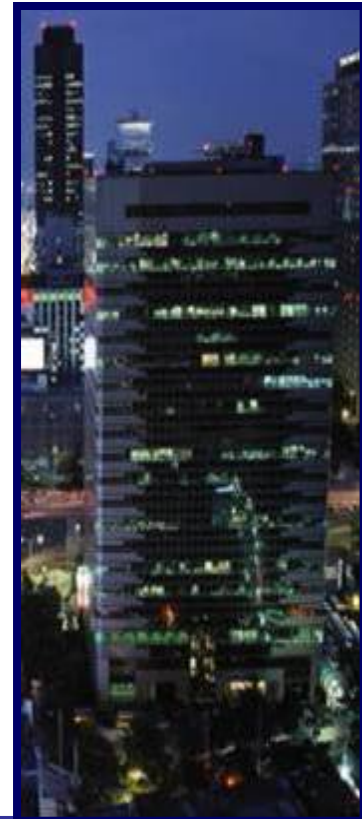


Defect Specific Diagnostics: Based on Ten Years of Field Experience

IEEE Insulated Conductors Committee
Subcommittee C

November 6, 2007

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IMCORP



Some of the technologies referenced herein are patented and proprietary IMCORP technology.

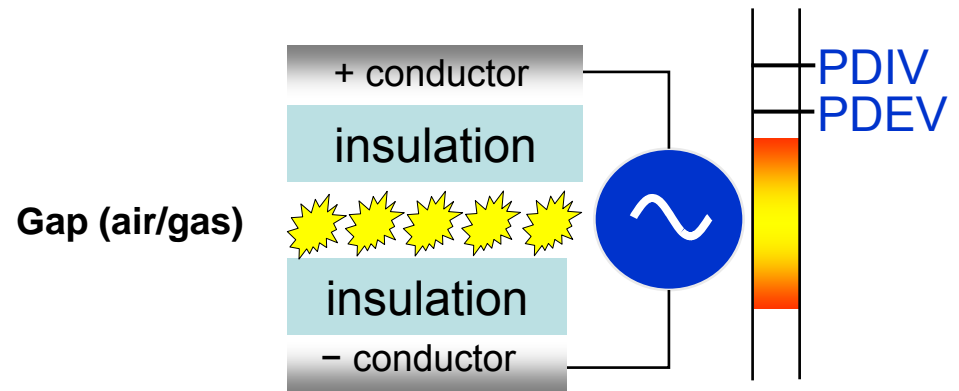


Background

- Over a decade of data collection
 - >9,000 miles of cable diagnosed
 - Extensive database of diagnostic information
 - Knowledge base system currently under development
 - Presentation built on small population of converted data
- Applications
 - URD Cable Reliability Program
 - Commissioning Contractor Installed Cable Systems
 - 7 year Industrial Plant Cable Reliability Case Study

Definitions

- pC, apparent PD magnitude (charge)
- PDIV: PD inception voltage interval
- PDEV: PD extinction voltage interval
- Defect: PD activity detected at a voltage stress level lower than ICEA and IEEE standards stipulate
- DSD: Defect Specific Diagnostics: predictive diagnostic test which detects, locates and characterizes defects





IEEE & ICEA Standards

IEEE 400-2001 General Guide

IEEE 48-1996 Terminations

IEEE 404-2000 Joints

IEEE 386-2006 Separable Connectors

ANSI/ICEA S-93-639-2000 MV Extruded Cable

IEEE 400.3-2007 Guide to Partial Discharge Testing

Shielded Power Cable Testing

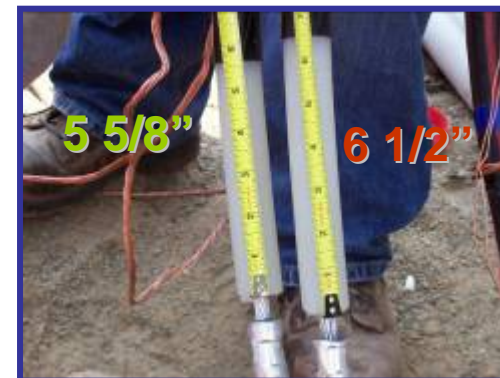
No PD $\geq 5\text{pC}$ at $\leq 1.5U_0^*$

No PD $\geq 3\text{pC}$ at $\leq 1.5U_0^*$

No PD $\geq 3\text{pC}$ at $\leq 1.3U_0^*$

No PD $\geq 5\text{pC}$ at $\leq 4.0U_0^*$

General description of PD test

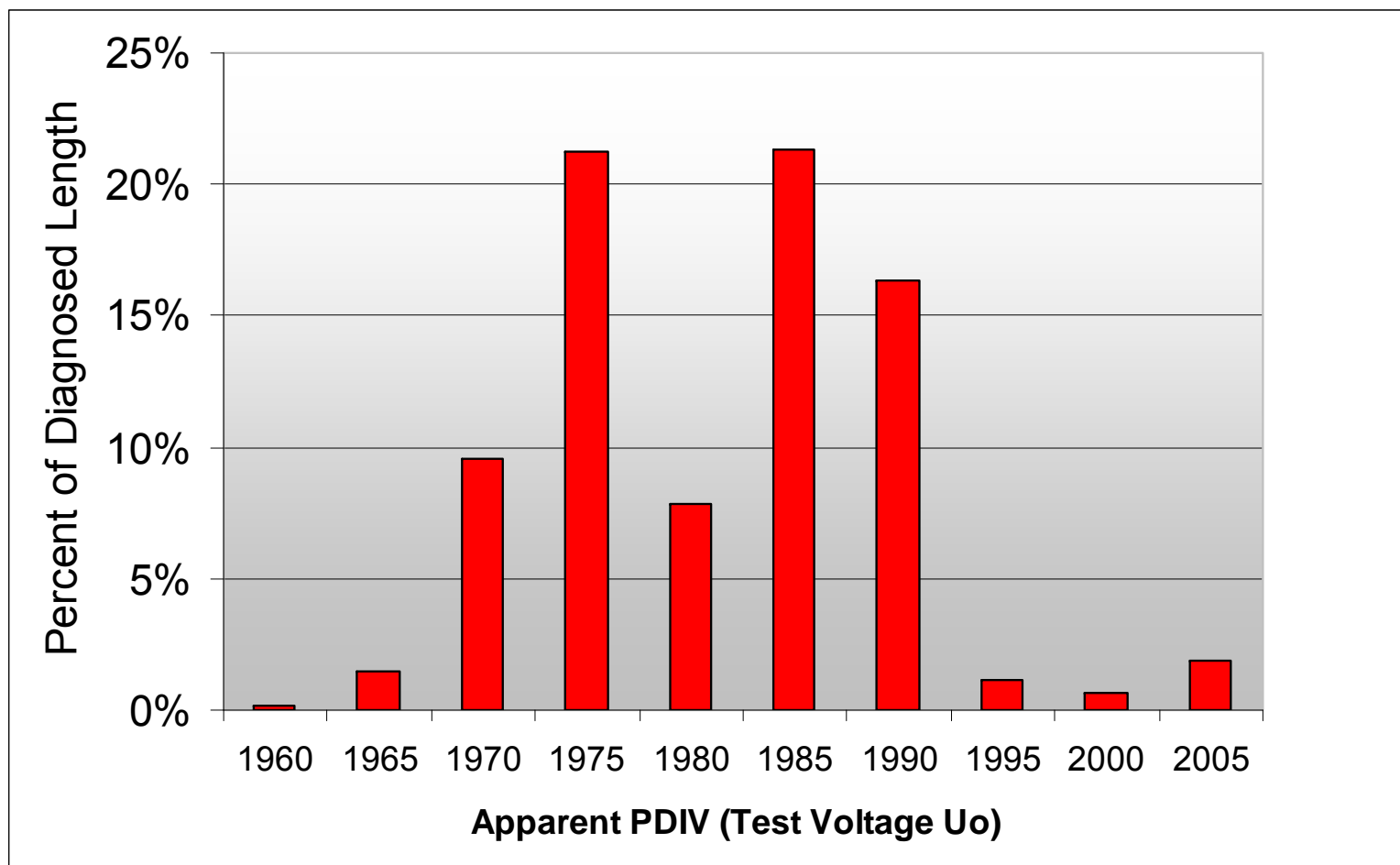


7/8" (2.2cm) difference!

Description of URD Cable Reliability Program Population

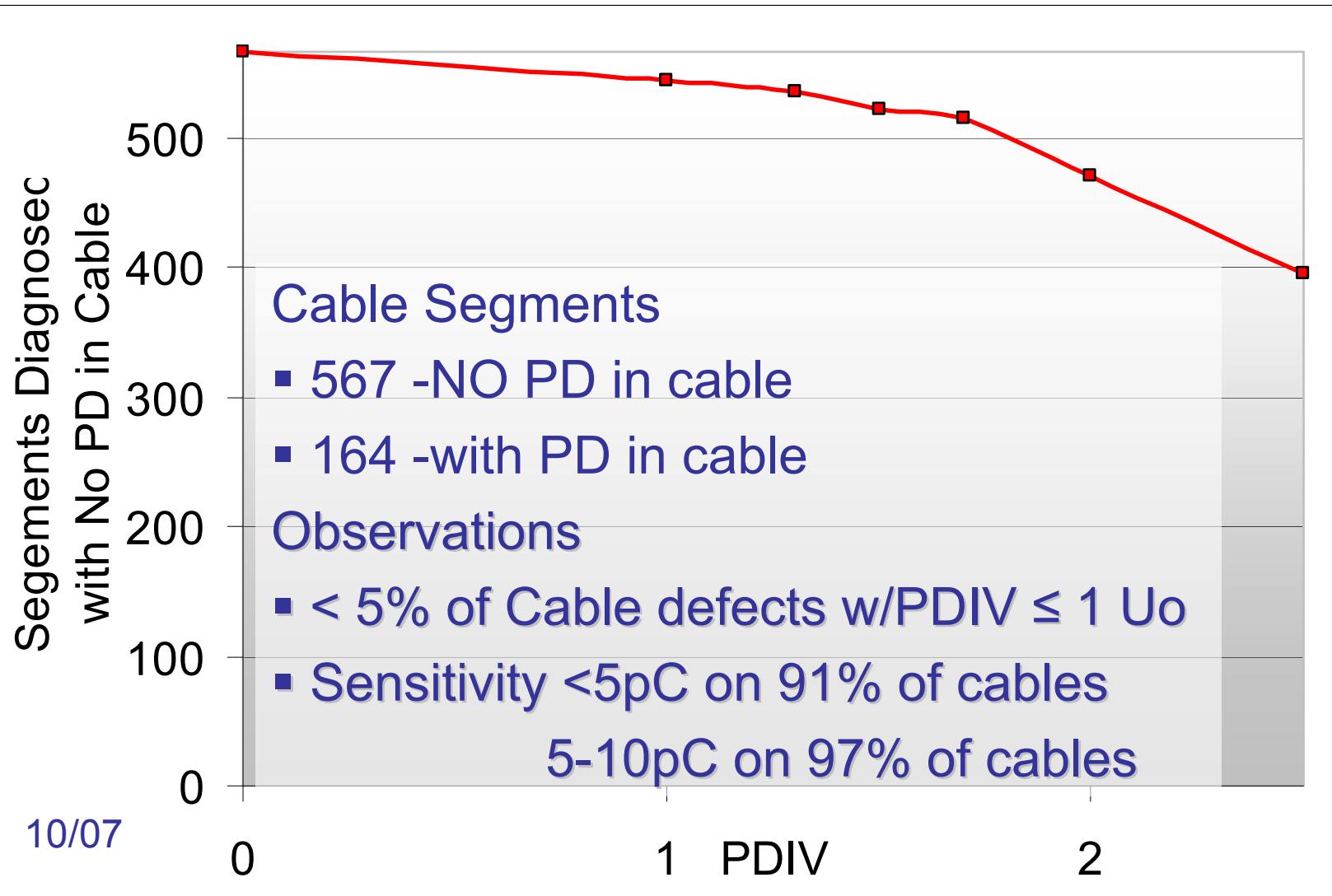
- Single Utility
- Failure rate 20/100miles/yr
- Total target population 705 miles
- Directly buried, Unjacketed
- Population diagnosed
 - 57 miles, 300,862ft, 567 segments (10/07)
 - Average segment length: 531ft
 - 460 segments (7/07)

Vintage of Population Diagnosed

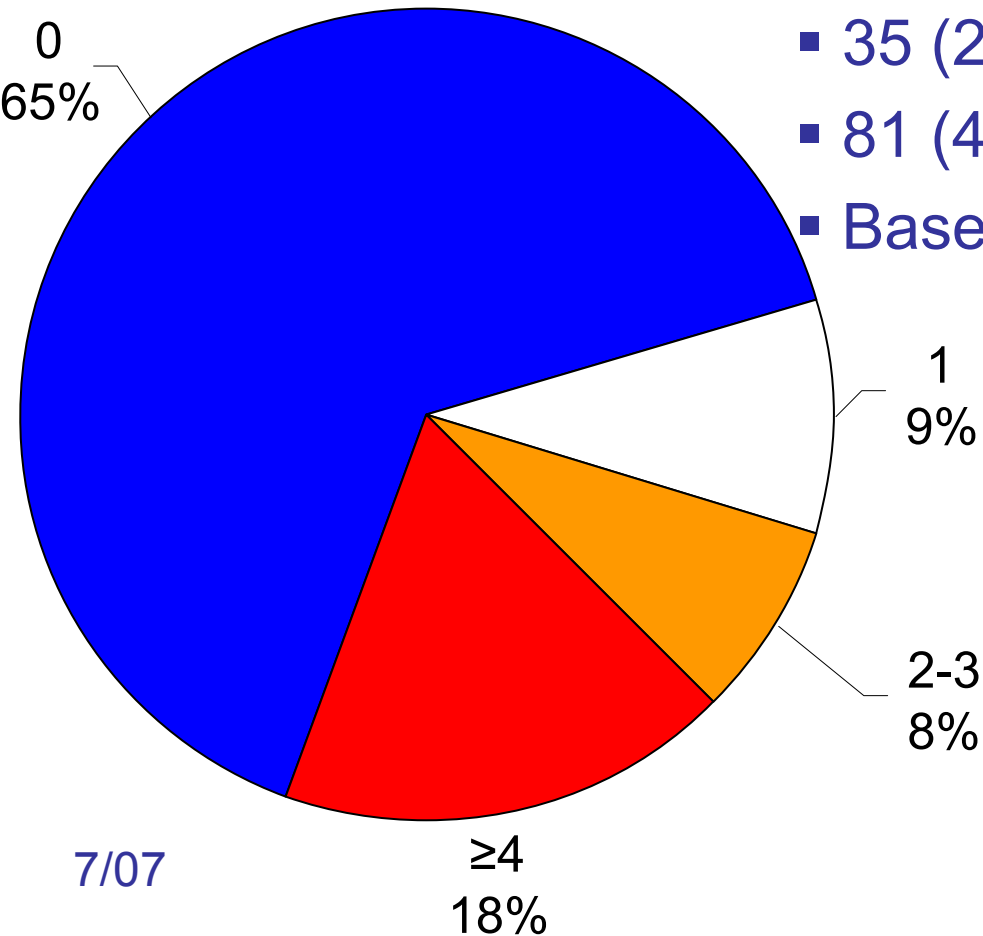


- 18% unknown vintage
- Based on 207,042ft

Distribution of Defect Free Cable vs. PDIV

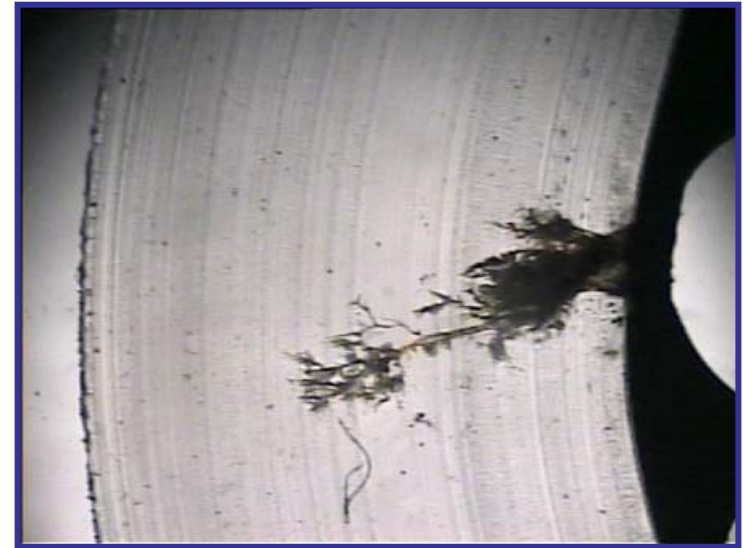


Multiple Cable Defects in Cable Segments

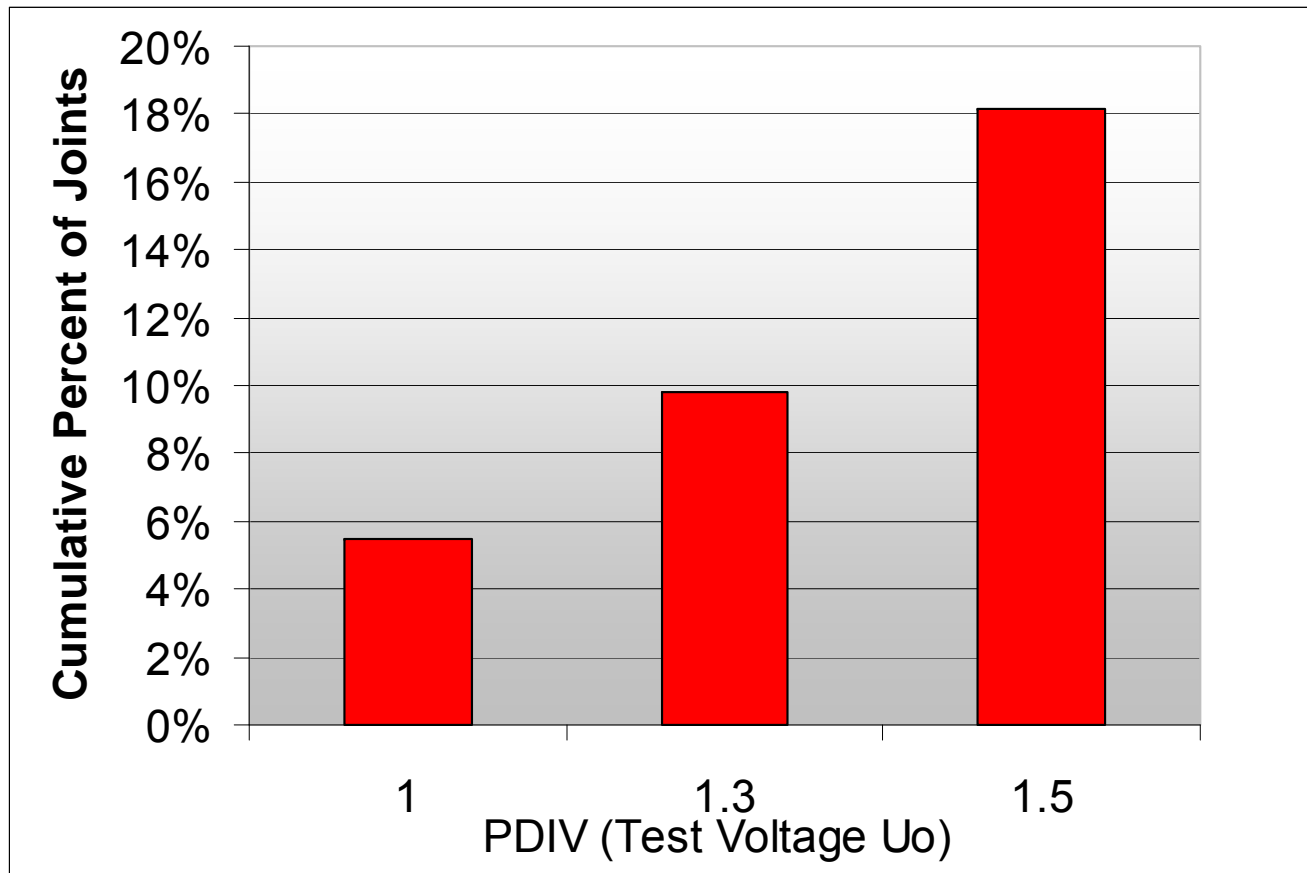


PD location groupings for section repair

- 35 (20%) PD sites within 100ft
- 81 (41%) PD sites within 300ft
- Based on 172 cable insulation defects



Cumulative Probability of PDIV in a Joint



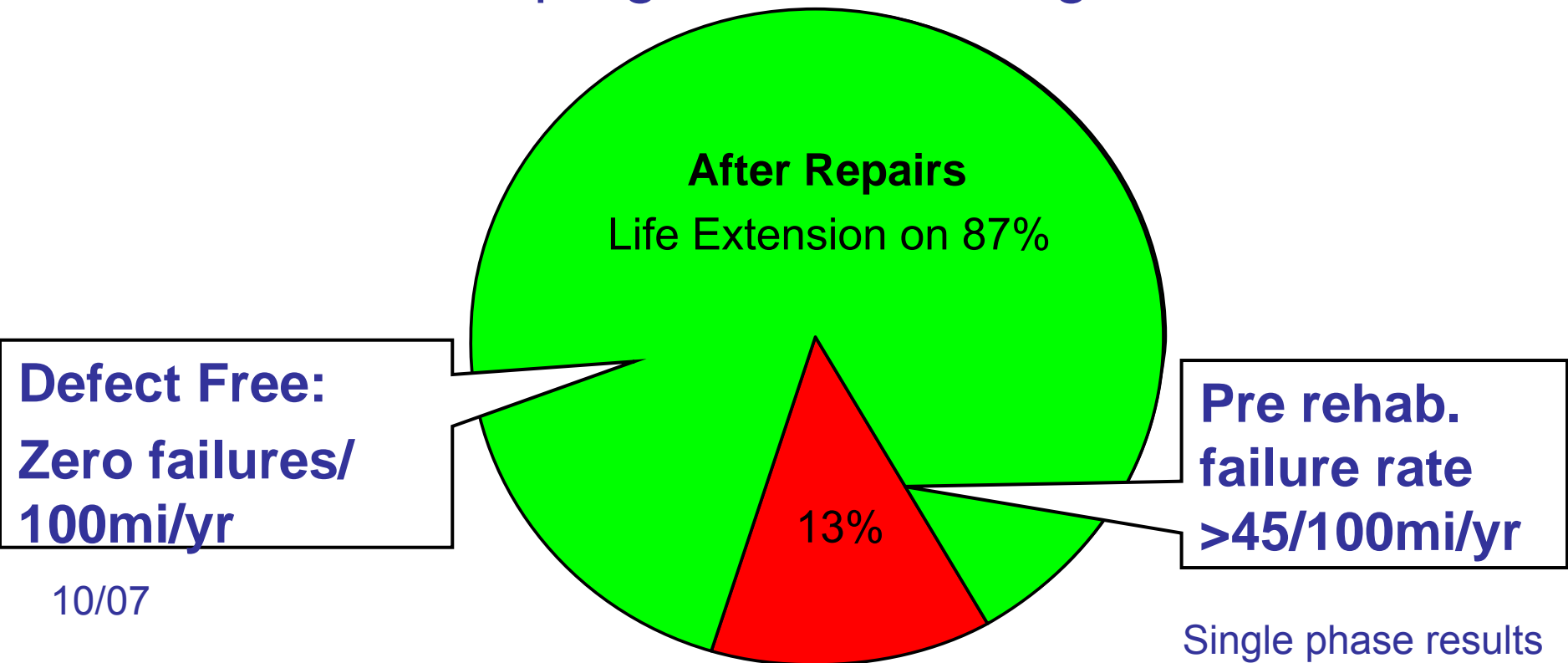
7/07

- Total population of Joints 825
- Percent of Joints with PDEV $\leq 1U_o$ 4%



DSD Based Reliability Program Results

- 705 mile failure rate prior to program 20/100mi/yr
- 14 months into program addressing 57 miles:



DSD Based Reliability Program Results 14 months

Failure rates:

- 705 mile target population
prior to reliability program 20/100mi/yr
 - 57 miles addressed by program 14/100mi/yr
 - 71% Defect free..... Zero failures/100mi/yr
 - 16% Repair
 - 13% Replace
- } Pre rehab. failure rate >45/100mi/yr

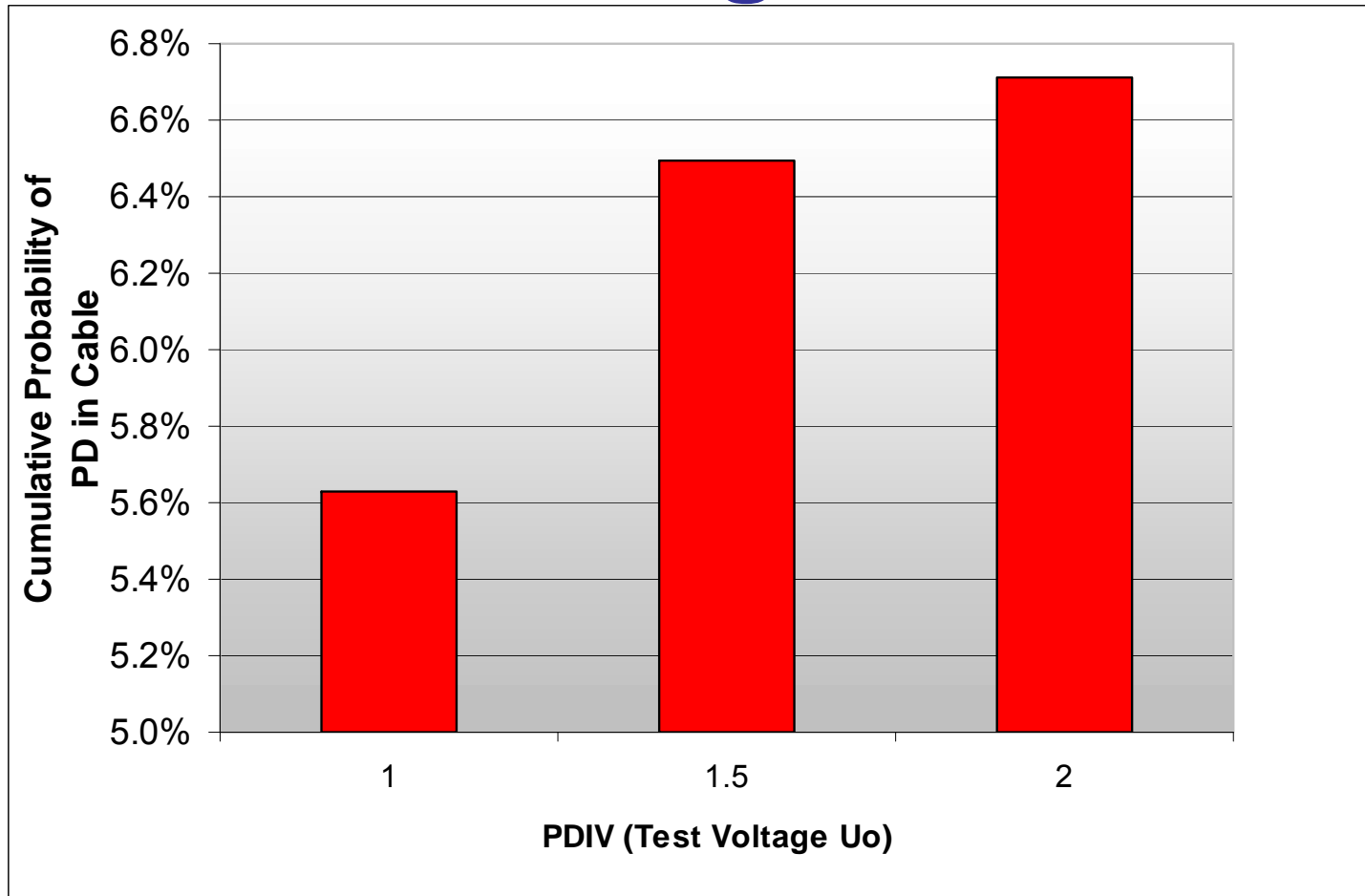
10/07

Commissioning Contractor Installed Cable Systems

Description of Population

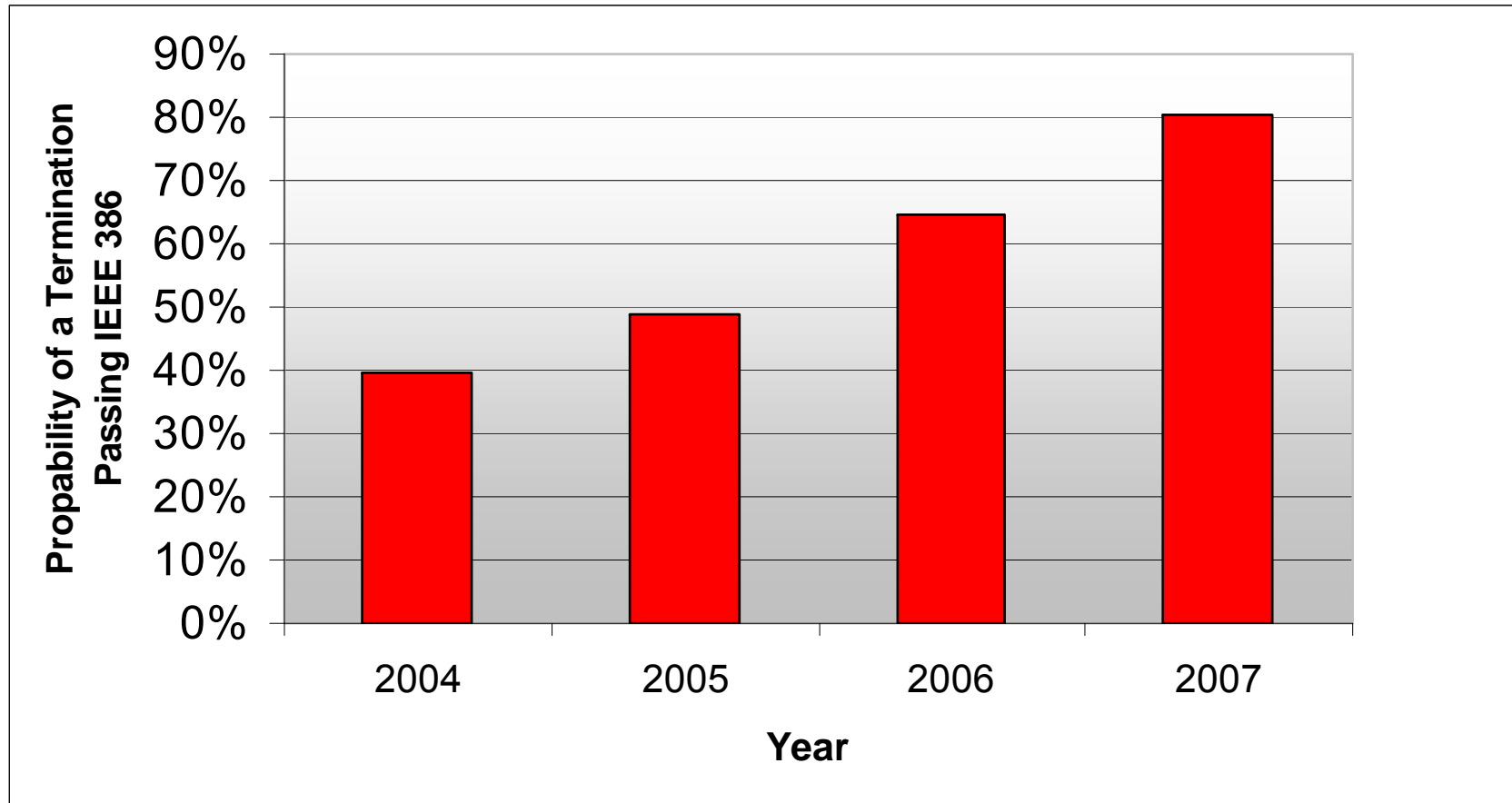
- 462 MV cable segments
- Average length ~2,500ft
- 218 miles, 1.2million circuit feet
- 2,772 Terminations
- 2,714 Joints
- 1/0 to 1000kcmil conductors

Commissioning Cable Insulation



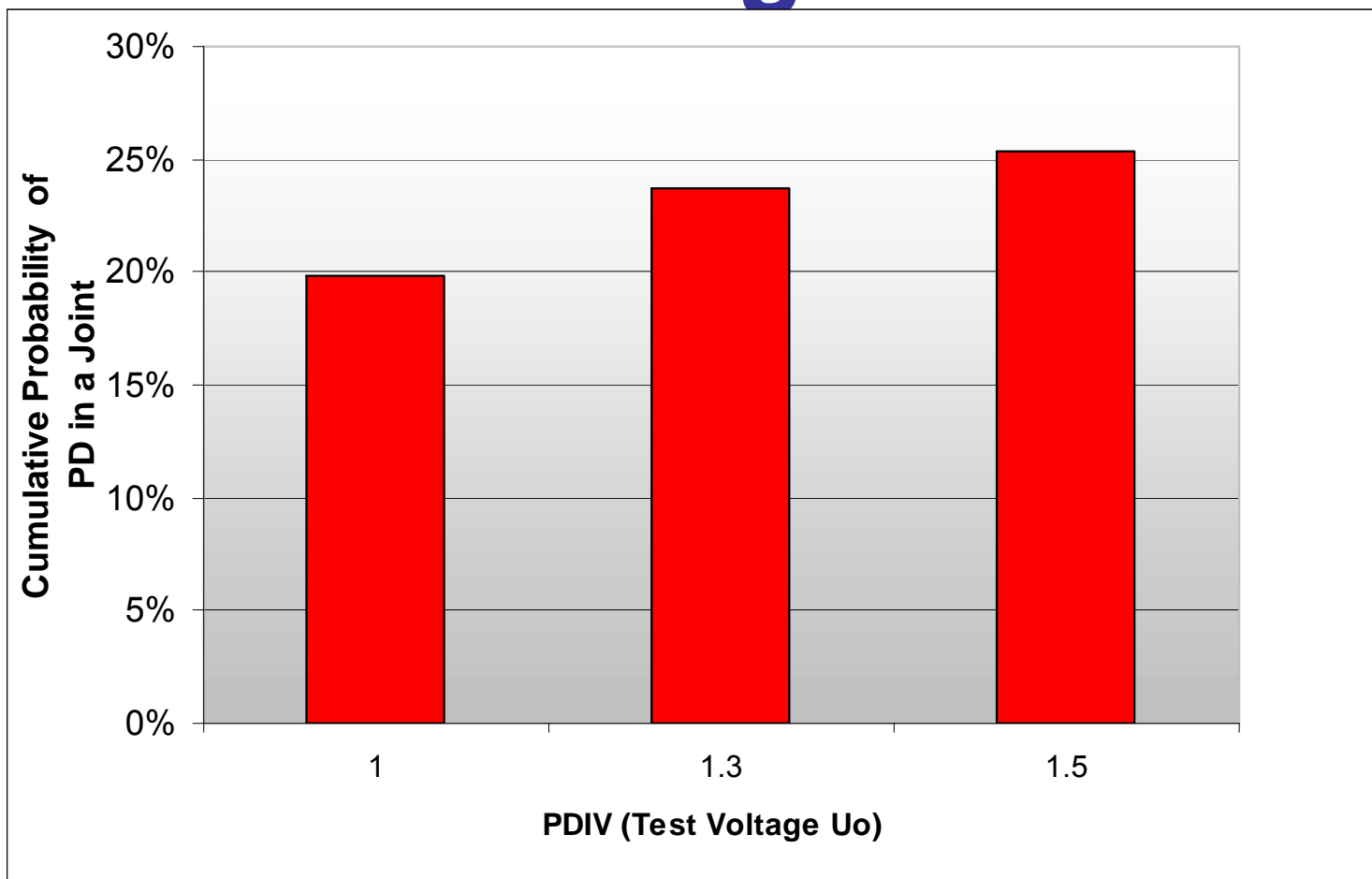
- 462 3-phase cable system diagnosed, 3.5% PDEV $\leq 1U_o$
- ICEA S-93-639-2000 MV Extruded Cable No PD $\geq 5pC$ at $\leq 4.0U_o^*$

Commissioning Terminations



- 2,772 Terminations Diagnosed –typically separable connectors
- IEEE 386-2006 Separable Connectors No PD $\geq 3pC$ at $\leq 1.3U_o^*$

Commissioning Joints



- 2,417 Joints diagnosed, 1% PDEV $\leq 1U_o$
- IEEE 404-2000 Joints No PD $\geq 3pC$ at $\leq 1.5U_o$

7 Year Industrial Plant Case Study

EPR insulated cable system

- Cable systems routinely pass DC maintenance test
- **Plant historical avg. 1 cable failure/ 3 years**
- Fault records indicates mostly termination issues
- Off-line PD diagnostic test performed in 2000
- 40 repairs recommended
- **Zero failures since diagnostic & repairs in 2000 (7yrs)**
- Historical failure rate predicted 2 more failures

Plant A: Pareto Analysis

Cables Diagnosed (3 phase)	44
Termination Defects	40
Joint Defects	9
Cable insulation Defects	3

Documented Actions Items Using DSD Results

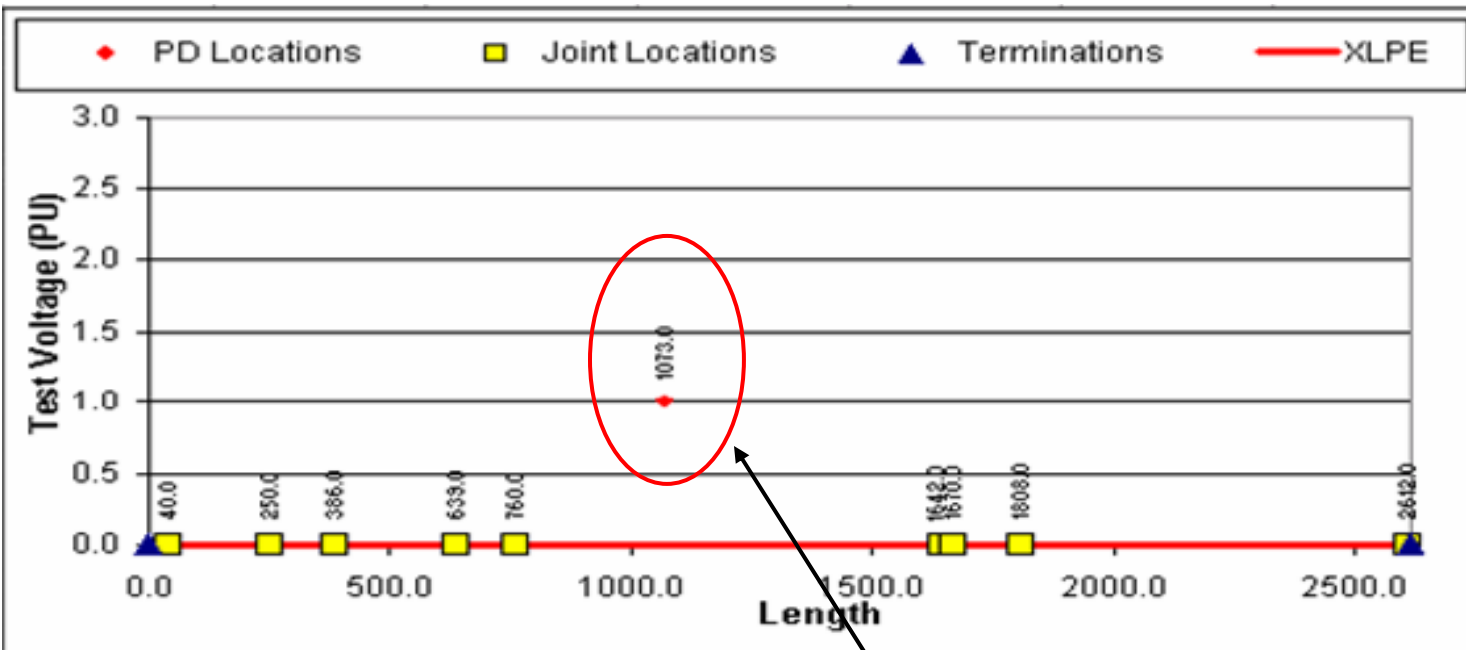
1. Replace
2. Defer action
3. Inspect & clean termination
4. Repair specific defect
5. Replace section
6. Protect with over voltage protection
7. Rejuvenate defect free cables with fluid

Summary

- Knowledge base system in its infancy
- Sampling of evolving knowledge base
- Results presented demonstrate asset management value for new and aged installations

Detailed Slides

Cable Defect Autopsy



Cable Information

Circuit 12 436
Tap / Source 805542
Tested From P1993150
Tested To P0761150

Defect pinpointed at 1073ft