclear Qualified)
- Superior mechanical properties
- Oil, sunlight, and moisture resistant
- Flame retardant
- 40/60 year qualified life

### Performance Standards

- Nuclear Qualified insulation & jacket
- Reference RSCC QR-5805 Report
- Independent test lab report available upon request (Test # 100012490 CRT-001
- Long term moisture resistance
- Impedance @ 31.25 Khz - 93 ohms
- Attenuation @ 39Khz 2.494 @78Khz 4.019
- Cross-linked polyethylene (XLPE) insulation and jacket in accordance with ICEA S-95-658
- Meets the the "FT-4/IEEE 1202" designation (flame test)

### Construction

**Conductor:**
16 AWG, 7 strand annealed tin copper, Class "B" strand per ASTM B-8 & B-33

**Insulation:**
Crosslinked polyethylene (XLPE) (.038)

**Circuit Identification:**
(1) Black (1) White, White is printed with Leg # (for multiple pairs)

**Shielded Pair:**
Twisted with tin copper drain wire and copper foil shield

**Fillers:**
Flame retardant/moisture resistant (When required)

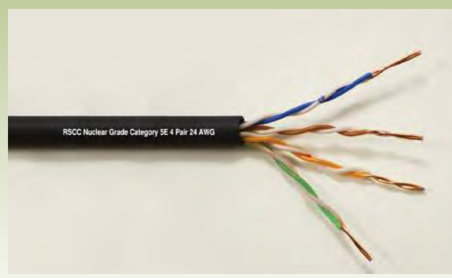
**Overall Shield (Multi Pair Optional):**
Copper foil shield with tin copper drain wire

**Armor (Optional):**
Continuously welded and corrugated aluminum

**Jacket:**
Flame retardant grey XLPE (.045)
Overall diameter .350"

Other Nuclear Fieldbus cable designs available upon request

# Communication Cable




Category 5E 4 Pair 24 AWG
With Crosslinked (Thermosetting)
Insulation And Jacket

Meets TIA/EIA-568B.2

Contains No PVC
Contains No Fluoropolymers

Meets IEEE 383, IEEE 1202 And FT-4 Flame Tests

Non - LOCA

# Communication Cable

## Scope

RSCC Nuclear Grade Communications Cable is a totally thermoset construction specifically designed for applications in utility generating plants and like environments. It offers proven support for Gigabit Ethernet applications and Broadband Video. It is intended for use in harsh and demanding areas, including Class 1E nuclear applications.

### Features

- Can be used for data, voice, P.O.E. (to 48 volts), security, audio-visual, access control and similar applications
- Thermoset insulation and jacket for enhanced thermal stability
- Extremely flame retardant
- Specifically formulated insulation for superior long term water resistance
- Radiation resistant
- Full traceability
- Excellent mechanical properties
- Various shielding options including continuous welded and interlock armor (Aluminum or galvanized steel)
- Mates with standard RJ-45 connectors

### Performance Standards

- Performance per TIA/EIA – 568 – B.2
- Quality assurance program in accordance with 10 CFR 50 Appendix B
- ETL verified to category 5E
- Radiation cross-linked insulation and jacket to ICEA S95-658
- Cable meets IEEE 383-1974 and 2003, ICEA 1202-1991, and FT-4 flame tests

### Construction

**Conductor:**
24 AWG solid B.C.

**Insulation:**
Proprietary heat, moisture and radiation resistant, crosslinked polyethylene

**Color Code:**

| Pair | Conductor #1 | Conductor #2 |
|---|---|---|
| 1 | Blue | White/Blue |
| 2 | Orange | White/Orange |
| 3 | Green | White/Green |
| 4 | Brown | White/Brown |

**Binder Tape:**
Helically applied

**Pairs:**
2 conductors twisted together with various Left Hand Lays

**Core Assembly:**
4 twisted pairs cabled together

**Jacket:**
Crosslinked flame-retardant polyethylene with colors as option

## Motor Lead Update

- Present Source Will Not Supply Material
- Working With Alternate Source
  - Need To Review Product Offerings
  - Need to Evaluate Testing Requirements

## Summary

- RSCC Will Be Able To Provide All Cables For Next Generation Plants
- Any New Requirements Let Us Know
- We Will Be LOCA Testing
  - Looking At Condition Monitoring

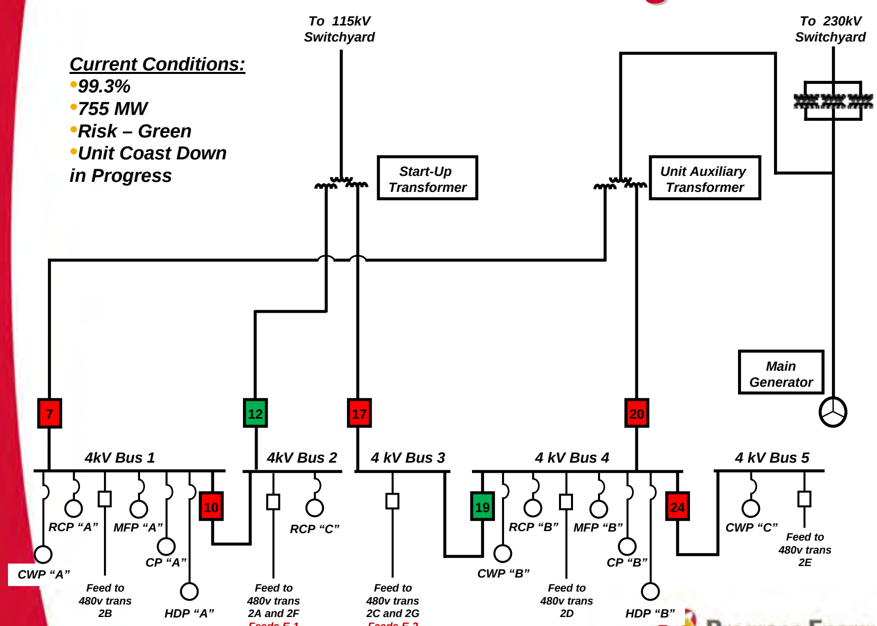
# QUESTIONS

# H.B. Robinson Electrical Event

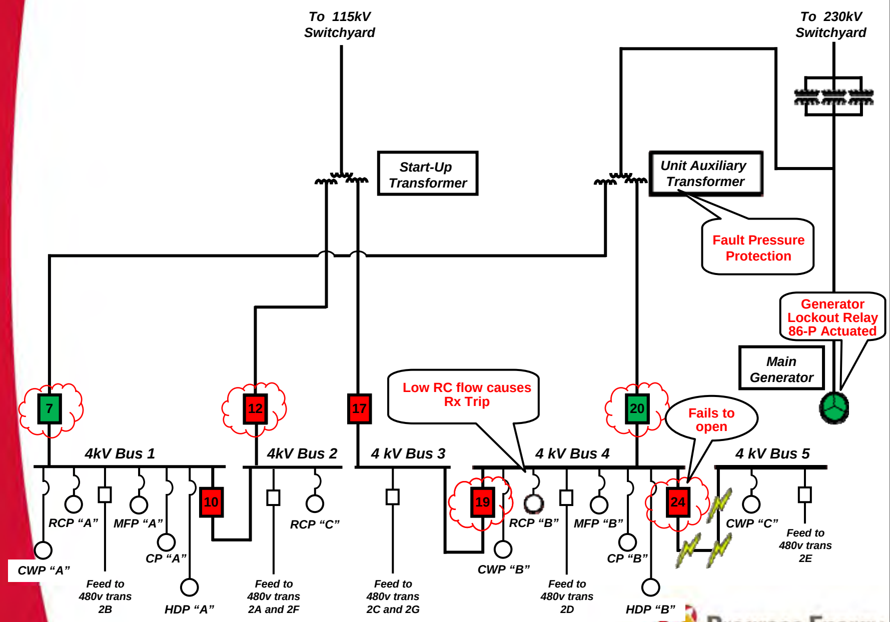
# RNP Normal at Power Alignment

***Current Conditions:***

- *99.3%*
- *755 MW*
- *Risk – Green*
- *Unit Coast Down in Progress*



# RNP 4 KV Initial Event






Progress Energy

# 4 kV - Bus 5



Progress Energy


DANGER
HIGH VOLTAGE
Progress Energy

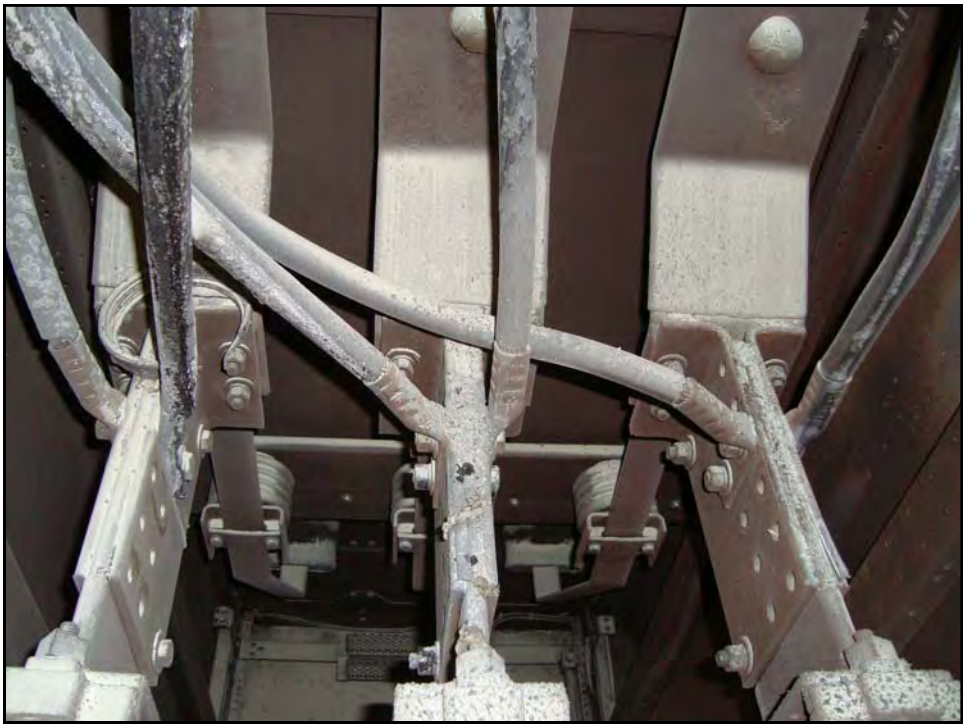

DANGER
HIGH VOLTAGE


4160V Bus 5
2010 3 29

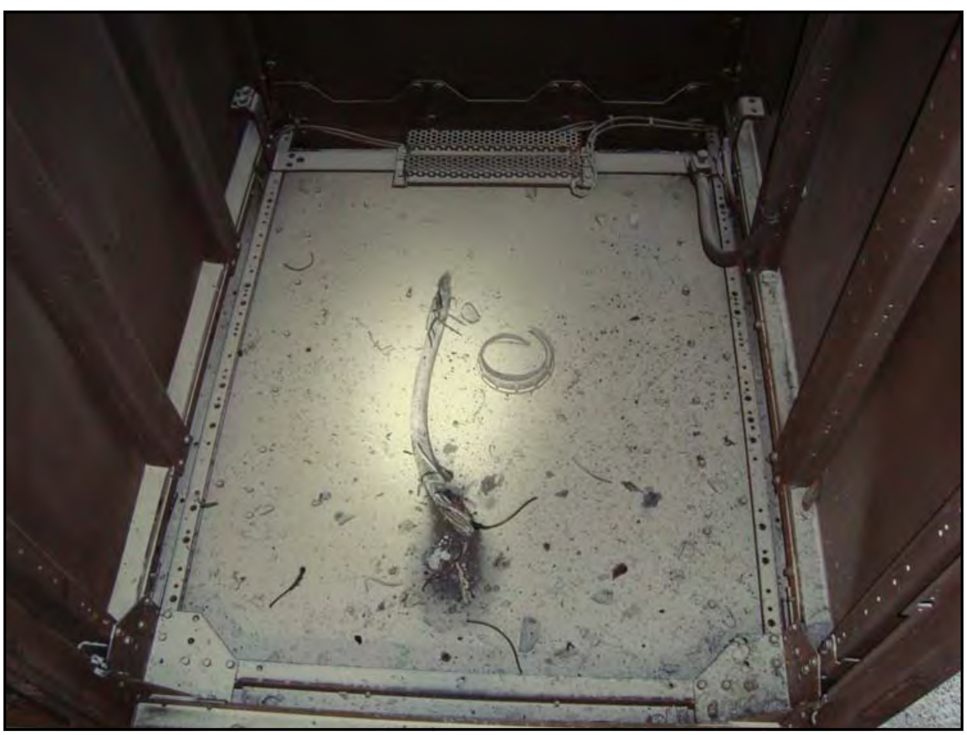

2010 3 29


2010 3 29

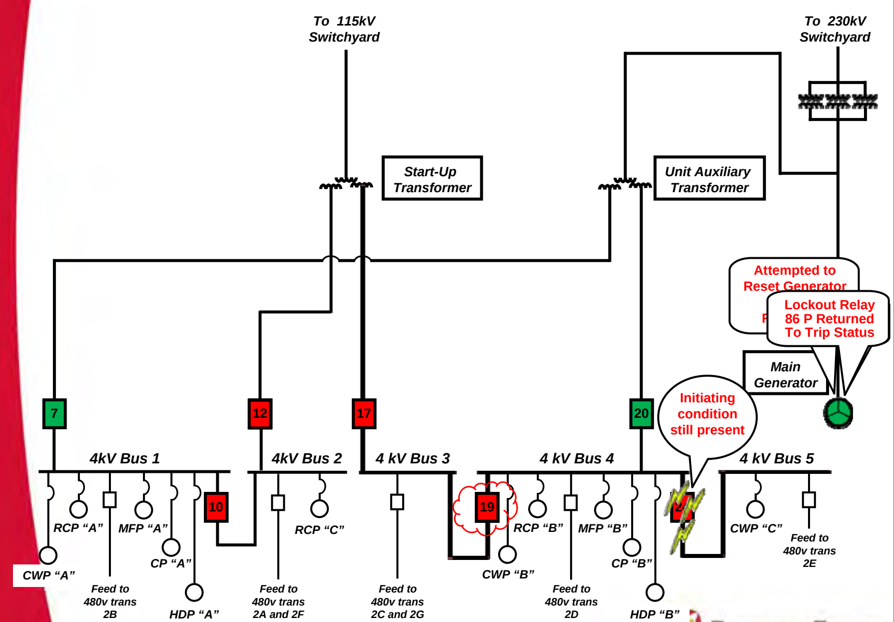
Progress Energy




2010 3 29



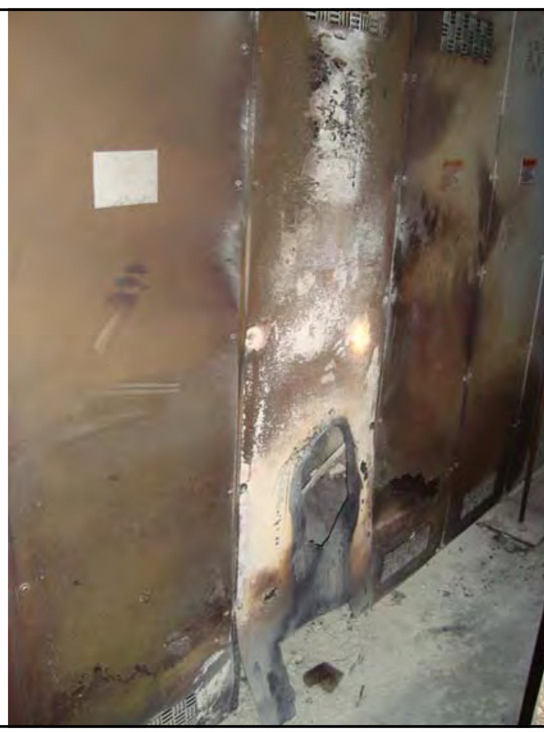

# RNP 4 KV Second Event





Progress Energy


Progress Energy



Progress Energy


Progress Energy


Progress Energy


2010 3 29


2010 3 29


Progress Energy




Progress Energy


e
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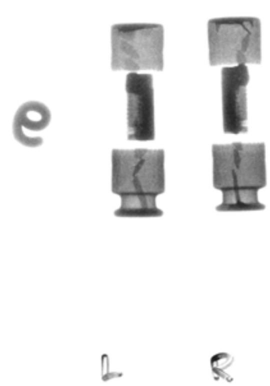
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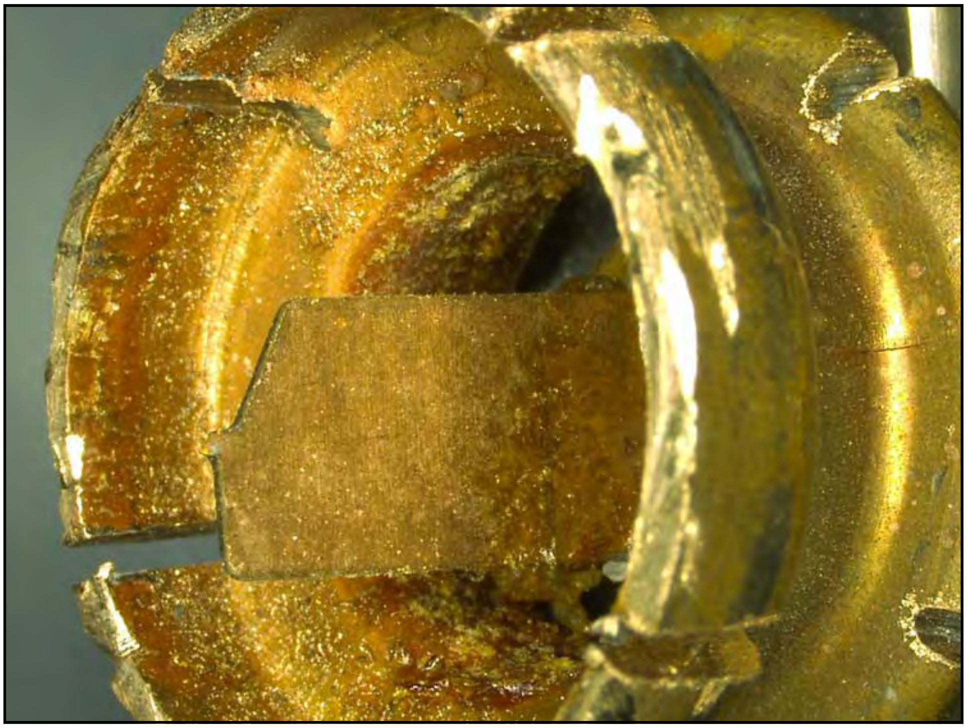
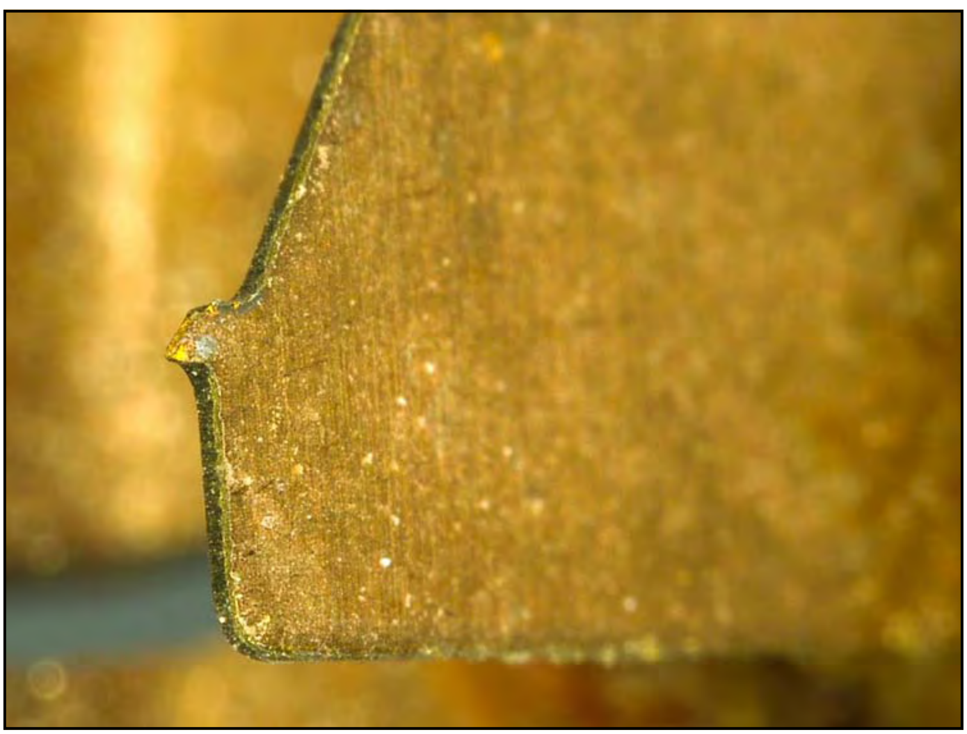
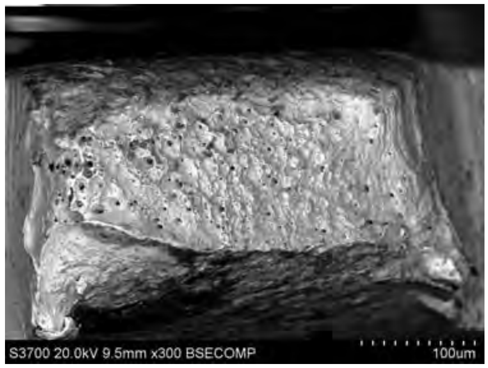
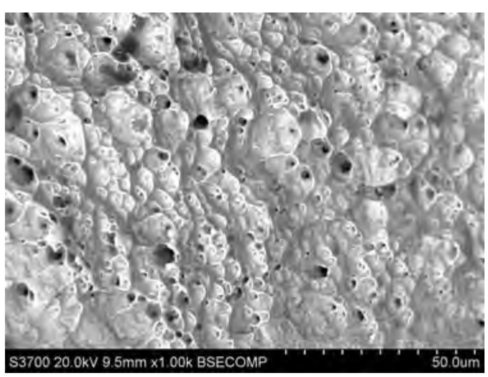
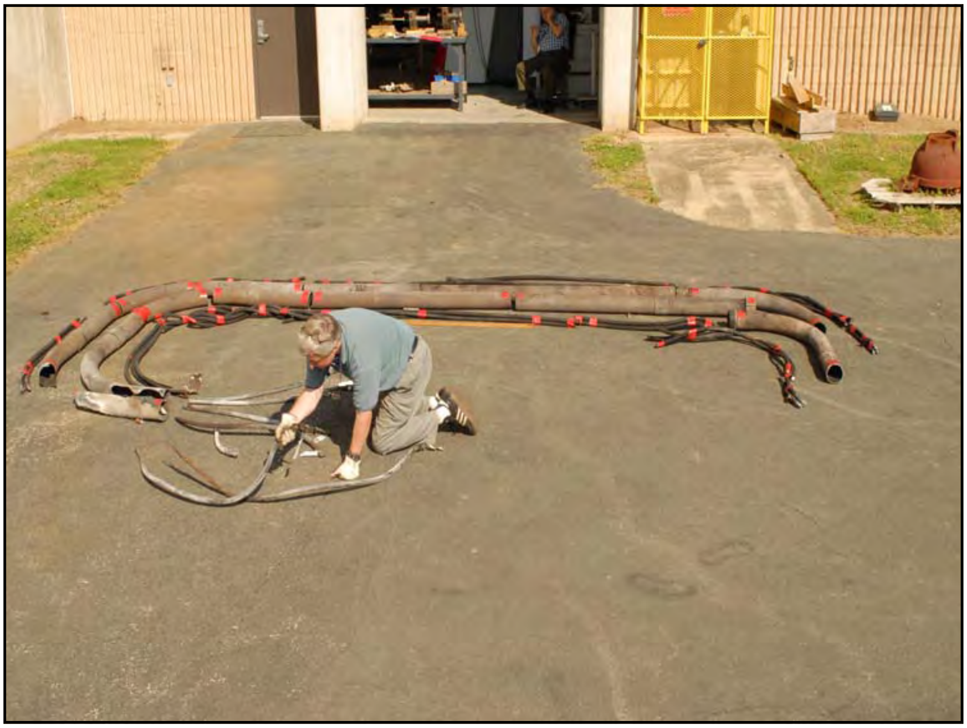




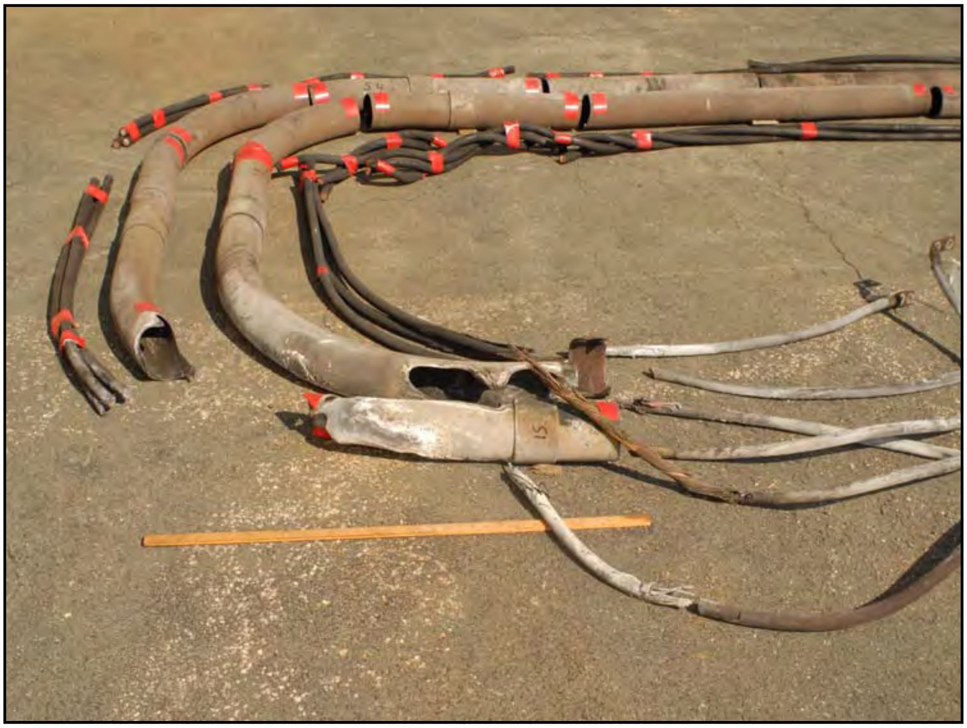

S3700 20.0kV 9.5mm x300 BSECOMP
100um




S3700 20.0kV 9.5mm x1.00k BSECOMP
50.0um




S1



# Questions?

Donna Young
Donna.Young@pgnmail.com
919-546-4889

# NPP Leibstadt (Switzerland)

# Results of

# VLF dissipation factor measurement

# at MV 6.6/10 kV EPR Cables

# during Outage 2010



## NPP Leibstadt (Switzerland)

## NPP Leibstadt - Main Data

- **Main Components**

| | | |
|---|---|---|
| Reactor / Containment (GE) | | BWR 6 / Mark III<br>73.1 bar / 286 °C |
| Turbine | (BBC) | 1 High Pressure + 3 Low Pressure |
| Generator | (BBC) | 2-poles (3000 rpm); 27 kV |

| **Power Output** | **Thermal** | **Electrical (net)** |
|---|---|---|
| Original at start up in 1984 | 3012 MW | 942 MW |
| First power upgrade 1986 | 3138 MW | 990 MW |
| Power upgrade program | | |
| • 112% | 3515 MW | 1145 MW |
| • 114.7% (since August 26th 2002) | 3600 MW | 1175 MW |



## MV (6.6/10 kV) EPR Cables Class 1E
## Manufacturer: Cossonay (CH)
## Year manufactured: 1982
## 2 different sizes (all cables installed in dry environment)
## Total length of installed cables 15‘000m

**3 x 1 x 185 mm² (350 MCM)**

**3 x 1 x 300 mm² (600 MCM)**

## Technical Data of MV Cable 6.6/10 kV

| | |
|---|---|
| Year manufactured: | 1982 |
| Manufacturer: | Cossonay (Switzerland) |
| Classification: | Class 1E |
| Standards: | IEEE 383 and different IEC Cable standards |
| Wire insulation: | EPR |
| Jacket insulation: | EPR |
| Test voltage: | 15 kV for 24 h |
| Operating temperature: (Conductor) at 50°C ambient temperature | 90°C continuous<br>130°C for 8 h, max. 100 h per year<br>300°C for max. 2 sec |



## Technical Data of MV Cable 10/6.6 kV

| | |
|---|---|
| Impulse test voltage: | 125 kV |
| Ambient temperature: | max. 65°C |
| Radiation: | 50 Mrad TID |
| Qualified life: | 40 years at 67°C (conductor temperature) |

Halogen free, high temperature

Dynamic short-circuit strength (Type test)

Thermal short-circuit strength (Type test)

## Measuring campaign MV Cable 6.6/10 kV outage 2010

**Total 4 lines 1’293 m (supply of main cooling water pump motors)**

Test system: BAUR cable diagnostics system PHG80 TD/PD

Test method: VLF truesinus® digital technology

Standards: IEEE 400.2-2004 “IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)”

VDE DIN 0276-620 “Power cables - Part 620: Distribution cables with extruded insulation for rated voltages from 3,6/6 (7,2) kV to 20,8/36 (42) kV”



## BAUR Test equipment

truesinus®

www.baur.at

## Configuration at feeder side



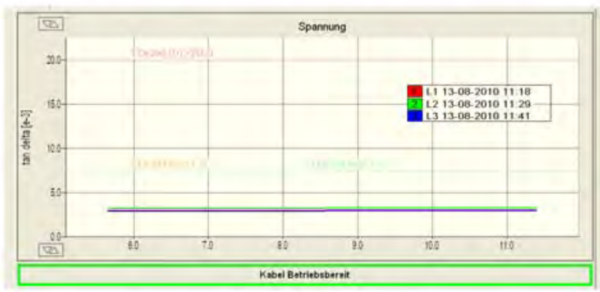
## Configuration at consumer side

- **MV Motor for main cooling water pump 1.9 MW**

# Results of tan delta (Cable 1)
# Lenght of cable 20VC02D101-CA01: 303 m

Zusammenfassung:

| Phase | Schritt | Spannung kV | Mittelwert tan delta | Standardab [e-3] | Anzahl | Last nF |
|---|---|---|---|---|---|---|
| L1 | 1 | 5.7 | 2.981 | 0.003 | 8 | 148.5 |
| L1 | 2 | 8.6 | 3.016 | 0.001 | 8 | 148.6 |
| L1 | 3 | 11.4 | 3.052 | 0.001 | 8 | 148.8 |
| L2 | 1 | 5.7 | 3.201 | 0.002 | 8 | 154.2 |
| L2 | 2 | 8.6 | 3.261 | 0.001 | 8 | 154.4 |
| L2 | 3 | 11.4 | 3.320 | 0.001 | 8 | 154.6 |
| L3 | 1 | 5.7 | 2.920 | 0.003 | 8 | 149.5 |
| L3 | 2 | 8.6 | 2.956 | 0.001 | 8 | 149.6 |
| L3 | 3 | 11.4 | 2.992 | 0.001 | 8 | 149.9 |

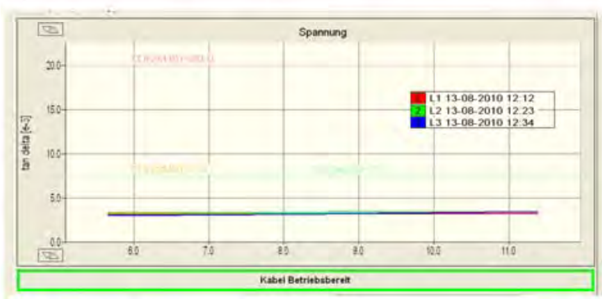





# Results of tan delta (Cable 2)
# Lenght of cable 10VC03D101-CA01: 342 m

Zusammenfassung:

| Phase | Schritt | Spannung kV | Mittelwert tan delta | Standardab [e-3] | Anzahl | Last nF |
|---|---|---|---|---|---|---|
| L1 | 1 | 5.7 | 3.184 | 0.002 | 8 | 170.6 |
| L1 | 2 | 8.6 | 3.243 | 0.002 | 8 | 170.7 |
| L1 | 3 | 11.4 | 3.300 | 0.001 | 8 | 171.0 |
| L2 | 1 | 5.7 | 3.346 | 0.001 | 8 | 160.2 |
| L2 | 2 | 8.6 | 3.391 | 0.001 | 8 | 160.3 |
| L2 | 3 | 11.4 | 3.440 | 0.001 | 8 | 160.6 |
| L3 | 1 | 5.7 | 3.046 | 0.011 | 8 | 172.2 |
| L3 | 2 | 8.6 | 3.198 | 0.010 | 8 | 172.3 |
| L3 | 3 | 11.4 | 3.489 | 0.004 | 8 | 172.6 |



## Evaluation

- Good values in general (compared with other EPR MV cables)
- Cables are normal aged
- The measured values over the three voltage levels are nearly constant
- The three phases are symmetrical

Proposal/recommendations from test engineer

- End covers should be replaced
- Think about a future monitoring system
- Next measuring between 5 and 10 years



## Lessons Learned / Experience

- Start with planning as soon as possible
- Good preparation is an absolute requirement
- Coordinate the measuring campaign well with the Operations personnel from the MCR and the maintenance personnel (electricians) who open the cable terminal (cubicle side /consumer side)
- Be sure on which side (switchboard/consumer or both) the shield is on ground
- Clarify if the test equipment is portable or not
- Using non portable test equipment, clarify the maximum length of the supply cable

## Lessons Learned / Experience (Cont.)

- Clarify the way from the test equipment to the connection points (are there penetrations, doors, … in between)
- The consequences of a cable failure during any high-voltage test should be considered (verify if there is spare cable available)
- Be aware: You work with high-voltage
  Personal safety is of utmost importance
  (Observe all plant safety operating procedures)
- Establish good communication between
  - test engineers at test equipment
  - connection point (cubicle) and
  - cable ends under test (consumer side)

# Remote and Automated Level Monitoring in Cable Manholes

Denise Thomas, Senior Engineer
Gregory M. Quist, Ph.D.

*09/22/10*

Exelon

SMARTCOVER® Monitoring & Alarm System

# Outline

- The Problem: Submerged Cables
- SmartCover® Level Monitoring System
- The Peach Bottom Install and Results
- Questions, Discussion

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# Submerged Cables

Discussion of problem of submerged cables
NRC actions
Need for complete closed-looped management
- Monitor
- Detect potential fault
- Take action - solve problem
- Verify that action was successful

Planning for manhole repair or maintenance

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# Goals of Remote Level Monitoring

- Closely track water levels in manholes
- Obtain information in timely manner for pumping
- Correlate levels with external events
- Eliminate need for, and cost of, manual inspections
- Prevent problems before they occur
- Provide data for upgrade and maintenance planning

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## SMARTCOVER®

# Features

- Remote, real-time monitoring
- Self-powered
- Highly reliable, independent communications
- Environmentally robust
- Simple and fast to install
- No confined space entry
- Does not touch water or cables
- Low maintenance
- Active management
- Easily adaptable to other measurements

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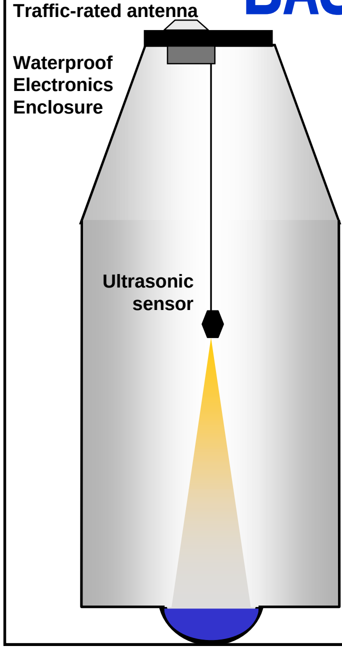
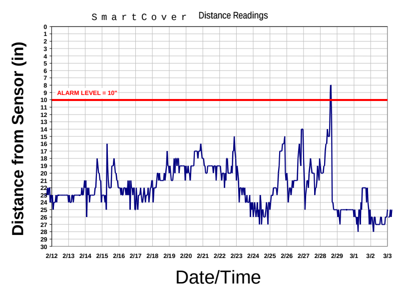
# BASIC FUNCTIONS

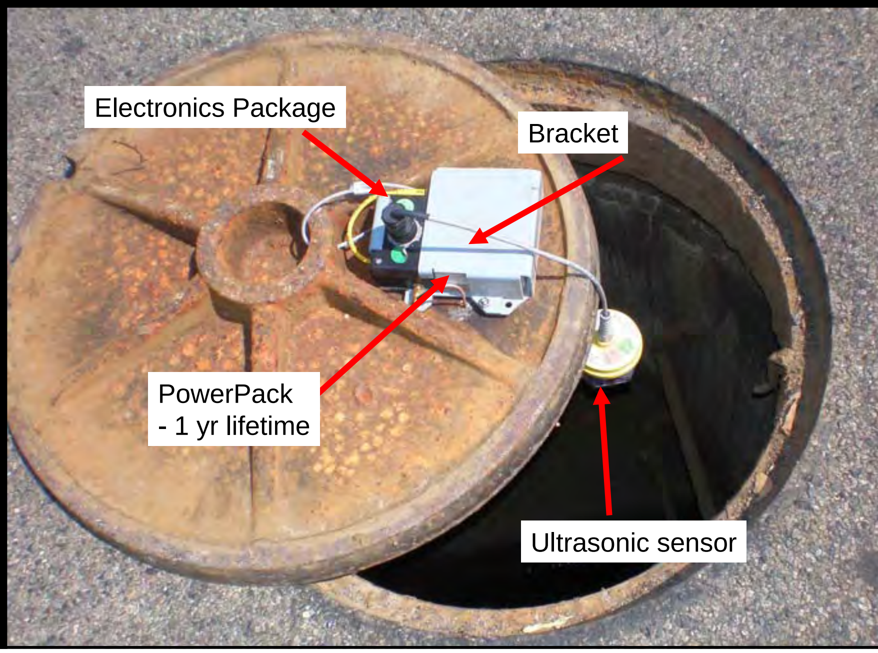



Data collection

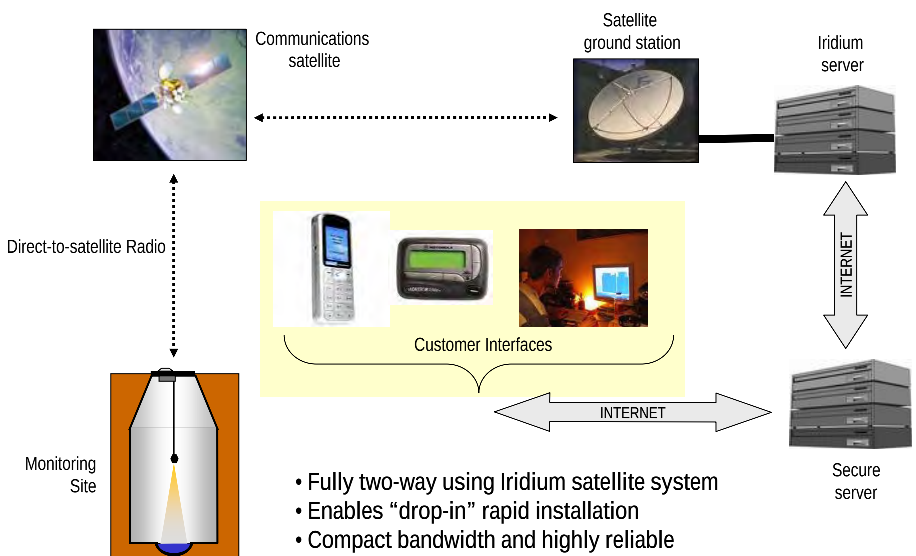



Alarms
- Surcharges
- Intrusions

# As Installed




# Communications Network Architecture




- Fully two-way using Iridium satellite system
- Enables "drop-in" rapid installation
- Compact bandwidth and highly reliable
- Requires no other infrastructure

## SMARTCOVER® - S
## Direct-to-Satellite

SaVi

## World-Wide Coverage

3G Cell Phones

SmartCover®-S Coverage

## Product Performance Record

As of August 30, 2010:

About 10.8 million operating hours
6 False alarms (in 108 million chances)
1 Missed event (our error, not equipment)
Operating in highly corrosive environment
MTBF exceeds 5 years (TBD)

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## System Reliability

- Communications: Iridium LEO system: **Availability = 100%**
- Electronics: >$10^7$ field hours, MTBF ~ 45K Hr
  MTTR ~ 30 min + travel
  => **Availability > 99.99%**
- Antenna: traffic rated, MTBF > 20K hr, MTTR ~ 30 min + travel
  => **Availability > 99.99%**
- Sensors: sealed and potted, MTBF > 30K hr,
  MTTR ~ 30 min + travel
  => **Availability > 99.99%**
- Power: MILSPEC power cells, failure rate ~ 0 **Availability = 100%**

**SYSTEM AVAILABILITY ~ 99.9%, expected downtime < 8 hr/year/site**

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# General Specifications

| | |
|---|---|
| Size: | < 6" x 6" x 4" |
| Weight: | 4.5 lbs |
| Sensor Range: | 3"-81" (standard) 11" - 240" (long range) |
| Sensor Resolution: | 1" (standard), 0.1" (high resolution) |
| Sampling Period: | 3 min to 2 days, 6 min (standard) |
| PowerPack Voltage: | 3.6 VDC |
| PowerPack Life: | 1yr to 5yr (depends on usage) |
| PowerPack Shelf Life: | > 10 yr |
| Wireless Communications: | Iridium satellite, fully two-way, 1.6 GHz, compact bandwidth |
| Antenna: | 0.25" x 3" x 2" low profile, traffic rated |
| Environmental: | IP-67, NEMA 4P, shock resistant |
| Alarms: | Water level, intrusion |
| Other Optional Capabilities: | Pressure, pump off, alternative low power sensors |

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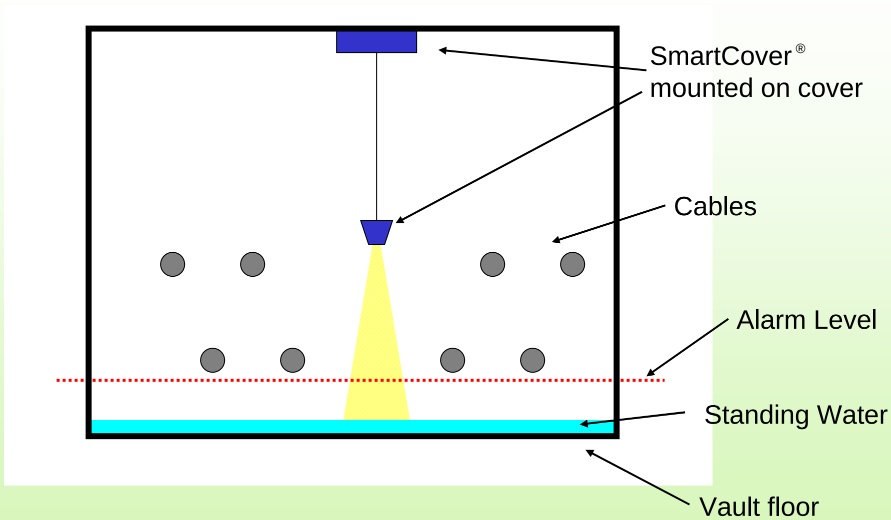
# Cable Vault Applications

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## Example Cable Vault

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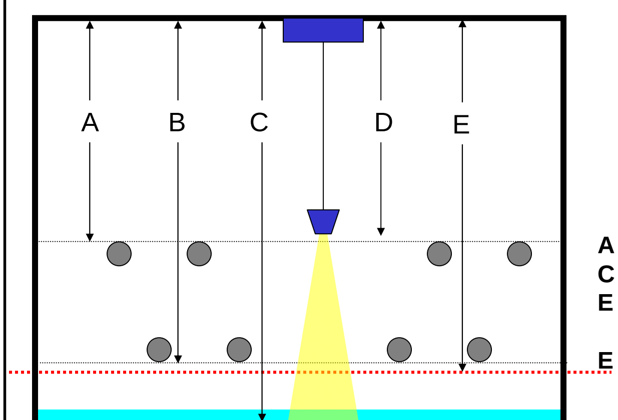
## Installation Set-Up




A: Top of cables
B: Bottom of cables
C: Bottom of manhole
D: Sensor length
E: Alarm depth

**A > D: sensor above top cables**
**C - D = Baseline level**
**E > B: Alarm before water hits cables**
**E - D = Alarm level**

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# Peach Bottom
## Phase 1a Level Monitor Installation

- 48 safety-related sites
- 24 Units installed over elapsed 2 week period August 2010
- On-site install team trained by Hadronex
- “Self-install” possible after 1 week of training
- One unit had installation problem - solved by on-site team
- Very difficult radio environment - satellite units work well
- Some operational training needed (e.g. parking)
- Rain events showed inflow at some sites
- Indoor installations delayed until shut-down complete

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# Installation Photos

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## Installation Photos

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## Installation Photos

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## Installation Photos

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## Installation Photos

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# Map-Based Web Interface


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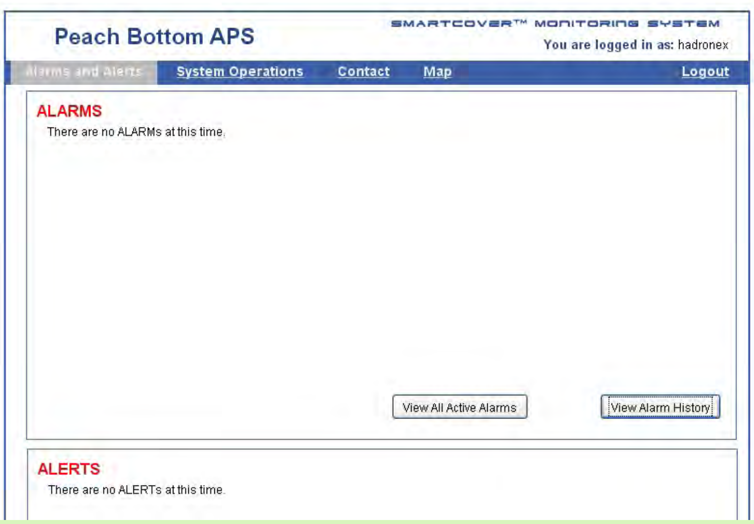
# Alarm and Alert Page

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# Alarm History and Response

Peach Bottom APS

SMARTCOVER™ MONITORING SYSTEM

You are logged in as: hadronex

ALARM HISTORY

| Location Desig | Location Desc | Dist | Alarm Date | Alarm Type | Ack | Ack Date | Ack By |
|---|---|---|---|---|---|---|---|
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 14:10:25 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 14:03:19 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 13:44:18 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 13:23:06 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 13:14:52 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 13 | Aug 22, 2010 13:06:50 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 14 | Aug 22, 2010 12:59:45 | SURCHARGE | ✓ | NA | Walt Merkle |
| Peach Bottom APS MH025d | | 14 | Aug 22, 2010 12:49:39 | SURCHARGE | ✓ | NA | Walt Merkle |

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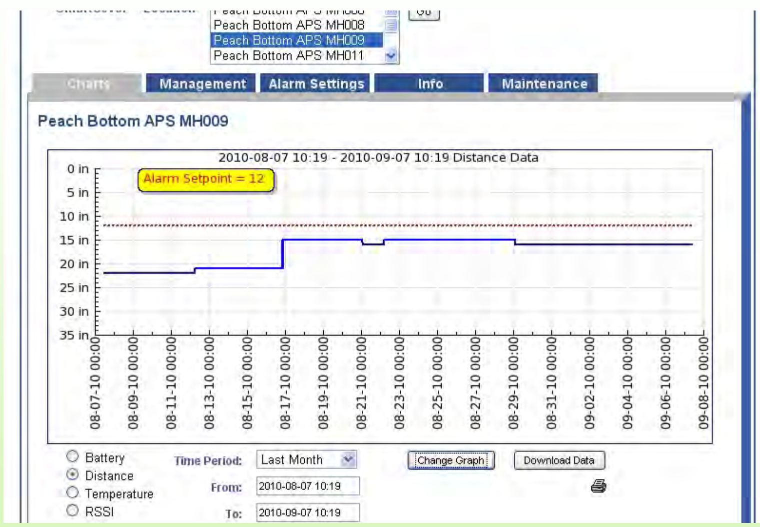
# Typical Water Level Chart

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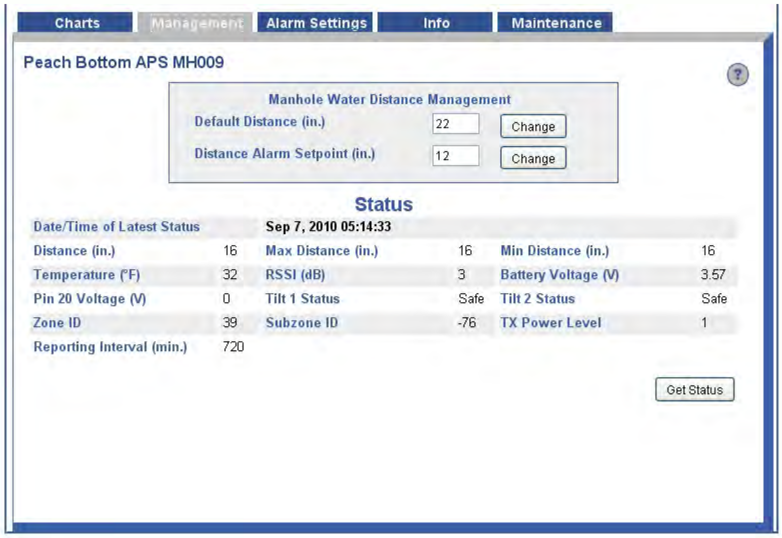
# Continuous System Monitoring

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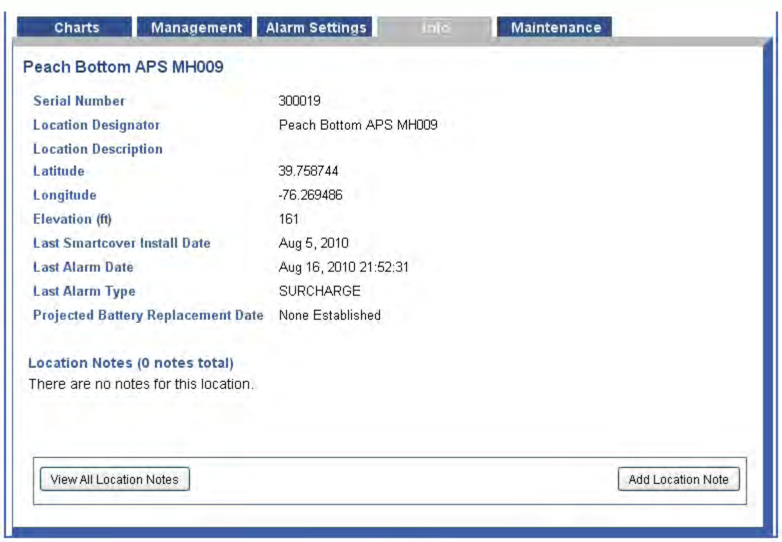
# Location and Maintenance Log

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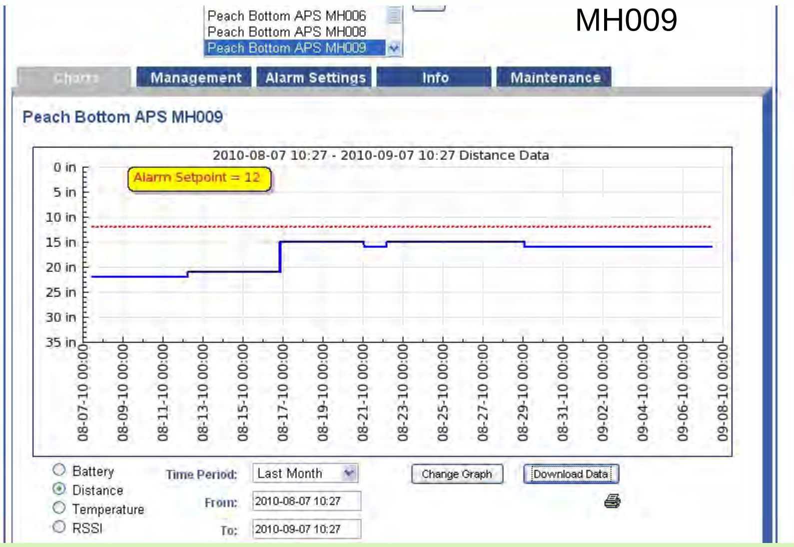
## Sample Data from Peach Bottom

MH009

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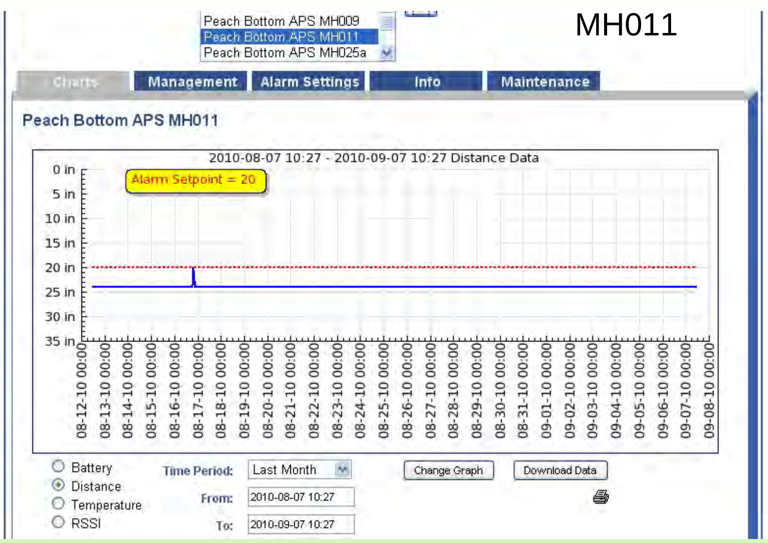
## Sample Data from Peach Bottom

MH011

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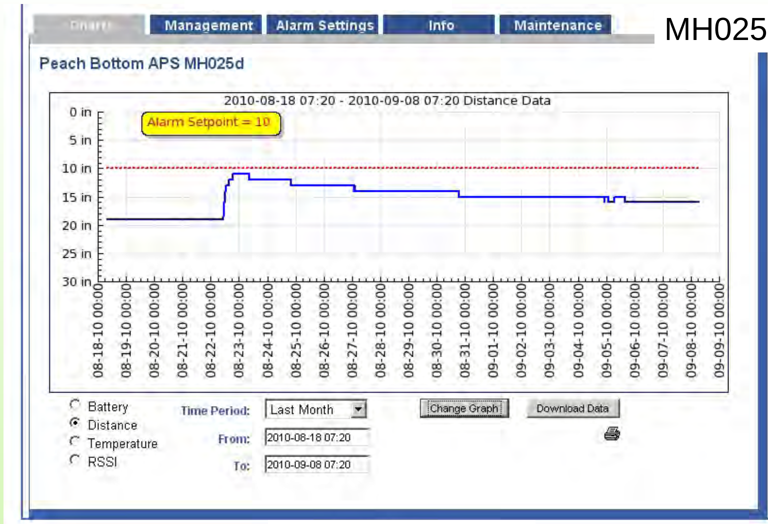
# Sample Data from Peach Bottom

MH025d

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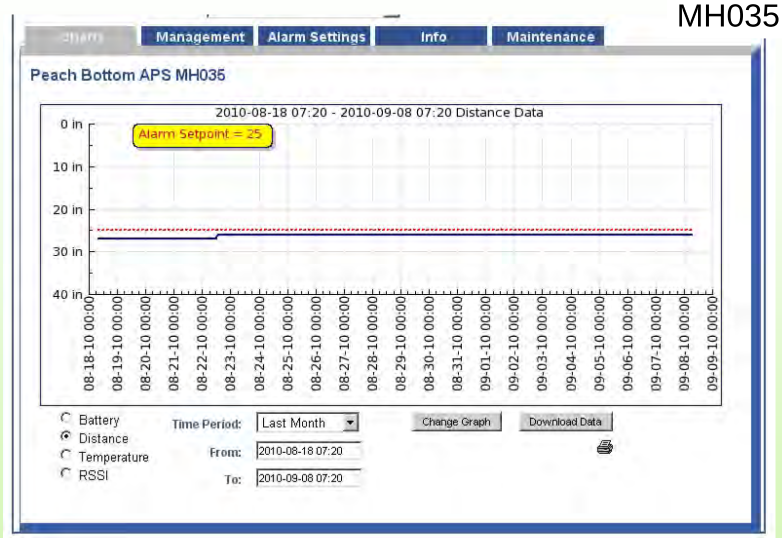
# Sample Data from Peach Bottom

MH035

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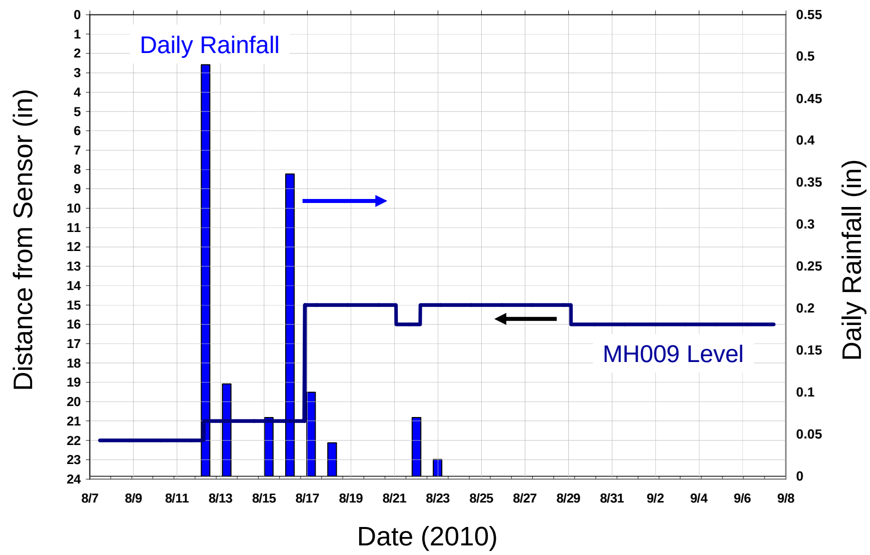
MH009

## Rainfall and Level Linkage Example




***Rainfall at***
***Red Lion, PA***

## Early Results from Peach Bottom

- Water level records show sensitivity to rain events
- Levels go up - and down
- Each manhole location is unique
- Long term trending can provide tool to determine repair or modification priorities
- Inflow vs. infiltration: both effects present, too early to quantify
- Two competing effects: external water & ground water
- Take action based on data

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# Questions and Discussion

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# Installation Challenges

1. Tornado Missile Shields
2. Indoor Installations

**GOALS**

- Minimize installation cost
- Maintain level monitoring effectiveness
- Avoid changing manhole access procedures
- Decrease overall risk - get the job done

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## Strengths and Limitations

- Installation is fast and generally simple
  - Exceptions: Tornado missile shields and indoors
- Level monitoring provides ability to perform diagnostics
- Satellite communications is everywhere and reliable
  - But - needs to have some sky access without metal shielding
- Built for sewer environment, cable vaults are more benign
- PowerPacks may last from 1 to 5 years (depending on use)
- Closed loop management control of units and system
- Integration and visibility of fleet resources is seamless
- High system reliability due to independent operation

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## System Input/Output

1. Digital input for the Distance sensing Module (DSM)
2. Two additional digital inputs for On/Off or pulse measurements
3. A 8 bit (24 bit option) analog to digital converter for 0 to 5 volts
4. Switchable 5 volt supply up to 100 mA

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## Optional External Integration

- Data collected and aggregated at Hadronex secure server
- Downloadable as .csv or Excel at any time
- Can be forwarded to SCADA or other data base systems:
  - SMTP mail
  - TCP/IP transactions
    - Flat file data
    - SQL
    - Formatted XML
- Independent system gives redundancy and high reliability

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## System Costs

**As of 09/08/10**
**Subject to change**

| | |
|---|---|
| Radio communications system | $0 |
| Operational software | $0 |
| User software | $0 |
| Basic Hardware* | $3571 ea |
| Active Site Management | $400 (ea, annual) |
| Installation Kit (H/W) | $250 ea |
| Installation | TBD (site dependent) |

***(No confined space entry or manhole breach required)***

Capital Based Purchase* (5 years): $5831 + Installation

| | |
|---|---|
| On-Site Training | $800 **(one-time)** |
| Replacement PowerPacks | $225 ea |
| Extended Warranty Options Available | |

*** Basic system on standard manholes: non-standard H/W and site-dependent engineering not included**

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## How Hadronex Supports Installed Systems

- SmartCover® Hardware and System
  - Operations
  - Power supply
  - Wireless communications
- Installation Support, Design and Guidance
- Post-Installation System Monitoring
- Fault Detection and Regulatory Report Support
- Data Analysis and Technical Recommendations

The

# SMARTCOVER®

# Remote Level Monitoring System

Denise Thomas, Senior Engineer
Gregory M. Quist, Ph.D.

*09/22/10*

Exelon®

SMARTCOVER® Monitoring & Alarm System

# Limerick Manual Scram Initiated by Cable Failure

**Presented By: Denise E. Thomas**

## Event Summary



On June 23, 2010, operators initiated a manual scram on Limerick Unit 1 due to the loss of both MG sets.

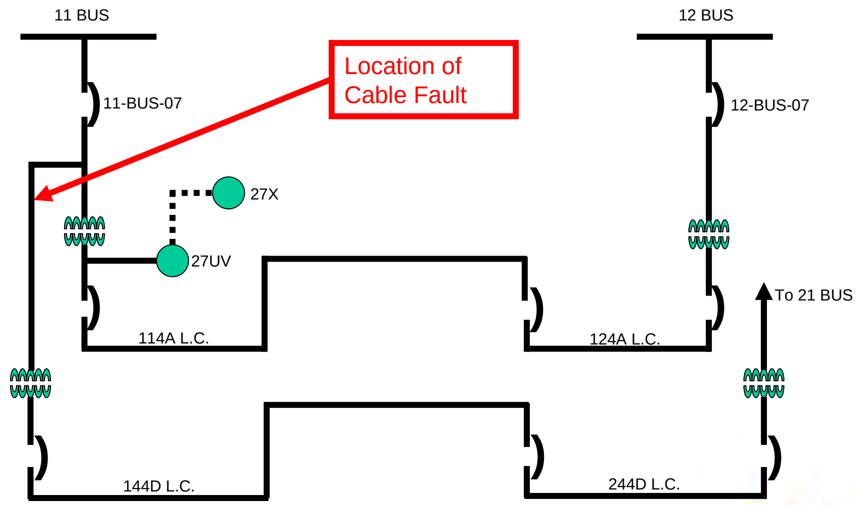
The loss of both MG sets was caused by loss of lube oil for the "A" MG set and a Stator Cooling Water (SCW) runback following the loss of both SCW pumps.

- ✓ This event was initiated by an underground cable fault that resulted in the loss of the11-Bus-07 feeder breaker due to an "A" phase over-current trip.
- ✓ This caused the 114A and 144D load centers to de-energize. The loss of the 114A caused the operating 1A SCW, 1A1 & 1B1 MG set lube oil pumps to trip. The 144D load center supplies power to the Technical Support Center( TSC).

## Focus Topic – Unit 1 Manual Scram

3

### Simplified Schematic Diagram:

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## Cable Info

4

- ✓ The cable that failed was a 15 KV 250 MCM Anaconda Unishield cable.
- ✓ Cable was an original plant installation.
- ✓ Limerick had scheduled cable for tan delta testing prior to cable failure.
- ✓ Failed section of the cable removed and remaining cable was spliced to a 350 MCM cable.
- ✓ As a result of this cable failure, Limerick has escalated testing of other underground medium voltage cables and recommended replacement of other cables that had poor tan delta testing results.
- ✓ Limerick has also initiated a manhole inspection program and will be installing telemetering level indication system and eventually will install a permanent pumping system.

Exelon.

## Manhole Containing Cable

5

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## Manhole Picture

6

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## Retrospect:

**During EPRI Cable Users Group Meeting 2009 in Charlotte NC, A. Mantey (Senior Proj. Manager) solicited Volunteer Plants for In-Plant Demonstration**



## KKL Actions:

**Tests with LIRA on LV 1E LOCA Cables with Paolo F. Fantoni from wirescan during Refueling Outage 2010**

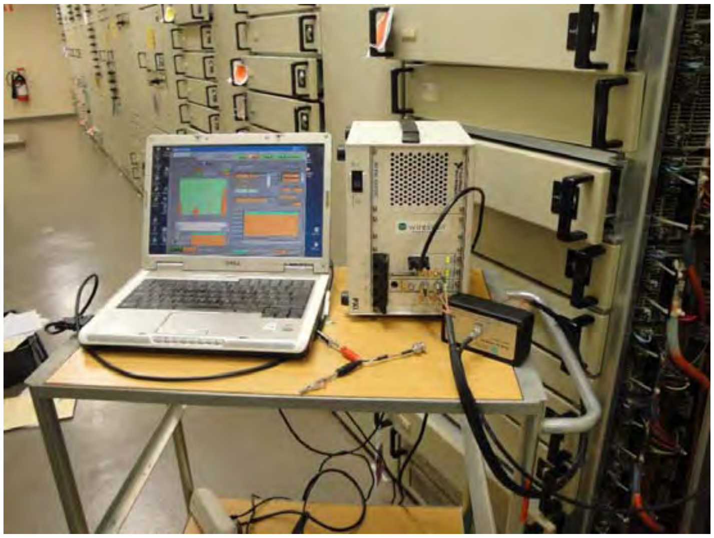
- **6 Cables XLPE 4 x 2.5 mm² (Length between 60m … 110m)**

  **Power Supply of MOVs**
  **(5 MOVs inside Steam Tunnel / 1 MOV inside Containment)**

- **4 Cables XLPE 2 x 2 x 2.5 mm² (Length between 35m … 46m) Instrument**

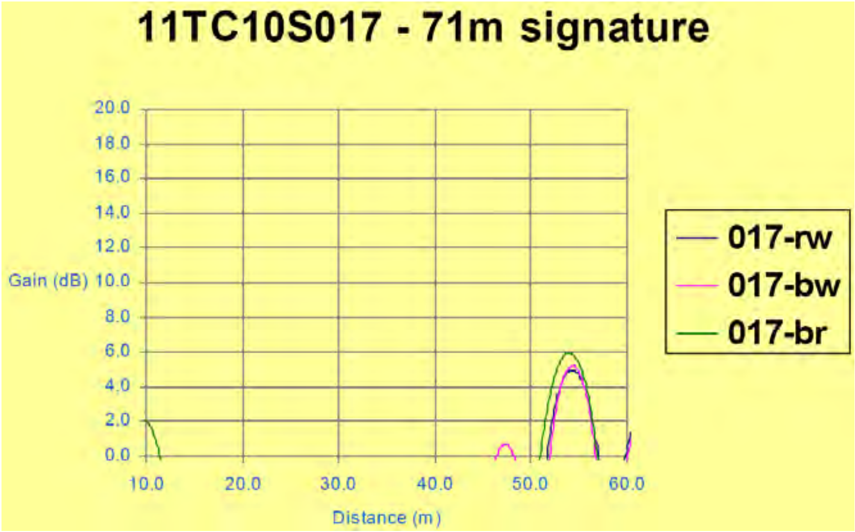
  **From terminal box in RSD Room to Limit Switch on MSIVs in Steam Tunnel**

## LIRA Test Equipment at KKL site



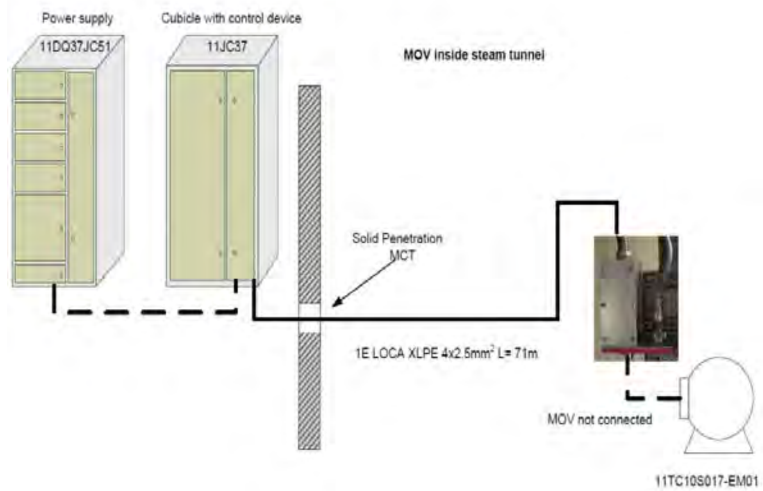


## Measurement Plot of LV-Cable 1E-LOCA (*Example*)



## Topologie Cable routing 1E-LOCA Cable to MOV

Cable: 11TC10S017-CD01






## 1E-LOCA Cable to MOV inside Steam Tunnel

## Status / Conclusions:

- Report “Wirescan” currently under KKL review
- Monitoring on Cable 11TC10S017 (MOV) showed one „hot spot“ at 53 m. P. Fantoni made a simulation where it is visible that this spot can be produced by a 6% change on the dielectric capacitance along 1m of cable. This is not considered as a critical situation (can wait).
- KKL planned action: Exchange the cable with a new one during outage 2011; cable will be investigated further by Mr. Fantoni.
- Further details are still in review
- Action will be continued in 2011

EPRI: Plant Support Engineering
Cable Users Group Meeting
September 2010

HV Diagnostics INC.

# Practical Testing Related Considerations When Performing Diagnostic Tests On MV Cables

By: Craig Goodwin
HV Diagnostics Inc

email: craig@hvdiagnostics.com
Web: www.hvdiagnostics.com

# What Diagnostic Tests Do You Plan To Perform?

Can't We Just Google "Cable Testing or Cable Diagnostics" ?

# Some Questions and Factors that Need to be Considered - And Answered Prior to Commencing a MV Cable Testing and / or Diagnostics Program

# Cable Installation Status?

- New Cable Installation – “Acceptance Test” – Installation Issues, Manufacturing Defects (Voids, Delamination etc), Transportation.
- Existing Cable – “Maintenance Test” – Environment, Degradation Aging, Corrosion etc.
- Cable on Reel- “Installation Test” – Manufacturing Defects, Transportation Damage.

# What Defect/s Are You Trying To Detect In The Cable?

- Types : Water Trees, Voids, Workmanship, Electrical Trees, Water Degradation, Shield Corrosion etc.

- Location of these Potential Defects – Splices, Cable, Terminations, Shield (corrosion).

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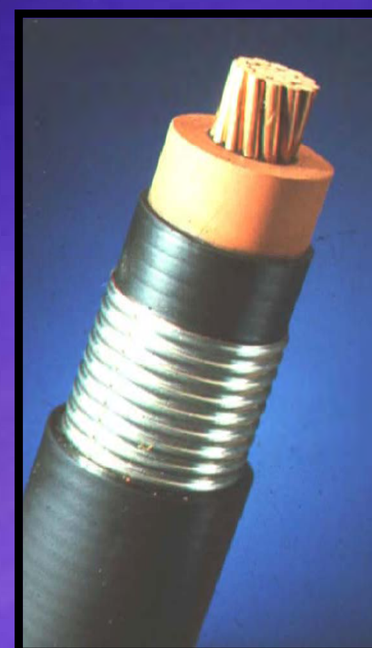
# What Type of MV Cable Shielding or Insulation do you have?

- Tape Shielded, Concentric Neutral, Drain Wires, LC Shield, OR UNSHIELDED?
- Type of Insulation?

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# Other Questions?

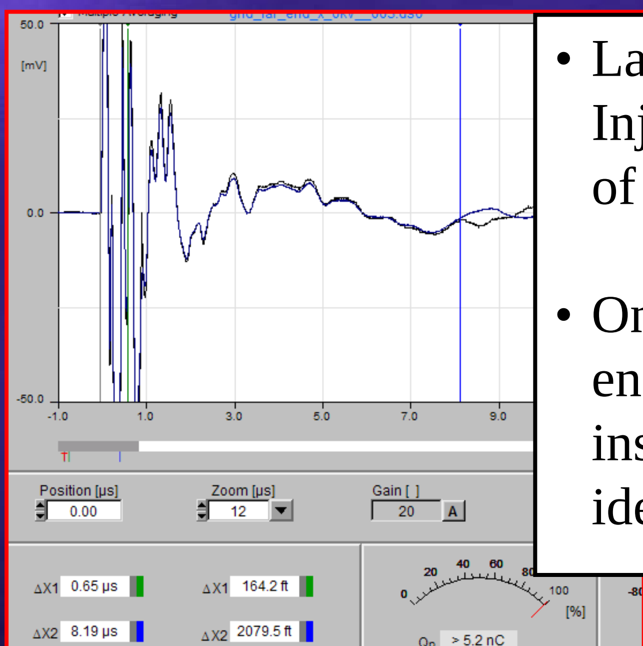
- Can cable be de-energized?
- Types of Terminations ?
- Can Cable Ends be “unlanded” ?
- Do we have sufficient Clearance on both ends?
- What is the length of the cable? Too Short or too long for a particular test?
- Others ?

# Important Considerations

# Tape Shielded Cable

- HF attenuation on aged Tape shielded cables – limits the use and viability of HF Diagnostic techniques – like Partial Discharge Detection and TDR (Time Domain Reflectometry -CFL)

Large 5nC Manually Injected PD Pulse




- Large 5nC Calibration Pulse Injected into a 2000ft/610m run of cable.
- One TDR Trace shows a open end and the other a manual installed ground to help identify the end of the cable.

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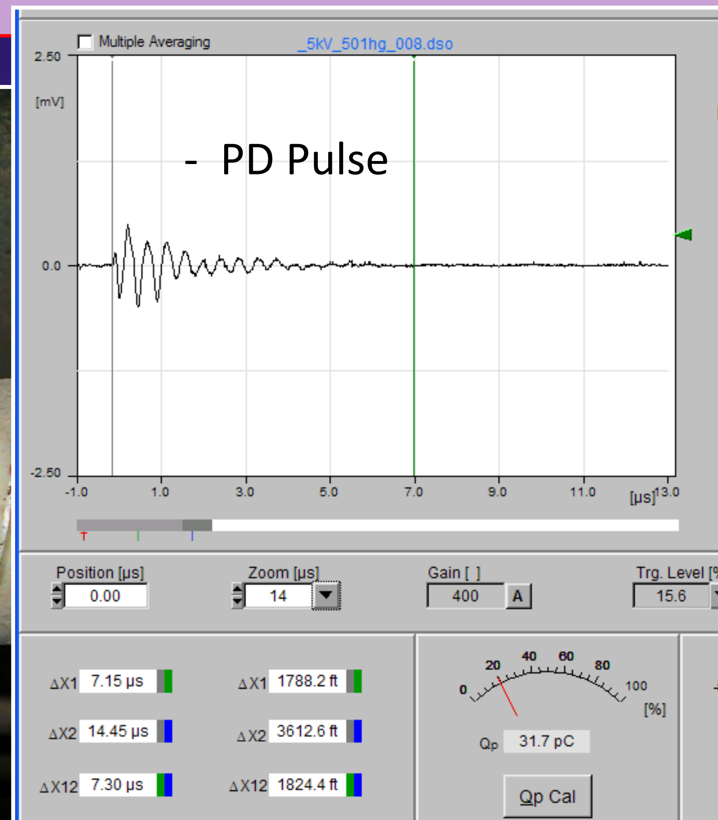
# Another Example of HF Attenuation

5kV EPR Tinned Taped Shield Cable from Nuclear Power Plant

PD Detection Difficult,
PD Location not possible.

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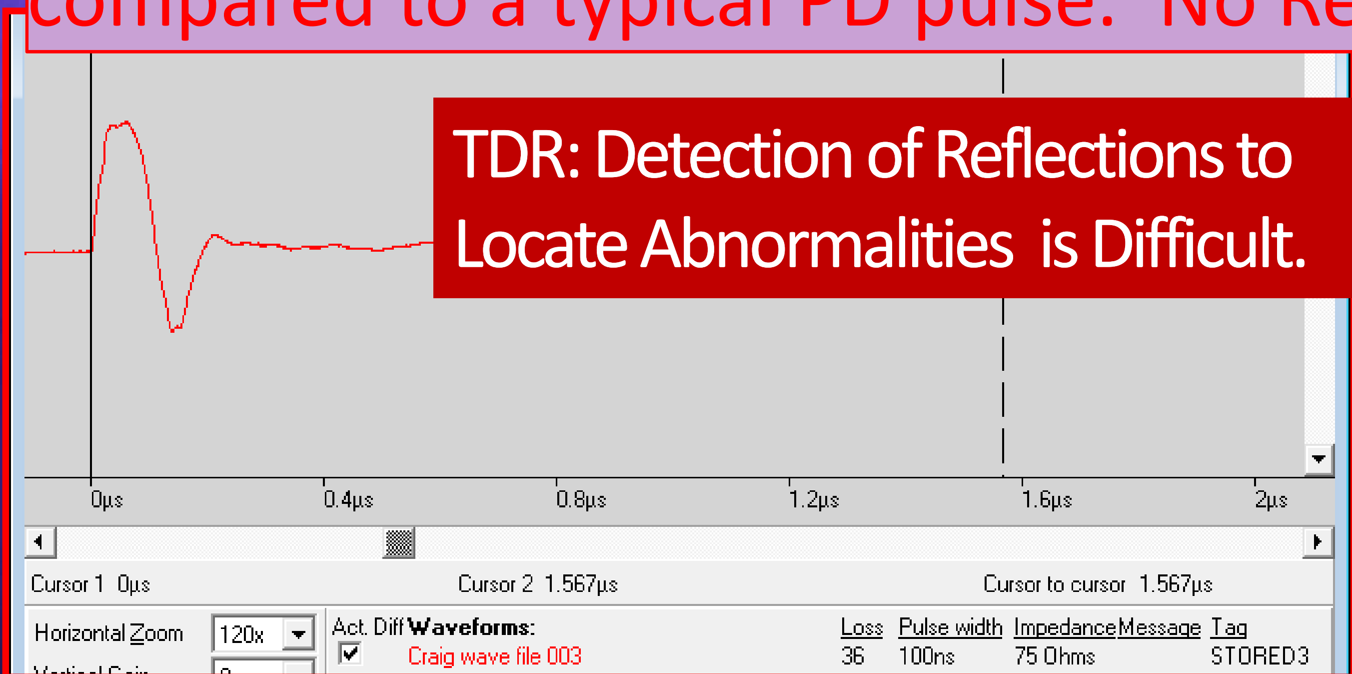
# HF Attenuation of TDR Injected Pulse in on Nuclear MV Cable:

EPR 5kV Cable (~2000 ft) -100nS pulse of about 12V injected - shows no reflection from far end. This is a "Tsumani " in magnitude and pulse width when compared to a typical PD pulse.  No Reflection !




TDR: Detection of Reflections to Locate Abnormalities is Difficult.

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# Types of Insulation

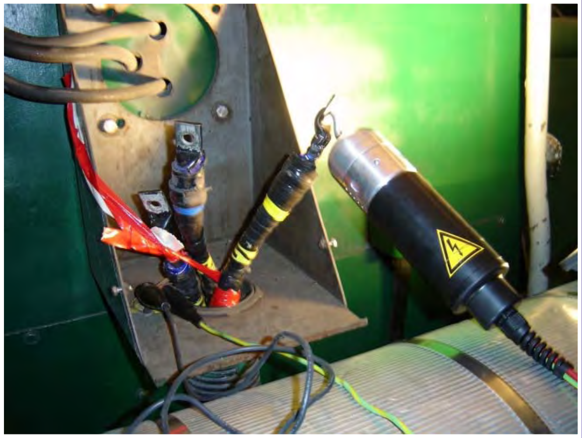
- EPR – Black / Pink / Brown /Orange
- XLPE – PE / XLPE / TR-XLPE
- Butyl Rubber


The Type and /or Interpretation of the Diagnostic Method used will often depend on the type of insulation medium.

# Types of Terminations And How To Interface To Them?

- Separable Connectors – Elbows / T Bodies
- Cold Shr
- Push On
- Taped Te … ne
- Porcelain Bushing / "pot head"

# Cable Ends and Clearances



- Can Terminations be Unlanded?
 - that is disconnected from electrical apparatus on both ends such as Motors / Switchgear / Lightning Arrestors / VT's / Transformers etc.

- Do you have sufficient Clearance on the ends of the cables to avoid flashovers OR excessive leakage OR Corona.

# Termination Clearances:

- Access and clearance is sometimes not an issue.

And Sometimes it is.....

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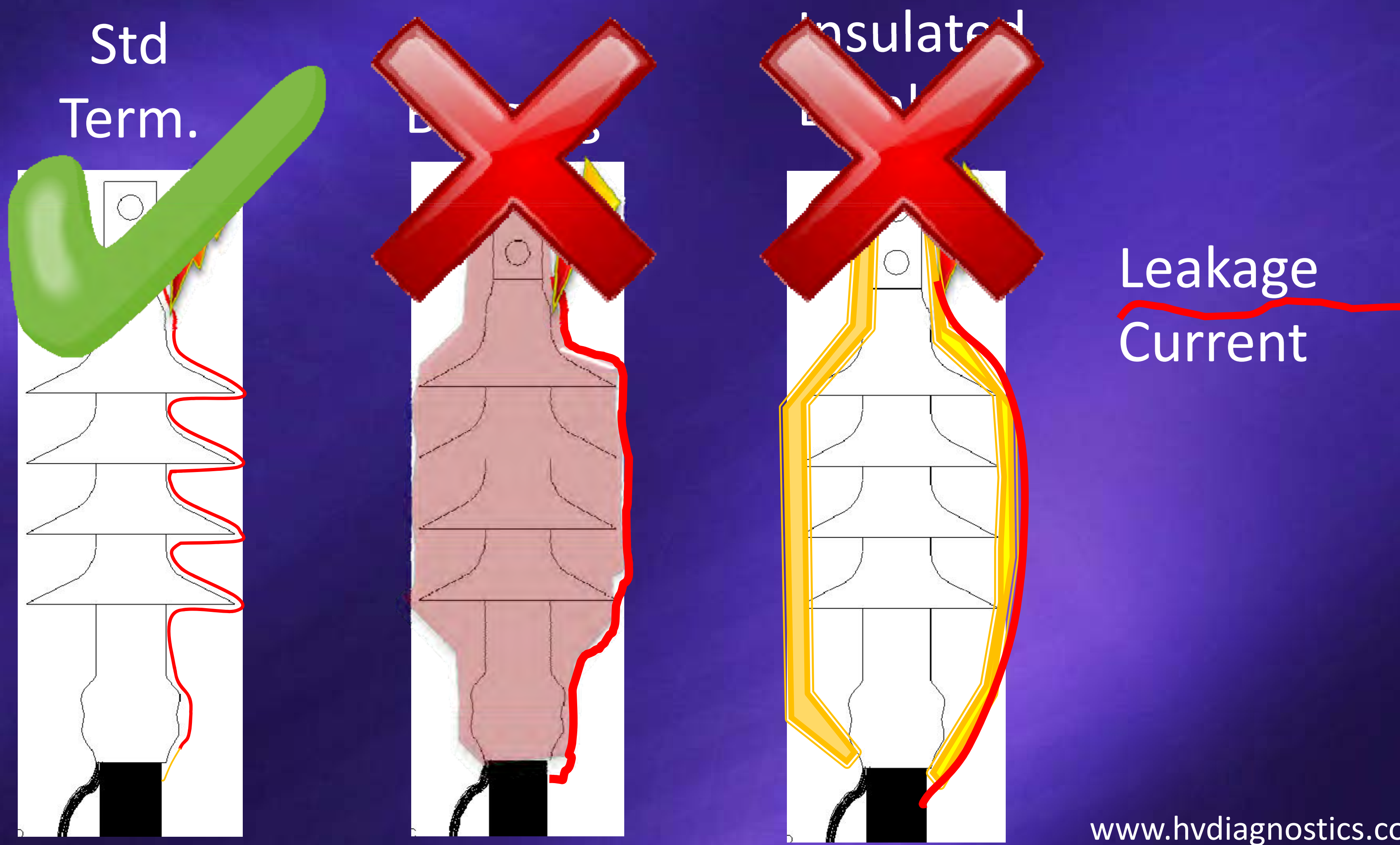
# Is Bagging or Placing Insulated Blanket around the cable end a good Idea?

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# Cable End Preparation

- Good Clearance

Bottom Line:

Housekeeping and preparation are important.

- Clean Test Equipment

# Typical Questions:

Q: Should we perform a VLF test or a Diagnostic (TD) Test First?

Q: I have heard / read that a VLF test is possibly a destructive test while a diagnostic test is not?

# IEEE Defines two types of withstand tests for MV Cables:

- Type 1: The Non-Monitored or Simple Withstand test

- Type 2: A Monitored / Diagnostic Test or Smart Withstand when combined with a Withstand Test

# The Simple Withstand Test

# The Simple Withstand Test (Cont.)

- Historically a traditional DC Withstand Test was performed in the field to verify the electrical integrity of the insulation of a MV cable. The cables either “held” the voltage or they did not.
- Also referred to as a “Hipot” or “Pressure Test”
- Although some simple parameters are sometimes measured like leakage current etc, traditional DC simple withstands tests where essentially pass / fail type tests.

# The Simple Withstand (Cont)

- A Hipot is still used on cables, but it is now a AC (albeit Low Frequency) Hipot and not a DC Hipot .

- Note that current is NOT a measure of good or bad condition of a cable – it is a normal and natural part of energizing a capacitor (cable).

# Which IEEE Table and Voltage parameter to use in determining the final Withstand Test Voltage?

**Table 4—VLF test voltages for cosine-rectangular waveform (see Note 1)**

| Cable rating phase to phase rms voltage in kV | Installation (see Note 2) phase to ground rms voltage/peak voltage | Acceptance (see Note 2) phase to ground rms voltage/peak voltage | Maintenance (see Note 3) phase to ground rms voltage/peak voltage |
|---|---|---|---|
| 5 | 12 | 14 | 10 |
| 8 | | | |
| 15 | | | |
| 25 | | | |
| 35 | | | |

Which Table and Test Parameters to Use ? Can be Confusing for many people.

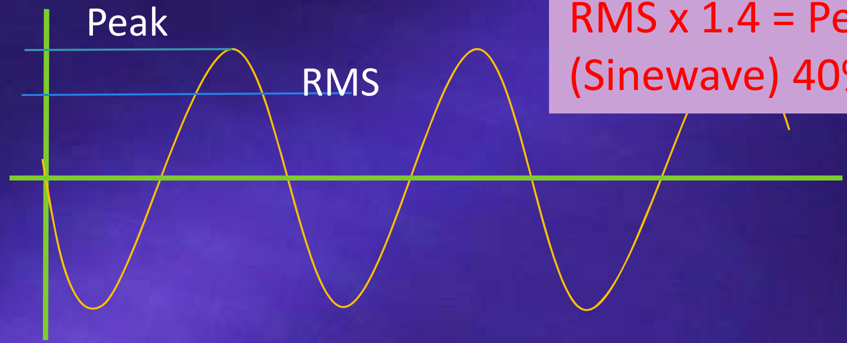
IEEE Guide for Field Test

**Table 5—VLF**

| Cable rating phase to phase rms voltage in kV | Installa pha rms or | | |
|---|---|---|---|
| 5 | | | |
| 8 | 11 (16) | 13 (18) | 10 (14) |
| 15 | 18 (25) | 20 (28) | 16 (22) |
| 25 | 27 (38) | 31 (44) | 23 (33) |
| 35 | 39 (55) | 44 (62) | 33 (47) |

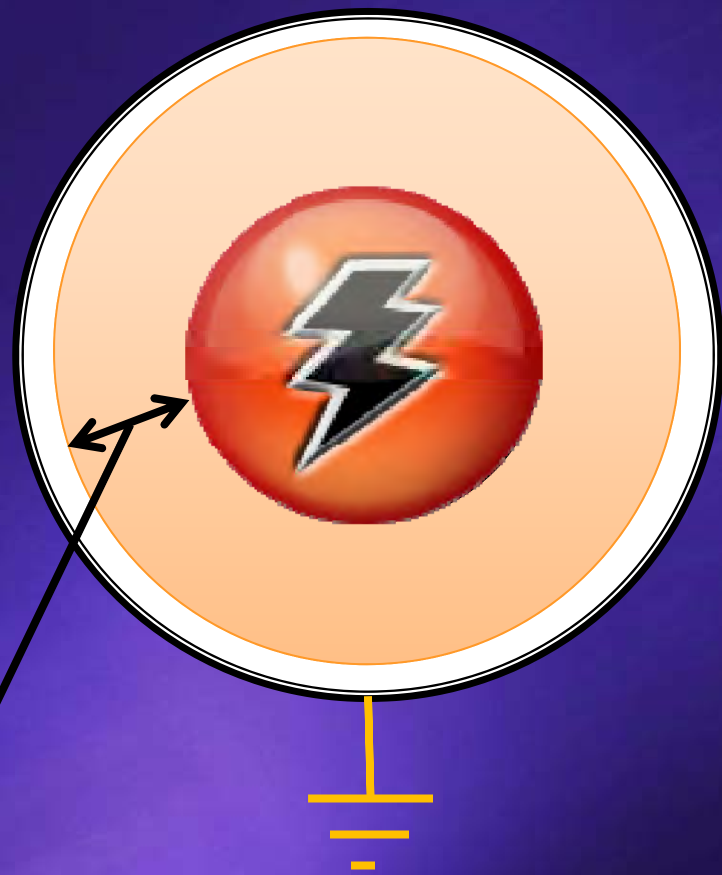
Ref: IEEE400.2

# RMS Versus Peak and Test Voltages




RMS x 1.4 = Peak
(Sinewave) 40% Dif

The Cable "sees" and "feels" the phase to ground operating voltage and not the conventional Phase to Phase Voltage as per the cable rating or nameplate.
So Vo or Uo is often used in IEEE for the RMS P-G Voltage



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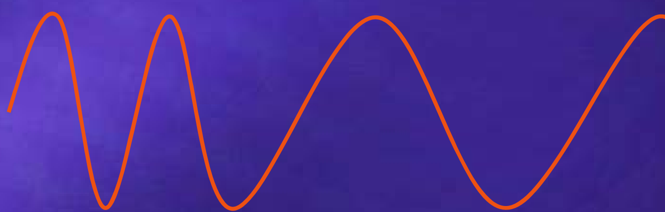
# IEEE: VLF Test Levels for Field Testing of Medium Voltage Cables

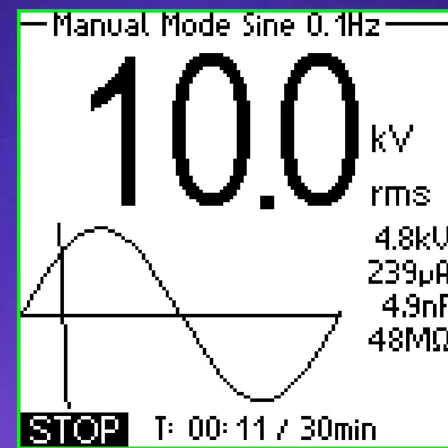
| Cable Rating (p-p) | Installation Test (p-g) | Acceptance Test (p-g) | Maintenance Test (p-g) |
|---|---|---|---|
| kV rms | kV rms | kV rms | kV rms |
| 5 | 9 | 10 | 7 |
| 8 | 11 | 13 | 10 |
| 15 | 18 | 20 | 16 |
| 25 | 27 | 31 | 23 |
| 35 | 39 | 44 | 33 |

Ref: IEEE400.2

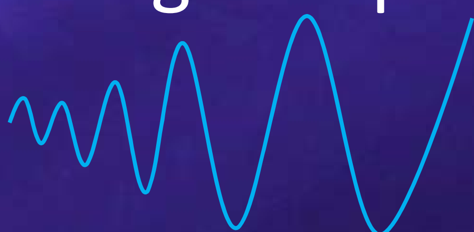
# Key Components to a Simple Withstand

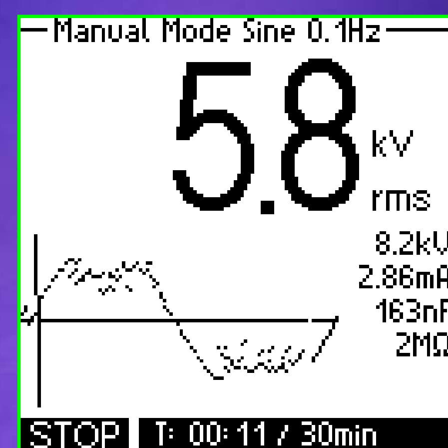
- Voltage Waveshape and Frequency






- Voltage Amplitude






- Duration

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# Benefits of Simple Withstand Tests

- Easy to apply with minimum training.
- Can be used on complex and long cable systems.
- Weeds out serious defects in a cable system for new and old installations in a controlled environment.
- Simple DOES NOT mean or imply ineffective – Case studies show that these “simple” tests result in improved cable system operational reliability.
- If Test Fails – it must be repeated from scratch after repairs made.

# The Second Type of Test is :

- Monitored or Smart Withstand Test


You now hook up the EKG to the patient.

# So Going Back to the Typical Questions:

Q: Should we perform a VLF test or a Diagnostic (TD) Test First?

Q: I have heard / read that a VLF test is possibly a destructive test while a diagnostic test is not?

# Application of a Smart Withstand Test on a MV Cable

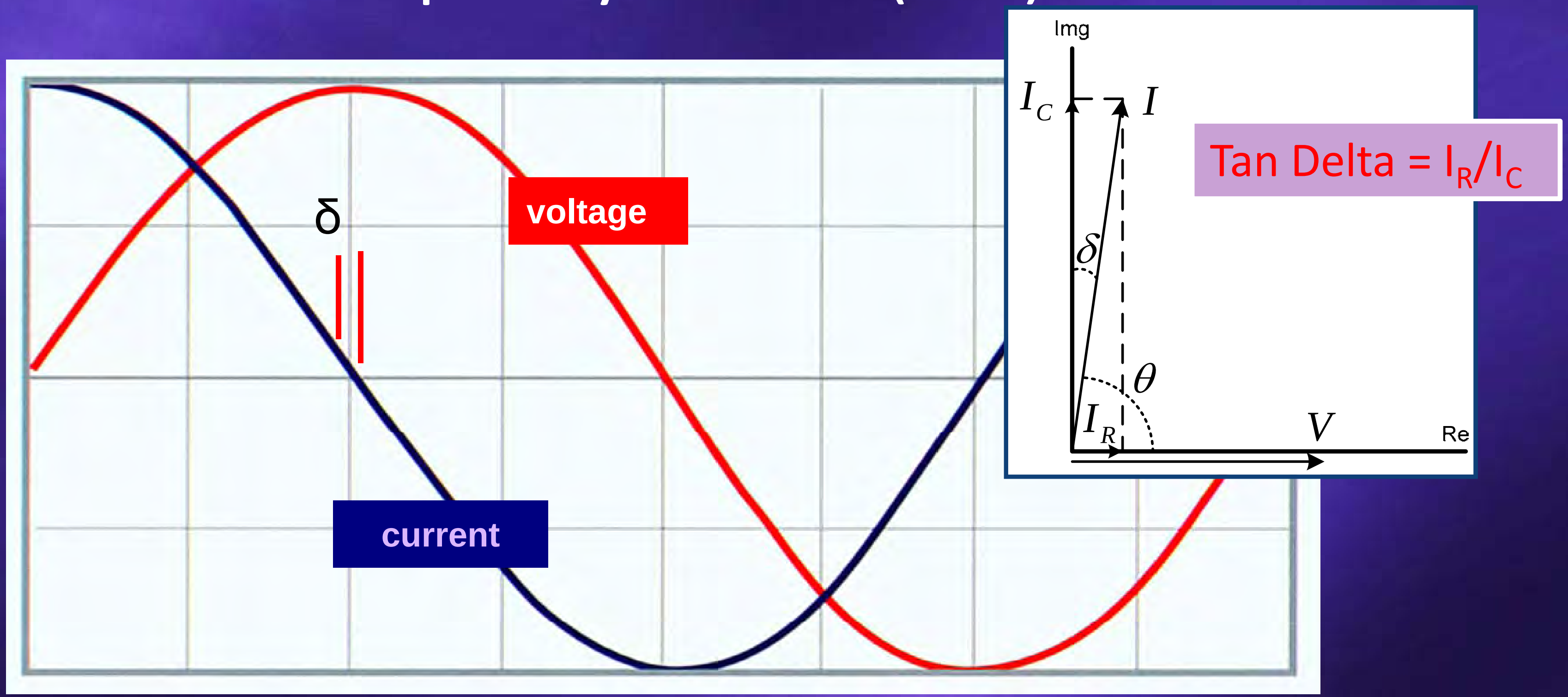
- The addition of one or more diagnostic measurement interfaces that are used during the application of a test voltage.

- The most common diagnostic test used for Tape Shielded MV Cables in Industrial Environments is:

  Tan Delta / Dissipation Factor Test -
  A measurement of an electrical parameter as a AC voltage is applied (and possibly increased.)

# Monitoring Tan Delta (TD)

- Tan Delta measures the Dielectric losses in the MV Cable. In the field this is usually done at a reduced frequency - 0.1Hz (VLF)

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# What is important is the min load required to perform a TD test – i.e. Minimum Cable Length.

- 5nF is the specified min load req. for the TD30 – ( really saying – to measure an appreciable current it needs some load. )

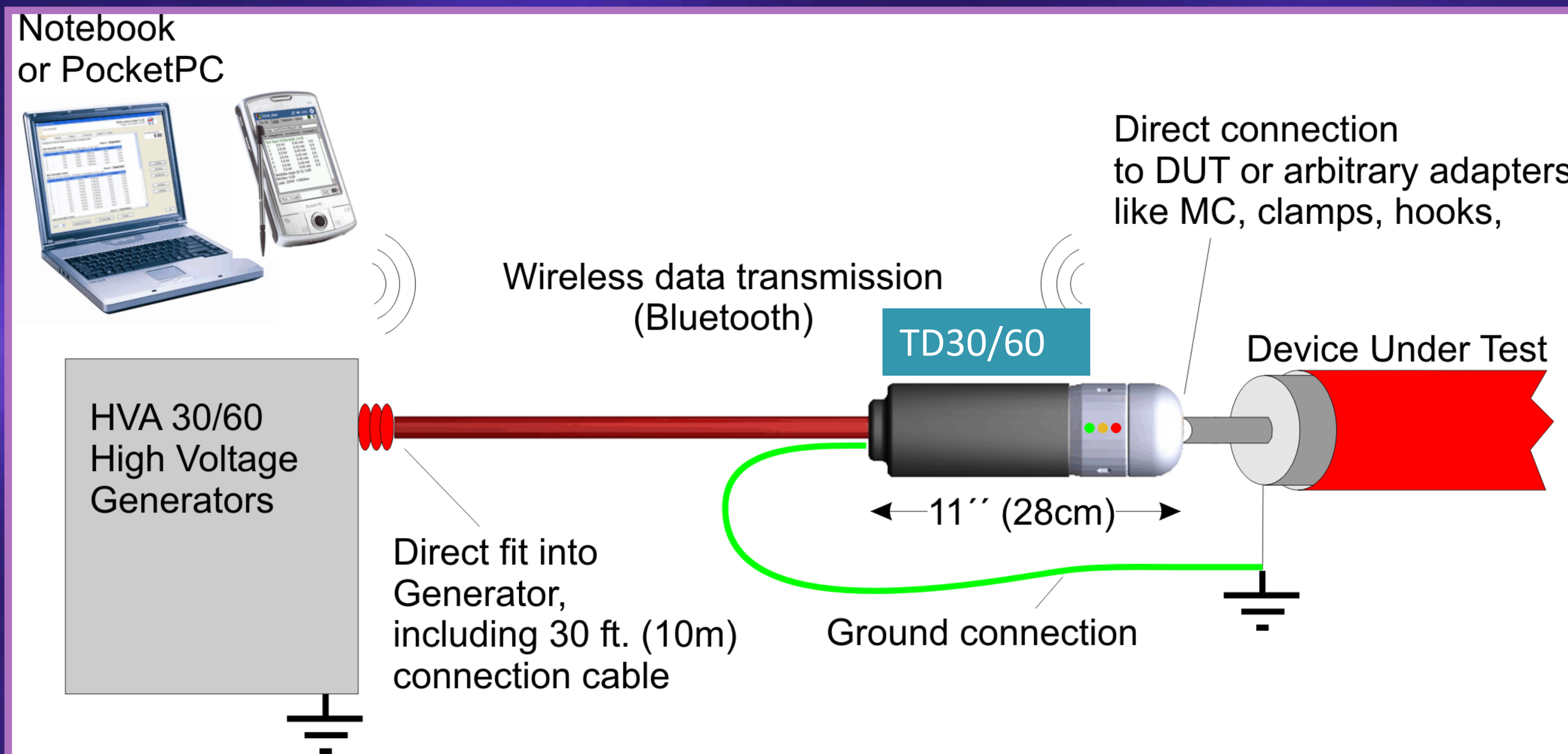
Example:

5kV Cable, 100pF/ft Capacitance – what is the min length required to perform a test.?

Answer:

5E-9 F/ 100E-12 F/ft = 50 ft of this cable.

# Tan Delta Setup

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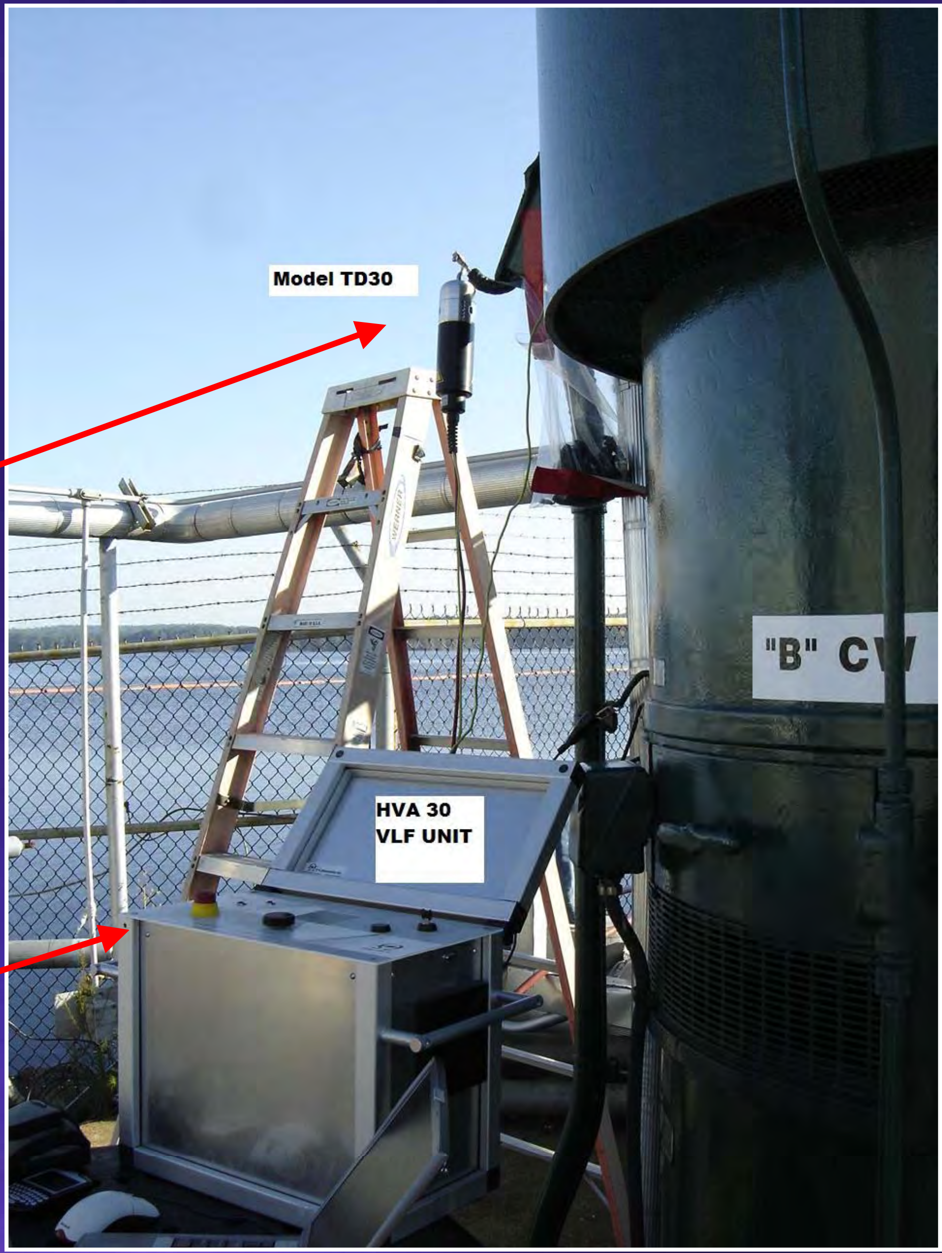
# Cable Diagnostic Field Testing using VLF (0.1Hz) and Tan Delta.

Model TD30/TD60

Model HVA30/HVA60

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# What do we look at when performing a TD Test?

1. Absolute TD number at a particular Voltage.

2. The change of TD with Voltage (gradient).

3. The deviation / stability of the TD values at a voltage level.

# How to setup a TD Test ?

- Set the **Number of Voltage Steps** to use – Recommendation is 4 Voltage Steps.
- Specify the **Voltage Levels** to be applied at those steps. Important is Vo and IEEE V.
- Specify the **Time Duration** at each voltage step.

# Example on How to setup the Voltage steps for a TD test:

Take a 15kV Rated In Service Cable:

So IEEE Test Voltage is 16kV RMS (from Table)

Divide 16kV by 4 to get 4 relatively even steps.

So Test Voltages are 4/8/12/16kV which are approx. 0.5Vo, 1Vo, 1.5Vo and 2Vo.

Note: Never recommended to go above the IEEE test voltage – treat this as a Voltage max.

# Test Duration at Each of the Voltage Steps

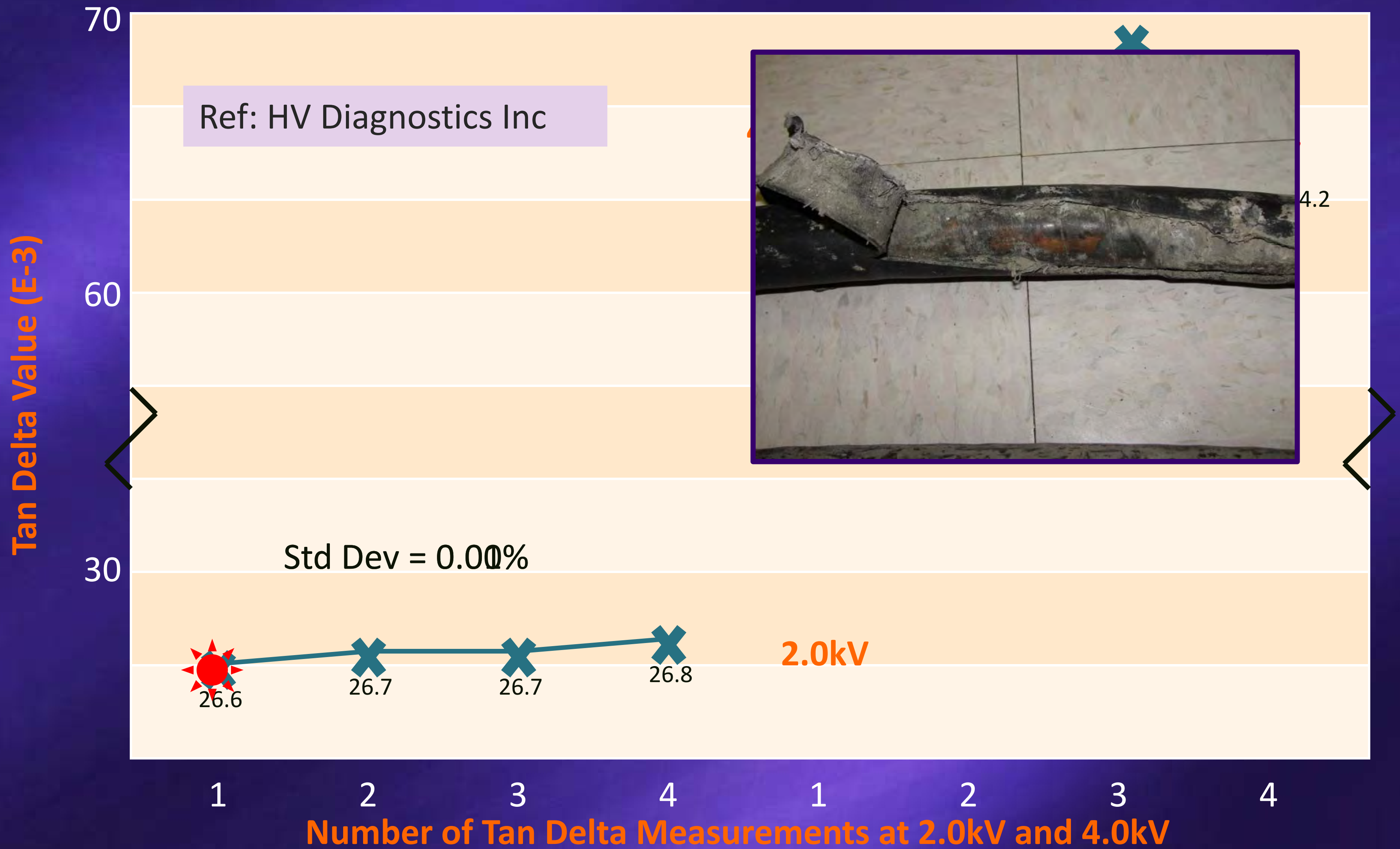
It is important to spend enough time at each voltage step to collect 8 – 16 (approx) data points to get a sample size to calculate the STD. So about 3 minutes per voltage step.

For the final voltage step, if above Vo of the cable, then duration of at least 30 minutes should be applied.

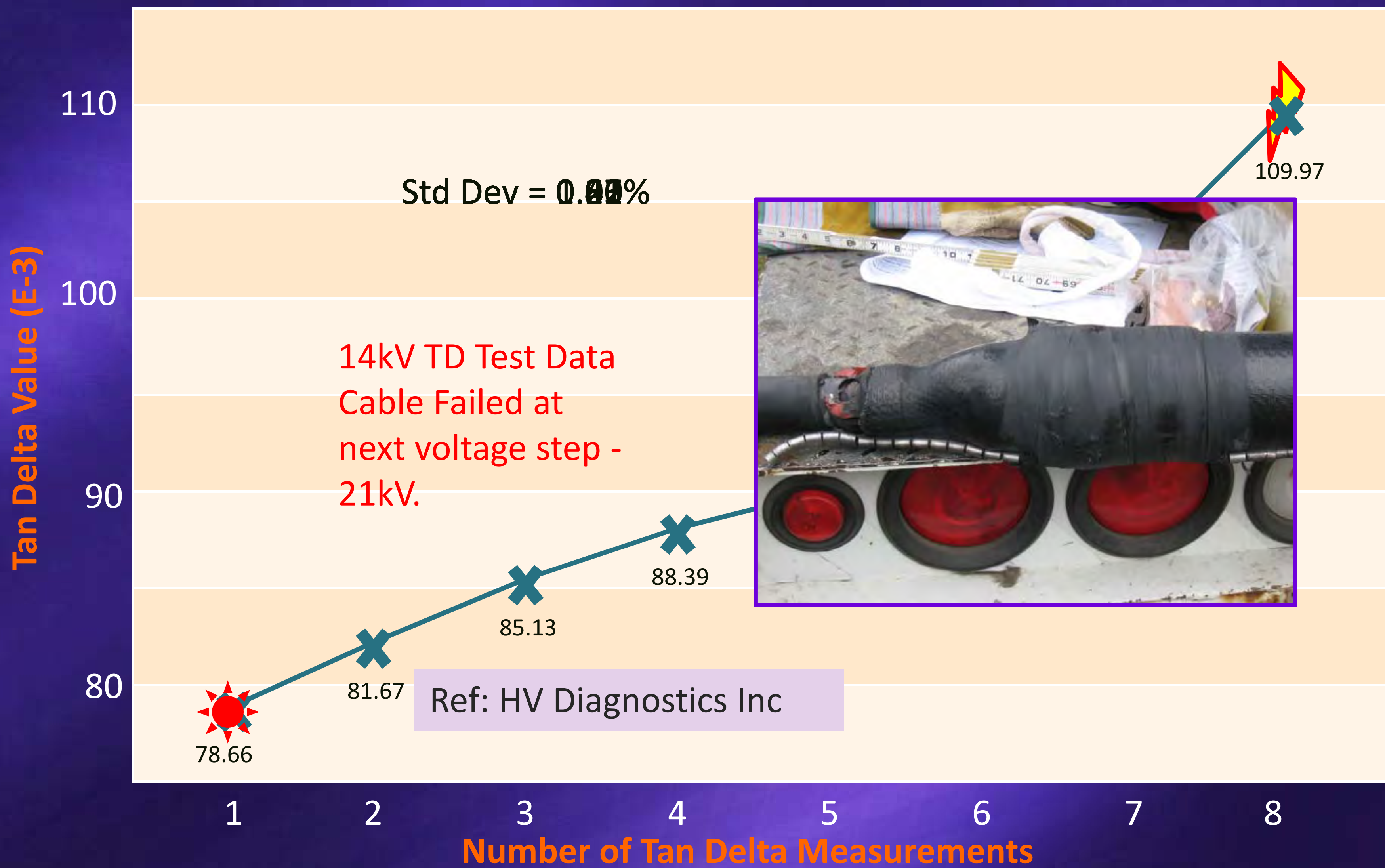
# Important Decision Review Point During Stepped Voltage Application in the Diagnostics Process.

**1 Uo or 1 Vo**

# Tan Delta Results
## Failure in 5kV EPR Cable (ID LC_U3) 1986 Installation

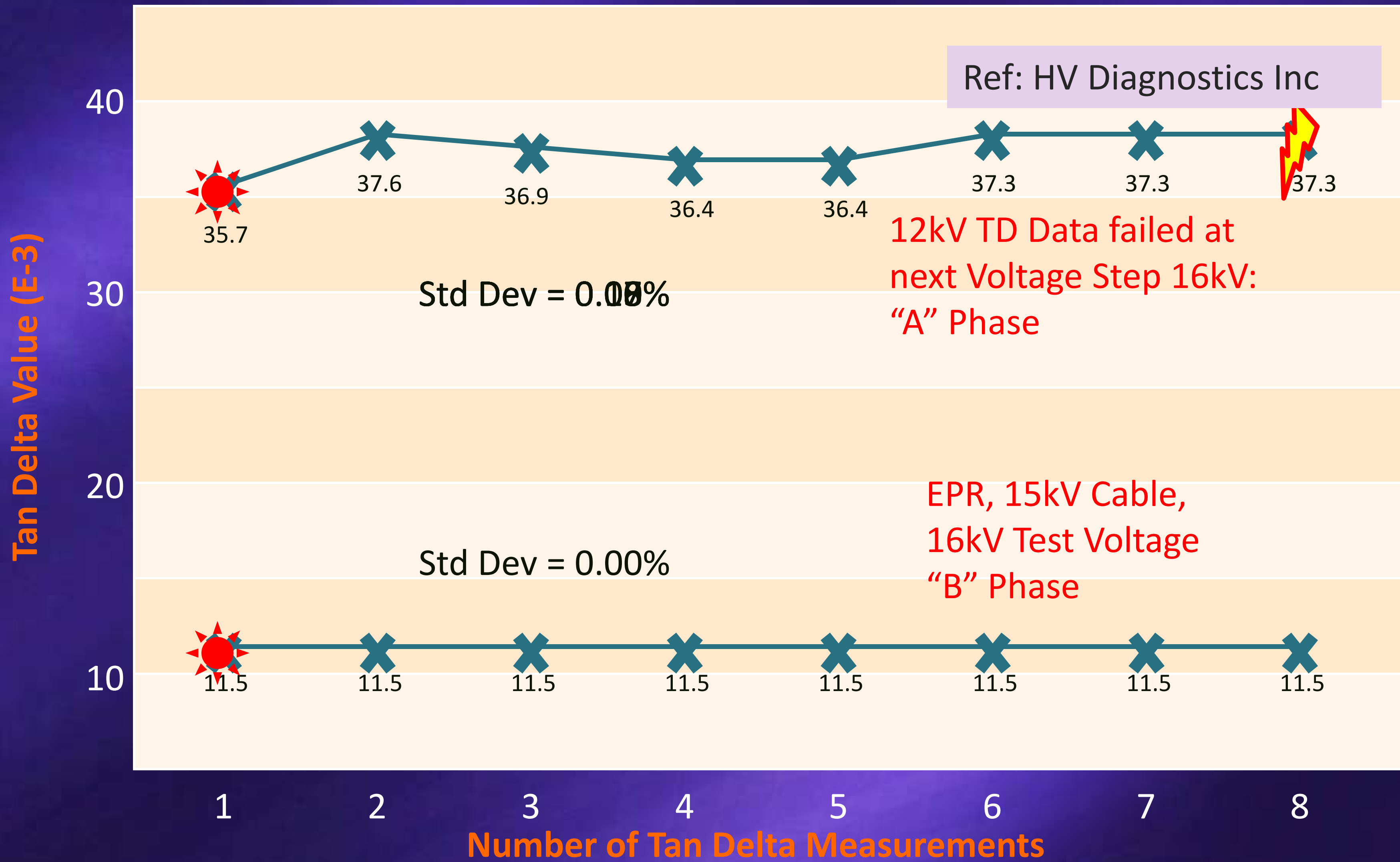


# Tan Delta Measurements of 25kV Cable: Operated at 25kV. Test Voltage 14kV then stepped to 21kV first cycle. XLPE. Failed at Joint. ID: D_M_B4_B5.



# Can You Also Use TD Diagnostics For New Installations?

# Tan Delta Comparison of Good Values versus Poor Values resulting in failure of 15kV EPR Cable ID: BM_T_F_ and ID: DEM_DO_



# Why does the Combination of a Withstand test and a Diagnostic Interface compliment one another.

- Limit the testing time on Good cables.
- Extend the testing time on cables that show “abnormalities”.
- By stepping up the voltage, limit test failures on highly degraded cables before the failure occurs.
- Some defects can escape detection by the monitored diagnostic, can be caught by the withstand voltage applied.

# Possible Test Outcomes to be considered:

- Cable Passes all tests ☺
- Cable Fails under test voltage – dielectric failure – cable cannot be re-energized. ☹
- Cable Passes voltage test, but fails one or more diagnostic test 😐.
- Risk / Reward: Test Failure versus Ops Failure?

# Is there any need to Still perform a DC  Hipot or Megger® Test on the cable?

No.

# Thank you.

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# Practical:

- Perform a VLF test on LV Cable
- Perform a full VLF TD Test "5kV Cable"

## Laboratory Testing of MV Cables From Nuclear Plants: Further Developments

Presented by

Bogdan Fryszczyn

Cable Technology Laboratories

New Brunswick, NJ

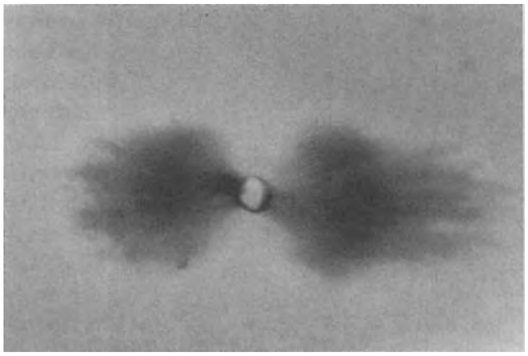
1

## Short History of Extruded Cable Failures

- XLPE cables in commercial use since early 1960
- In less than 10 years of service, premature failures of unexplained nature reported
- In 1969, during a conference in Boston, MA, a paper titled "Deterioration of water-immersed polyethylene coated wire by treeing" was presented
- First American report on water treeing in PE published in 1971.

2

## Bow-Tie Tree



Tree Length: 0.40 mm (16 mil)
Nucleus: void 0.03 mm (1.2 mil)

3

## Bow-Tie Trees

with contiguous electrical trees at extremities:

Nucleus: a void

Nucleus: a contaminant

4

## Once the problem of water treeing was recognized, a two pronged approach was utilized:

Insulation Improvement | Insulation Diagnostics

5

## Insulation Improvement

- Many improvements in manufacturing processes introduced
- Work on making XLPE insulation tree retardant was initiated
- In 1983 tree inhibitive XLPE compound 4202 was introduced by Union Carbide
- In our experience, as of 2010, no water treeing failures of TR XLPE insulated cables reported

6

## Insulation Diagnostics

- Work on diagnostics of field installed cables initiated in ~1974
- Sponsored by American Public Power Association: to develop instruments for in-service non-destructive evaluation of PE and XLPE insulated cables

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## Insulation Diagnostics

- In 1977, IEEE transaction paper by G. Bahder, G. Eager, et al, “In service evaluation of polyethylene and crosslinked polyethylene insulated power cables rated 15 to 35 kV”
  - Equipment used –
    - 0.1 Hz HV Power Source
    - Inverted dissipation factor bridge
- In 1981, IEEE transaction paper by G. Bahder, C. Katz, et al, “Life expectancy of crosslinked polyethylene insulated cables rated 15-35 kV”
  - Life expectancy assessment was based solely on 60 Hz dissipation factor data of laboratory aged cable
  - Ways to rehabilitate installed PE and XLPE with poor performances were proposed

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## Water Treeing

- Water trees grow in a wide range of hydrophobic polymeric materials exposed to combinations of moisture and electric stress
  - Reduce electrical strength of insulation
  - Observed as a dendritic pattern of water filled micro-cavities
    - Micro-cavities are connected by oxidized tracks where polymer molecule chains are broken and oxidized
    - Tracks are approximately 10 nm (4 x $10^{-3}$ mil) wide
    - Oxidized polymer becomes hydrophilic, facilitating condensation of water molecules from surrounding polymer matrix to form liquid water in the tracks and micro-voids.

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## MV EPR Insulated Cables

- Introduced to the market in the late 60s
- From CTL's perspective over 30 years:
  - Failed extruded cable samples received
    - ~600 samples of PE or XLPE
    - ~10 samples of EPR cables
- A 1996 study of wet electrical performance of EPR cable insulation concluded:
  - Water trees are formed in EPR insulation
  - The density of trees (number of trees / insulation volume) in EPR are:
    - For Vented trees ~ 0.1 of XLPE
    - For Bow-Tie trees ~ 0.001 of XLPE
  - A lack of support for hypothesis that water trees cause failures of EPR insulation.

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## Nuclear Power Plants

- Oldest nuclear power plant in the United States: Oyster Creek, NJ. Online December 1, 1969
- Youngest nuclear power plant in the United States: Watts Bar 1, TVA. Online February 7, 1996

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## Failure Mechanisms of EPR

- In the middle of 2006, EPRI's sponsored project "Failure Mechanism Assessment of Medium Voltage Ethylene Propylene Rubber Cables" was initiated.

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## Primary Results of Investigation MV EPR Insulated Shielded* Cables

- Correlation between dissipation factor value and AC breakdown voltage
- Wet Aging Failures in MV EPR due to water treeing

*Shielded-type cable. A cable in which each insulated conductor is enclosed in a conducting envelope (substantially every point on the insulation surface is at ground potential)

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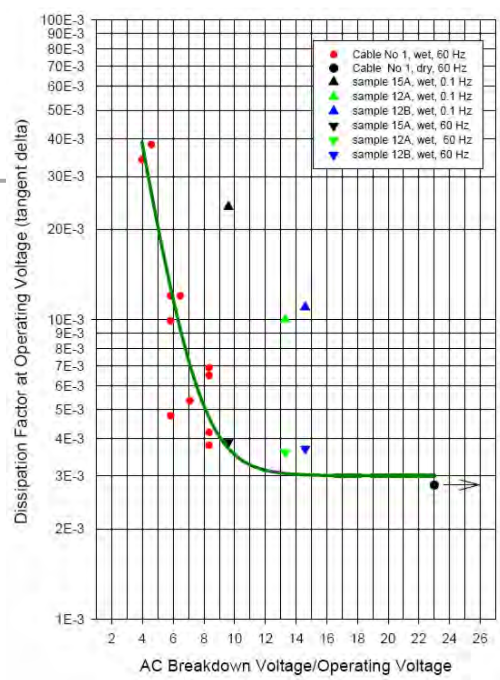
## Dissipation Factor vs. AC Breakdown Voltage

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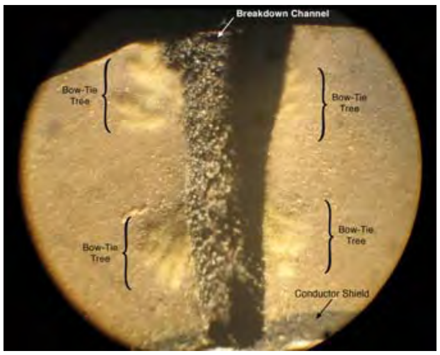
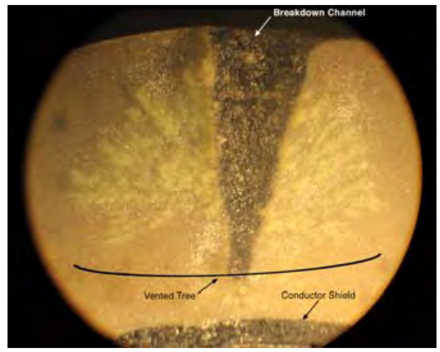
## Water Trees in Rubber Insulation

EPR (Pink)

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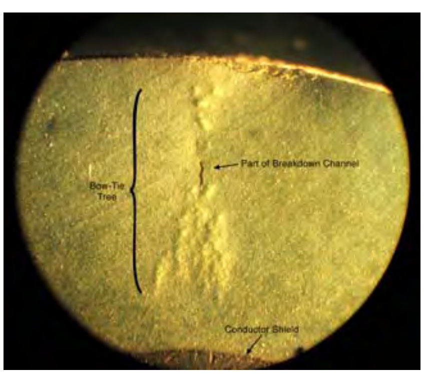
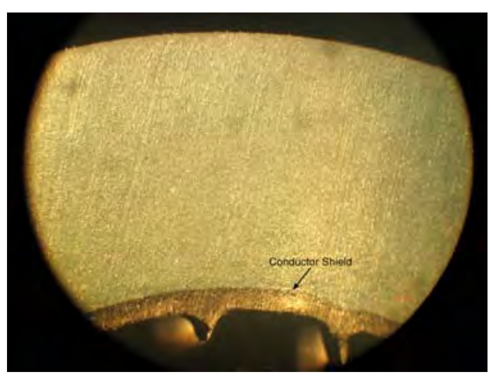
## Water Trees in Rubber Insulation

EPR (Pink)

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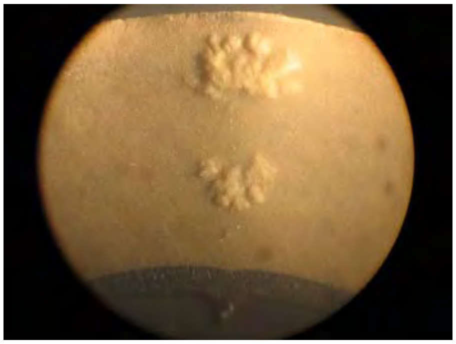
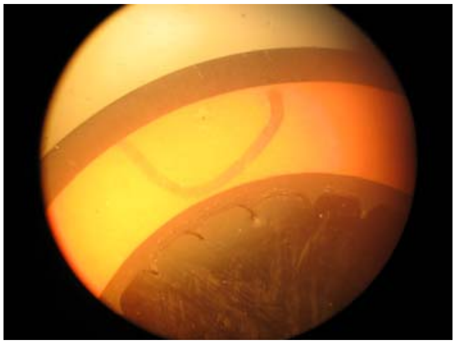
## Water Trees in Rubber Insulation

EPR (Pink)





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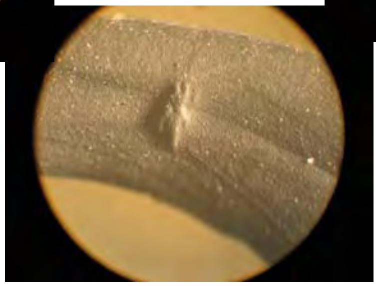
## Water Trees in Rubber Insulation

Black EPR



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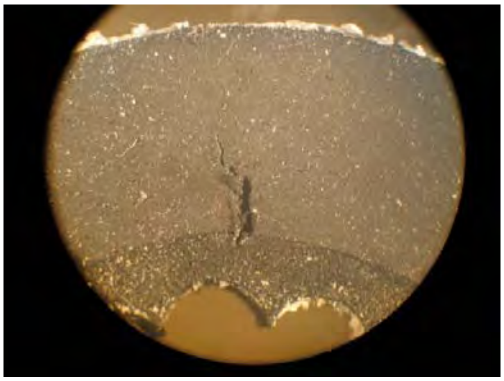
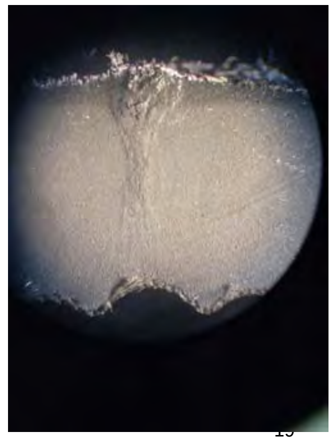
## Water Trees in Rubber Insulation

Butyl Rubber





## Water Trees in Rubber Insulation

Brown EPR

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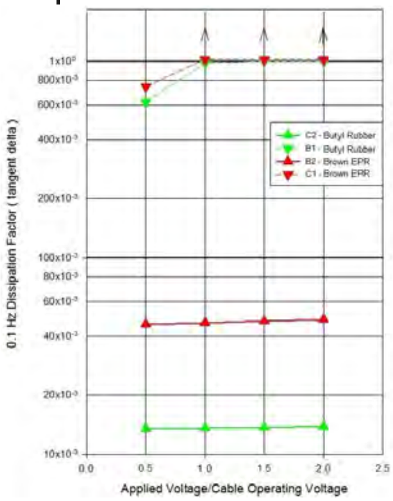
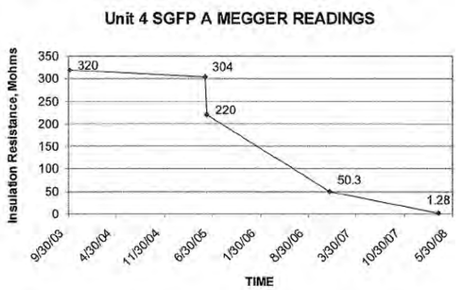
## Water Trees in Rubber Insulation

Brown EPR

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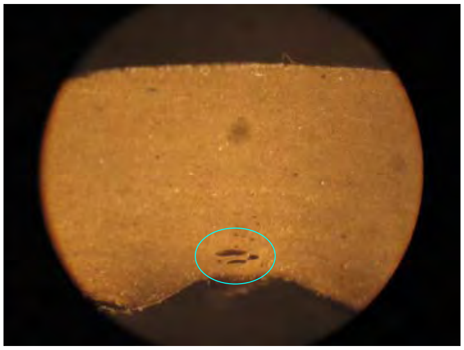
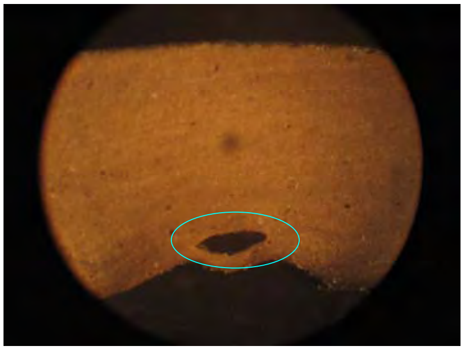
## Water Trees in Rubber Insulation

Brown EPR





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Based partially on work initiated in 2006, Gary J. Toman of EPRI single-handedly prepared "Aging Management Program Guidance for Medium Voltage Cable Systems for Nuclear Plants."

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## Attempts to Evaluate Insulation of 5 kV Unshielded Cables

- CTL received:
  - Unshielded, armored, EPR insulated cable. Condition unknown
  - Unshielded, un-armored EPR insulated cable. Condition unknown
  - Unshielded, armored XLPE cable. Insulation in bad shape

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## 3/C Unshielded, Armored XLPE Insulated Cables With Weak Insulation

Natural XLPE insulation

Cable Length: 3 ½ ft – 14 ft

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## 3/C Unshielded, Armored EPR Insulated Cables

- Testing –
  - 0.1 Hz Dissipation Factor measured
- Results -
  - Dissipation Factor values: high
  - Dissipation Factors vs. applied voltage: flat
  - AC Breakdown voltage of the insulation: high
- Conclusions –
  - Cable is in good condition
  - Dissipation Factor as a diagnostic tool – no inference

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# 3/C Unshielded, Un-armored EPR Insulated Cables

- Testing –
  - Only 60 Hz (bridge) dissipation factor measured
- Results –
  - Very low apparent capacitance
  - Dissipation factor: very high and flat
  - AC breakdown voltage of the insulation: high
- Conclusions –
  - Cable is in good condition
  - Dissipation Factor as a diagnostic tool – no inference

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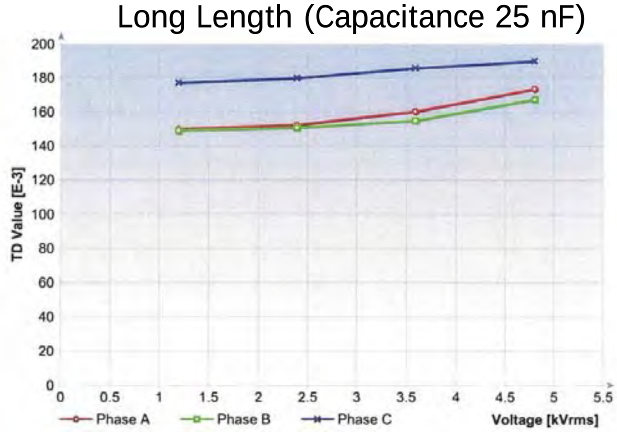
# Field Test Results

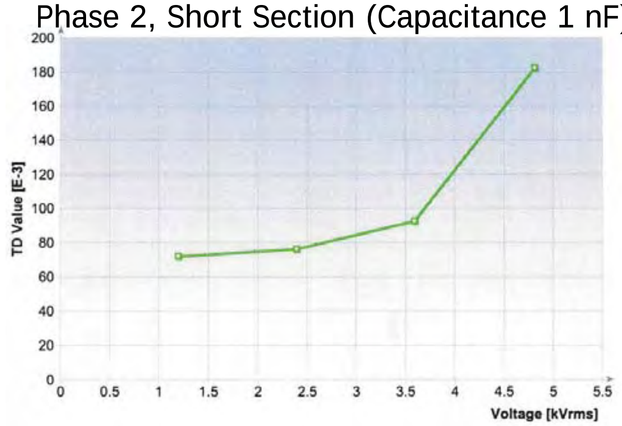
New 5 kV, 3/c unshielded, armored XLPE (natural) cable
Long Length (Capacitance 25 nF)




Dissipation factor of new XPLE insulation is about 0.2 x $10^{-3}$ 28

## Field Test Results

27 year old 5 kV, 3/c unshielded, armored XPLE (natural) cable
Phase 2, Short Section (Capacitance 1 nF)




Dissipation factor of new XPLE insulation is about $0.2 \times 10^{-3}$ 29

## Test Set Up

*Connection of cable sample during DF measurement at 60 Hz.*

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# 60 Hz DF and Capacitance Laboratory Measurements

| CTL # A | Phase 1 | | Phase 2 | | Phase 3 | |
|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 1.2 kV | 604.0 | 93 | 562.1 | 81 | 613.9 | 93 |
| 2.4 kV | 603.0 | 90 | 563.1 | 81 | 614.6 | 94 |
| 3.6 kV | 603.0 | 96 | 563.4 | 81 | 615.2 | 94 |
| 4.8 kV | 604.0 | 98 | 563.8 | 82 | 615.8 | 95 |
| | | | | | | |
| CTL # B | Phase 1 | | Phase 2 | | Phase 3 | |
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 1.2 kV | 753.1 | 134 | 739.3 | 195 | 774.9 | 128 |
| 2.4 kV | 756.5 | 131 | 742.2 | 193 | 774.0 | 129 |
| 3.6 kV | 759.1 | 130 | 742.9 | 192 | 774.9 | 128 |
| 4.8 kV | 757.1 | 134 | 734.1 | 193 | 778.5 | 128 |

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# 60 Hz DF of Cable With Unshielded Phases In Water

| Applied Voltage (kV) | Phase 1 | | Phase 2 | | Phase 3 | |
|---|---|---|---|---|---|---|
| | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 1.2 | 1875 | 1.2 | 1925 | 3.5 | 2012 | 11.6 |
| 2.4 | 1875 | 1.2 | 1925 | 3.5 | 2012 | 11.6 |
| 3.6 | 1875 | 1.3 | 1925 | 3.7 | 2012 | 11.6 |
| 4.8 | 1875 | 1.5 | 1925 | 3.8 | 2012 | 11.6 |

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## 60 Hz DF of Shielded and "Converted" 15 kV TR-XLPE Cable

| Applied Voltage kV | Regular Shielded Cable DF ($x10^{-3}$) | Cable Converted From Unshielded DF ($x10^{-3}$) |
|---|---|---|
| 1.2 | 0.240 | 0.251 |
| 2.4 | 0.236 | 0.251 |
| 3.6 | 0.248 | 0.255 |
| 4.8 | 0.252 | 0.257 |

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## 60 Hz DF "Converted" (Shielded) Phases 1 & 3

| Applied Voltage (kV) | Phase 1 | | Phase 3 | |
|---|---|---|---|---|
| | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 1.2 | 2031 | 0.44 | 2032 | 0.67 |
| 2.4 | 2031 | 0.44 | 2032 | 0.78 |
| 3.6 | 2031 | 0.46 | 2032 | 0.84 |
| 4.8 | 2031 | 0.51 | 2032 | 0.92 |

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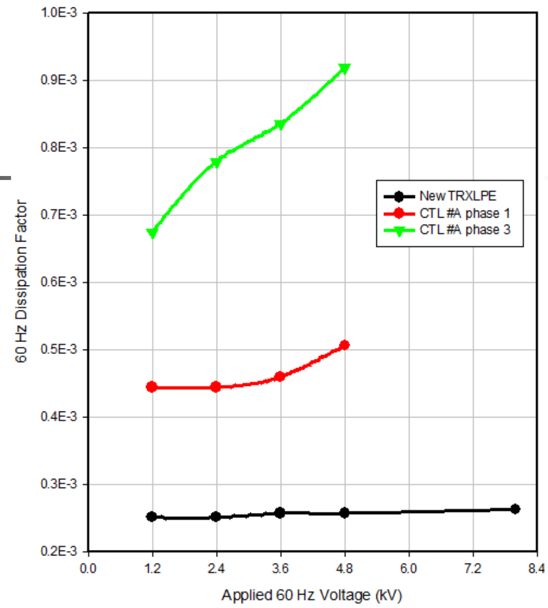
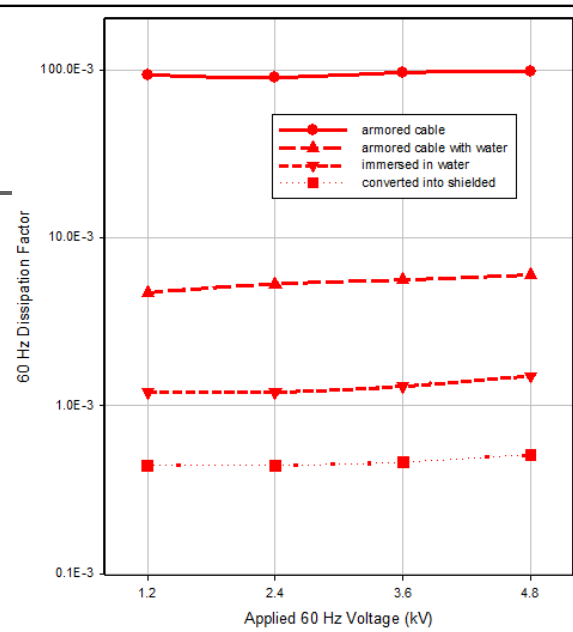



Comparison of dissipation factor of new and old “converted” cables

35




60 Hz dissipation factor of phase 1, measured under varied conditions.

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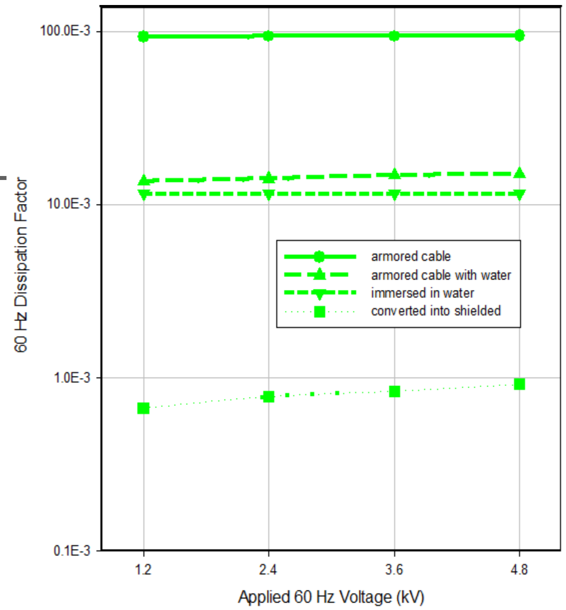


60 Hz dissipation factor of phase 3, measured under varied conditions

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# AC Breakdown of Natural XLPE

| Applied Voltage kV | Avg. Electrical Field (V/mil) | Time Under Voltage (min) | | | |
|---|---|---|---|---|---|
| | | CTL #A Phase 1* | CTL #A Phase 2* | CTL #A Phase 3* | CTL #D** Phase 1 |
| 8 | 83 | 5 | 5 | 5 | 5 |
| 11 | 116 | 5 | 5 | 5 | 5 |
| 14 | 146 | 5 | 5 | 5 | 5 |
| 17 | 177 | 5 | Failure at 4.5 | 5 | 5 |
| 20 | 208 | 5 | --- | 5 | 5 |
| 23 | 240 | Failure at 1.5 | --- | 5 | 5 |
| 26 | 271 | --- | --- | 5 | 5 |
| 29 | 302 | --- | --- | Failure at 4.7 | 5 |
| 32 | 333 | --- | --- | | 5 |
| 35 | 365 | --- | --- | | 5 |
| 38 | 396 | --- | --- | | 5 |
| 41 | 427 | --- | --- | | 5 |
| 44 | 458 | --- | --- | | 5 |
| 47 | 490 | --- | --- | | 5 |
| 50 | 521 | --- | --- | | 5 |
| 53 | 552 | --- | --- | | 5 |
| 56 | 583 | --- | --- | | 5 |
| 59 | 615 | --- | --- | | 5 |
| 62 | 646 | --- | --- | | 5 |
| 65 | 677 | --- | --- | | 5 |
| 68 | 708 | --- | --- | | Failure at 1.2 |

* Cable insulation with approximately restored original water content by immersion in ambient water for one week.
** After drying the cable insulation for one week in 95°C oven.

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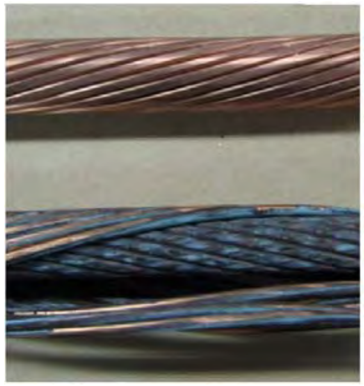
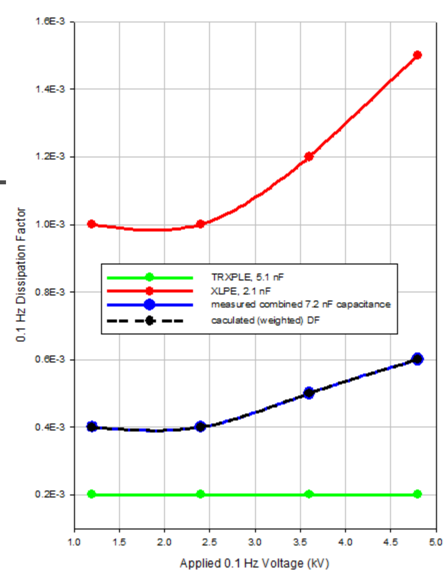
# Cable Conductor



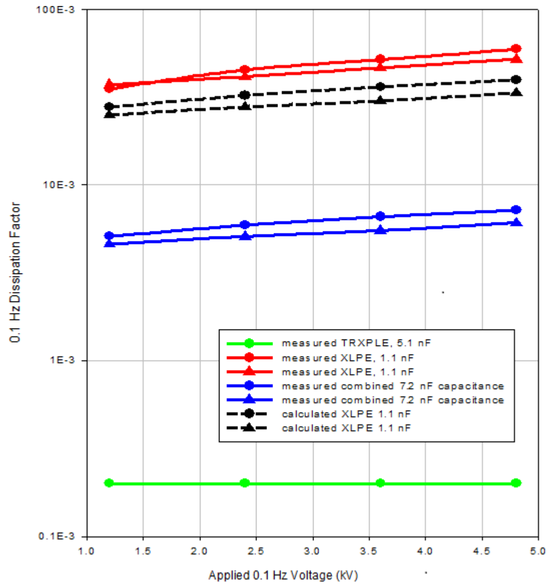
Conductor of phase 3 (bottom) with water induced corrosion products (blue/green copper hydrates). Top – corrosion free cable conductor (for comparison).






$$DF_c = \frac{DF_1 \text{ x } C_1 + DF_2 \text{ x } C_2}{C_1 + C_2}$$

Measured 0.1 Hz dissipation factor of two individual samples (5.1 nF and 2.1 nF) and of combined sample (7.2 nF), solid line. Dashed line - calculated dissipation factor.




$$DF_c = \frac{DF_1 \text{ x } C_1 + DF_2 \text{ x } C_2}{C_1 + C_2}$$

Measured 0.1 Hz dissipation factor of two individual samples (5.1 nF and 2.1 nF) and of combined sample (7.2 nF), solid line. Dashed line - calculated dissipation factor.

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# Preliminary Conclusions

- 0.1 Hz DF may be suitable for assessment of the insulation condition in unshielded, armored cables
- Assessment will probably be based on the curvature of DF vs. applied voltage
- Very short samples (capacitance ~ 1 nF) can be measured using commercially available 0.1 Hz DF equipment
- The above gives hope of using diagnostics of unshielded, un-armored MV cables.

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## 3/C, 5 kV, Shielded Cable:

Test results on 300 ft of an 800 ft cable run from 1981, which failed in June 2010

- Cable Construction:
  - 250 kcmil compact Cu conductor
  - Extruded conductor shield
  - 0.175" of pink EPR insulation
  - Extruded insulation shield (Unishield) DRTP
  - Manufactured by Anaconda in 1981

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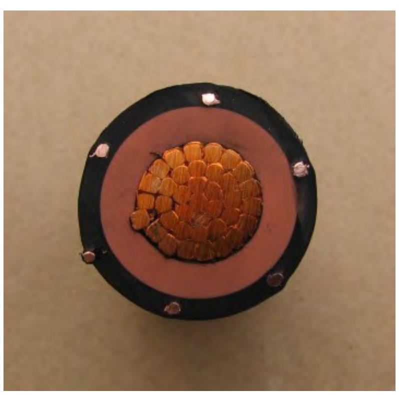
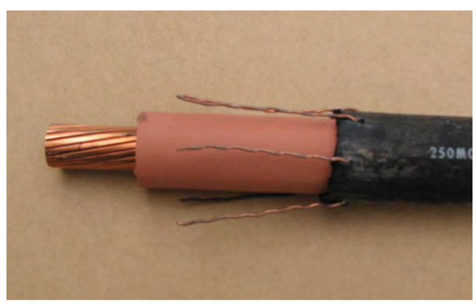
## Cable





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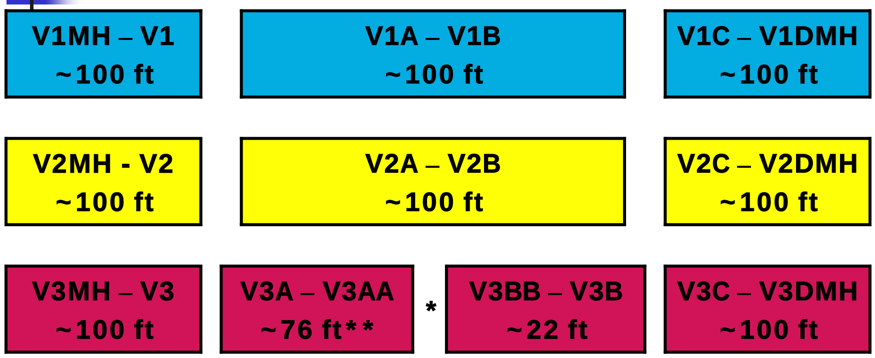
# Anaconda 1981, EPR (pink) 15kV

## Initial Map of 300 ft Cable Sections




* Service Failure
** 0.1 Hz Dissipation Factor measurement failure

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# Anaconda 1981, EPR (pink) 15kV

## Laboratory 60 Hz Dissipation Factor

| V1 | V1MH-V1 (~100 ft) | | V1A-V1B (~100 ft) | | V1C-V1DMH (~100 ft) | |
|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 9700 | 3.05 | 9800 | 3.46 | 10850 | 24.50 |
| 8 kV | 9700 | 3.14 | 9800 | 3.61 | 10850 | 25.00 |
| 12 kV | 9700 | 3.36 | 9800 | 3.79 | 10850 | 25.80 |
| 16 kV | 9700 | 3.70 | 9810 | 4.35 | 10850 | 27.00 |

| V2 | V2MH-V2 (~100 ft) | | V2A-V2B (~100 ft) | | V2C-V2DMH (~100 ft) | |
|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 9700 | 3.03 | 10070 | 3.59 | 10838 | 23.80 |
| 8 kV | 9700 | 3.10 | 10070 | 3.59 | 10836 | 24.20 |
| 12 kV | 9700 | 3.22 | 10070 | 3.82 | 10836 | 25.00 |
| 16 kV | 9700 | 3.50 | 10070 | 4.29 | 10836 | 26.20 |

| V3 | V3MH-V3 (~100 ft) | | V3A-V3AA (~76 ft) | | V3BB-V3B (~22 ft) | | V3C-V3DMH (~100 ft) | |
|---|---|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 9710 | 3.20 | 7580 | 3.75 | 2230 | 3.21 | 11210 | 40.70 |
| 8 kV | 9710 | 3.26 | 7580 | 4.01 | 2230 | 3.32 | 11220 | 42.60 |
| 12 kV | 9720 | 3.37 | 7590 | 4.21 | 2230 | 3.56 | 11230 | 44.70 |
| 16 kV | 9720 | 3.63 | 7590 | 4.70 | 2230 | 4.57 | 11250 | 48.20 |

** Field failure in phase V3 between V3AA and V3BB ends*

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# Anaconda 1981, EPR (pink) 15kV

## Laboratory 0.1 Hz Dissipation Factor

| V1 | V1MH-V1 (~100 ft) | | V1A-V1B (~100 ft) | | V1C-V1DMH (~100 ft) | |
|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 10100 | 9.2 | 10400 | 15.3 | 13000 | 235 |
| 8 kV | 10100 | 9.3 | 10400 | 16.6 | 13000 | 320 |
| 12 kV | 10100 | 9.5 | 10400 | 17.9 | 13000 | 406 |
| 16 kV | 10100 | 10.0 | 10400 | 19.3 | 13000 | 494 |

→

| V1C-V1CC (~50 ft) | | V1DD-V1DMH (~50 ft) | |
|---|---|---|---|
| Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 6400 | 379 | 6600 | 176 |
| 6400 | 520 | 6600 | 239 |
| 6400 | 662 | 6600 | 307 |
| 6400 | 803 | 6600 | 376 |

| V2 | V2MH-V2 (~100 ft) | | V2A-V2B (~100 ft) | | V2C-V2DMH (~100 ft) | |
|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 10200 | 9.1 | 10600 | 19.1 | 13300 | 289 |
| 8 kV | 10200 | 9.9 | 10600 | 21.2 | 13300 | 397 |
| 12 kV | 10200 | 11.4 | 10600 | 23.4 | 13300 | 505 |
| 16 kV | 10200 | 12.9 | 10600 | 25.7 | 13300 | 614 |

→

| V2C-V2CC (~50 ft) | | V2DD-V2DMH (~50 ft) | |
|---|---|---|---|
| Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 7100 | 366 | 5800 | 118 |
| 7100 | 505 | 5800 | 157 |
| 7100 | 644 | 5800 | 119 |
| 7100 | 782 | 5800 | 243 |

| V3 | V3MH-V3 (~100 ft) | | V3A-V3AA (~76 ft) | | V3BB-V3B (~22 ft) | | V3C-V3DMH (~100 ft) | | V3C-V3CC (~50 ft) | | V3DD-V3DMH (~50 ft) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Voltage | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) | Cap (pF) | DF ($x10^{-3}$) |
| 4 kV | 10300 | 8.2 | 8000 | 15.7 | 2400 | 15.2 | 14700 | 389 | 7400 | 513 | 7000 | 275 |
| 8 kV | 10300 | 8.3 | 8000 | 17.2 | 2400 | 16.2 | 14700 | 547 | 7400 | 719 | 7000 | 385 |
| 12 kV | 10300 | 8.6 | 8000 | 18.7 | 2400 | 16.9 | 14700 | 703 | 7400 | 919 | 7000 | 413 |
| 16 kV | 10300 | 8.9 | 8000 | 99.7** | 2400 | 17.7 | 14700 | 858 | 7400 | 1000 | 7000 | 603 |

** Field failure in phase V3 between V3AA and V3BB ends*

*** Test failure*

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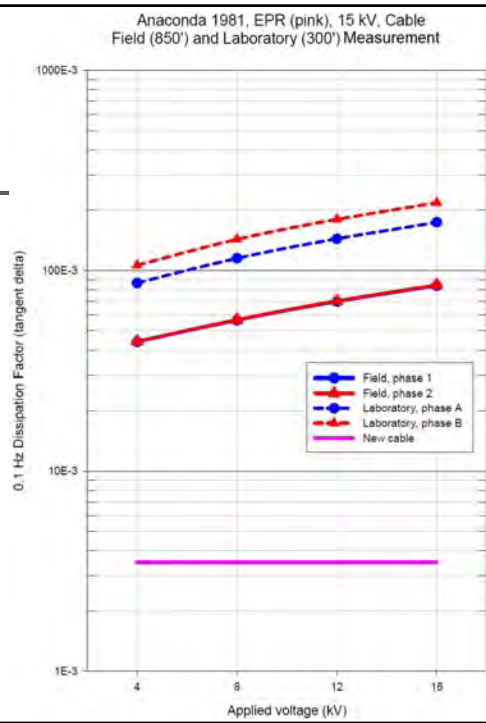


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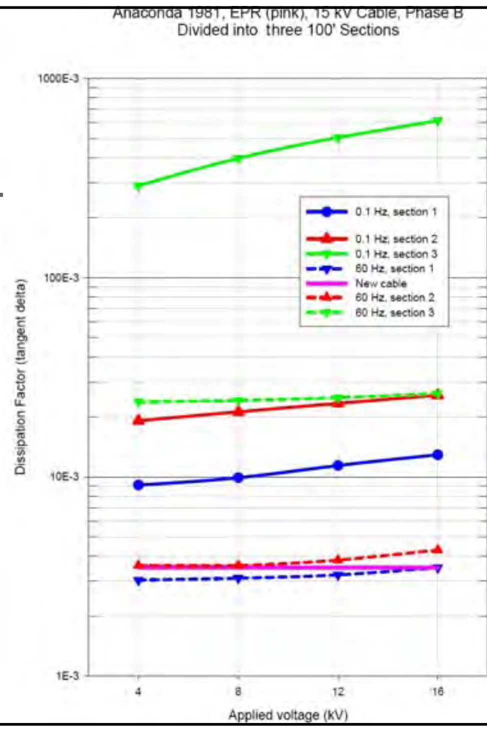


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# Anaconda 1981, EPR (pink) 15kV

## Diagnostic Data

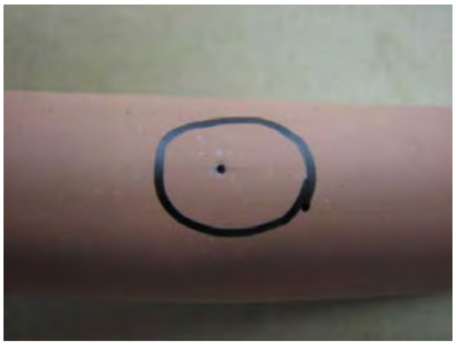
| V1 | V1MH-V1 (~100 ft) | V1A-V1B (~100 ft) | V1C-V1DMH (~100 ft) | V1C-V1CC (~50 ft) | V1DD-V1DMH (~50 ft) |
|---|---|---|---|---|---|
| Dissipation Factor ($x10^{-3}$) | 10.0 | 19.3 | 494 | 803 | 370 |
| Resistance in Ω | $3.8 \times 10^{11}$ | $4.5 \times 10^{10}$ | $1.7 \times 10^{9}$ | $2.0 \times 10^{9}$ | $3.5 \times 10^{9}$ |
| MΩ per 1000' | 38 000 | 4 500 | 170 | 100 | 175 |
| Breakdown Voltage | $>7.9 \times V_0$ | $7.4 \times V_0$ | ------- | ------- | $6.3 \times V_0$ |

| V2 | V2MH-V2 (~100 ft) | V2A-V2B (~100 ft) | V2C-V2DMH (~100 ft) | V2C-V2CC (~50 ft) | V2DD-V2DMH (~50 ft) |
|---|---|---|---|---|---|
| Dissipation Factor ($x10^{-3}$) | 12.9 | 25.7 | 614 | 782 | 243 |
| Resistance in Ω | $3.5 \times 10^{11}$ | $4.2 \times 10^{10}$ | $1.7 \times 10^{9}$ | $1.6 \times 10^{9}$ | $7.0 \times 10^{9}$ |
| MΩ per 1000' | 35 000 | 4 200 | 170 | 80 | 350 |
| Breakdown Voltage | $3.2 \times V_0$ | $7.4 \times V_0$ | ------- | ------- | $6.8 \times V_0$ |

| V3 | V3MH-V3 (~100 ft) | V3A-V3AA (~76 ft) | V3BB-V3B (~22 ft) | V3C-V3DMH (~100 ft) | V3C-V3CC (~50 ft) | V3DD-V3DMH (~50 ft) |
|---|---|---|---|---|---|---|
| Dissipation Factor ($x10^{-3}$) | 8.9 | 99.7 | 17.7 | 858 | >1000 | 603 |
| Resistance in Ω | $3.5 \times 10^{11}$ | ------- | $2.0 \times 10^{11}$ | $1.3 \times 10^{9}$ | $1.4 \times 10^{9}$ | $3.0 \times 10^{9}$ |
| MΩ per 1000' | 35 000 | ------- | 4 400 | 130 | 70 | 150 |
| Breakdown Voltage | $8.4 \times V_0$ | $2.0 \times V_0$ | $>7.4 \times V_0$ | ------- | ------- | $>5.8 \times V_0$ |

50

# Laboratory and Field Failure



51

# Anaconda 1981, EPR (pink) 15kV

## Map and Data, Phase 2

V2C ~100' V2DMH

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 614 (0.1 Hz) |
| Resistance in Ω | $1.7 \times 10^9$ |
| MΩ per 1000' | 170 |
| Breakdown Voltage | ------- |

V2C ~50' V2CC

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 782 (0.1 Hz) |
| Resistance in Ω | $1.6 \times 10^9$ |
| MΩ per 1000' | 80 |
| Breakdown Voltage | ------- |

V2DD ~50' V2DMH

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 243(0.1 Hz) |
| Resistance in Ω | $7.0 \times 10^9$ |
| MΩ per 1000' | 350 |
| Breakdown Voltage | $6.8 \times V_0$ |

V2C ~17' V2CA

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | ------- |
| Resistance in Ω | ------- |
| MΩ per 1000' | ------- |
| Breakdown Voltage | $>6.8 \times V_0$ |

V2CB ~17' V2CD

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | ------- |
| Resistance in Ω | ------- |
| MΩ per 1000' | ------- |
| Breakdown Voltage | $>6.8 \times V_0$ |

V2CE ~17' V2CC

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | ------- |
| Resistance in Ω | ------- |
| MΩ per 1000' | ------- |
| Breakdown Voltage | $>6.8 \times V_0$ |

52

## Diagnostic (Cont.)

| V2CC | ~17 ft | V2CE |
|---|---|---|

After 1 month
60°C water (full cable)

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 51 (60 Hz) |
| Resistance in Ω | $1.2 \times 10^{10}$ |
| MΩ per 1000' | 170 |
| Breakdown Voltage | $>6.8 \times V_0$ |

After 1 month
60°C water (shield removed)

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 47 (60 Hz) |
| Resistance in Ω | $1.6 \times 10^{10}$ |
| MΩ per 1000' | 240 |
| Breakdown Voltage | $>6.8 \times V_0$ |

After 18 hours
Drying, 50°C oven

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 47 (60 Hz) |
| Resistance in Ω | $1.5 \times 10^{10}$ |
| MΩ per 1000' | 220 |
| Breakdown Voltage | $>6.8 \times V_0$ |

After 3.5 days
Drying, 50°C oven

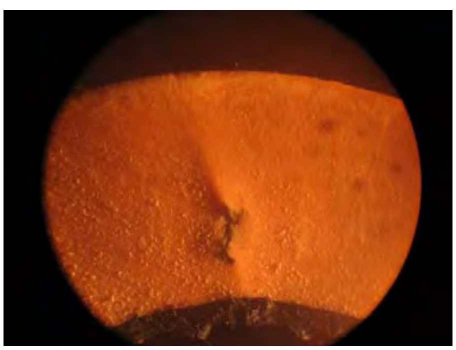
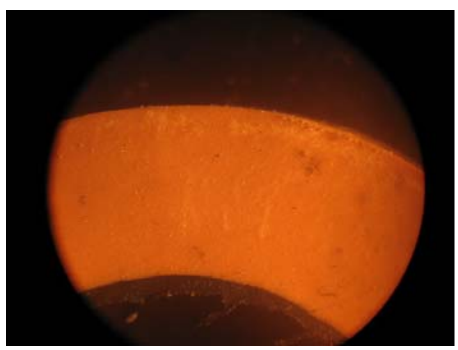
| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 42 (60 Hz) |
| Resistance in Ω | $2.4 \times 10^{10}$ |
| MΩ per 1000' | 360 |
| Breakdown Voltage | $>6.8 \times V_0$ |

After 4 Days
Drying, 95°C oven

| | |
|---|---|
| Dissipation Factor ($x10^{-3}$) | 19 (60 Hz) |
| Resistance in Ω | $3.0 \times 10^{11}$ |
| MΩ per 1000' | 4500 |
| Breakdown Voltage | $>7.4 \times V_0$ |

53

## Photomicrograph of Laboratory Failure Insulation Wafers

54

## Preliminary Conclusions

- Occasionally (rear occurrence) high 0.1 Hz DF not always indicative of very weak insulation strength
- In this case it likely suggests a large amount of moderately long water trees

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Institute of Nuclear Power Operations

# INPO Perspective on Cable Aging Management

Wes Frewin

Cable Users Group Meeting – September 2010



## INPO Focus

- INPO evaluations and review visits have included cable vulnerabilities since 2007
- Added as an INPO Configuration Management focus area in April 2010
  - Critical functions supported by cables subject to adverse conditions.
  - Aligned with EPRI Guides on Cable Aging Management
  - Evaluation "How To"

# Description of Problem

- Cable failure potential increases as:
  - cable age increases
  - exposure duration to adverse conditions such as heat and wet environments increases
- Cable monitoring is not in place at many sites
  - Test methods are not available for all cable types
  - Cable monitoring is at varying stages



# Analysis of Current Performance

- 21 cable failures have been reported to INPO from 2005 to May 2010.
- 13 cable failure events affected safety-related equipment, including emergency service water, component cooling, and emergency power.

## Analysis of Current Performance

- Contributing adverse condition
  - Eleven cable failures were cables in wet conditions.
  - Two cable failures were related to high temperature environments.
- Two were categorized as significant [Robinson (SER 3-10) and Point Beach (SEN 272)]
  - Significant – The event caused or had the potential to cause an appreciable reduction in plant safety or reliability, excessive radiation exposure, the discharge of radioactivity off site, or serious harm to individuals.

INPO



## Evaluations Results

2009-2010

9 Areas for Improvement

3 Performance Deficiencies

INPO

## Basis for Evaluation Results

- The condition of underground cables and transition supports have not been evaluated for:
  - supporting functions important to safety
  - submerged duration
  - Cable support integrity (supports are corroded or have failed, placing increased stress on cables)
- The water in manholes not adequately managed to keep the water from contacting cables or supports, and the water level is not trended to ensure the PM frequency is adequate



## Recommended Actions

- Establish a method for managing low and medium voltage power cable aging and adverse condition mitigation
- Perform inspections of manholes for water and a course of action to manage wetted conditions
- Monitor condition of low and medium voltage power cables supporting important plant equipment that are (or have been) subjected to adverse conditions.

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# INPO Supporting Resources

- Operating experience
- Topical Report TR10-69, *Cable Aging and Monitoring*
- INPO evaluation “how-to”



# INPO Supporting Resources

- Benchmarking information
- AFI and Strength database
- Cable Working Meeting notes and presentations posted– 8/2010
- Develop web page to communicate good practices – 10/2010

## AFI

- Actions to address adverse conditions affecting underground cables have not been adequate to prevent repeat submergence. Cable submergence increases the potential for cable failure. Contributing is that engineering supervisors have not set standards for monitoring, reporting health, and resolving cable submergence issues. (Posted 7/12/10)

INPO



## AFI

- Some medium- and low-voltage power cables are submerged or partially in water, and the conditions of all cables have not been determined. This presents a vulnerability for a loss of power to transformers that supply power to safety-related 4-kV buses, condensate pumps, and recirculation pumps. The perceived risk for failure to submerged medium-voltage cables is low because the cable type used has not failed from water degradation alone, and the risk of failure for submerged low-voltage power cables was not understood.
(Posted 7/12/10)

INPO

# AFI

- Timely actions have not been taken to address previously identified problems with submerged cables and degraded cable supports in manholes. Also, a strategy for conducting periodic diagnostic testing and trending to monitor cable insulation conditions has not been implemented. These program weaknesses could increase the vulnerability to an unplanned loss of a safety-related cable or a cable important to plant operations. Contributing to this is that engineering personnel do not fully recognize the risk posed by adverse conditions associated with underground cables and how the lack of predictive diagnostic testing increases the potential for cable failure.
  (Posted 5/5/10)



# Strength

- STRENGTH 5/2010: An innovative solution has been implemented to address water intrusion into underground nonsafety related cables by the installation of solar-powered sump pumps. Approximately 80 manholes have been equipped with the pumps. The use of solar power and periodic preventive maintenance activities addresses water intrusion without the need for traditional pump power cable routing and power sources.

Examples

- Approximately 60 solar-powered sump pumps have been installed to remove water from approximately 80 manholes. The pumps have been installed in various locations inside and outside the protected area to remove water that accumulates in the manholes.
- The design requires no cable routing and minimal structural changes. It uses core drills to connect adjacent manholes when practical to reduce the number of solar stations. These features result in a solution that minimizes implementation resource requirements.
- Preventive maintenance (PM) activities are performed annually to check the level switches and pump, and visual inspections are performed to check for water and the condition of the solar panels. These PM activities have been effective in identifying and correcting equipment issues and minimizing the exposure of underground cables to water.
- INFORMATION CONTACT: Ken House, South Texas, 361-972-8922

# Beneficial Practices

- Engineering has implemented an aggressive cable monitoring program for underground wetted medium-voltage cables. The condition of medium-voltage cable systems and connections are tested to identify degraded conditions and minimize the probability of failures, prioritize cable replacements, and improve system reliability. The staff uses very low frequency tan delta and partial discharge testing to assess cable insulation and connections. To date, engineering has tested over 30 cables out of a risk population of 51 cables. During the evaluation, site personnel identified a degraded splice on a 7-mile, 24-kV cable feeder to the Caswell Beach pumping station. Other examples include degraded cables that were identified and repaired for the 1A and 2B control rod drive pumps and the 2A residual heat removal service water booster pump.

**STATION CONTACT: Brunswick (Posted 5/26/09)**



# Beneficial Practice

- Engineering staff developed and implemented a comprehensive cable monitoring program that includes annual cable vault and support inspections, water level trending, and cable condition monitoring of instrumentation and switchyard control cables that are susceptible to submergence. This exceeds the scope of the fleet designed program for medium-and-low voltage cables. As a result, the condition of over 1,400 cables is monitored, tracked, and trended providing a comprehensive evaluation of cable conditions.

Byron Station 7/2010

# Evaluator's Guide

- Power Cable Aging Management – June 2010
- Station performance indicating a potential AFI includes the following:
  - A consequential event has occurred as a result of a cable circuit failure during the evaluation period in which the cable circuit was subject to adverse conditions and condition monitoring was not being performed.
  - Manholes, vaults, or handholes containing power cables supporting critical plant functions are not kept clear of water, and the condition of those cables has not been evaluated.
  - Other examples in which station performance resulted in an AFI are provided in Attachment 3, Area for Improvement. (for example: a plan has not been developed or cable condition is not known)



# INPO 09-008: *Achieving Excellence in Transformer, Switchyard, and Grid Reliability*

- TSG-related cables are not subjected to prolonged submergence or other environmental conditions that could lead to premature failure. To the extent practicable, the condition of these cables is monitored to proactively identify and address aging and degradation issues.
- Basis: The industry has also experienced a number of events related to cable failures. The types of failures are associated with jackets, insulation, splices, and terminations. Some of the failures resulted from degradation caused by the cable being exposed to submerged conditions for prolonged periods or latent damage from installation. Actions are needed to prevent and address cable flooding concerns and to test or monitor cables that may be degraded because of exposure to known degradation mechanisms.

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# TSG Recommendation

- March 2007 - The station should establish a plan to ensure that a cable aging program is developed and includes consideration of both power and control cables from transformers and within the switchyard. Although industry recommendations focus on safety related cables, cables that are maintenance rule risk significant should also be considered as a minimum. This will ensure that adequate attention is given to redundant DC control cables within the switchyard that are routed without physical separation and cables routed via under ground ducts and man-holes that are prone to occasional water submergence.



## TSG Switchyard Observation

- Feb 2008: The station has experienced four control cable failures since 2003, and one resulted in a shut down. At the time of the review visit, at least one of the cable trenches was filled with water. In addition, medium-voltage cables located in transitioning manholes were visually confirmed to be submerged. There is no active mitigation plan for this condition and industry research has shown that moisture accelerates the effect of aging. The original qualification requirements, related to wet environments, for these cables could not be verified during the review.



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SimonSM@Inpo.org

# QUESTIONS?

INPO

MARMON

# Marmon Wire & Cable LLC

A Berkshire Hathaway Company


***Robert E. Fleming***
***Director of Nuclear Development***
***Marmon, Innovation & Technology Group***


MARMON

Marmon Wire & Cable LLC

A Berkshire Hathaway Company

**Building Wire**

cerrowire

**Energy**

**Marmon Utility LLC**

HENDRIX

Kerite

OWLWIRE

**Specialty**

RSCC

TEW&C

PMC Wire & Cable

Dekoron Wire & Cable, Inc.

aetna INSULATED WIRE

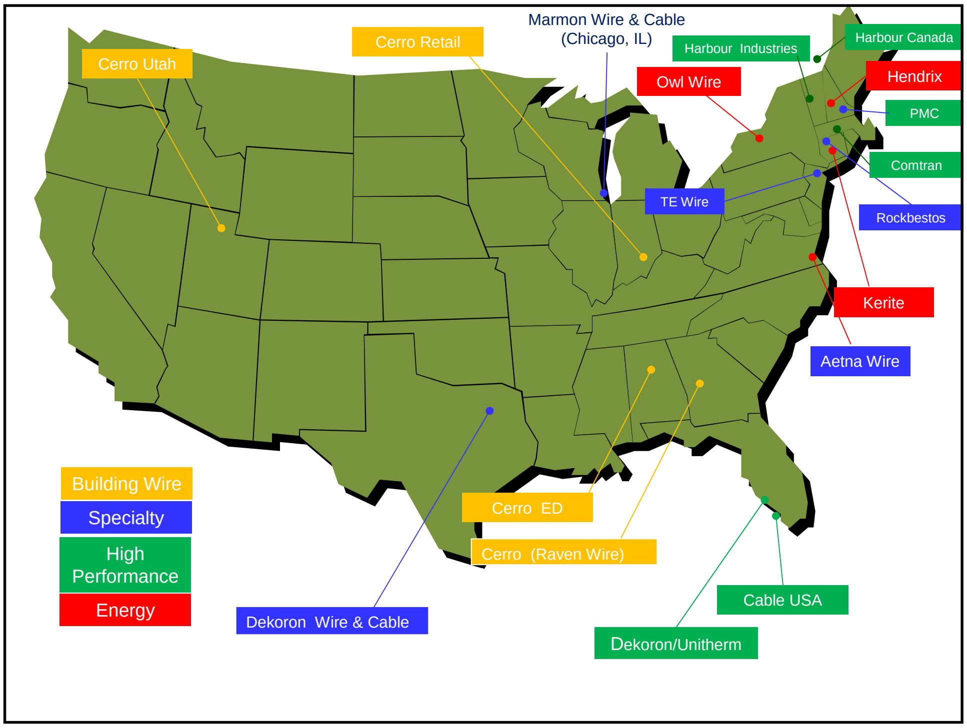
High Performance

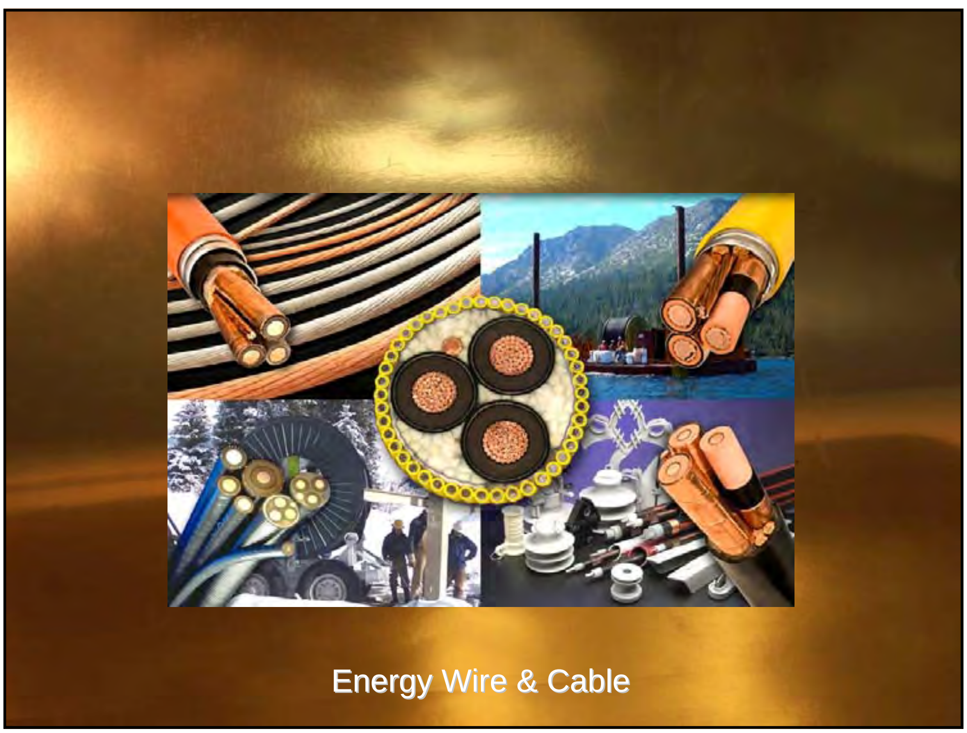
Harbour INDUSTRIES

CABLE USA

COMTRAN Corporation

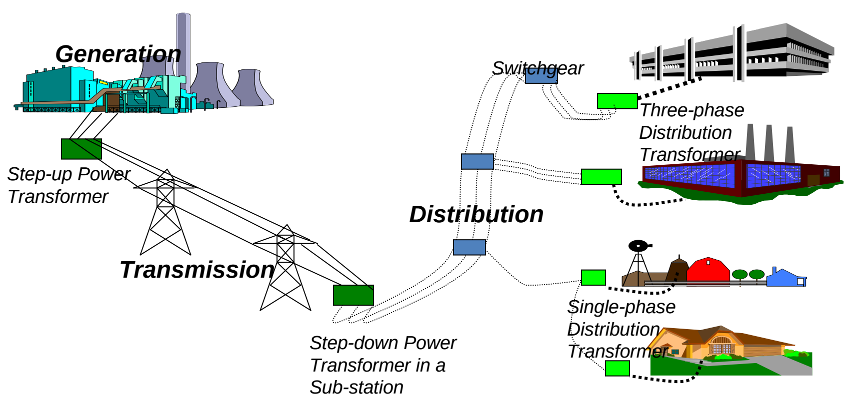
DEKORON Unitherm


Marmon Wire & Cable
(Chicago, IL)
Cerro Utah
Cerro Retail
Harbour Industries
Harbour Canada
Hendrix
Owl Wire
PMC
Comtran
TE Wire
Rockbestos
Kerite
Aetna Wire
Building Wire
Specialty
High Performance
Energy
Cerro ED
Cerro (Raven Wire)
Dekoron Wire & Cable
Cable USA
Dekoron/Unitherm


Energy Wire & Cable

# CABLE BASICS

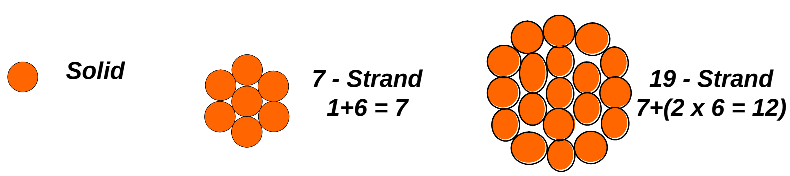
*Where Does Underground Power Cable Fit?*



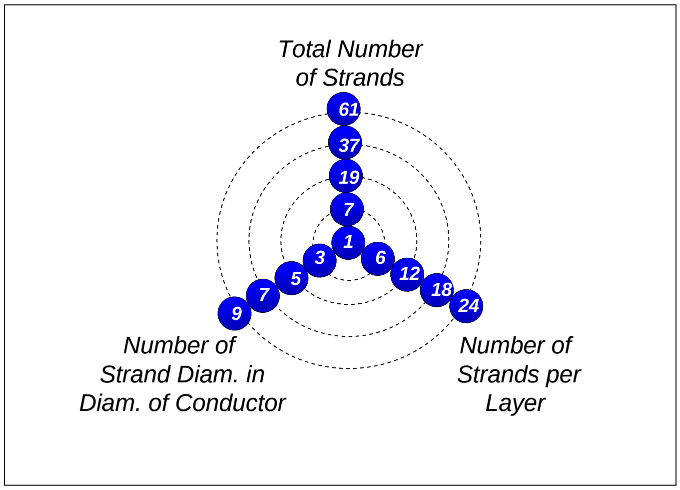

***Transmission (High Voltage) over 42,000 volts***
***Distribution (Medium Voltage) 5,000 to 35,000 volts***
***Service (Low Voltage) 480/240/120 volts***

# CABLE CONSTRUCTION

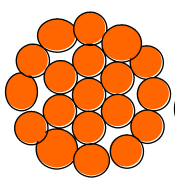
# Conductor Stranding



# Concentric Build-up

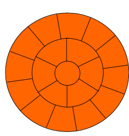



# Types Of Conductor



***Full Round***
***(standard conductor)***

***Compressed = 2% Smaller Than Concentric***



***Compact = 10% Smaller Than Concentric***

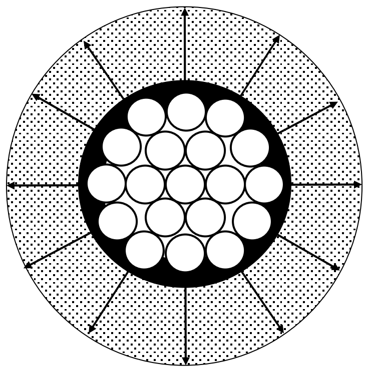
# Conductor Materials

- Silver 9.80 ohm-cmils/ft 106% Cu
- Copper 10.37 ohm-cmils/ft 100% Cu
- Gold 14.55 ohm-cmils/ft 71% Cu
- Aluminum 16.06 ohm-cmils/ft 62% Cu
- Lead 123.5 ohm-cmils/ft 8.4%Cu

# Materials Selection

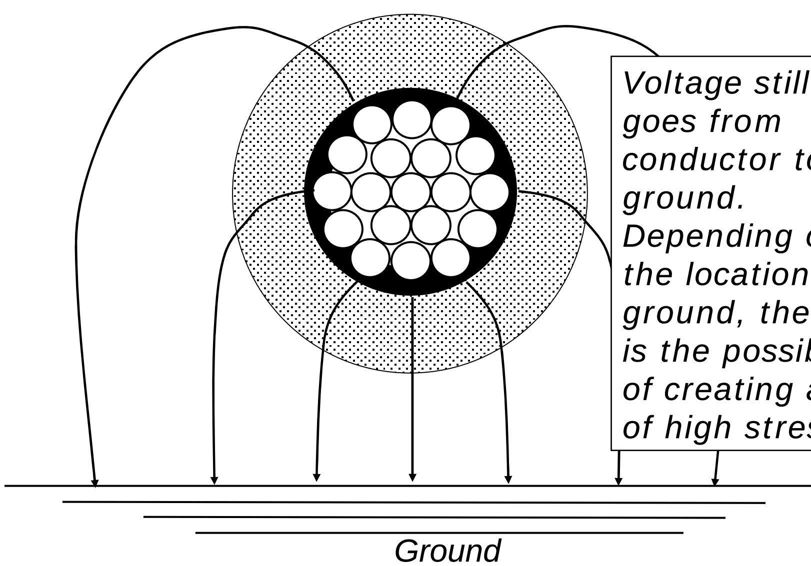
- Conductivity
- Weight
- Mechanical Strength
- Diameter
- Cost

*Applying a Conductor Shield*



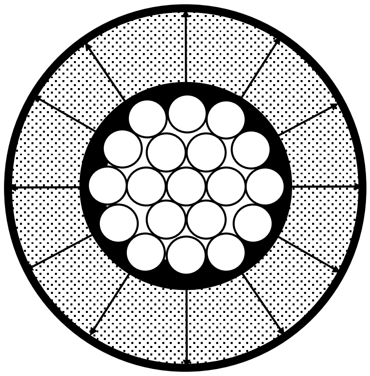
*Applying a conductor shield distributes the electrical stress at the conductor to avoid points of high stress*

*Effects of a Close Ground*



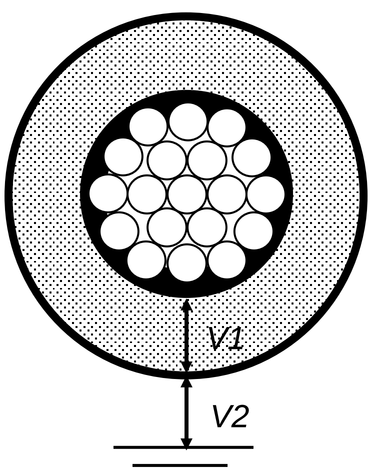

*Voltage still goes from conductor to ground. Depending on the location of ground, there is the possibility of creating areas of high stress.*

## *Applying an Insulation Shield*



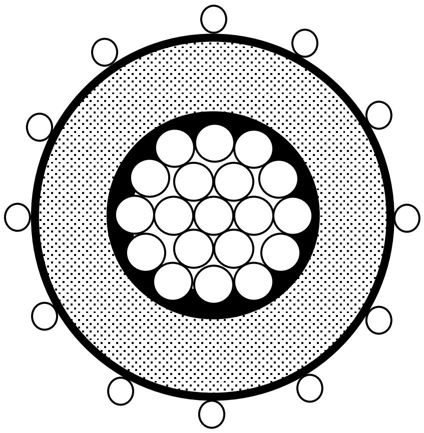
*Electrical stress can be Controlled by applying an insulation shield which keeps the electrical field symmetrical, and contained within the solid insulation*

## *Effect of Ground Location*




*However, the voltage is still between the conductor and ground, and in this configuration the cable acts as a long-line capacitor, with voltage and charging currents developing on the surface of the insulation shield – which will eventually erode the shield and fail the cable*

## *Applying a Metallic Component*



*By adding a grounded metallic component, the charging current is effectively drained to ground without damaging the cable*

## *Functions of the Metallic Shield Component*

*1st* *To ground the surface of the insulation shield.*

*2nd* *To provide a ground path for charging currents and fault currents.*

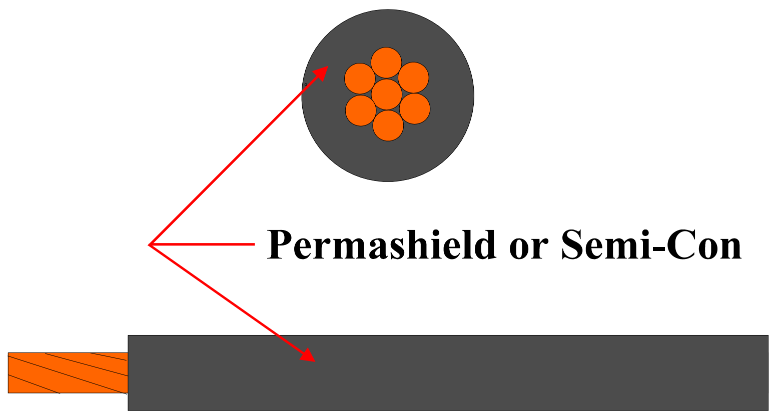
*3rd* *Provide a system neutral.*

*Jacket Functions*

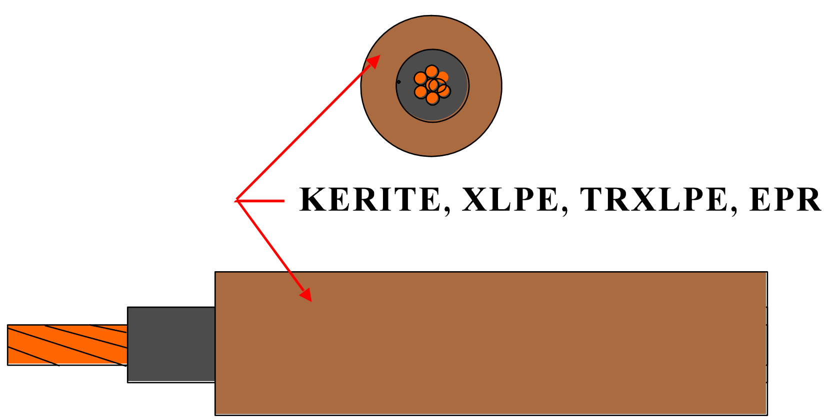
- *To protect the cable core from physical abuse.*
- *To protect the cable from chemical attack.*
- *To protect metallic shield from corrosion.*
- *To protect the cable core from water attack.*
- *To protect the cable insulation from ionic attack.*
- *To add flame resistance.*
- *To add sunlight resistance.*

# **SHIELDED POWER CABLE**

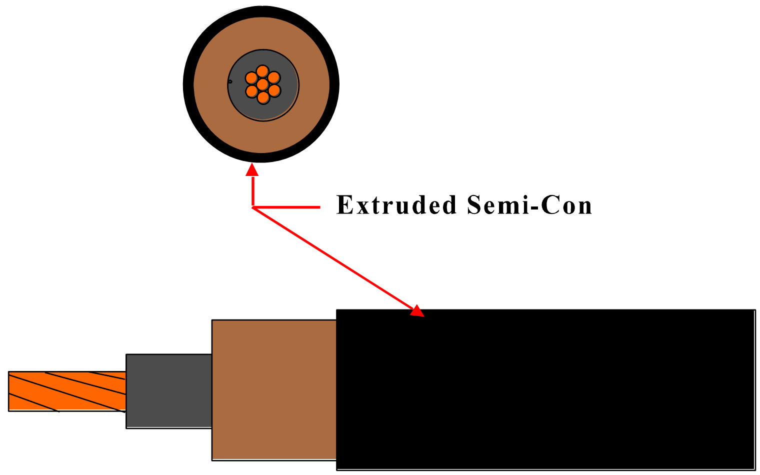
# Strand Shields



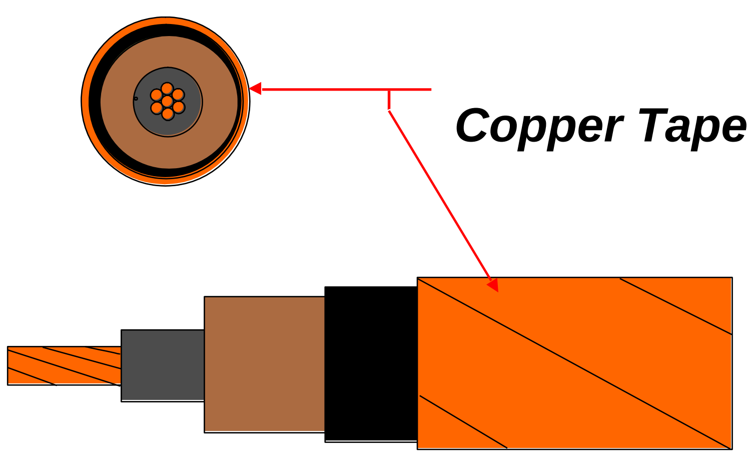

# Insulations



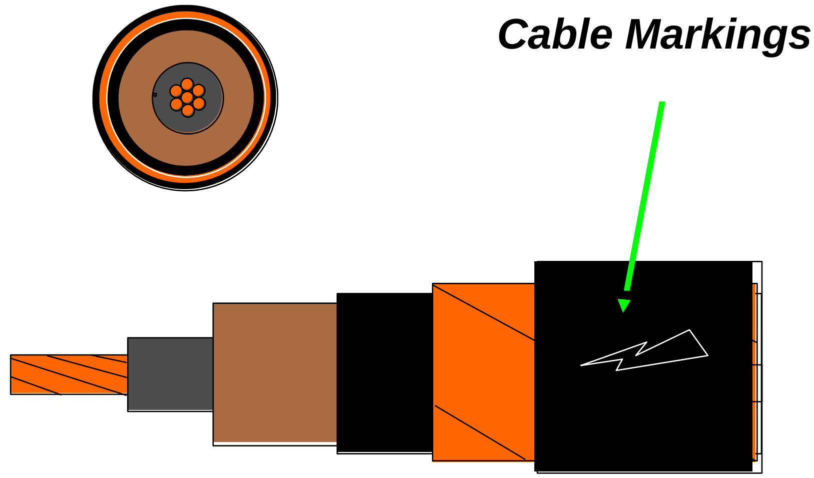
# Insulation Shields




# Tape Neutral



# Outer Jacket



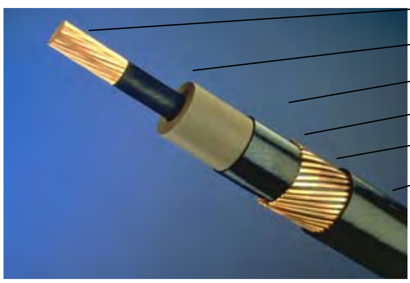

# Why Select Kerite Over Other EPR Insulation's ?

- Lowest Total Cost of Ownership
  - Highest Demonstrated Reliability
    - Compounding Experience 100+ Years
    - Permashield Concept 50+ Years
  - Easiest Installation
  - Faster Cable Preparation

# Why Select Kerite Over Other EPR Insulation's ?

- **Insulation System Suited for Use Without Water Barriers**
  - **Permashield / Kerite EPR**
  - **Same Insulation System In-Service at 138kV**
    - **First 138 kV Installation 1976**
    - **Over 2.2 Million Feet Installed and Operational at Transmission Voltages**
    - **Several Million Feet of 35kV and up Submarine Cable Installation**

# KERITE CABLE DESIGN



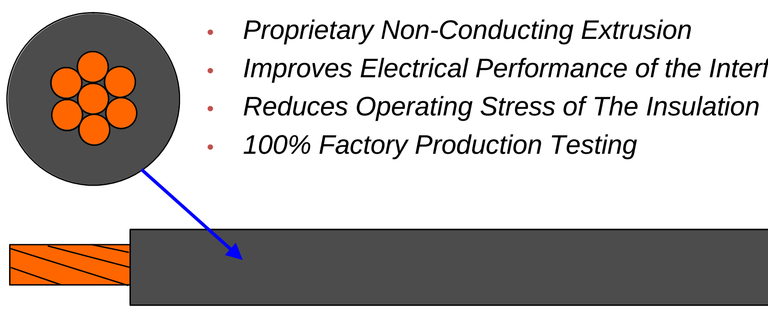
# The Kerite Differences

### Our Unique Cable Qualities

- Permashield® Conductor Shield (NonConducting Stress Control Layer)
- Discharge Resistant Insulation
- Field Proven Performer

## Permashield® Conductor Shield

- *Proprietary Non-Conducting Extrusion*
- *Improves Electrical Performance of the Interface*
- *Reduces Operating Stress of The Insulation*
- *100% Factory Production Testing*



# Permashield

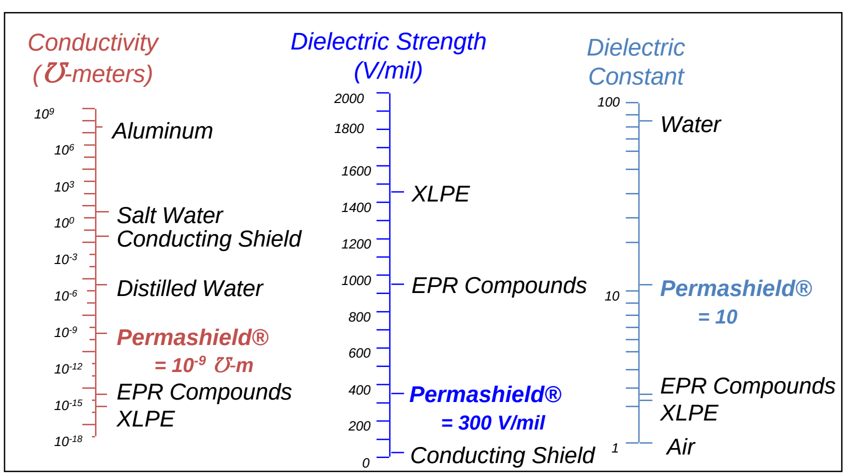
**HISTORY**

- **Lab Discovery in 1958**
- **Commercial Cable Production 1961**
- **Reduced Insulation Wall Thickness Without Compromise in Dielectric Strength Or Change In Insulation Material**

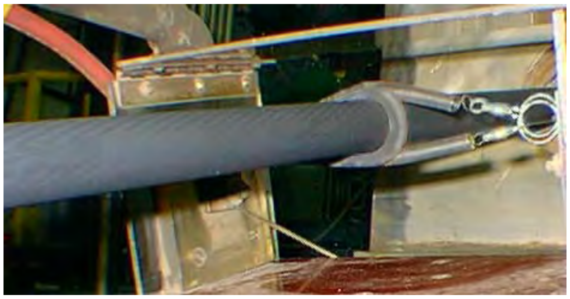
**PROPERTIES**

- **Low Conductivity - 10 mho-meter**
- **Moderate Dielectric Strength - 300 Volts/Mil**
- **High Dielectric Constant - 10**

## *Permashield® Electrical Properties*

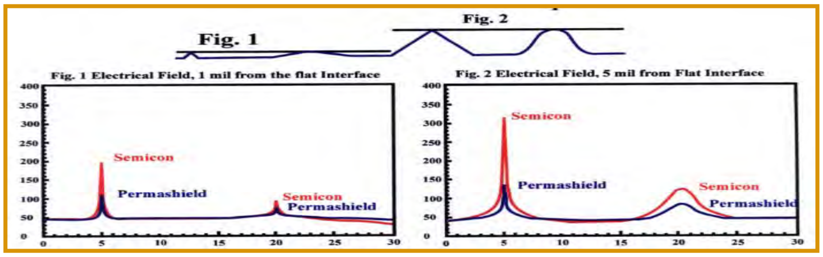


# In-Line 2kV Production Testing



*This Integrity Test Cannot be Done with Semi-Conducting Shields !!*

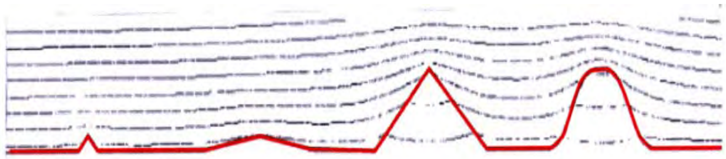
# Fundamental Study on Conductor Shields Electrical Smoothness?




- ***Nonconductive Shields***
  - *Reduce local electric field at insulation interface*
    - *Protrusion size of 5 mils currently permitted by AEIC specifications*
    - *Occur as a result of real world manufacturing "abnormalities"*
  - *Provides barrier to the free flow of electrical charge to the insulation interface thus reducing chance of charge injection into the primary insulation*

## *Permashield® vs Semi-Conducting Shields*

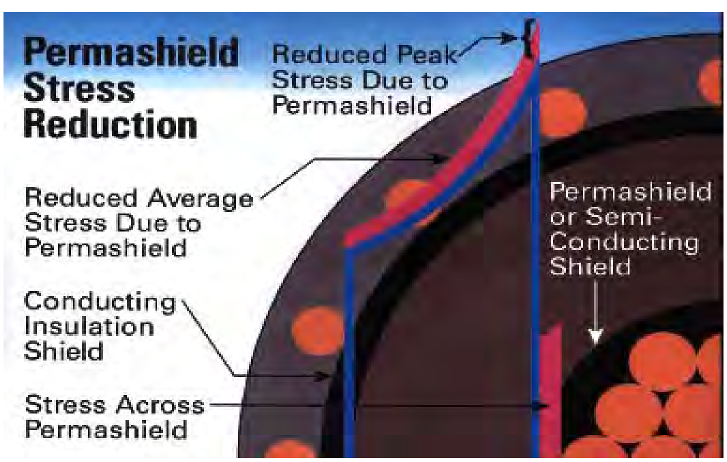
***Electrical Stress Enhancement***



*Voltage Contour in Permashield®*

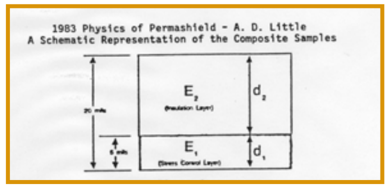
*Voltage Contour in Semi-Conducting Shield*

# Permashield



# A.D. Little Research Study on Conductor Shields

- Develop a theoretical understanding of the Physics of Permashield
- Experiments were conducted to test theoretical concepts
  - Slab samples
  - 60hz breakdowns
- Results
  - Breakdown is initiated by local (microscopic) electric field that exist at the interface
  - Structure of Pemashield® is such that the local field is reduced allowing for higher working stress




1983 Physics of Permashield - A. D. Little
Summary of Results

| Material Type | Average* Breakdown (kV) | Insulation Stress at Breakdown (V/mil) |
|---|---|---|
| Semi-Conducting/Insulation | 20.4 | 1194 |
| Permashield/Insulation | 34.0 | 1704 |
| Improvement | 66% | 42% |

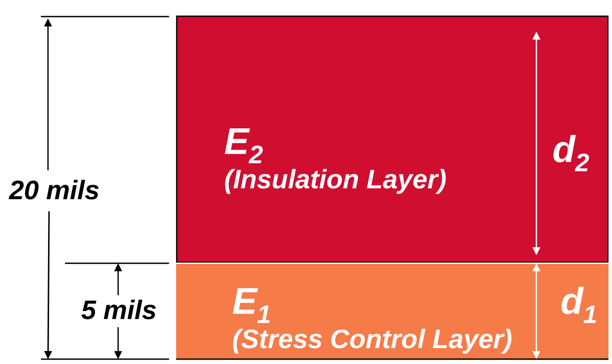
* Adjusted to common wall thickness and ratio of individual material thickness

*Arthur D. Little Inc Physics of Permashield*

*August 1983*

## A.D. Little Testing Setup

### A Schematic Representation of the Composite Sample



## A.D. Little Testing Results

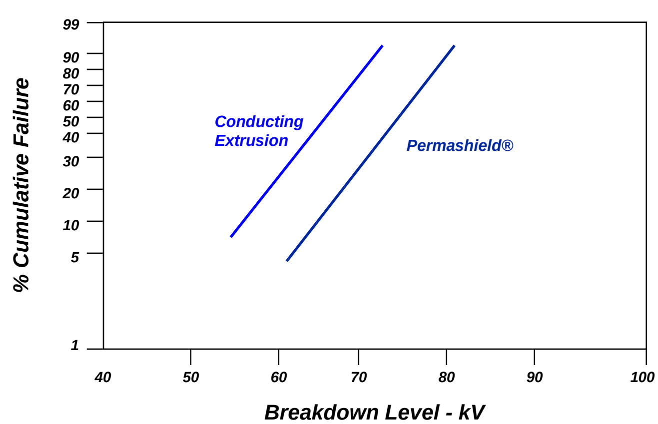
### Improved Electrical Performance of the Insulation/Conductor Shield Interface

| Material Type | Average Breakdown * (kV) | Insulation Stress at Breakdown (Volts/mil) |
|---|---|---|
| Semi-Con/Insulation | 20.4 | 1,194 |
| Permashield®/Insulation | 34.4 | 1,704 |
| Improvement | 66% | 42% |

* Adjusted to Common Wall Thickness and Ratio of Individual Thickness

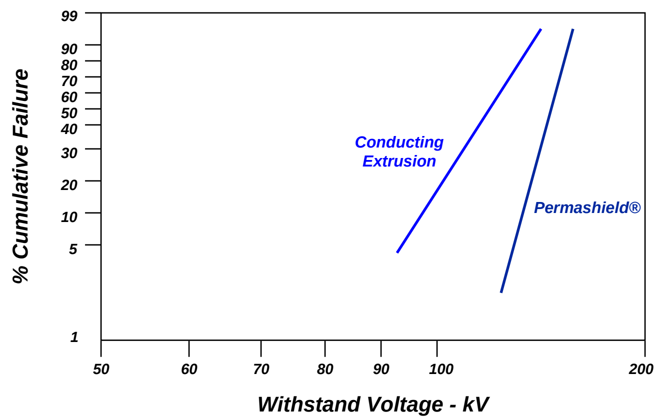
## Cable Testing Comparisons

### 60 Hz Step Test Performed on a #6 AWG 5kV Cable



# Cable Testing Comparisons

## Impulse Test Performed on a #6 AWG 5kV Cable



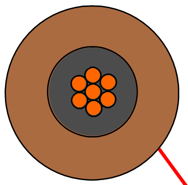

# Permashield® Summary

## Benefits to Users

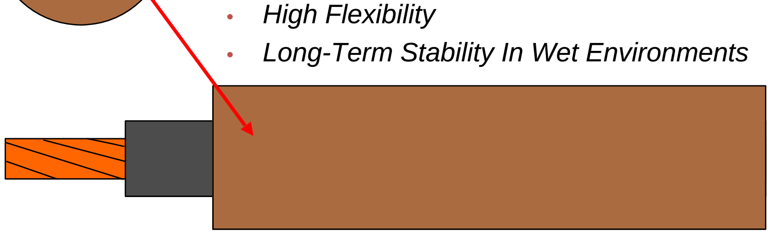
- Reduces Operating Stress on the Insulation System
- Reduces Stress Magnification Caused By Irregularities On Conductor Surface
- 100% Production Testing
- Lowest Probability of Failure
- Recognized in Both ICEA and AEIC Standards as a "Nonconductive" Stress Control Layer.

*Greater life for common average operating stress*
*or*
*Greater average operating stress for common life.*

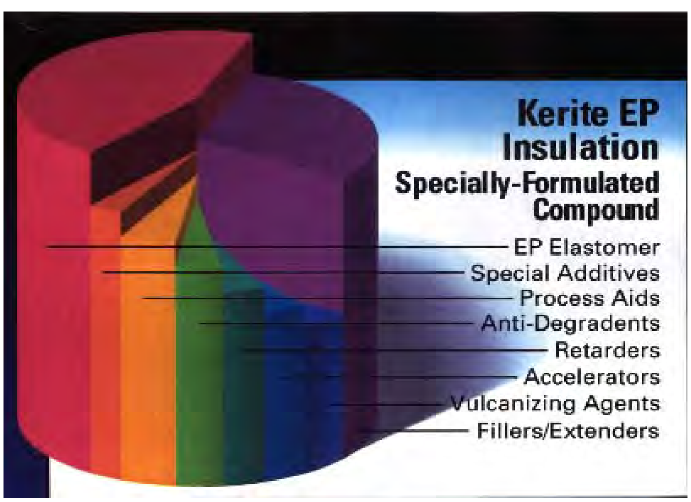
# Kerite Insulation



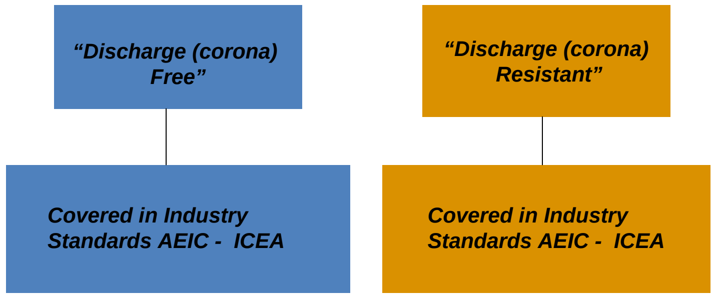
- *Proprietary EPR/EPDM Based Compound*
  - *-Formulated / Mixed / Extruded In House*
  - *-40+ Years of Successful Field History*
  - *-Application Voltage up to 138kV*
- *Formulated Resistance To Partial Discharge*
- *High Flexibility*
- *Long-Term Stability In Wet Environments*



# Kerite Insulation



## Two Design Concepts are Allowed




## Partial Discharge

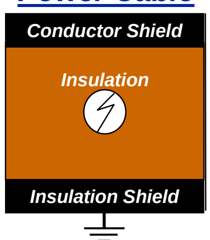
- It is well known that PD in solid-dielectric insulations can lead to premature cable failure
- Standardized methods are available to measure and compare materials
- Insulating materials can be formulated to resist PD initiated degradation

# Partial Discharge Overview

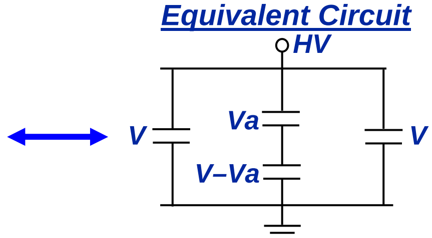
## Corona

- *Electrical Breakdown Pulses Occurring in Microscopic Voids / Contaminants*
- *Causes Fracturing of the Insulation Resulting in Points of High Stress*
- *Found in All Solid Dielectrics*

**Power Cable**




**Equivalent Circuit**




***PD Occurs When:***
***Va > Breakdown Threshold of the Gas***

# Partial Discharge

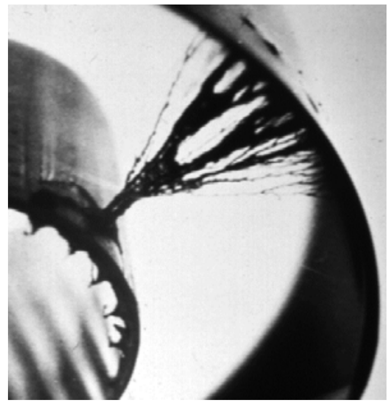
## Testing of Manufactured Cable

- *Extruded Dielectric Cables Cannot be Made 100% PD Free*
- *AEIC and ICEA Standards Allow up to 5pC*
- *Some Partial Discharge is Undetectable at time of manufacturing*
- *PD Also Causes Premature Failure Through Water Trees*
- *Discharge Resistant vs Discharge Free*

***Only Kerite is Discharge Resistant!***

## “Discharge Free” vs. “Discharge Resistant”

- The major difference between Kerite and all other MV cable insulation is discharge resistance
- Discharge, or corona, is what electrically ages cable – voids and contaminants are sites for the initiation of this deterioration – which results in “treeing”



## The Number Of Simultaneously Discharging Voids Required To Produce A 5pc Signal Are

» 100 1 - mil voids
» 9 5 - mil voids
» 3 10 - mil voids

**Undetectable Voids At Time Of Manufacturing**

**Filled With Gas Or By-Products Of Cure**

**Filled With A Water Soluble Material**

# Measurement Of Discharge Resistance

- **Surface Discharge**
  - U-Bend Test
  - **Cylindrical Electrode Method (ASTM D2275-80)**

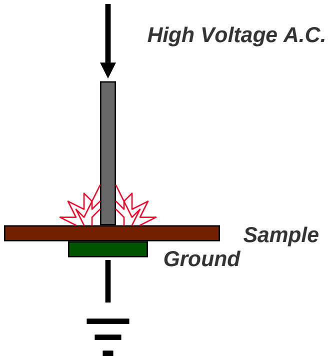
# U-Bend Plate Test

- #2 AWG 15kV Cable
  - 175 mil Insulation
  - Remove
    - Jacket
    - Metallic Shield
    - Insulation Shield
  - Test Voltage
    - 44kV (250V/mil)

# Cylindrical Electrode Method

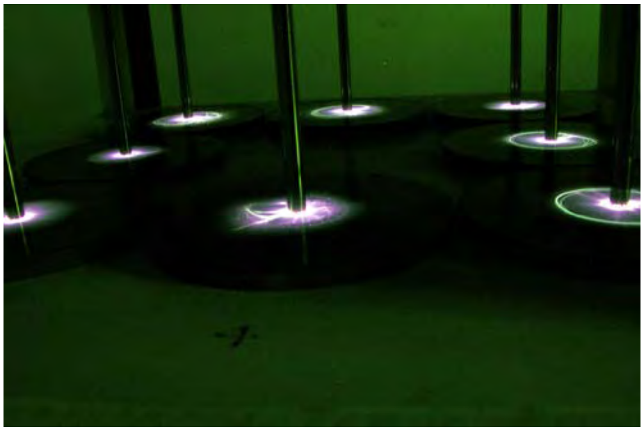
*ASTM D2275 - 89*

*Test Voltage = 21kV*
*Sample Thickness = 60 mils*
*Environment = 25°C & 20% RH*
*Pass/Fail 250 Hours without Erosion*




# *Discharge Resistance*

*Electrical Discharge Glow*



# Discharge Resistance

*Insulation Surface Degradation Results*

| | | | |
|---|---|---|---|
| TIME TO INCEPTION OF EROSION (HOURS) | | | |
| >2,000 | 48 | Immediate | Immediate |
| TIME TO DIELECTRIC FAILURE (HOURS) | | | |
| >2,000 | 120 | 80 | 45 |

*Discharge Resistant EPR*

*Discharge Free EPR*

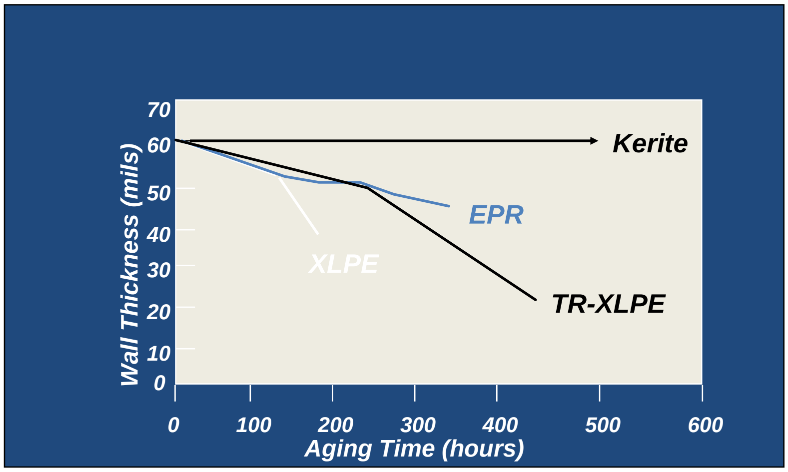
*TR-XLPE*

*XLPE*

# Cylindrical Electrode Summary

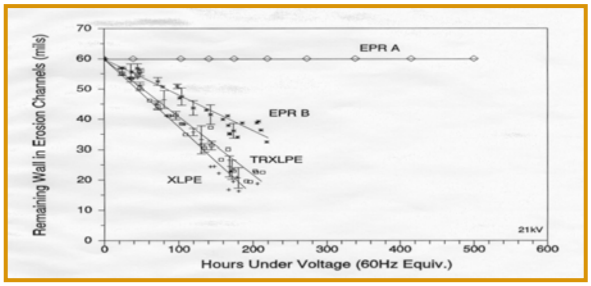
| *INSULATING MATERIAL* | *INCEPTION TIME OF EROSION (HOURS)* | *AVERAGE EROSION RATE MIL/HOUR* |
|---|---|---|
| XLPE | Immediately | 0.15 |
| TRXLPE | Immediately | 0.10 |
| EPR | 48 | 0.05 |
| Kerite | >2,000 | 0 |

## *Remaining Insulation Wall In Erosion Channels*




# Resistance to Partial Discharges

- The presence of PD in service aged cables is a matter of statistical likelihood. As such, the selection of materials that can better tolerate PD activity would add a comfort margin to any reliability assessment.




*Evaluation of Discharge Resistance of Solid Dielectric Power Cable Insulation, IEEE Insulation Magazine March/April 1995*

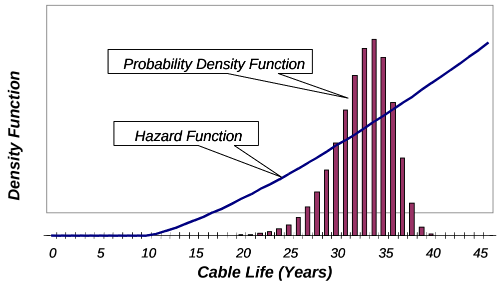
**Kerite Is**
**The Only Insulation**
**To Be Resistant To Degradation Caused**
**By Partial Discharge**

## Long Life Benefits

# Estimating Life Expectancy

*A Discussion of Cable Life is Difficult Because:*
- *The Benefit is not Realized Until Many Years in the Future*
- *The Topic is Confused by Competing Claims*
- *Many Configurations Have Not Been Around Long Enough*

*Cables Follow a Weibull Life Distribution, which is dependent on:*
- *The Hazard Function: Proneness to Fail as it Ages*
- *The Probability Density Function: Population Life Distribution*




# 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 an Extrapolation to End-of-Life Can Not Be Made*
- *Cable Should Last Another 28 Years, or even More.*

# Why Use Kerite ???

- ***Lowest Total Cost Of Ownership***
- ***Complete Factory Support***
- ***Application Technical Support***
- ***Field Proven Product Reliability***
  - ***Permashield***
  - ***Kerite EPR Insulation***

Kerite®

*Quality Cables Since 1854*

Thank you