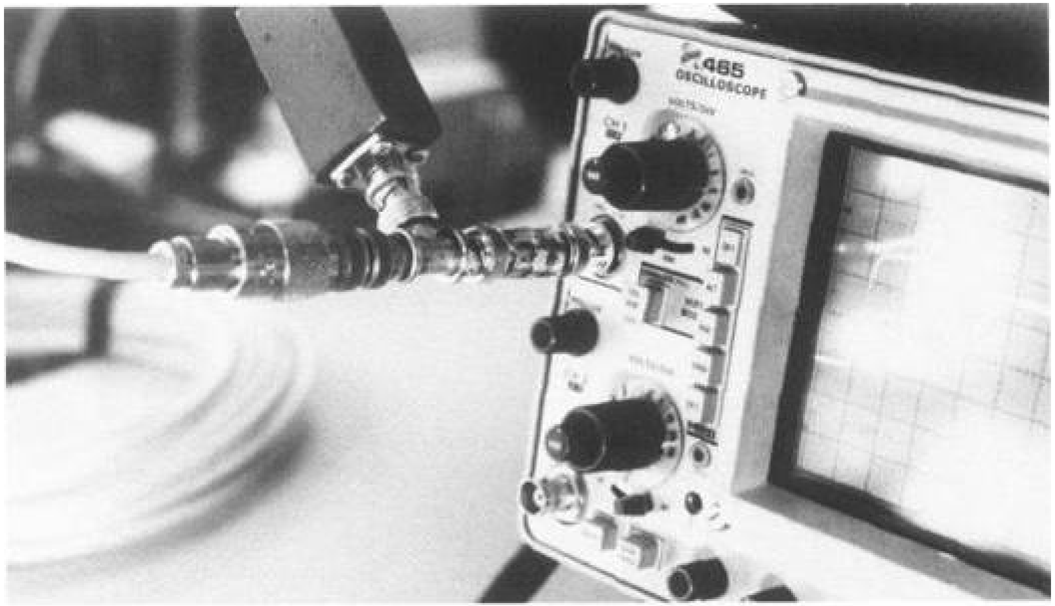
Cable Aging Assessment and Condition Monitoring with LIRA



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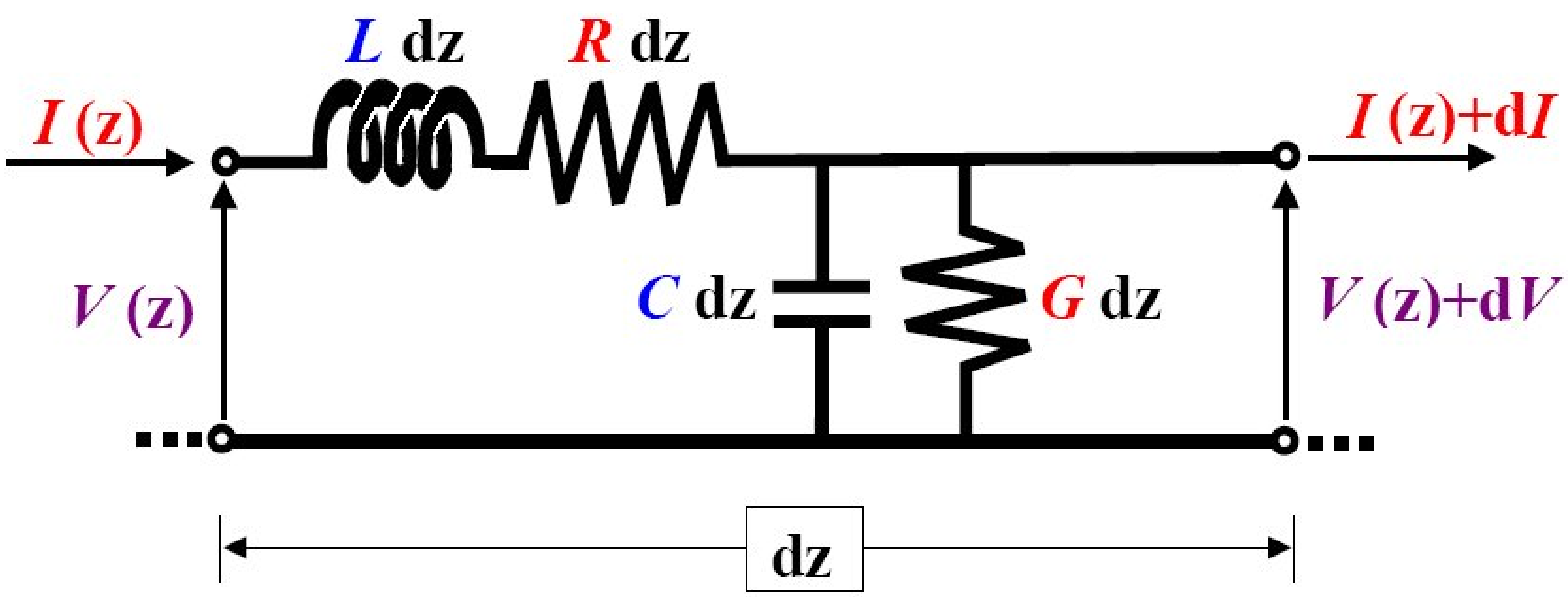
IEEE SC2 Meeting, Newport Beach, CA, 7-8 November 2006

HRP Project on Cable Aging
The LIne Resonance Analysis (LIRA) method

- Based on frequency domain analysis of high frequency resonance effects of unmatched transmission lines.
- Sensitive to small changes of wire electric parameters, mainly the insulation permittivity, that are a significant condition indicator of the cable state (thermal and radiation aging, humidity, insulation defects, mechanical damage).
- Possibility to detect and localize small insulation cracks, in spite of different structures (insulation type, geometry) and not-aging related effects.

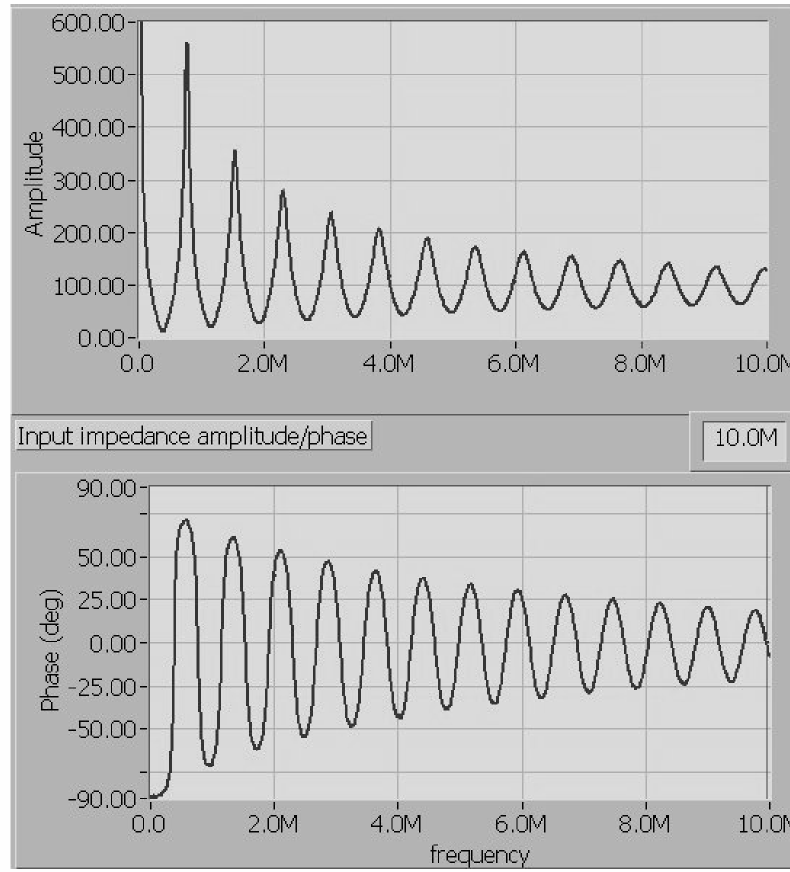
Electric parameters in a cable



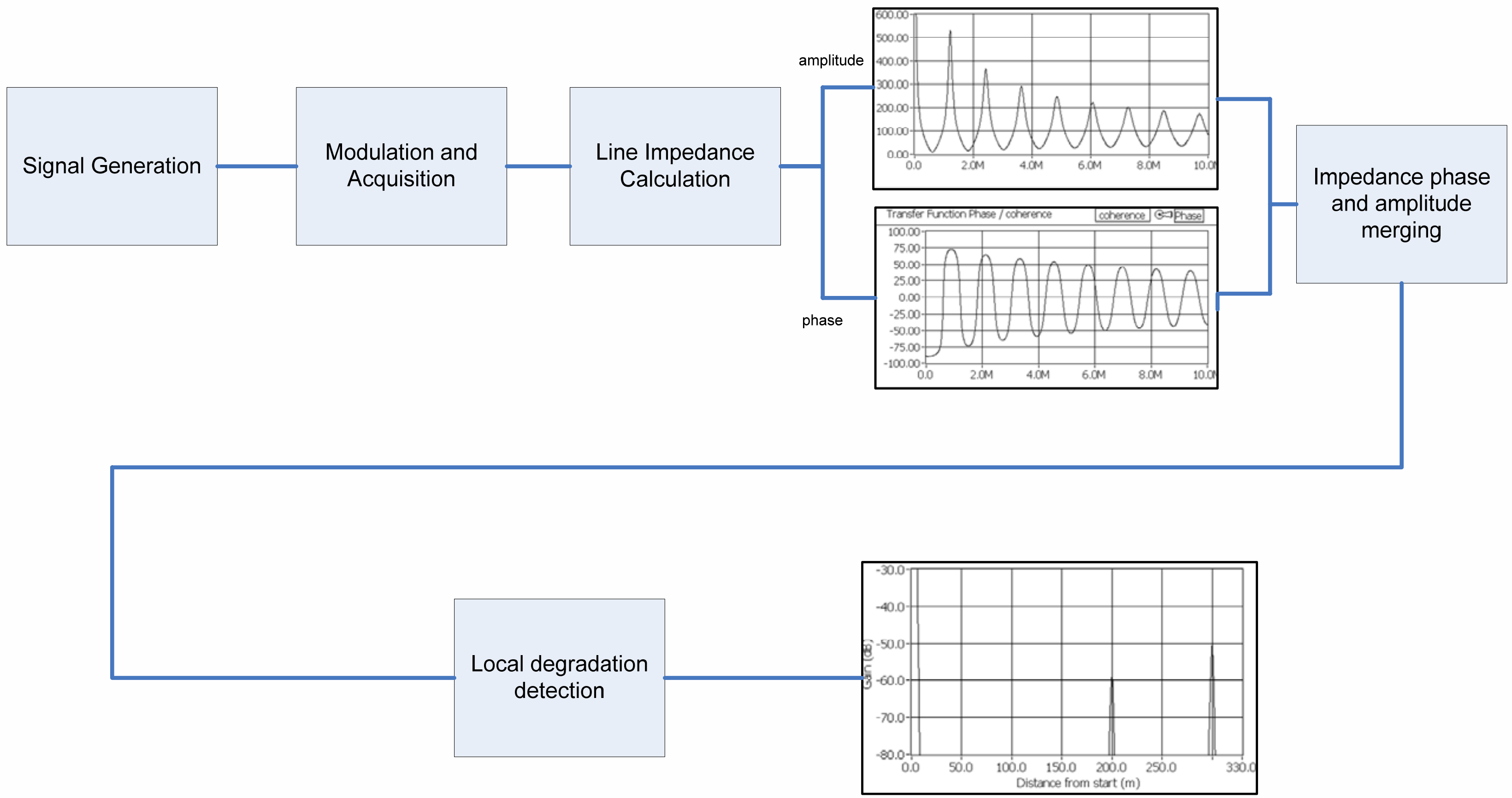
LIRA as a Condition Indicator

Analysis of the line input impedance amplitude/phase provides:

- Accurate estimation of the *phase velocity*, correlated to the global cable condition
- Detection and localisation of one/many hot spots along the cable

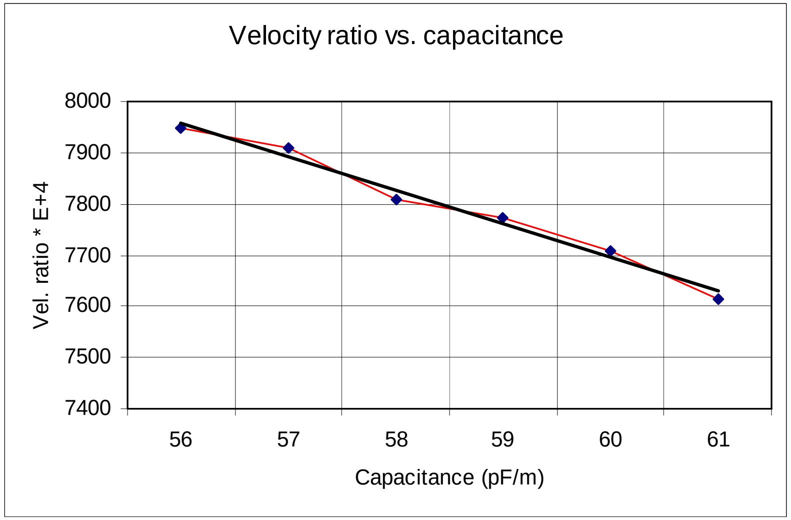


Hot spot detection in LIRA



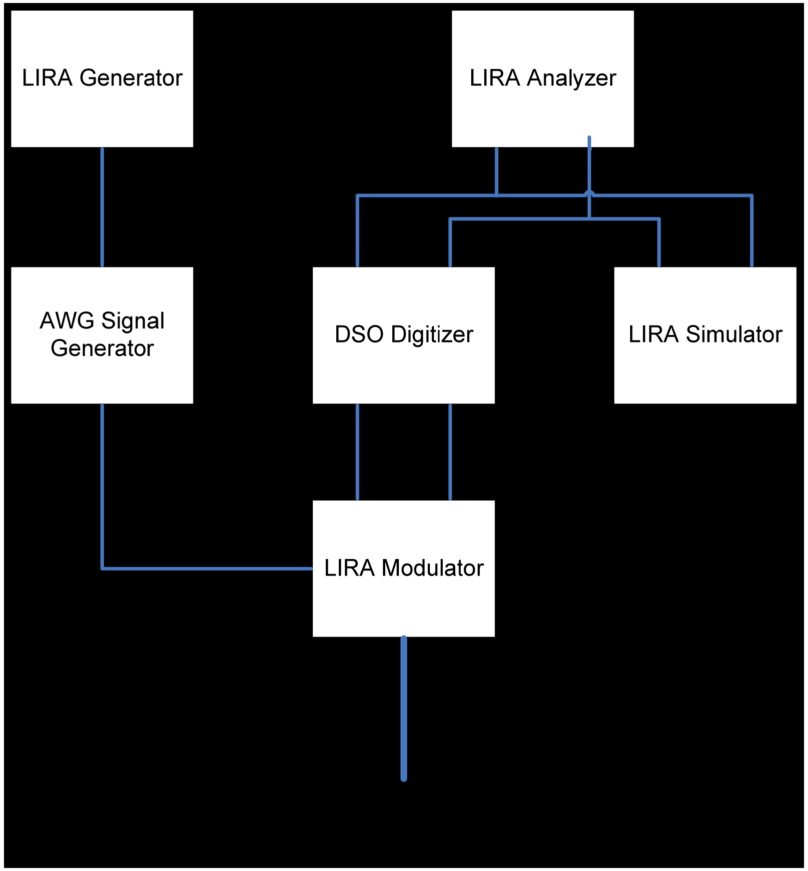
Global Condition Indication

- Phase Velocity (PV) in LIRA is estimated with 4 precision digits (0.XXXX). PV is a decreasing function of global insulation degradation.
- PV can be correlated to any other accepted Condition Indicator (ie EAB), for condition assessment and residual life estimation (EPRI tests, November 2006)

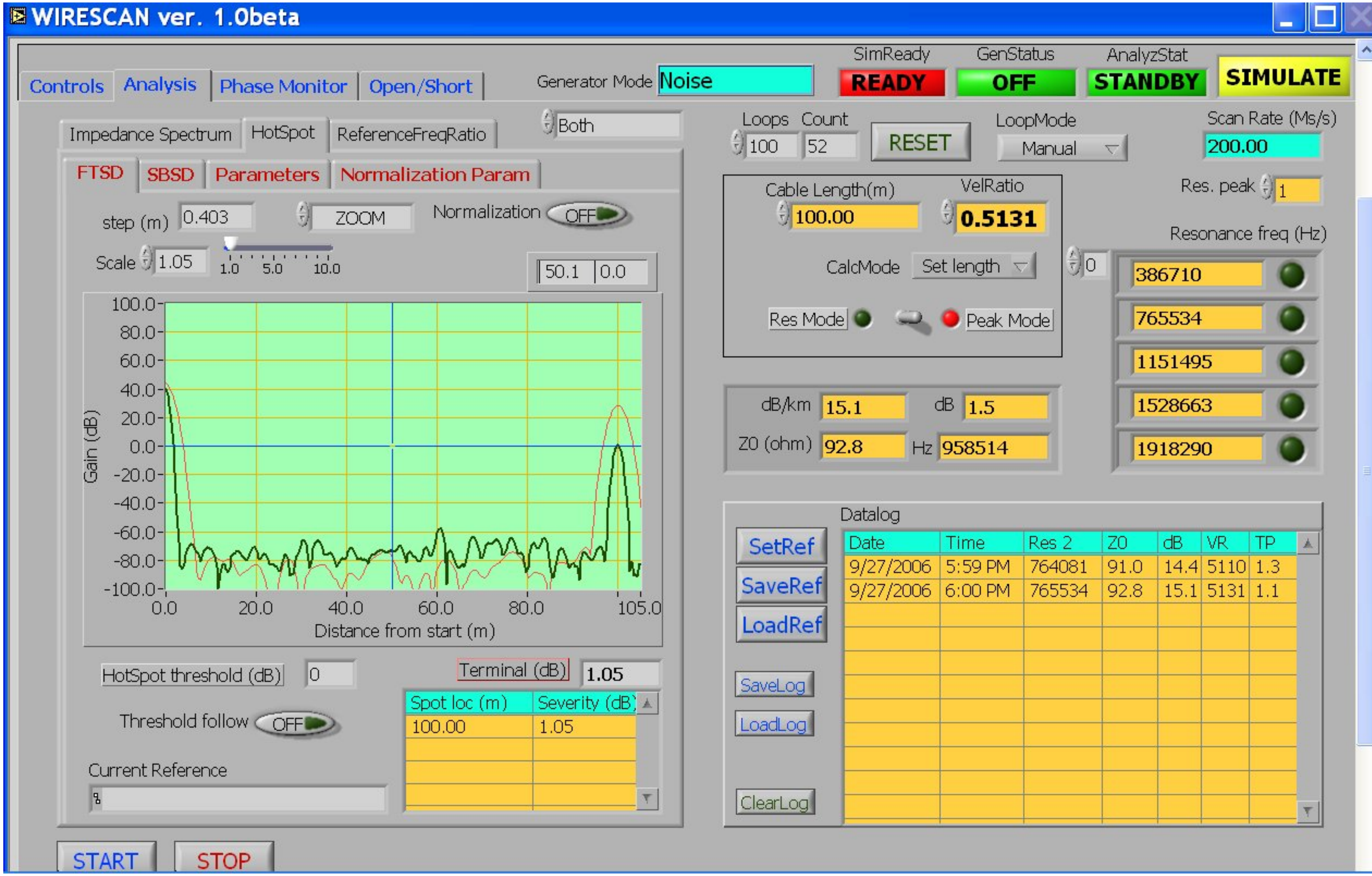


Wirescan, implementing the LIRA engine

- 3 SW modules:
  - Generator controller
  - Analyzer
  - Simulator
- 3 HW modules:
  - AWG Generator (NI-PXI)
  - DSO Digitizer (NI-PXI)
  - Modulator (Wirescan)



Wirescan beta version (Aug. 2006)



Wirescan in a field experiment

Projects/Experiments

- **EPRI (2005 – 2006)**
- Norsk Hydro (2005)
- NKS, **Ringhals**, Barseback (2005 2006)
- PETROMAKS (NFR, Hydro, Shell, 2006-2008)
- NEXANS, 2006

EPRI Tests

- **September 2005**: preliminary, feasibility tests on Okonite and Rockbestos specimen
- **May 2006**: detection of cuts and gouges(EPR and XLPE)
- **November 2006**: local and bulk degradation. Effect of wet vs. dry

EPRI Tests (September 2005)

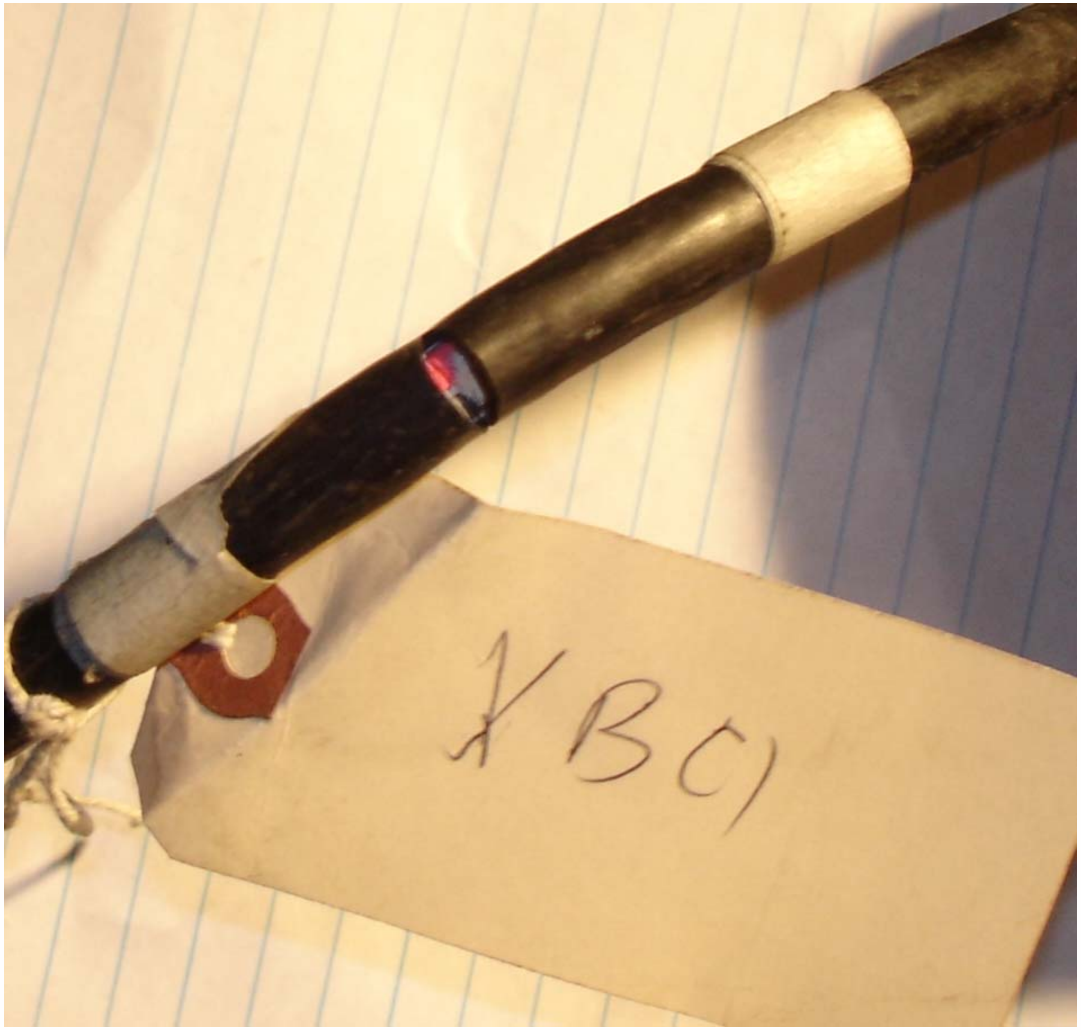
- 10 EPR and XLPE specimens have been tested at EPRI, Charlotte, on September 15th and 16th
- The cable samples had passed bulk accelerated aging and local spots in different positions
- LIRA was used to identify both severity and position of the local thermal spots and the bulk aging.

EPRI Experiment (May 2006)

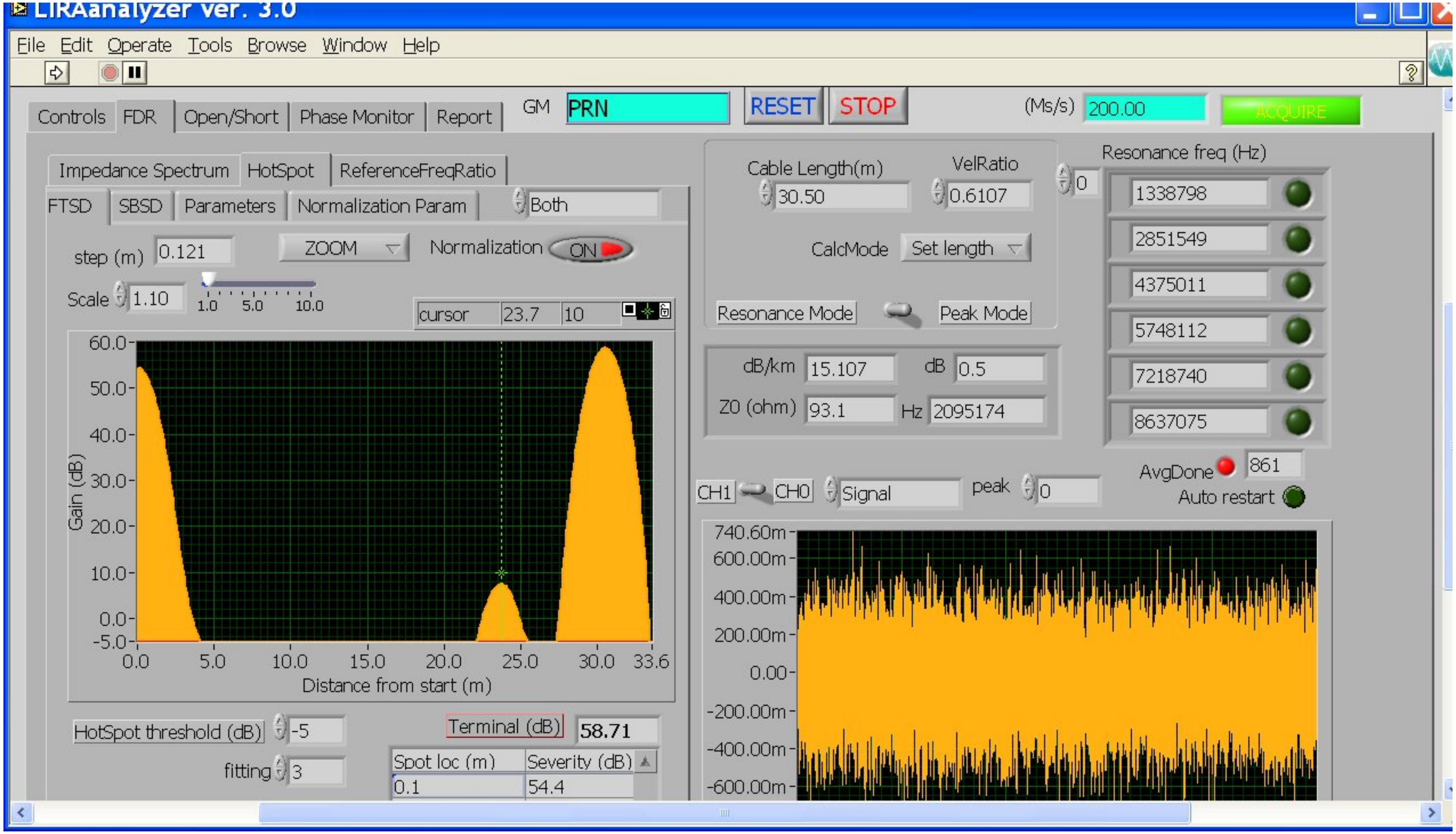
- EPR and XLPE I&C cables from several vendors (Brand Rex, Rockbestos,Dekoron, Okonite) were tested for detection of cuts and gauges, both in dry and wet conditions.
- Initial measurements on good cables were taken. These cables will go through accelerated thermal aging in the period June-September 2006. New tests on these cable will be carried on in November, to evaluate the LIRA performance in assessing local and bulk thermal degradation.

EPRI Experiment, May 2006

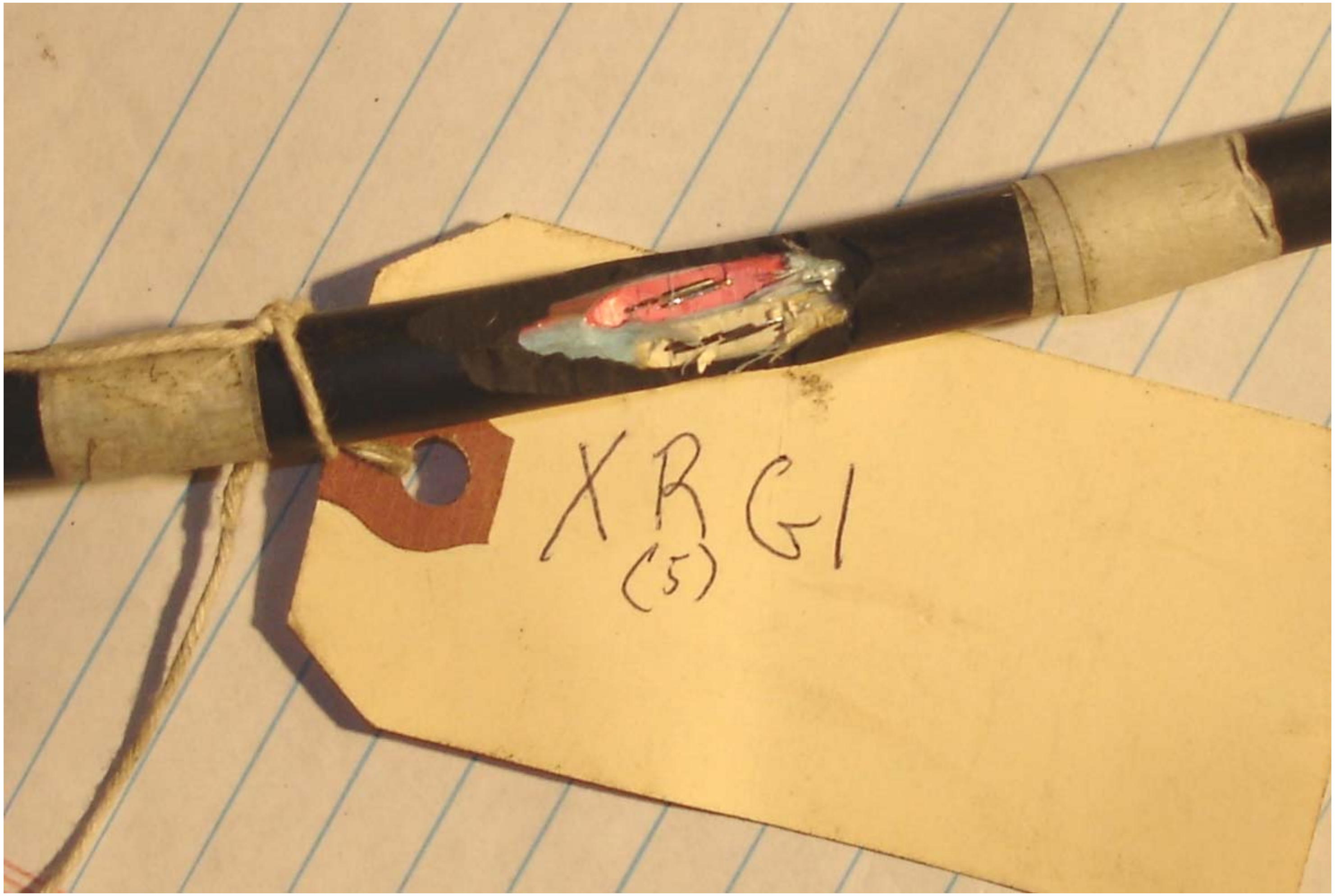
XLPE Brand Rex. Cut (at 24m) down to the insulation, 2 wires, dry



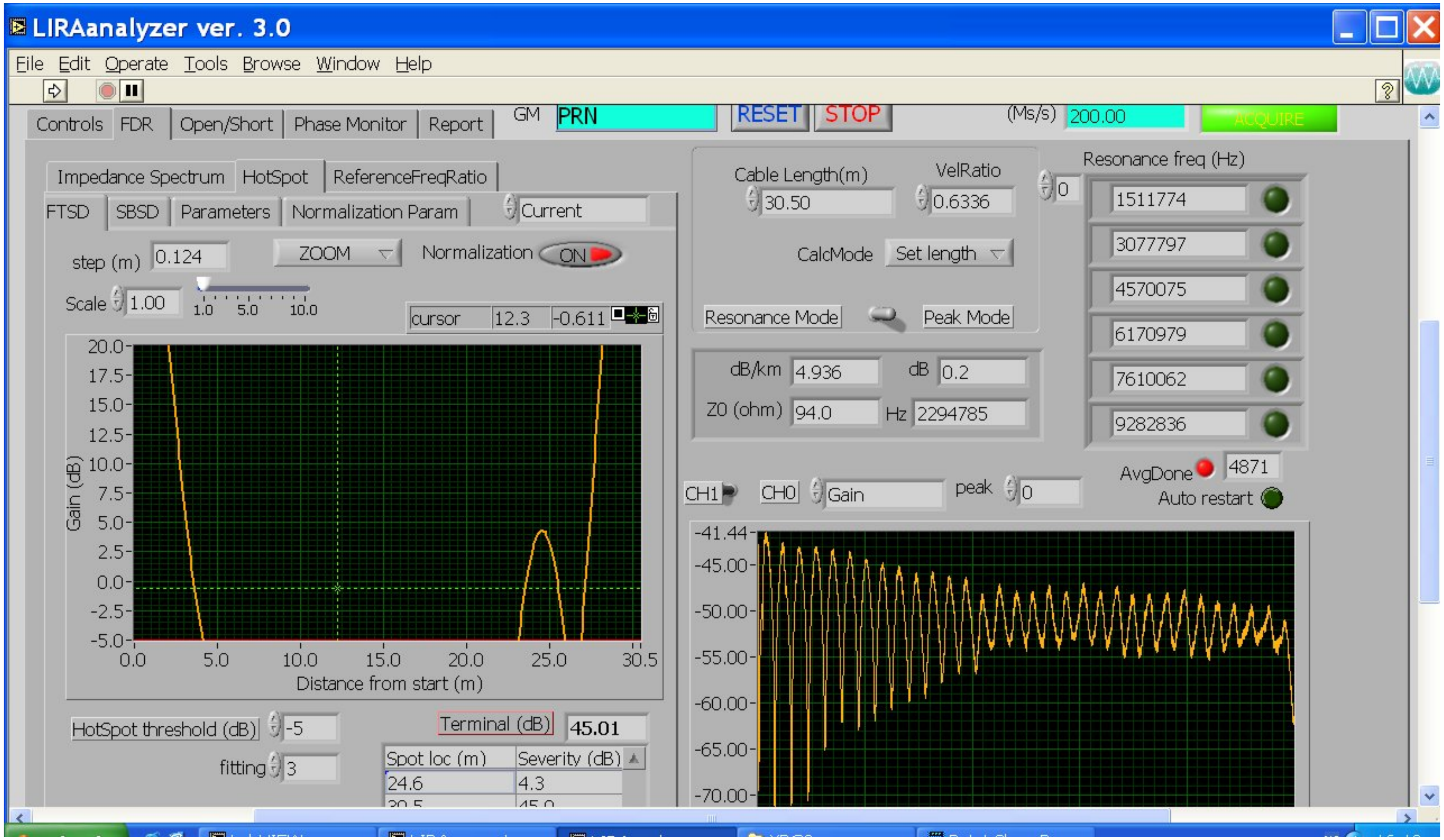
Specimen XBC1, LIRA spot detection



XLPE Rockbestos. Gouge (at 24m) down to the insulation, 2 wires, dry



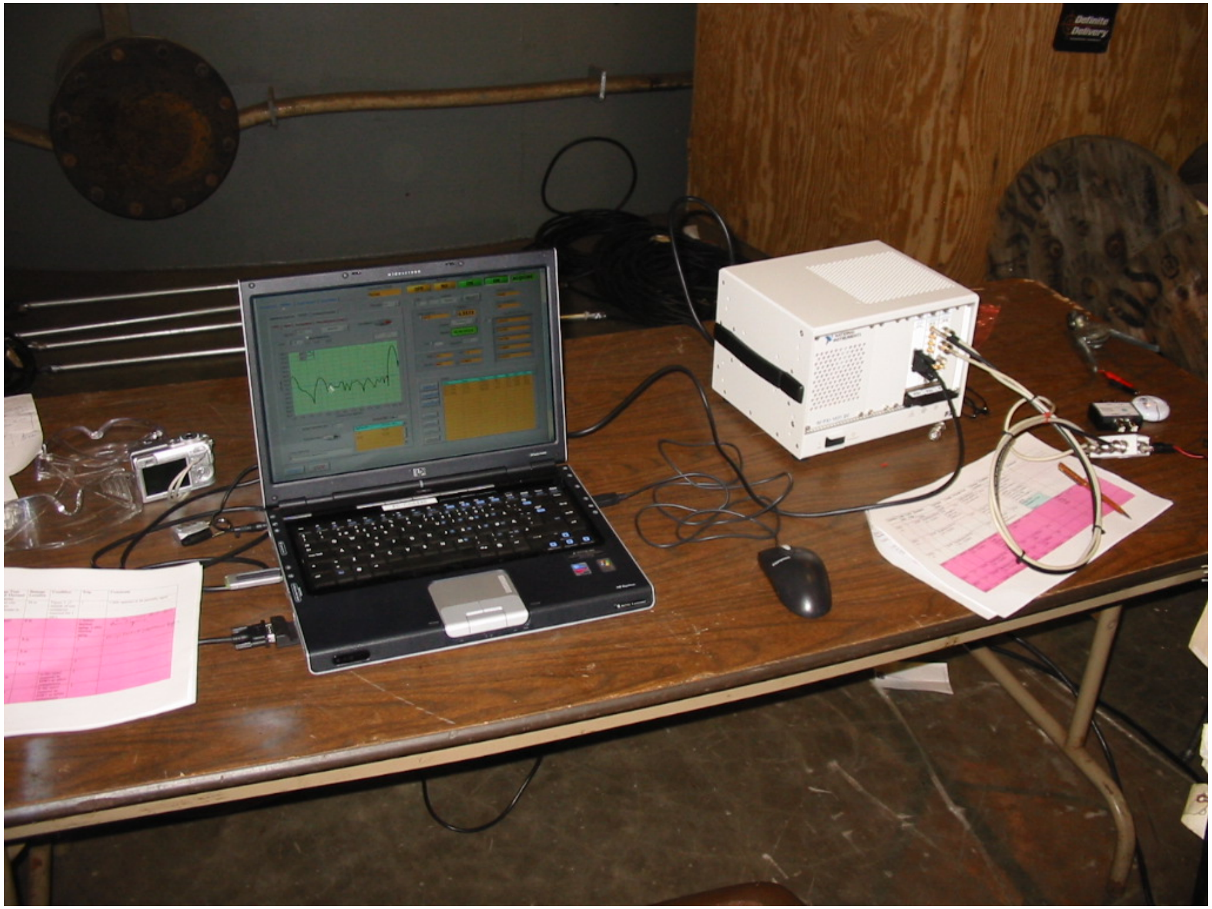
Specimen XRG1



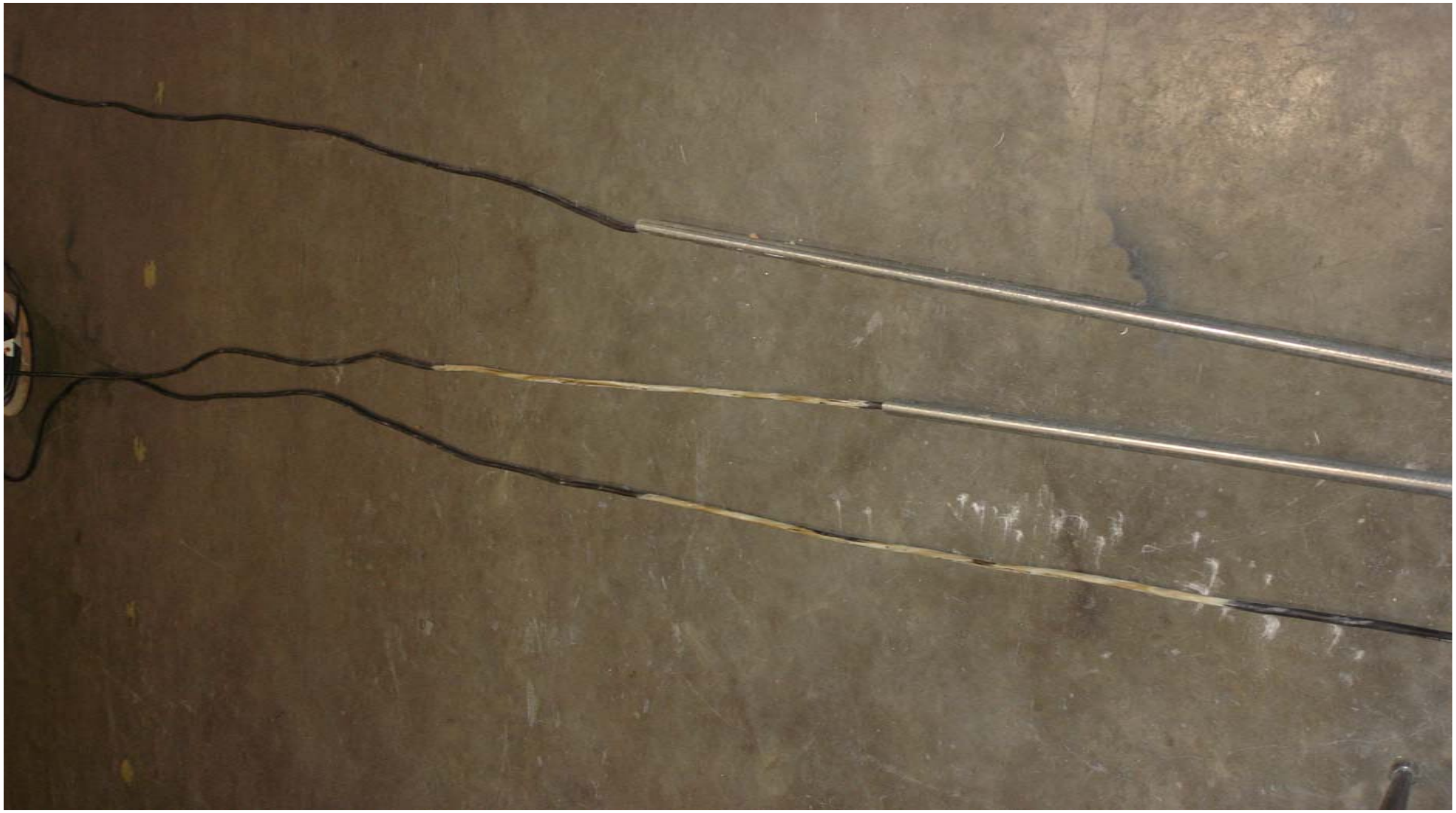
EPRI tests, May 2006, conclusions

- LIRA performed well in detecting hot spots in both Okonite and Rockbestos cables (September tests).
- The localization accuracy is **lower than 0.5%**.
- Tests with cuts and gauges showed that LIRA can detect mechanical defects in wet and dry conditions.
- Reference measurements were taken with cables that will be locally and globally aged (used in November 2006 tests)

EPRI tests, November 2006



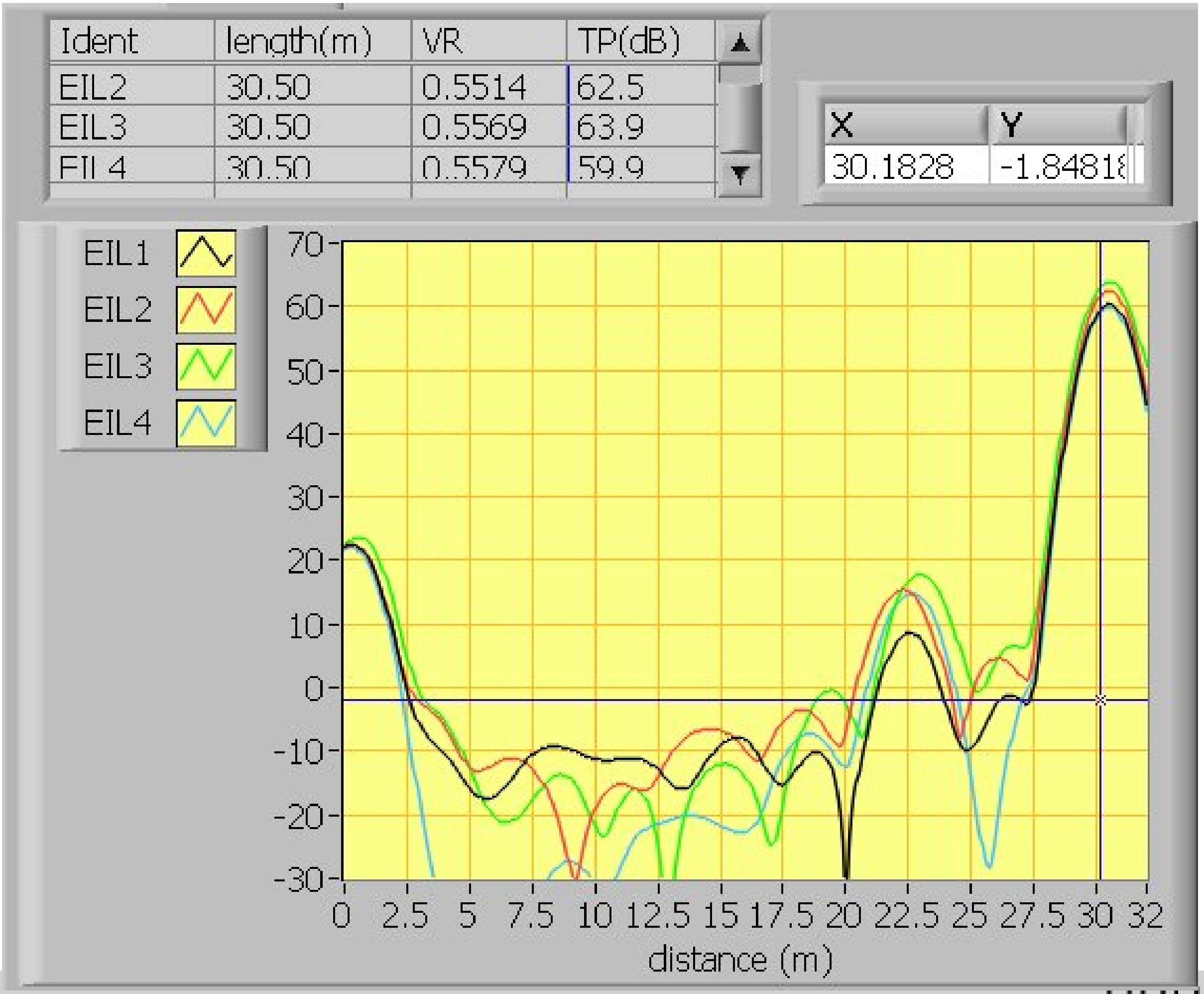
Thermal hot spots at 8m (22.5m)



Hot spots (22.5m), 4 aging times, EPR

1m thermal aging
At 8m (22.5)

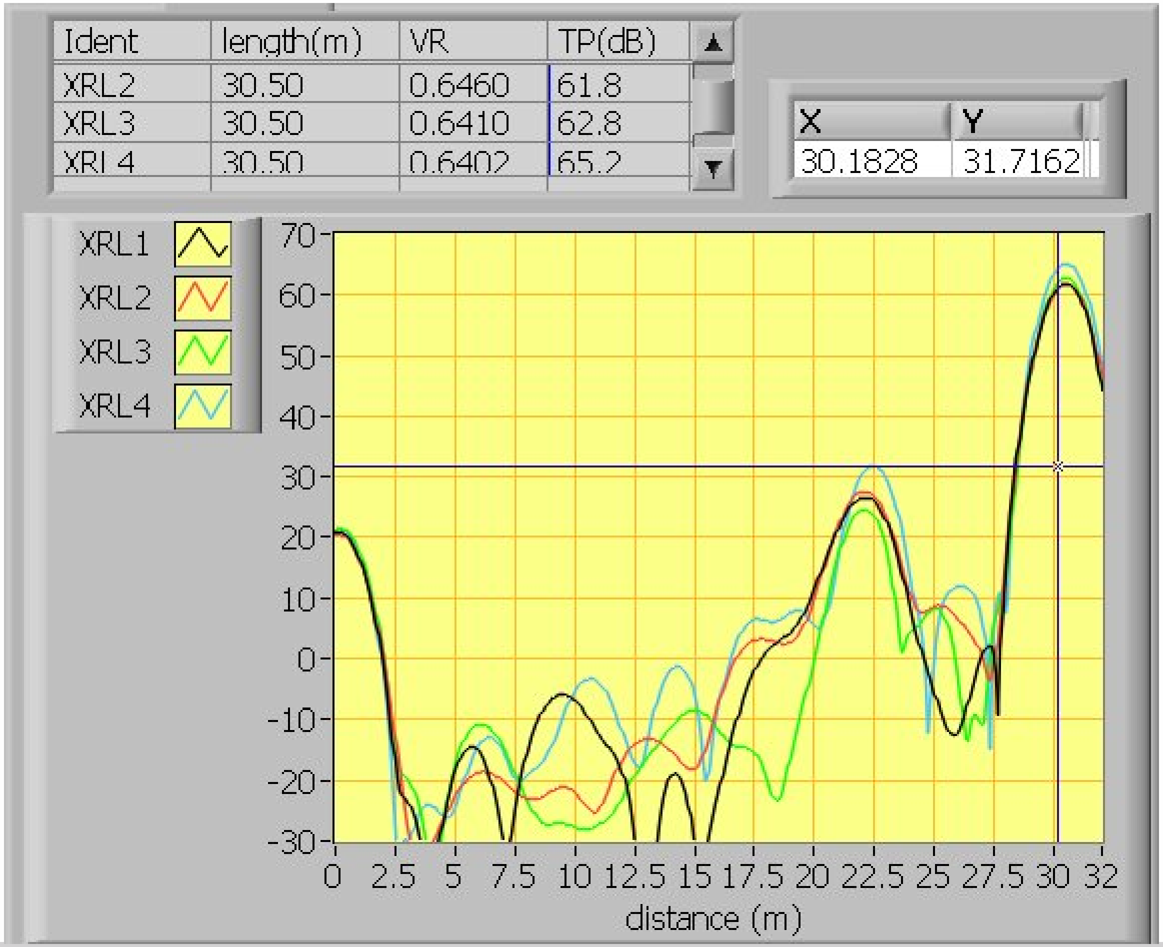
EIL1: 216hrs at 150C
EIL2: 479hrs at 150C
EIL3: 527 hrs at 150C
EIL4: 575 hrs a 150C



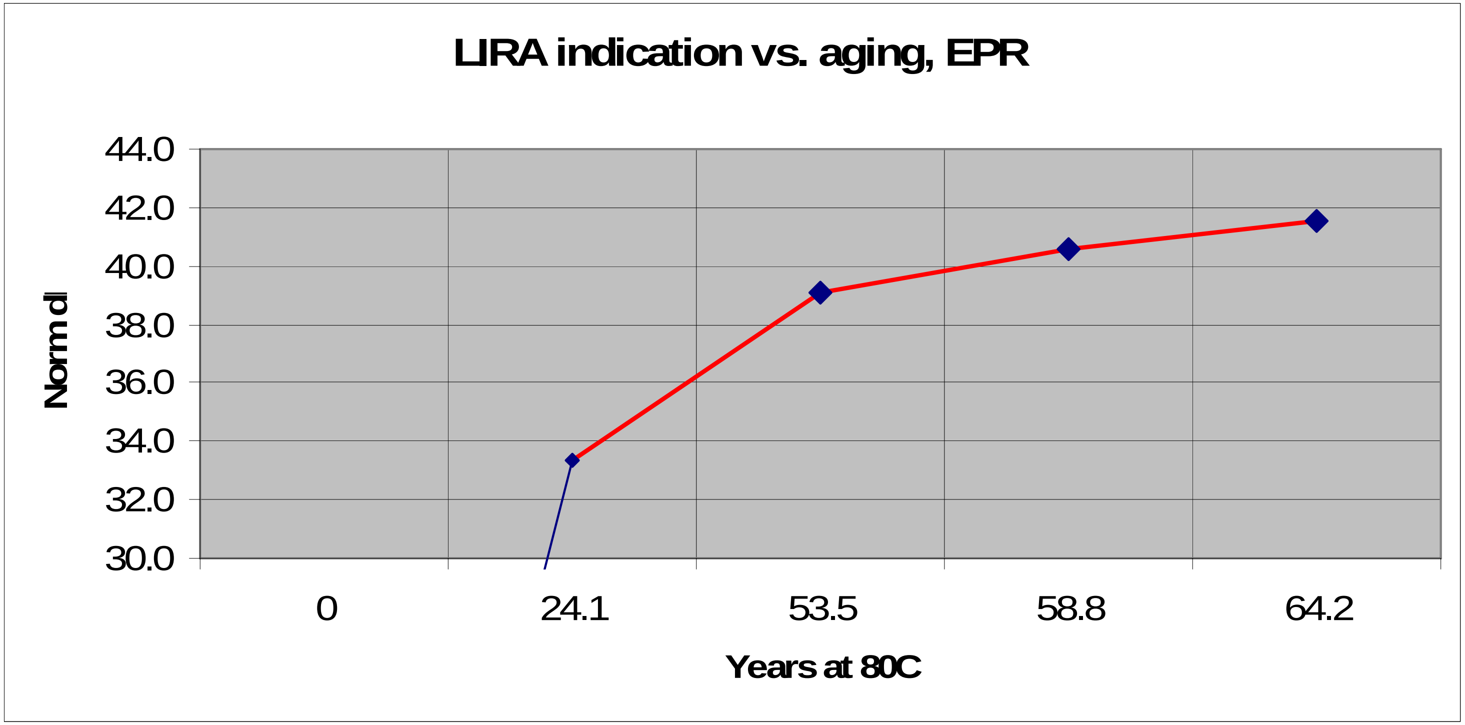
Hot spots (22.5m), 4 aging times, XLPE

1m thermal aging
At 8m (22.5)

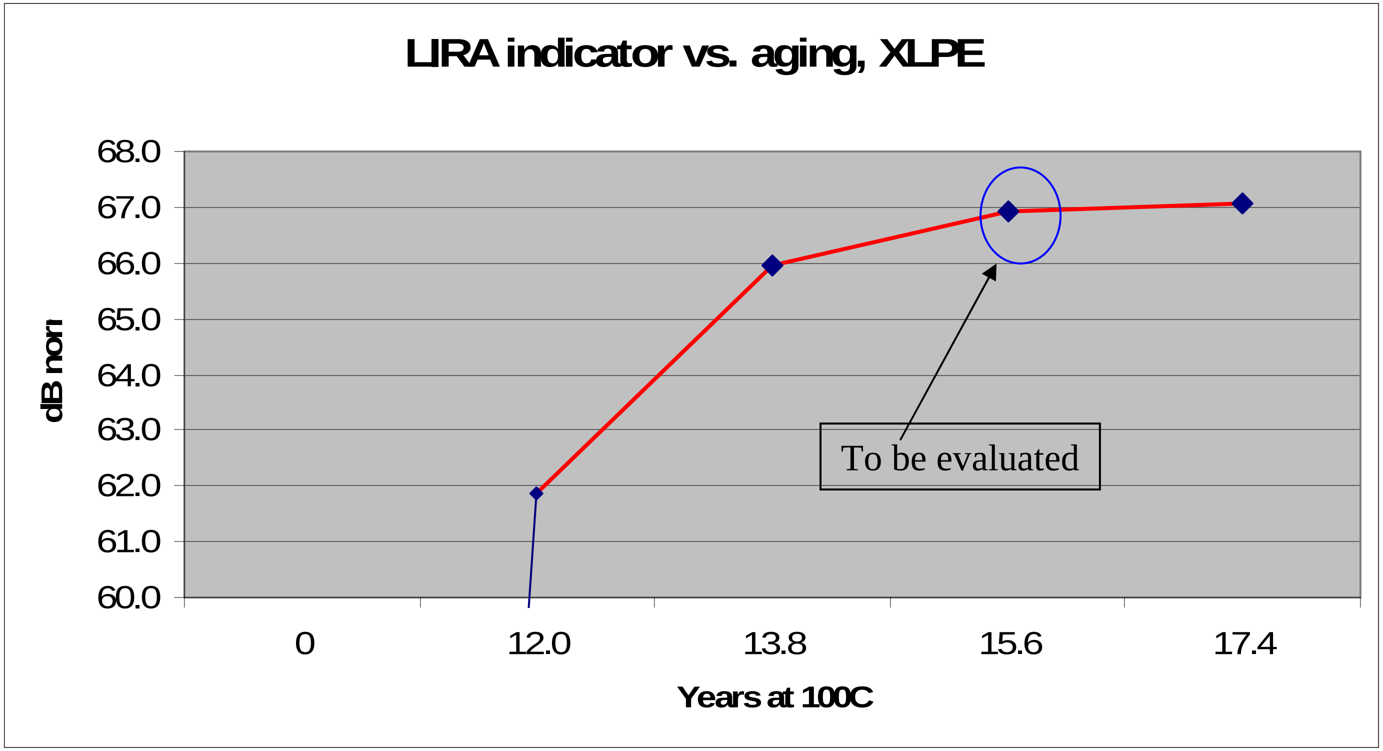
XRL1: 1002hrs at 150C
XRL2: 1150hrs at 150C
XRL3: 1300hrs at 150C
XRL4: 1450hrs at 150C



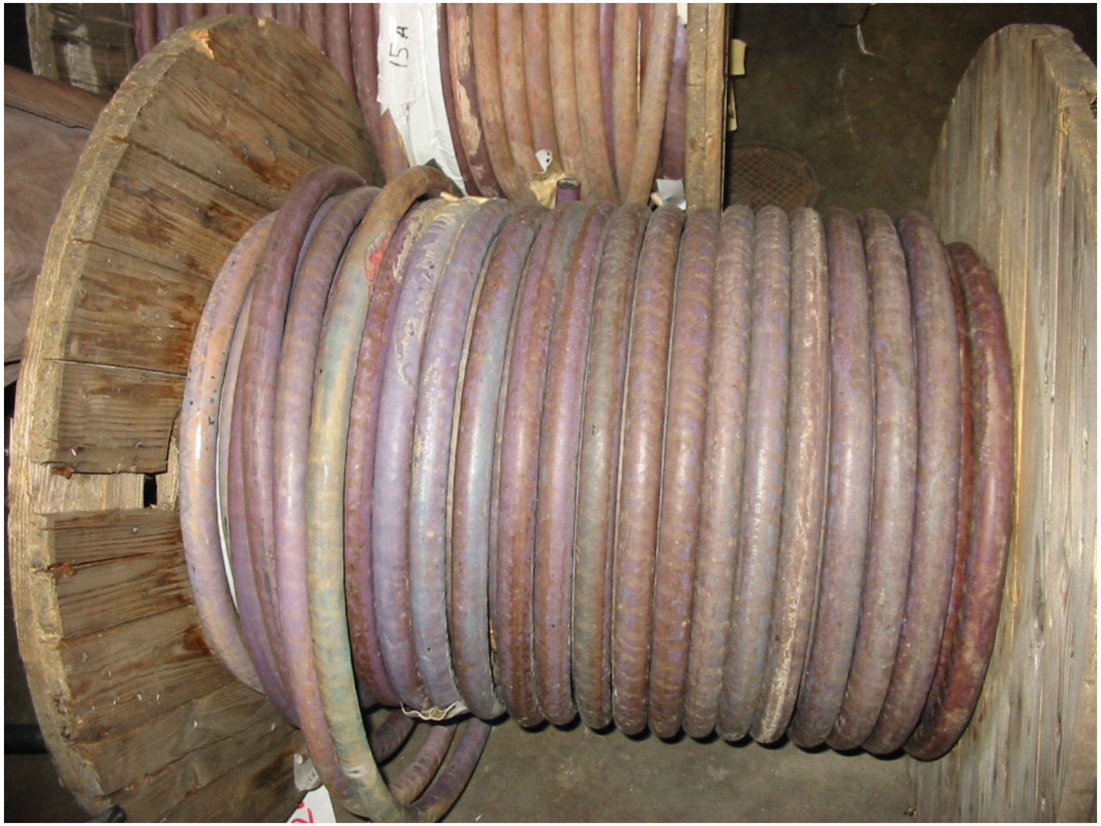
Hot spots, correlation with aging, EPR (BIW)



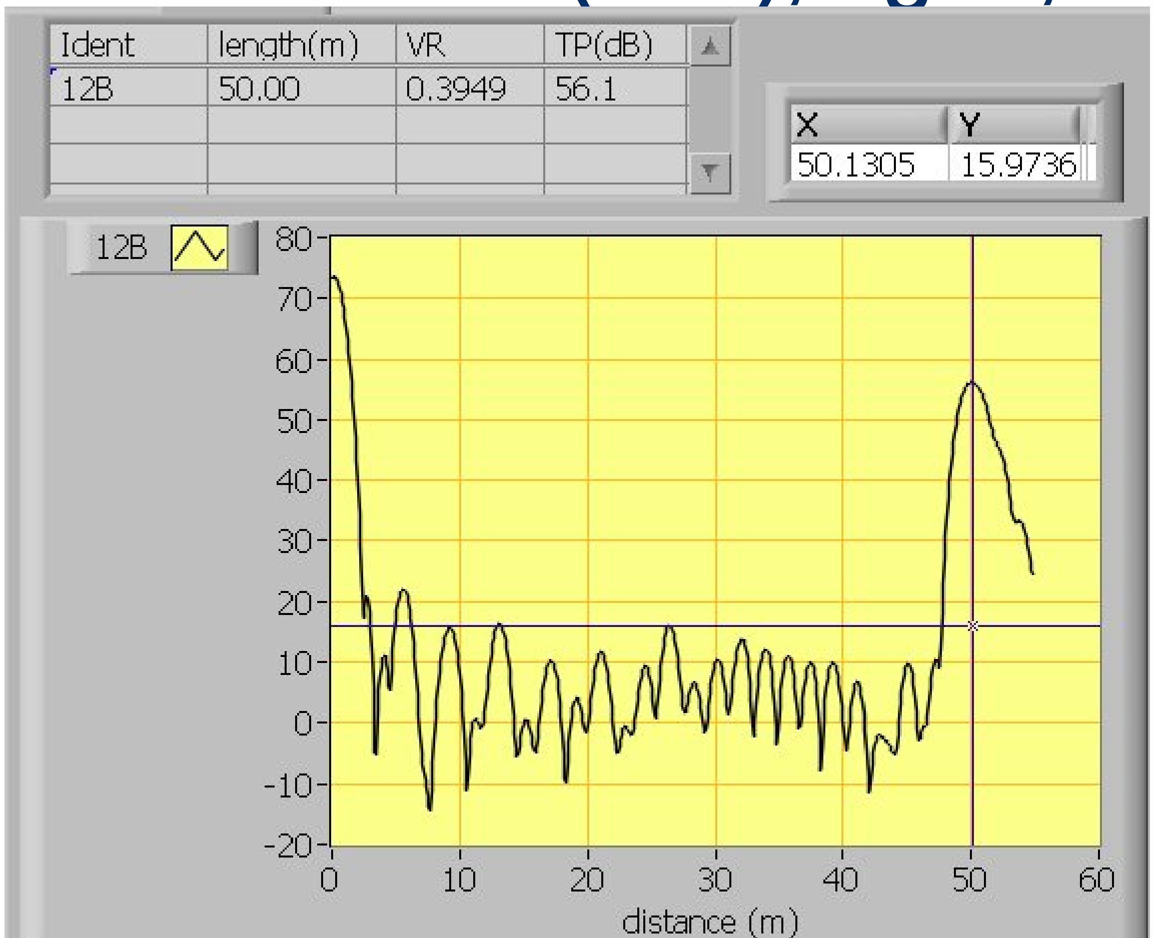
Hot spots, correlation with aging, XLPE (Rockbestos)



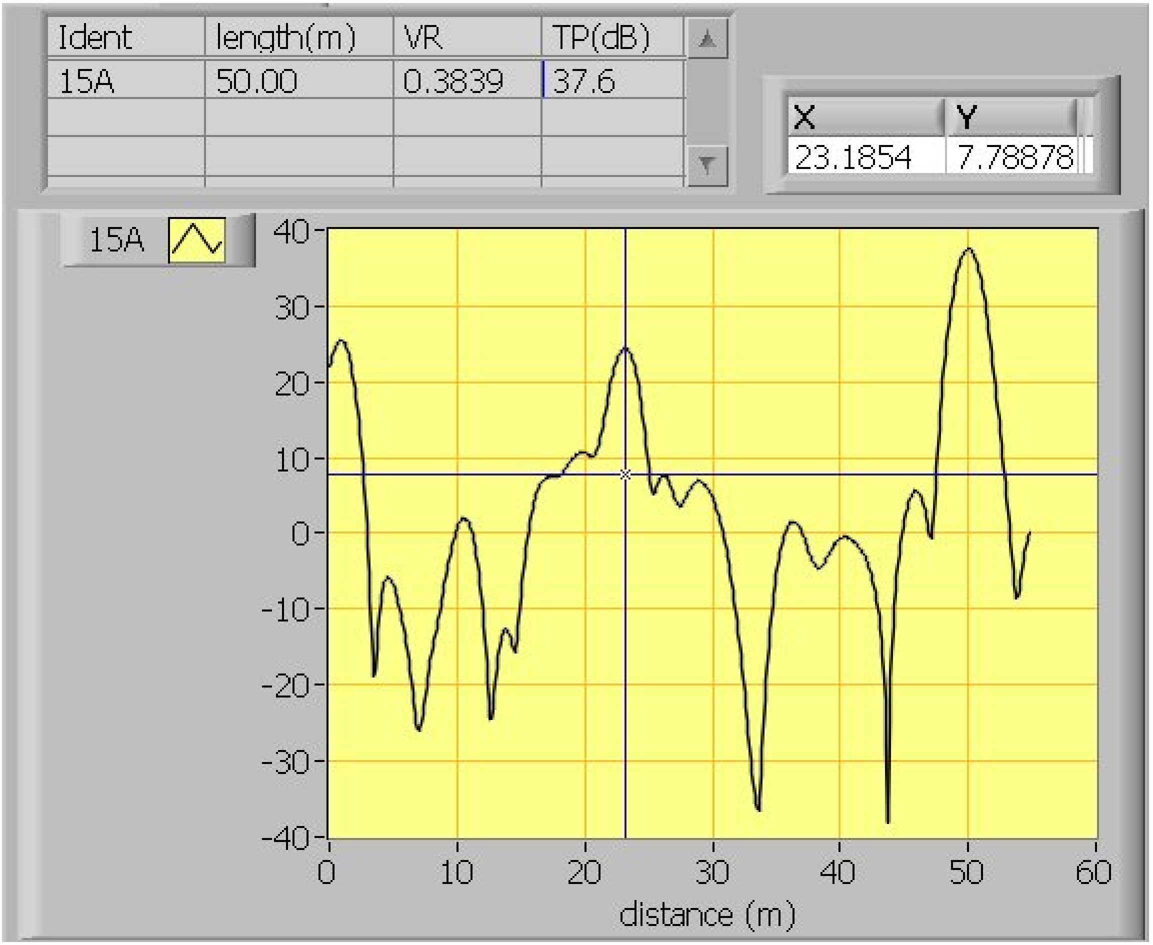
Tests on 5kV, EPR, aged and wet



5kV EPR cable (12B), aged, wet

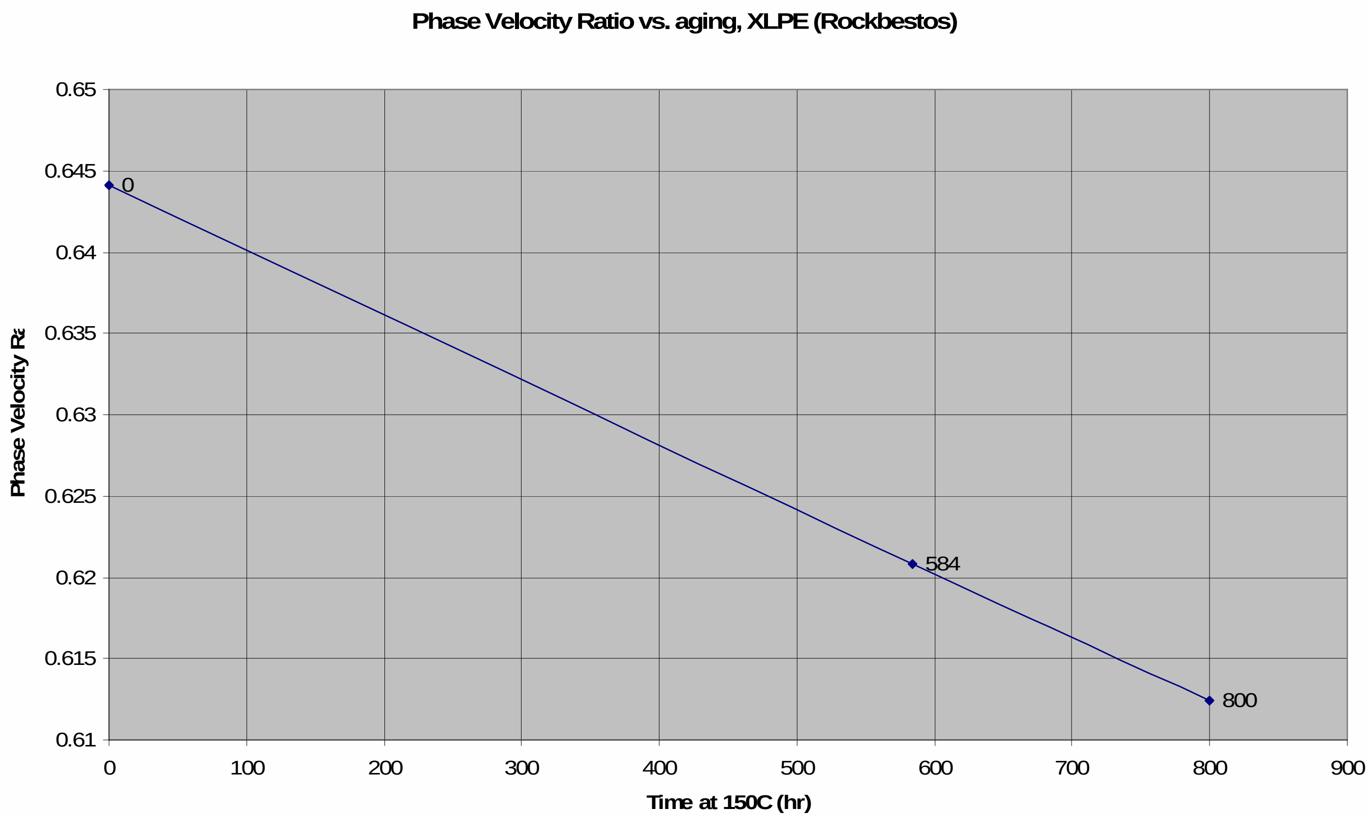


5kV EPR cable (15A), aged, wet



Bulk aging tests

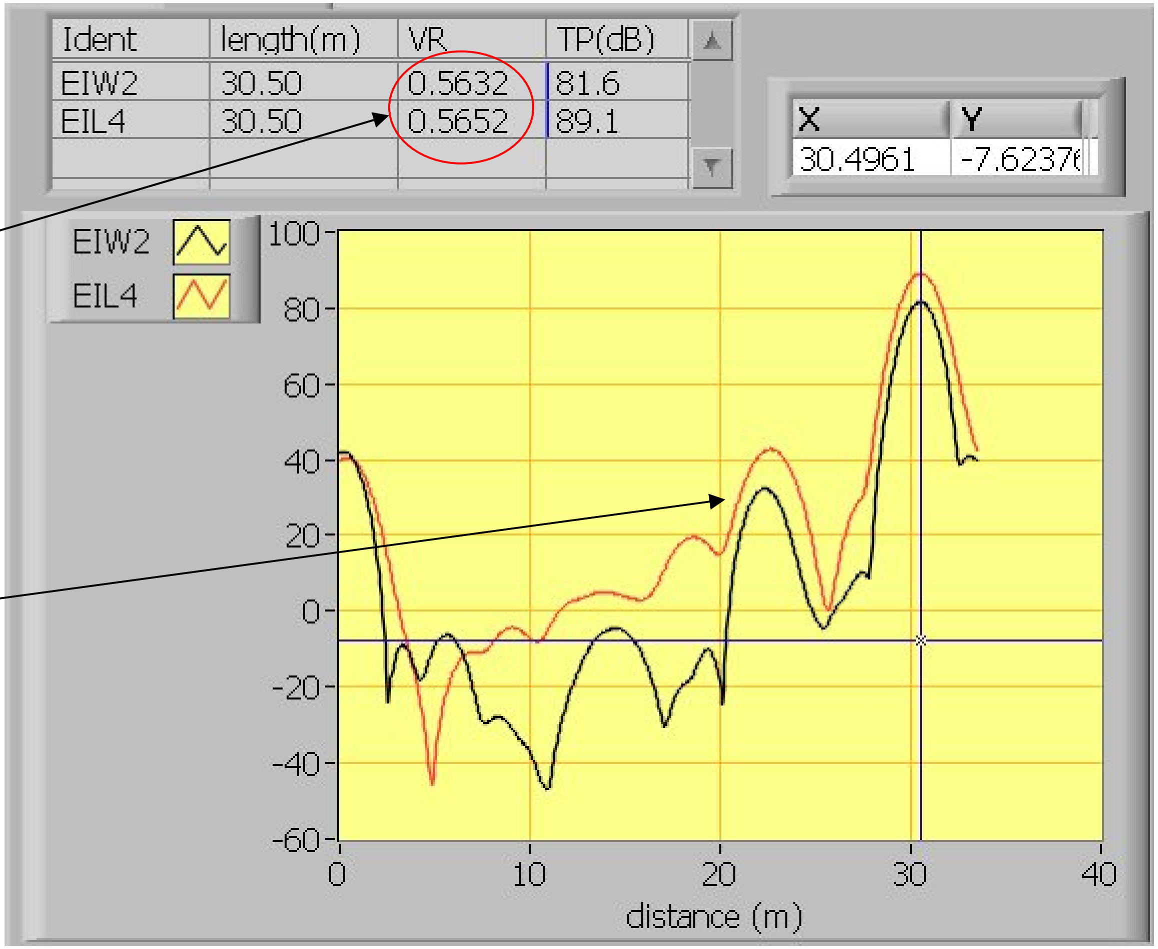
Bulk aging, XLPE



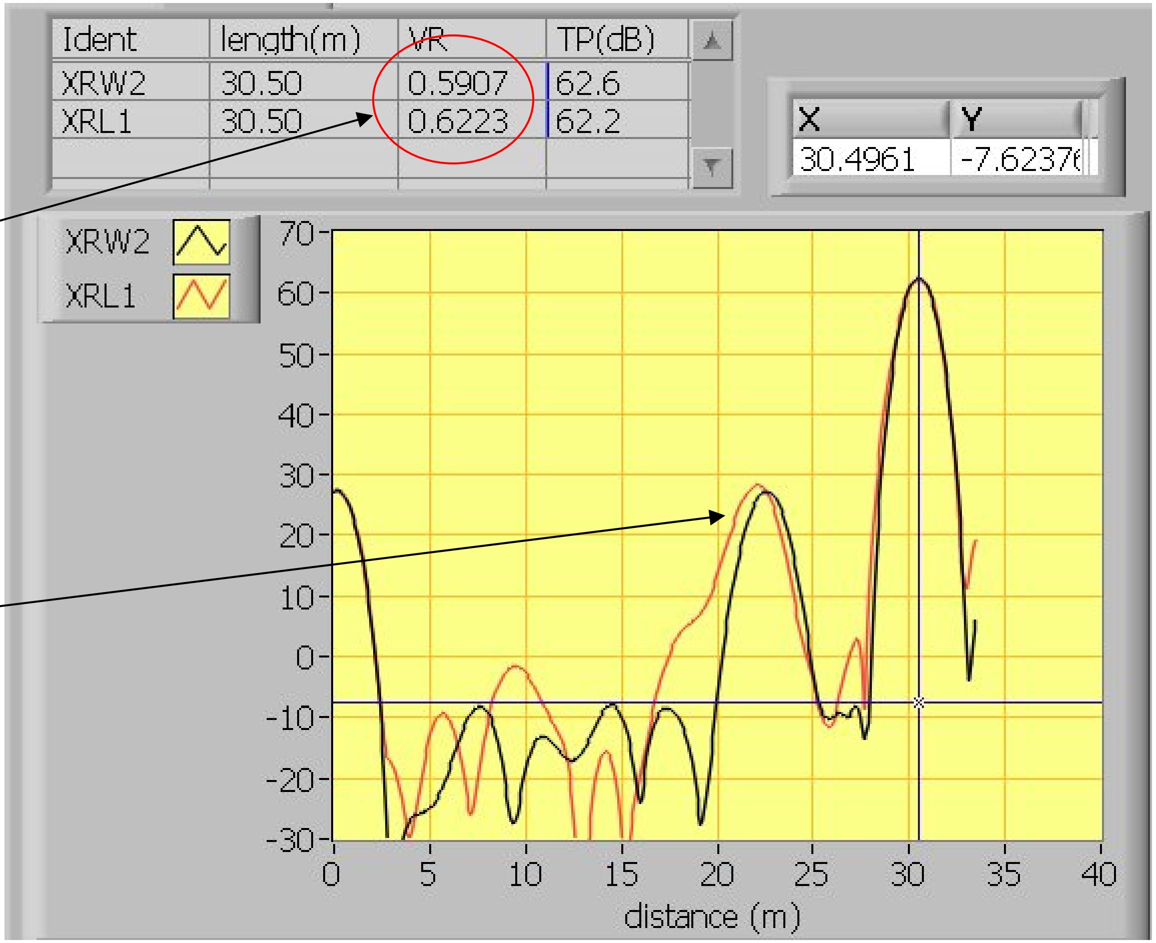
Wet vs. dry, EPR

No change in VR

Hot spot at 22.5m



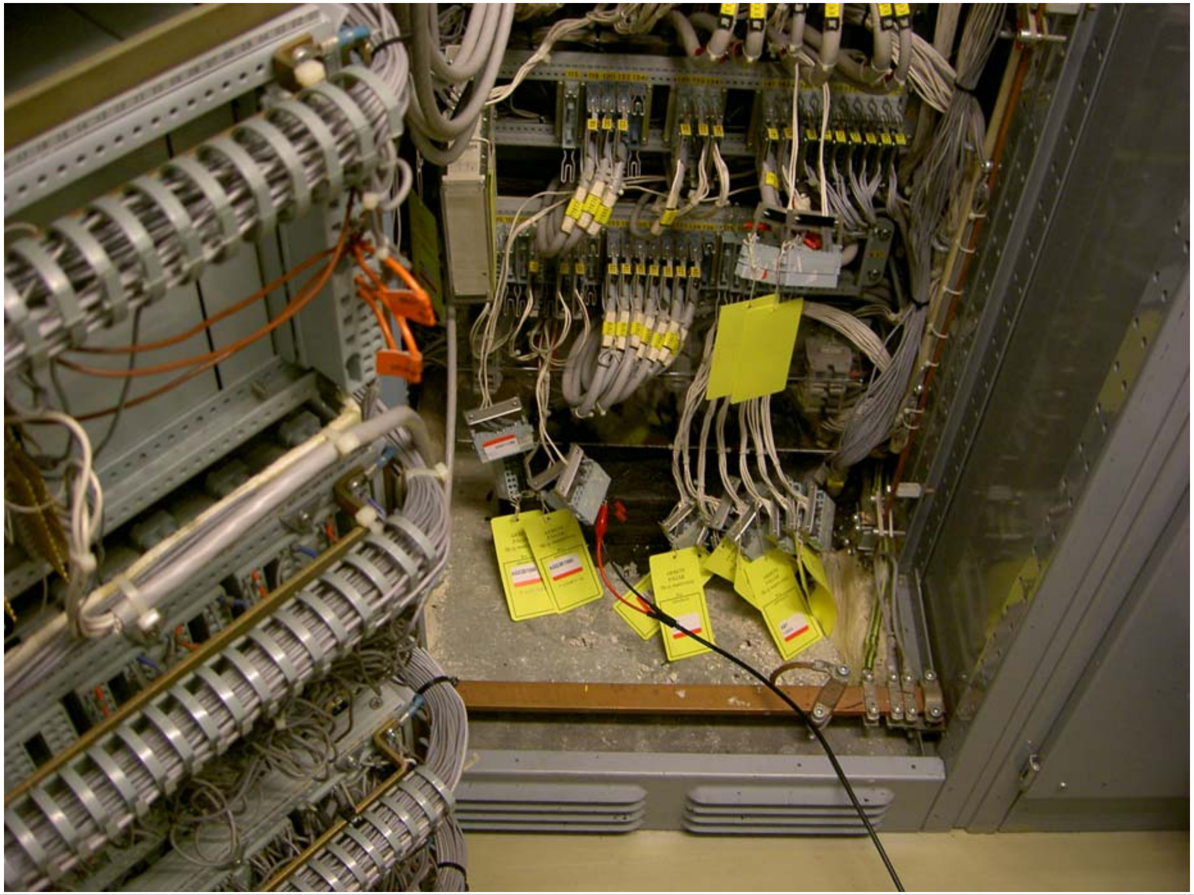
Wet vs. dry, XLPE



Much lower VR in wet conditions

Hot spot at 22.5m

Ringhals experiment, June 2006

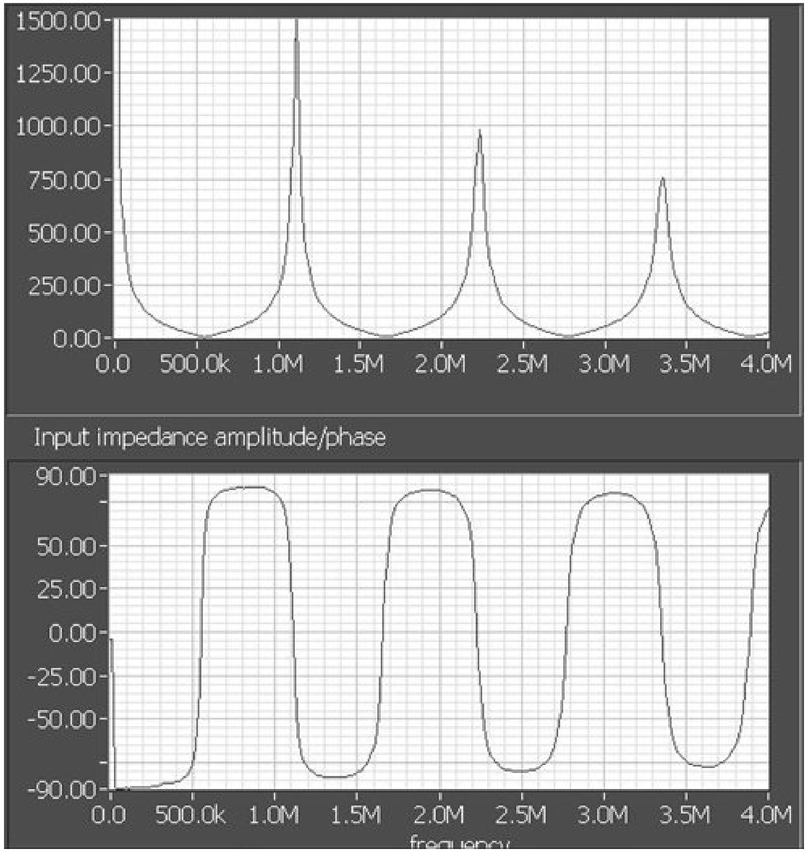


Ringhals Experiment

Low voltage, 140m triaxial cable with PVC insulation, 20-25 years aging condition.

Verify that cable extraction and reinsertion does not cause jacket/insulation damage

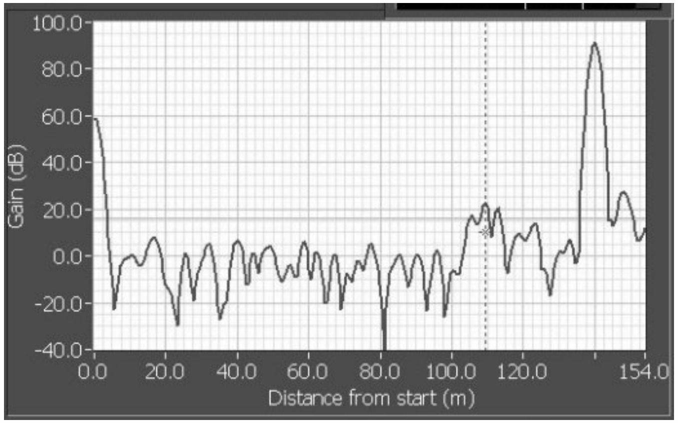
Line impedance signature →



First on-site test

- Top signature: analysis of the 140m cable with penetration at 105m
- Bottom signatures: analysis of the 105m disconnected cable (at the penetration), before and after relocation

No detectable damage as a consequence of cable movement



Recent Reports on Cable Aging

- **IAEA TECDOC 1188**, December 2000, Assessment and management of ageing of major nuclear power plant components important to safety
- Report of the IAGE Task Group on Wire System Aging (NEA). Final report released August 2004 (**NEA/CSNI/R(2004)12**).
- State-of-the-art report (**HWR-746**) released April 2004 (Halden Reactor Project Report).
- Workshop on Wire System Assessment and Condition Monitoring, Zurzach (CH), October 29-30, 2004 (**HWR-787**)
- LIRA Technology (**HWR-788**), October 2005