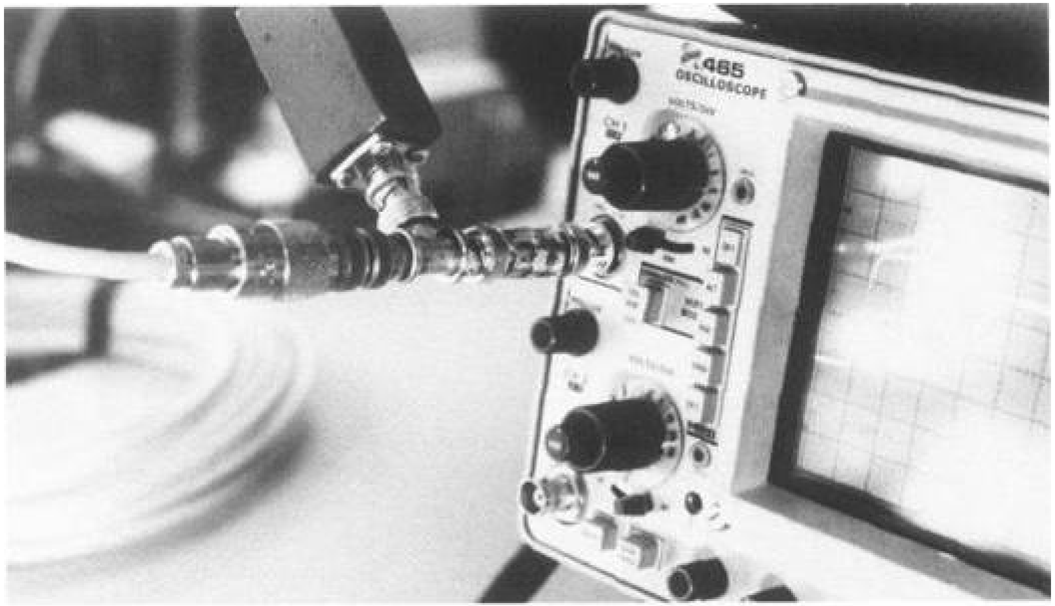
Wire System Aging Assessment and Condition Monitoring NKS-R WASCO



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Aging of electrical cables in harsh environment

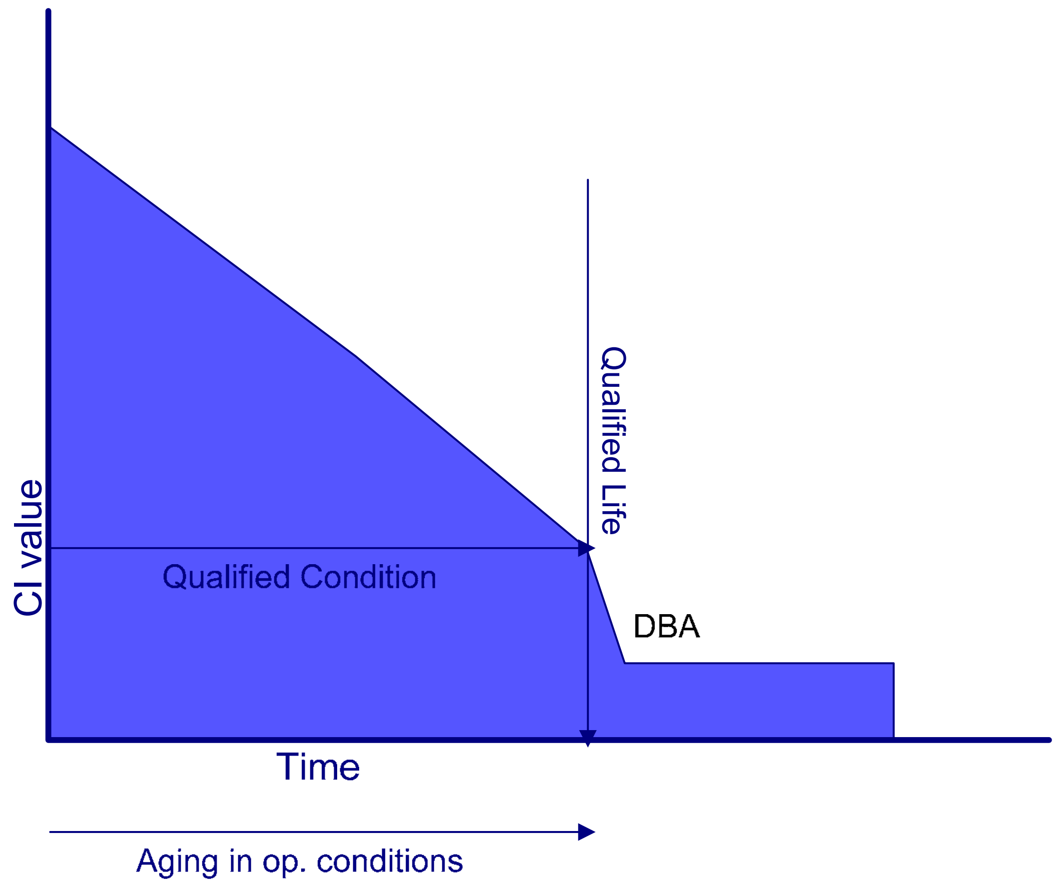
- Operation environment in NPP challenges cable insulations and jackets integrity. Aging parameters include:
  - Temperature (45-50 deg in containment)
  - Gamma radiation
  - Humidity, steam

- Long term operation of cables in harsh environment can lead to insulation degradation and consequent loss of functionality

Assessment of aging components

- Many plants currently in operation are approaching their end of the qualified life (that is: they are old)
- Plant life extension (+ 20 years) brings up the question of the assessment of aging components (including cables)
- Recent events in operating NPP suggest that some cables can be in a worse than expected condition (hot spots issue)

Qualified Life vs. Qualified Condition



Objective of Artificial Aging of Equipment intended to be installed in NPP

To bring the equipment in a condition equivalent to its condition at the end of the desired qualified life

Qualified life is the period of time under normal operational conditions when aging does not prevent satisfactory performance of the equipment during a subsequent DBE condition

IEEE-323

IEC-60780

Uncertainties in qualified life determined from artificial accelerated aging

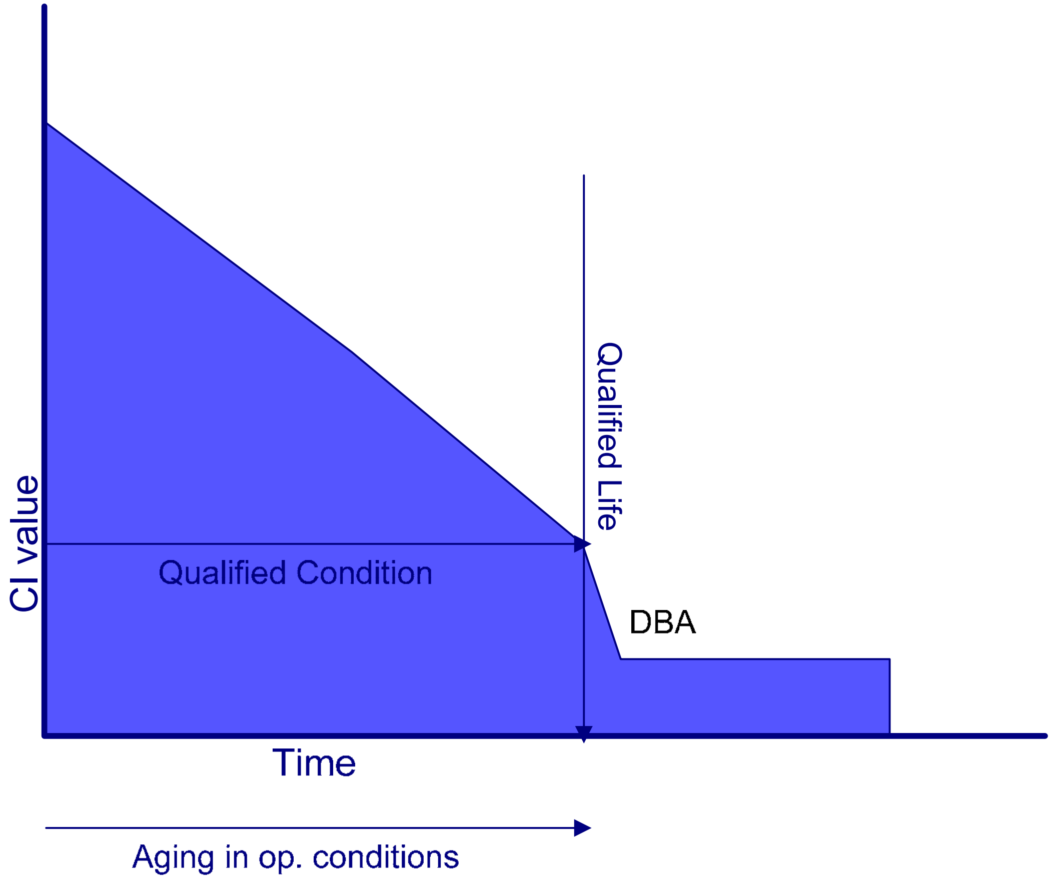
- Severities of environmental parameters during normal operation
- Uncertainty in activation energy values
- Non-Arrhenius behaviour when test temperatures exceed threshold values (insulation dependent)
- Number of test samples
- Effects of simultaneous exposure to more than one environmental factor
- Effect of simultaneous exposure to several degradation agents (radiation, temperature,…)

Qualified condition

- **the level of degradation due to aging at which the equipment has been demonstrated to perform satisfactorily during a subsequent DBE test**

- **given as a CM indicator value, e.g. elongation-at-break (EAB)**

Qualified Life vs. Qualified Condition



Advantages of the Qualified Condition approach

- No dependence on uncertainties as activation energy, environment conditions, dose rate effects.
- When the cable is exposed to milder environment conditions, it can justify operation beyond qualified life.

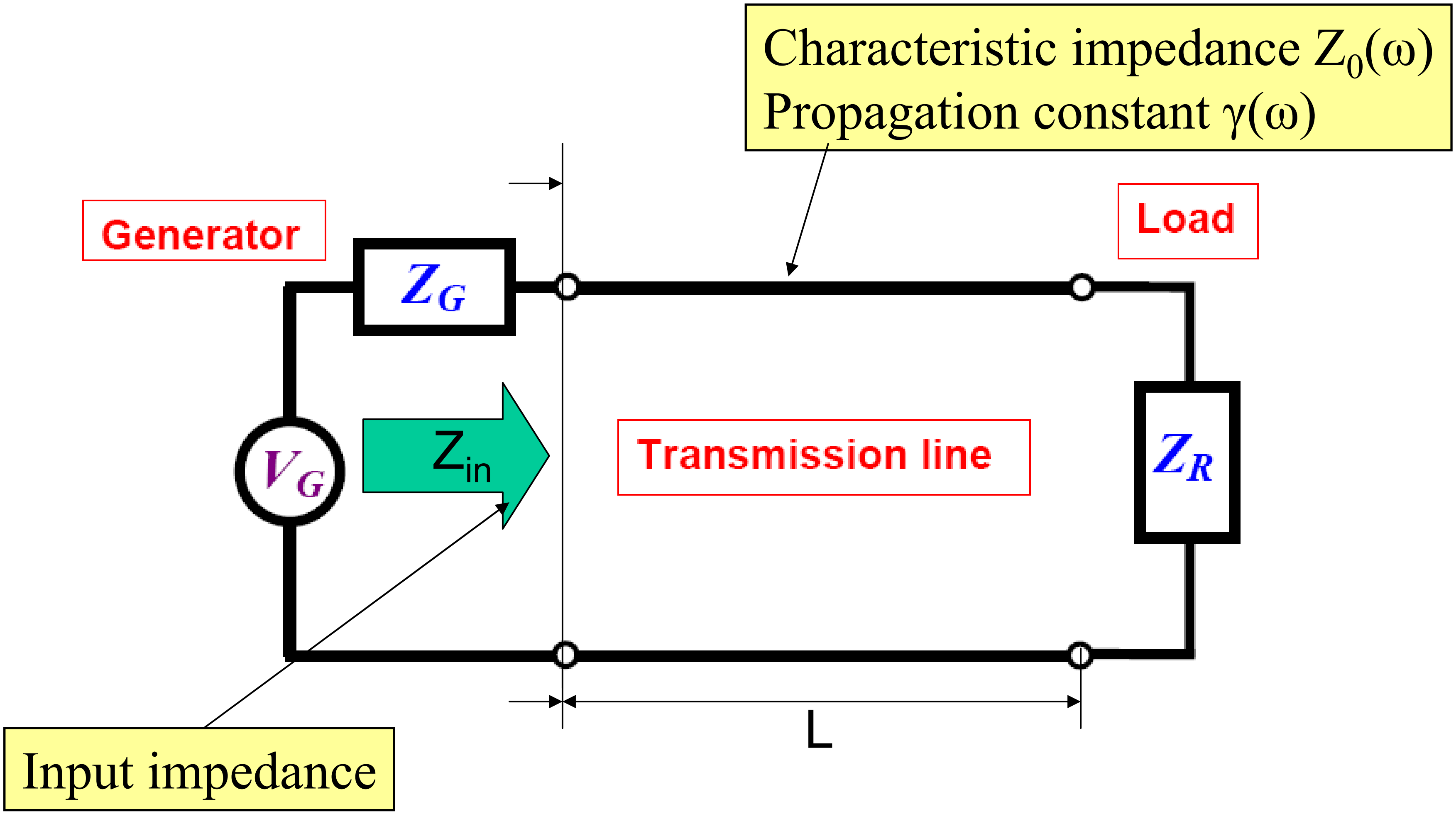
However....

A Condition Monitoring technique is needed

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

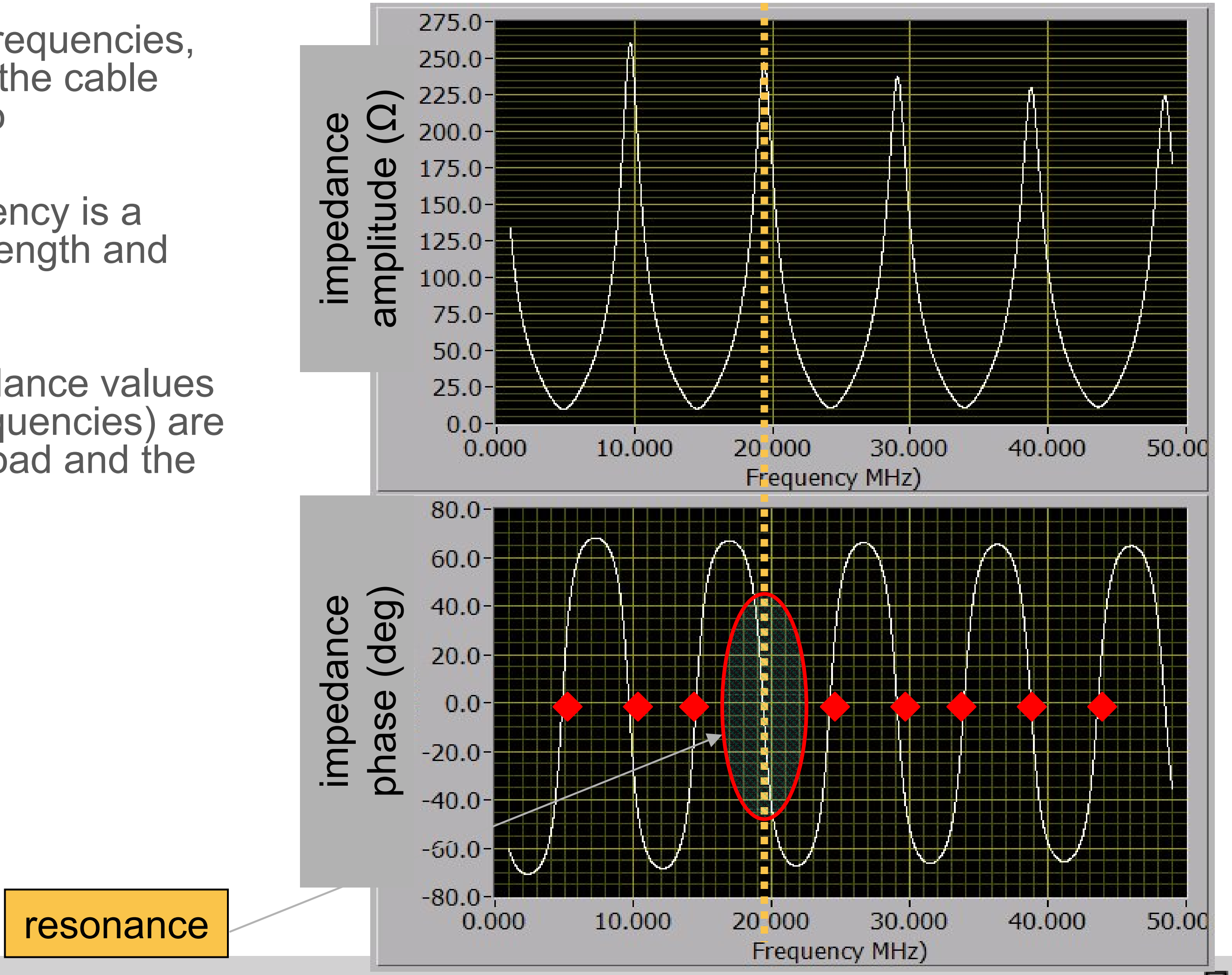
- Based on frequency domain analysis of high frequency resonance effects of unmatched transmission lines.
- Sensitive to small changes of wire electric parameters, mainly the insulation permittivity, that are a significant condition indicator of the cable state (thermal and radiation aging, humidity, 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.

LIRA is based on transmission line theory



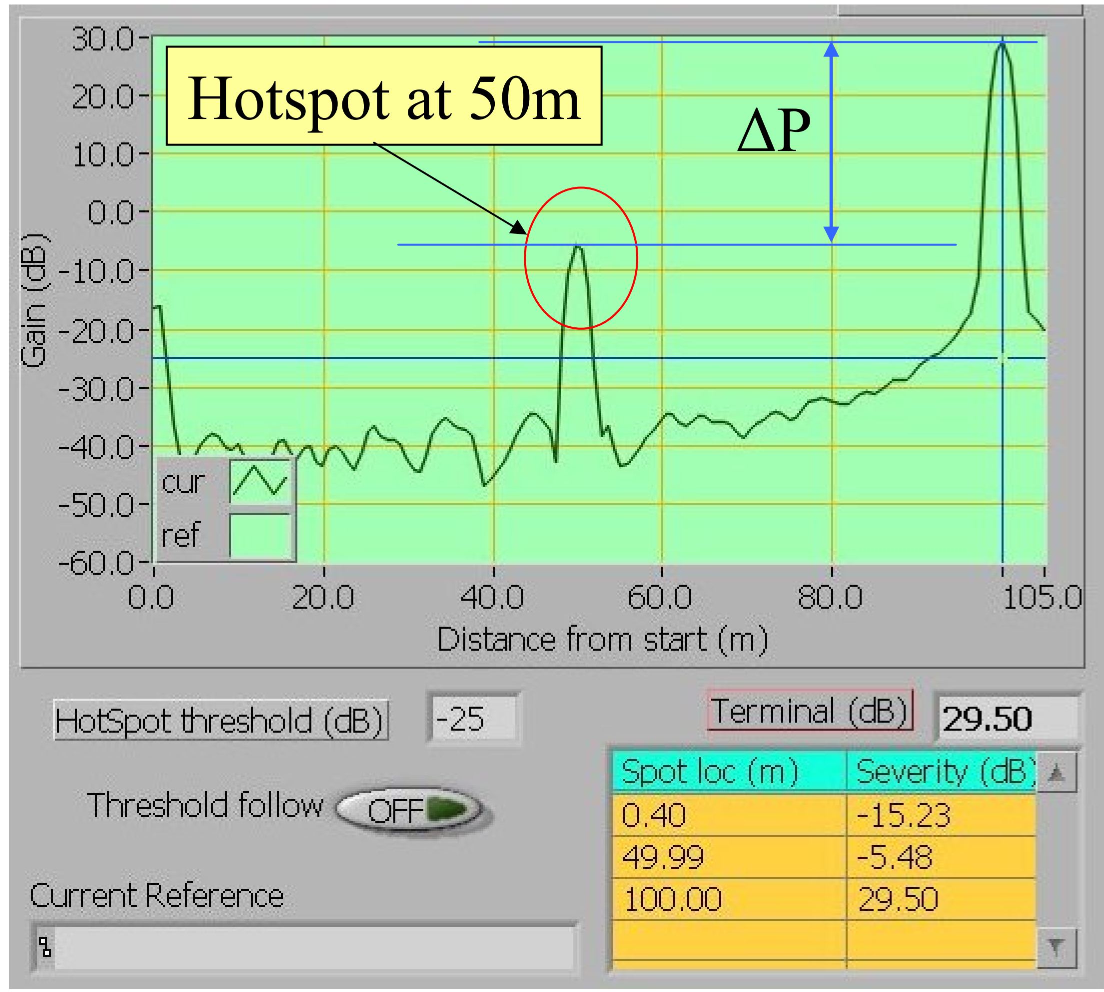
Resonance analysis of cables

- At all resonance frequencies, the phase shift of the cable impedance is zero
- Resonance frequency is a function of cable length and cable properties
- Cable peak impedance values (at resonance frequencies) are a function of the load and the cable attenuation



Local degradation detection

- Based on discontinuities of the characteristic impedance caused by mechanical or thermal degradation
- Sensitive to very small electric properties change (5pF/m for 0.3m in the picture)
- Localization error average less than 0.3% of total length



NKS WASCO (2006)

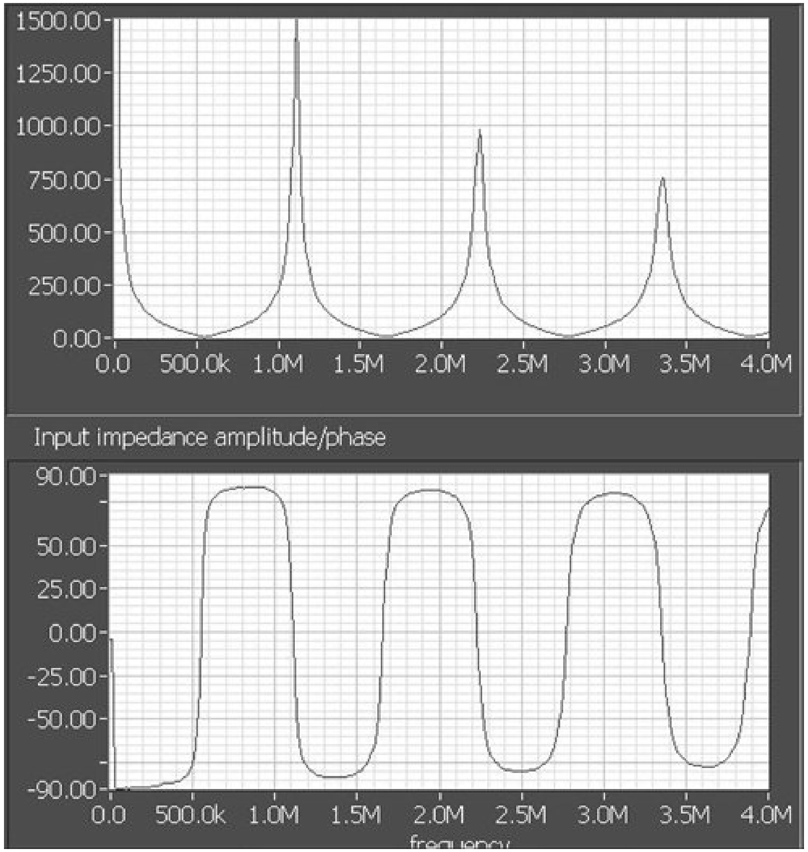
- NKS (Nordic Nuclear Safety Research) is supporting the LIRA project with additional funds (NKS-R 2005 “WASCO – Wire System Ageing and Condition Monitoring”).
- The NKS project addresses specific issues on cable aging for the nuclear industry in Norway, Sweden, Denmark and Finland.
- First experiments performed in **Barseback**, February 2006. Experiment in **Ringhals**, 26/06/2006

Ringhals Experiment

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

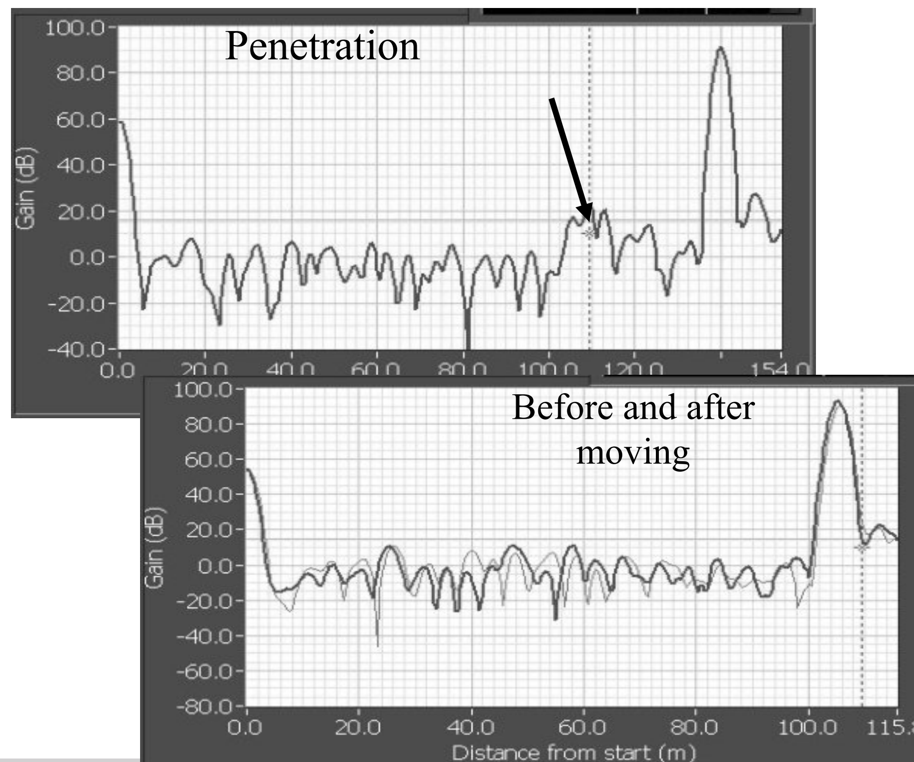
Verify that cable extraction and reinsertion does not cause jacket/insulation damage

Line impedance signature →



Test during plant revision June 2006, Sweden

- Tests on installed low-voltage cables, > 20 years old
  - Check for any local degradation
  - Check whether moving the cable degrades the cable insulation
- Results:
  - Status OK for the cable



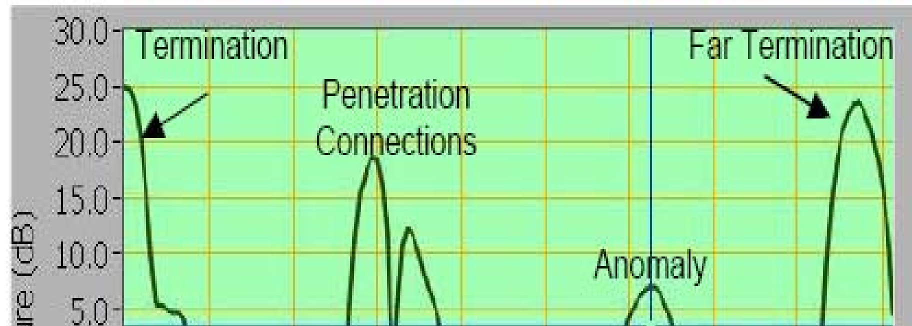
Test during plant revision June 2007, Sweden

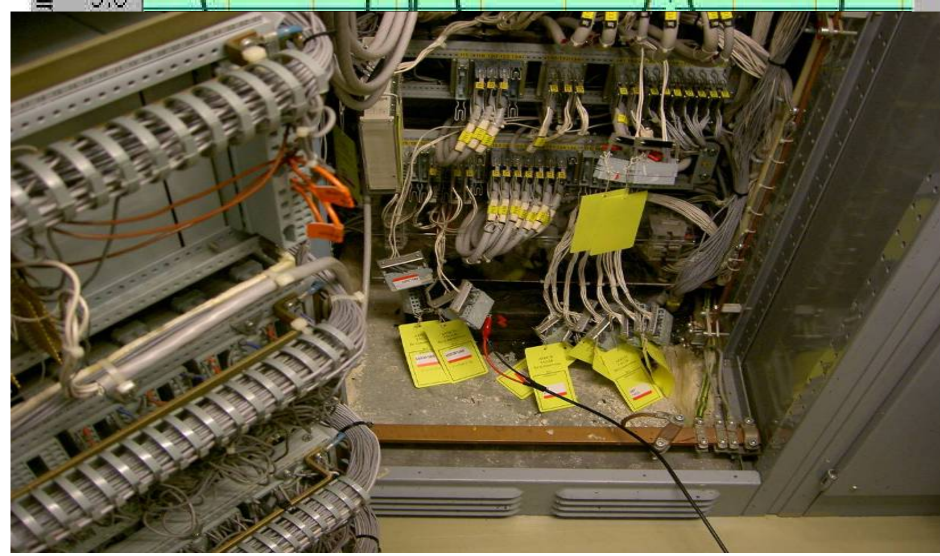
Signal cable to control level transmitters

- 30 m PVC outside containment
- 2 m penetration connection area
- 57 m EPDM inside containment

<u>LIRA Result</u>

- Penetration clearly detected; 30-32 m
- Unknown joint detected at 62,5 m
- End termination at 89 m

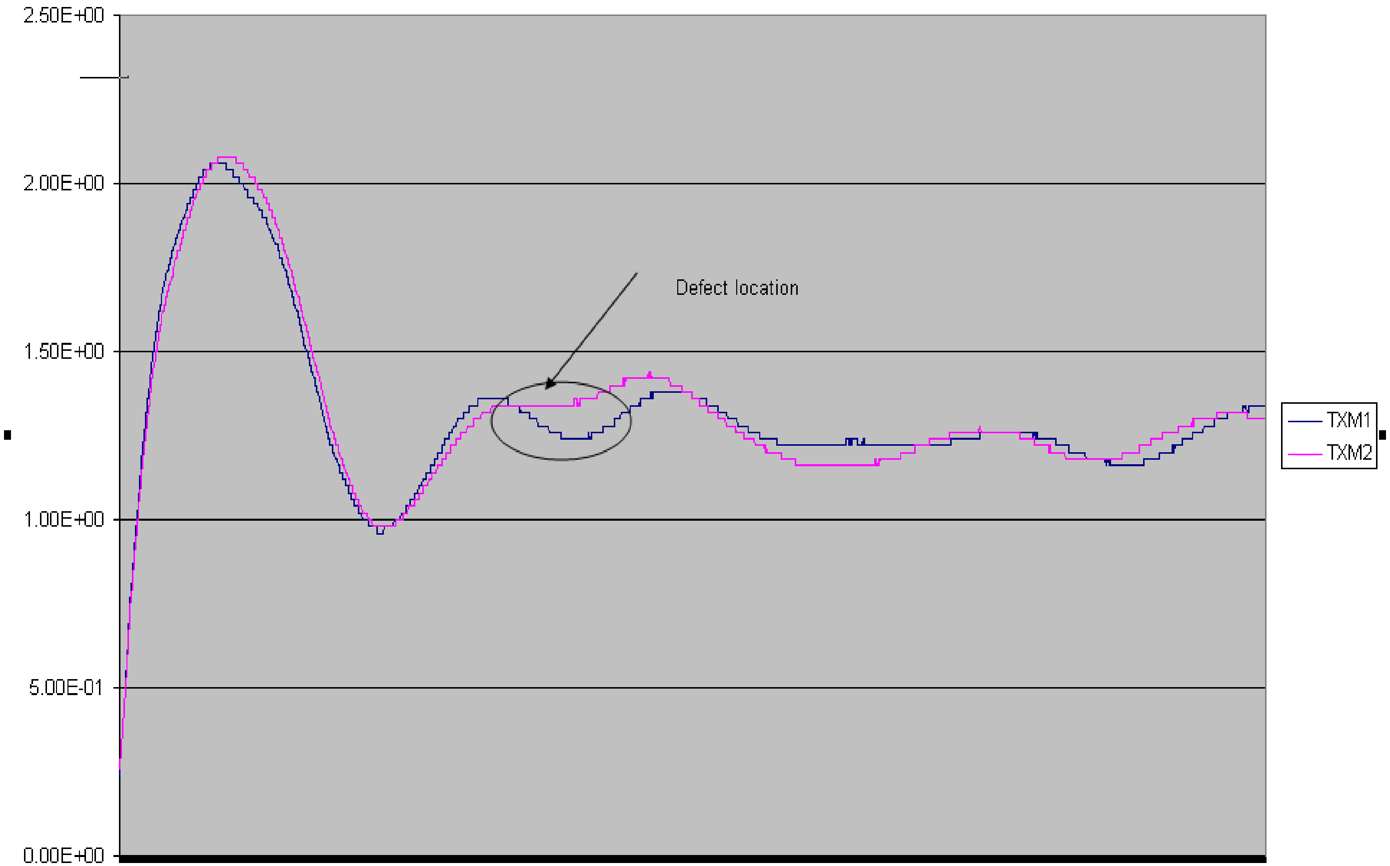




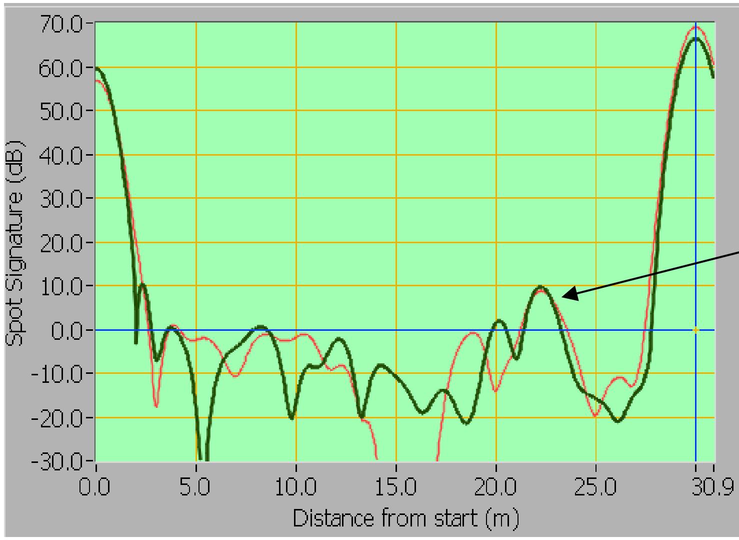
NKS WASCO (2008) in collaboration with Tecnatom (Spain)

- Perform reference tests on new cable samples (both EPR and XLPE) using the following techniques:
  - Elongation-at-break (EAB)
  - Indenter
  - Time Domain Reflectometry (TDR)
  - Line Resonance Analysis (LIRA)
- Perform tests on cable samples with local mechanical defects, using TDR and LIRA

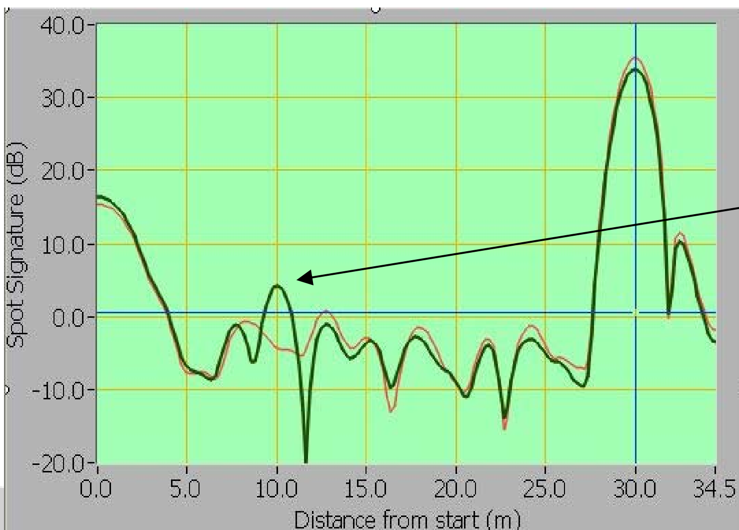
MECHANICAL DAMAGE
TDR TRACES FOR TXM1, TXM2



MECHANICAL DAMAGE
LIRA TRACES FOR TXM1, TXM2

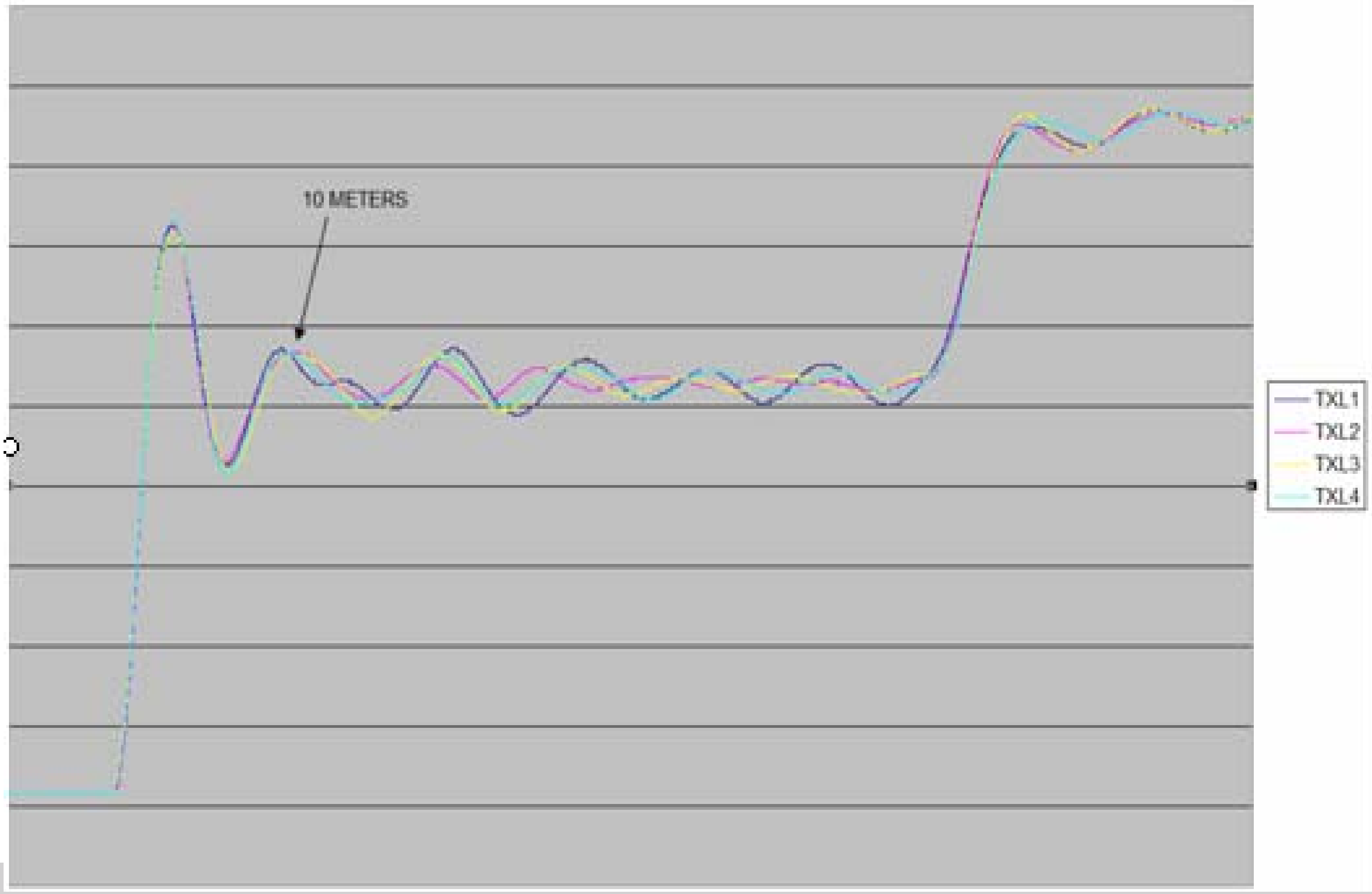


Insulation cut

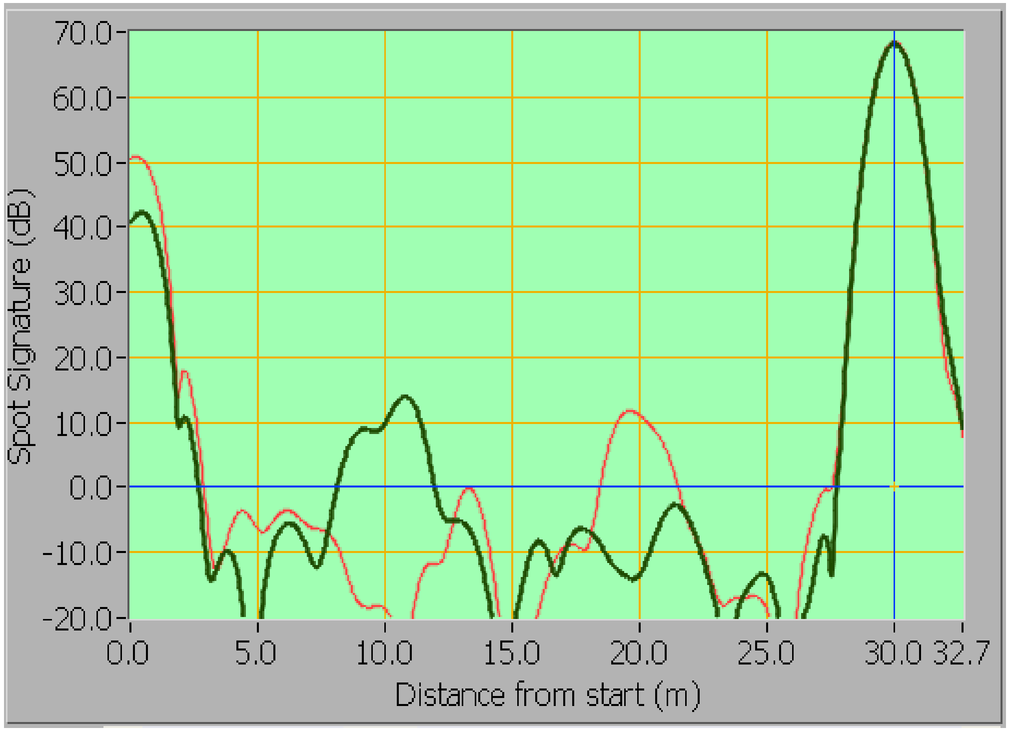


Insulation gouge

TDR Tests on local Hot Spots, XLPE



LIRA XLPE (TXL1)



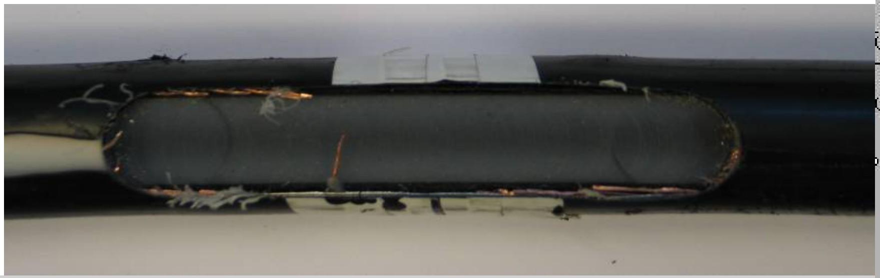
Hot Spot detected at 10m (dark trace)
and the same spot seen from other side (red trace)

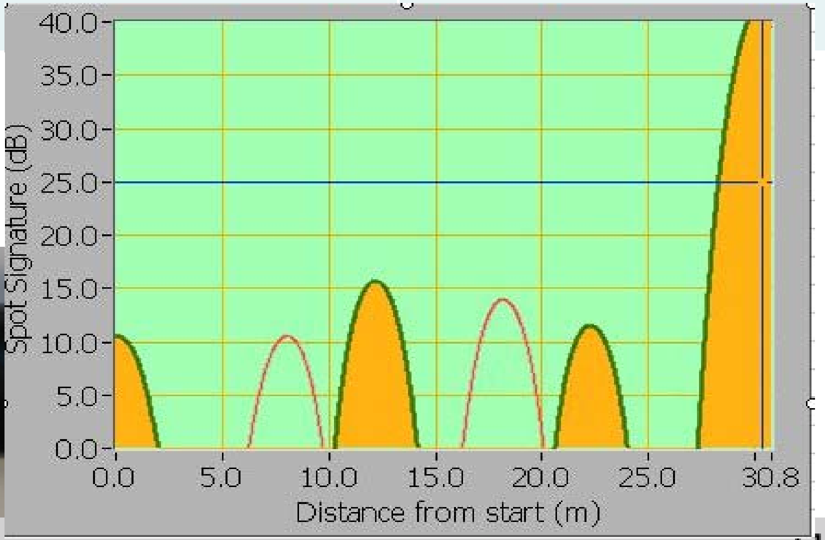
Accuracy and severity assessment in mechanical faults detection

Cable condition assessment (XLPE, 24kV – 240 mm2)

	IR (Insulation resistance)	TDR (Time Domane Reflecyometry)	LIRA
Fault Detection	Poor	Sometime	Good
Accuracy (ERR%)	n/a	Avg. 0,43 Std. 0,29	Avg. 0,23 Std. 0,08
Severity Assessment	n/a	No	Good

XLPE, 24 kV, Al 240 mm2



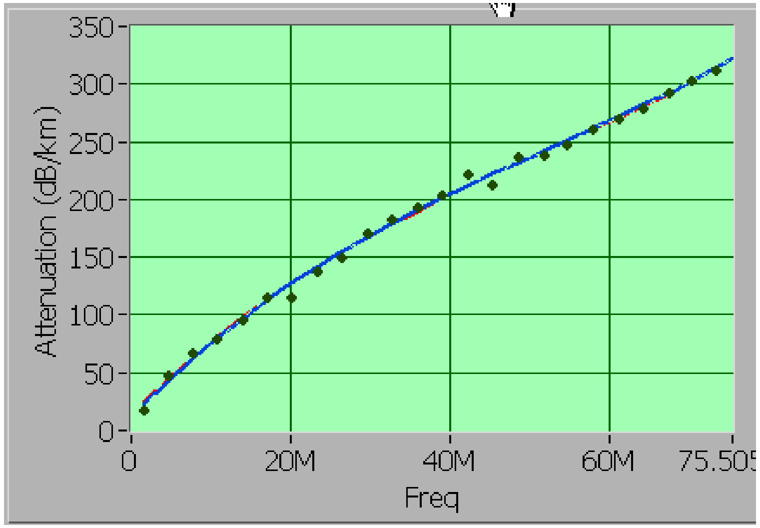


Global Condition Assessment – The High Frequency Attenuation as an indicator (WASCO 2009)

- Condition assessment of Lipalon insulated cables in Forsmark and Ringhals
- Partners:
  - KTH, Dep. Of Fiber and Polymer Technology, Sweden
  - Forsmark AB, Sweden
  - Ringhals AB, Sweden
  - IFE, Norway
  - Wirescan, Norway
- Activity funded by NKS, Ringhals AB and Wirescan

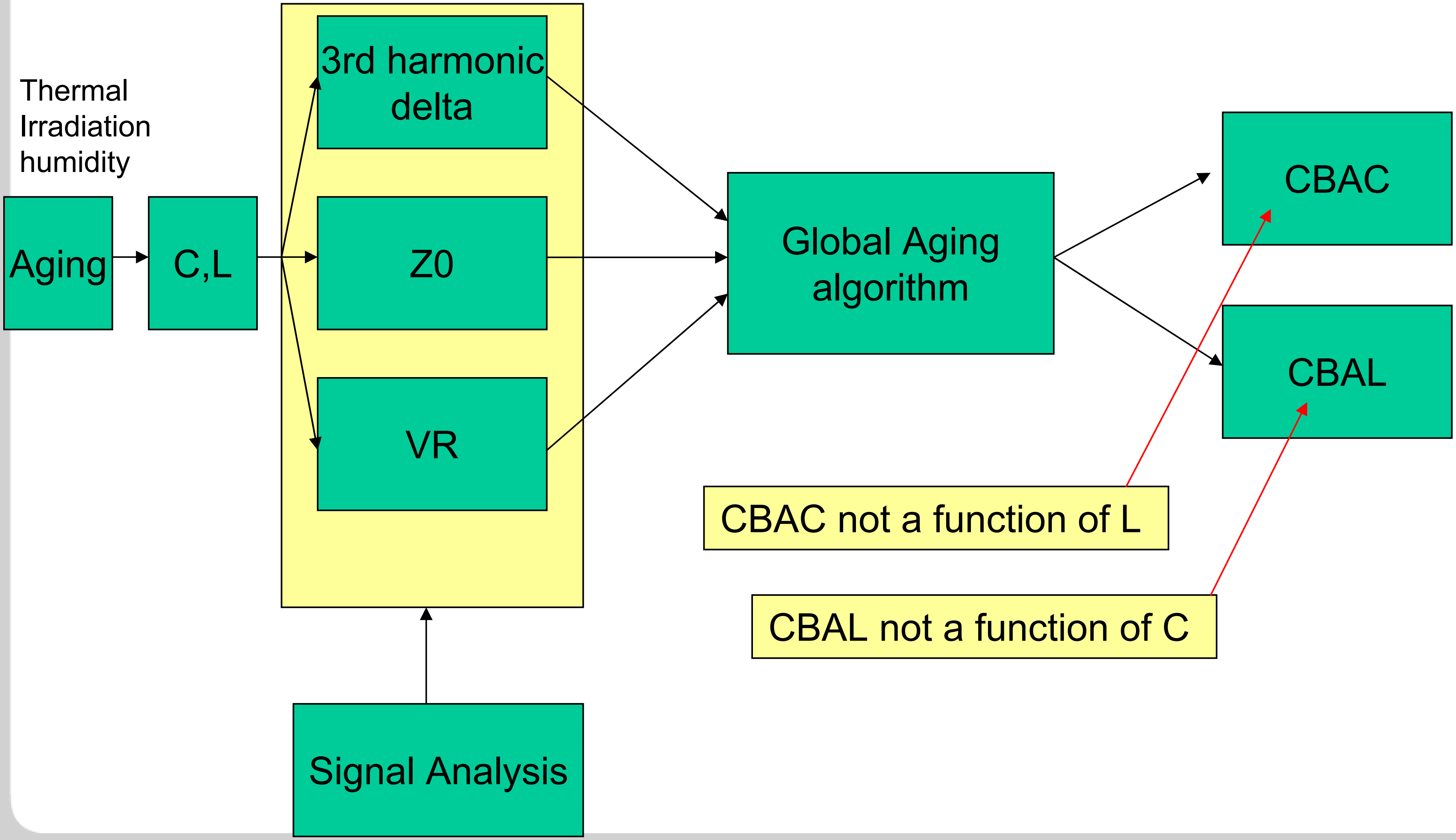
Global Condition Assessment – The High Frequency Attenuation as an indicator

$$\alpha = Kf^{a}\sqrt{\frac{C}{L}}$$



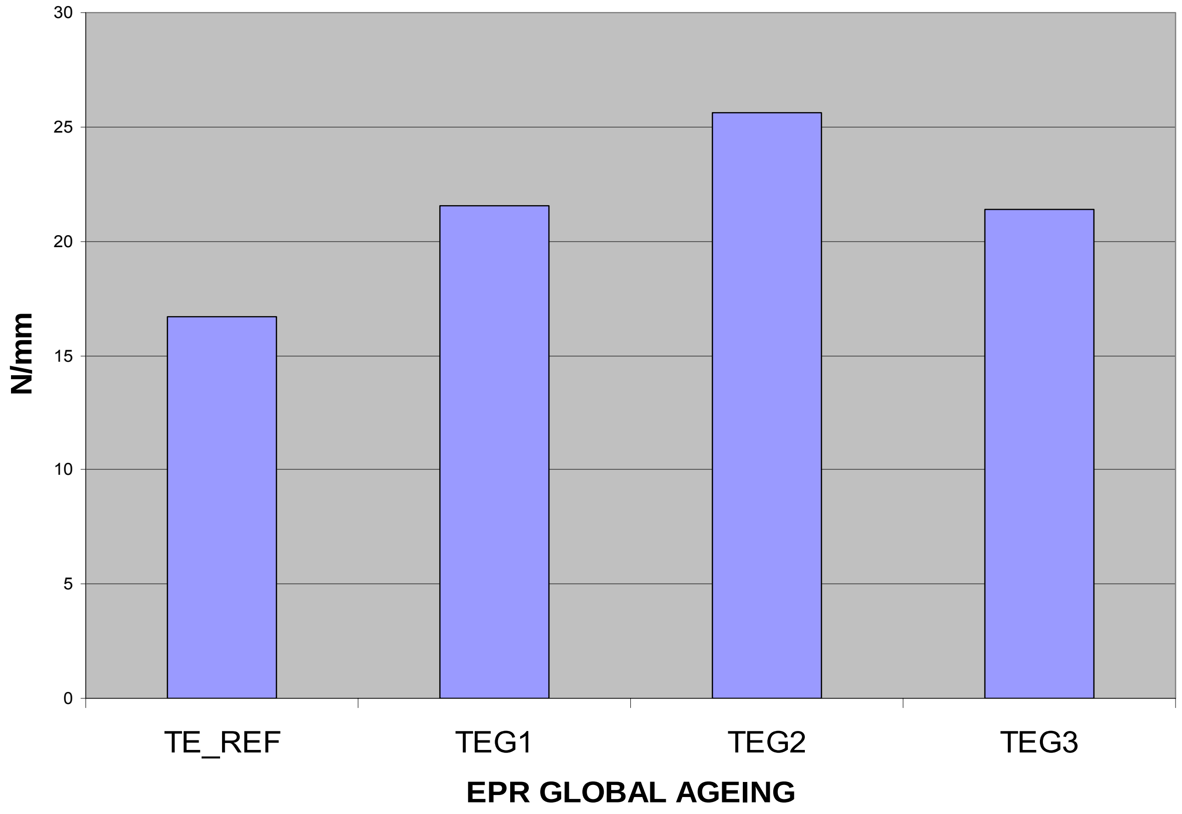
- High frequency amplifies the effect of C and L on the attenuation (*a* = 0.5-1.1, depending on cable type*)*
- Attenuation is a *combined* effect of C and L
- Both C (more) and L (less) are sensitive to thermal and irradiation aging

Isolation of the effects of C and L on the LIRA aging indicators

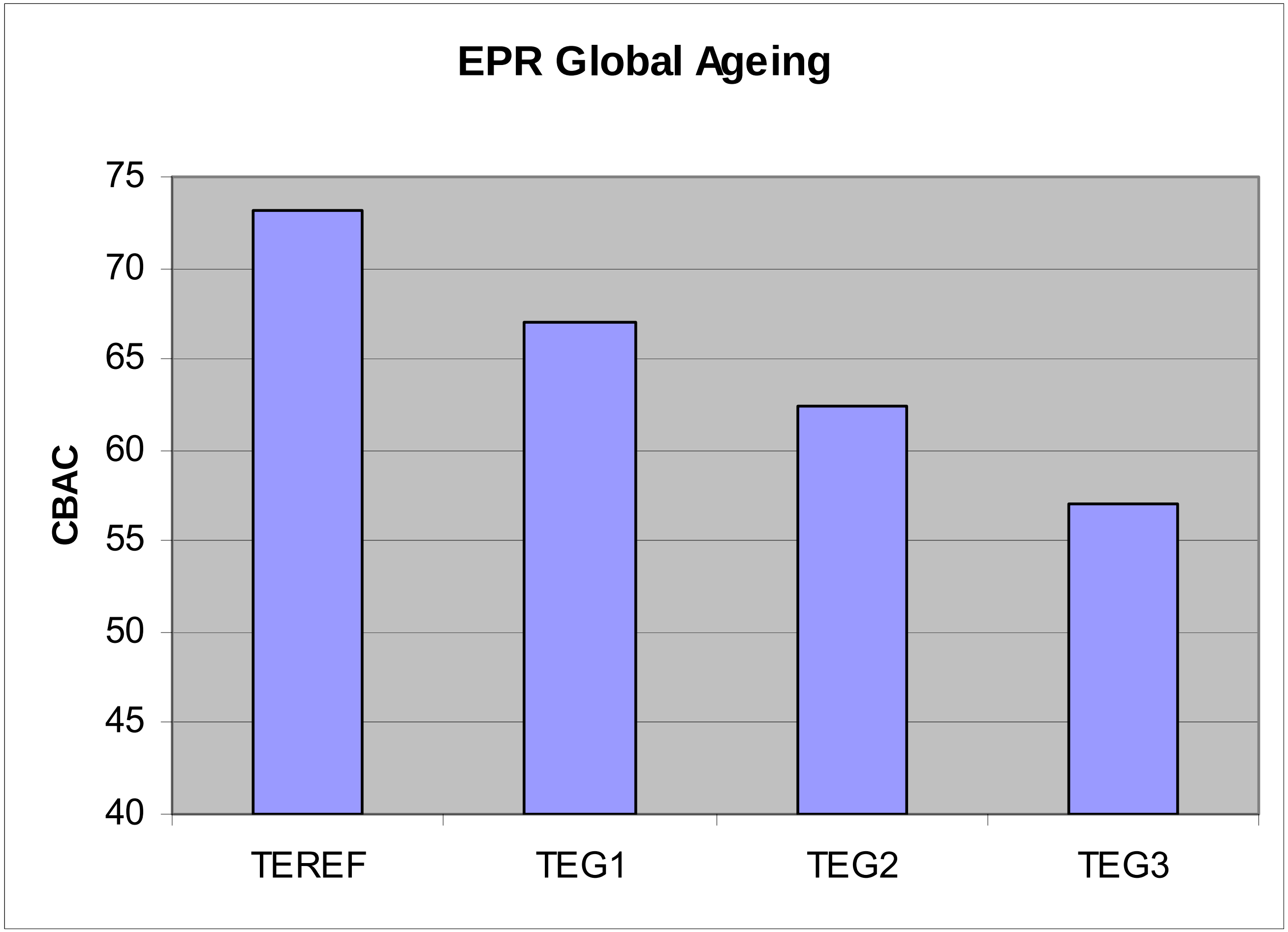


Indenter results

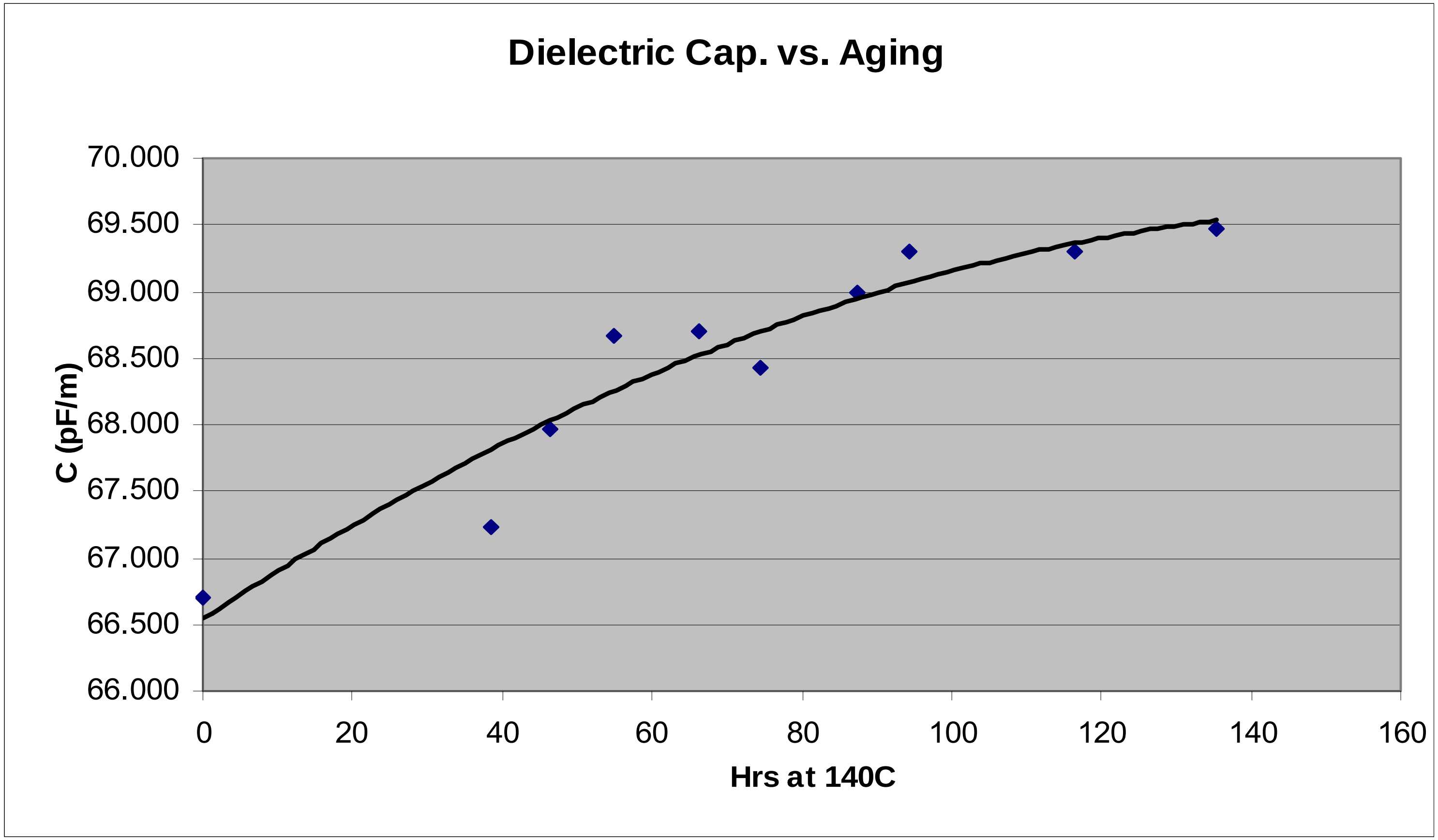
(Measurements performed by TECNATOM)



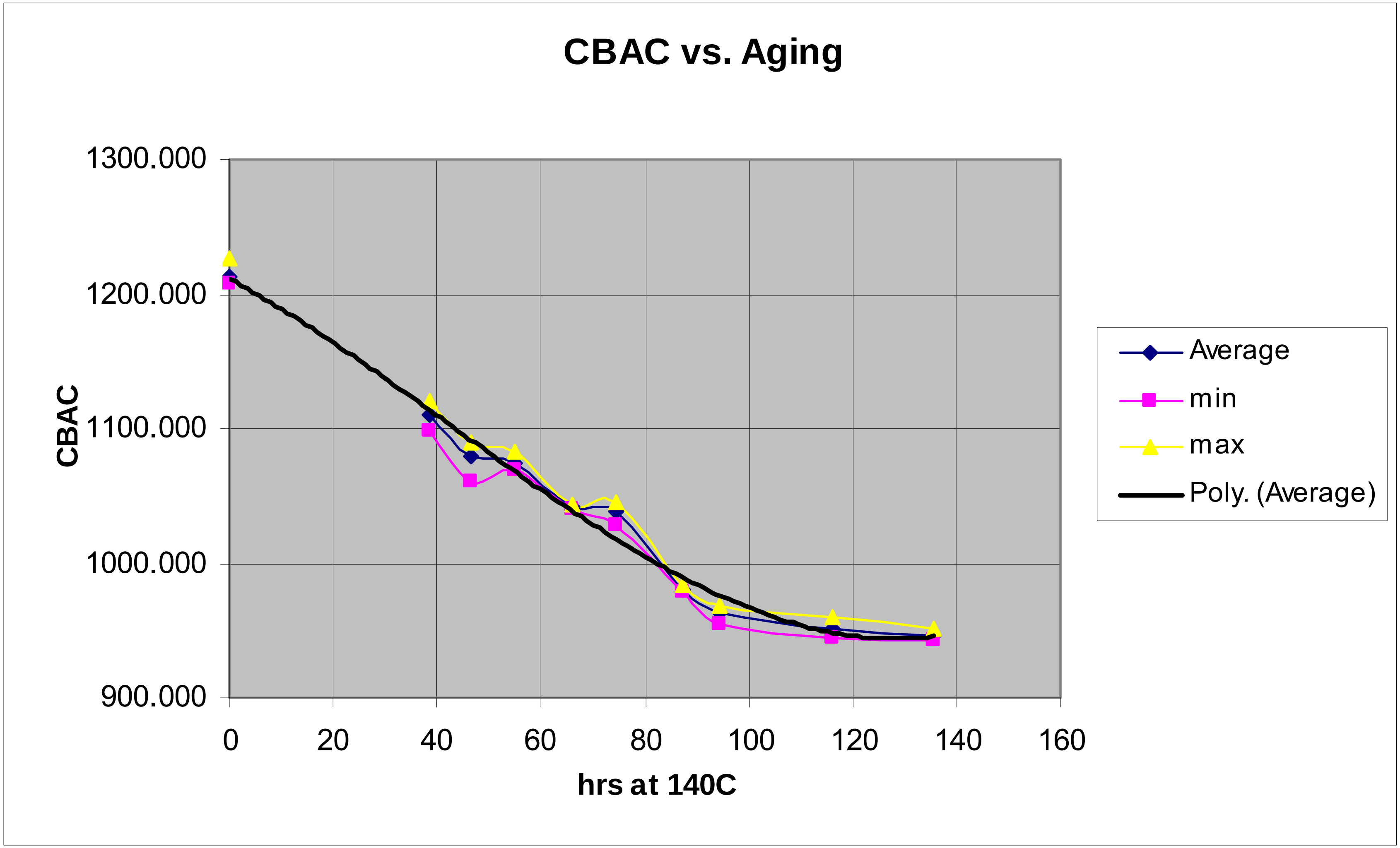
LIRA results using CBAC (TECNATOM)



Dilectric Capacitance vs. Aging - EPDM (2009)



CBAC vs. Aging - EPDM insulation (2009)



Conclusions

- LIRA methodology looks promising in assessing cable conditions, both locally and globaly.
- Work (NKS) on EPDM insulated cables of different types is still in progress in 2009.
- Experimentation is still needed to study the capability of LIRA and other methods to assess degradation after gamma irradiation (together with thermal degradation)