Ageing of Cables: Principles and Characterization Techniques

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Generalities

- Ageing of polymers. Life-time
- General methods for ageing characterization

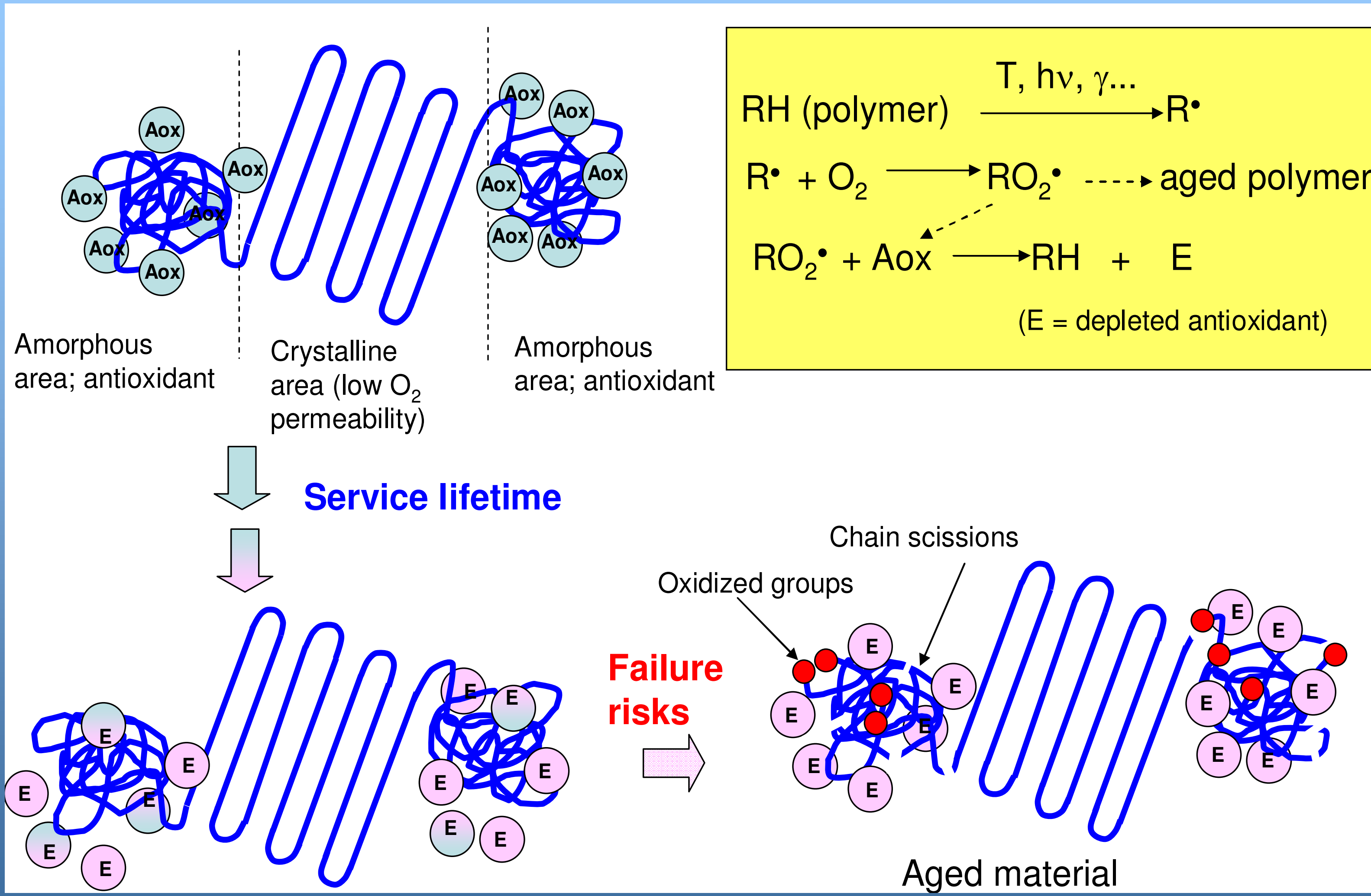
DSC in characterization of the cable insulators ageing

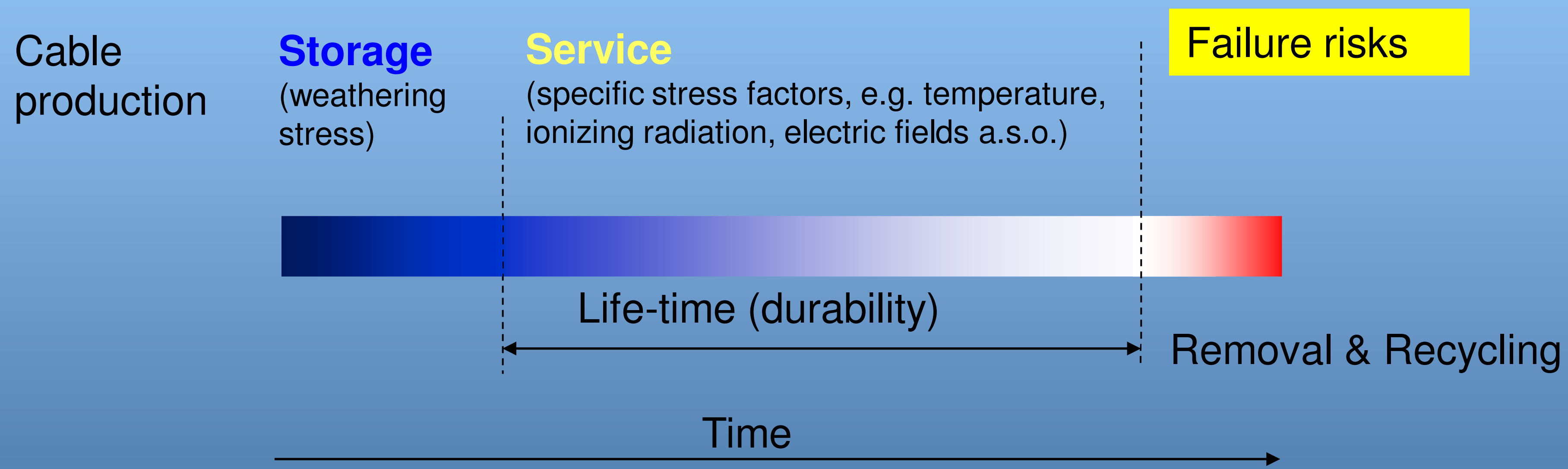
- Isothermal DSC
  - OIT
  - Applicable materials
- Non-isothermal DSC
  - OOT
  - Calculation of OIT fro OOT data
- The kinetic degradation model
  - Time-based model
  - Dose-based model

Examples of ageing characterization

- Radiation-ageing
- Non-radiation ageing

Conclusions


Aox
E
Amorphous area; antioxidant
Crystalline area (low O_2 permeability)
Amorphous area; antioxidant
T, hν, γ...
RH (polymer) → R•
R• + O_2 → RO_2• - - - → aged polymer
RO_2• + Aox → RH + E
(E = depleted antioxidant)
Service lifetime
Failure risks
Chain scissions
Oxidized groups
Aged material


Cable production
Storage
(weathering stress)
Service
(specific stress factors, e.g. temperature, ionizing radiation, electric fields a.s.o.)
Failure risks
Life-time (durability)
Removal & Recycling
Time

General methods for polymeric materials ageing characterization - large amounts of sample material available

Mechanical tests (elongation, tensile strength, modulus...)
large amounts of sample;
applicable for materials characterization
Thermal analysis (DSC, CL, DSC-TG, DTA, DMA...)
FTIR
RES
Electric properties
...

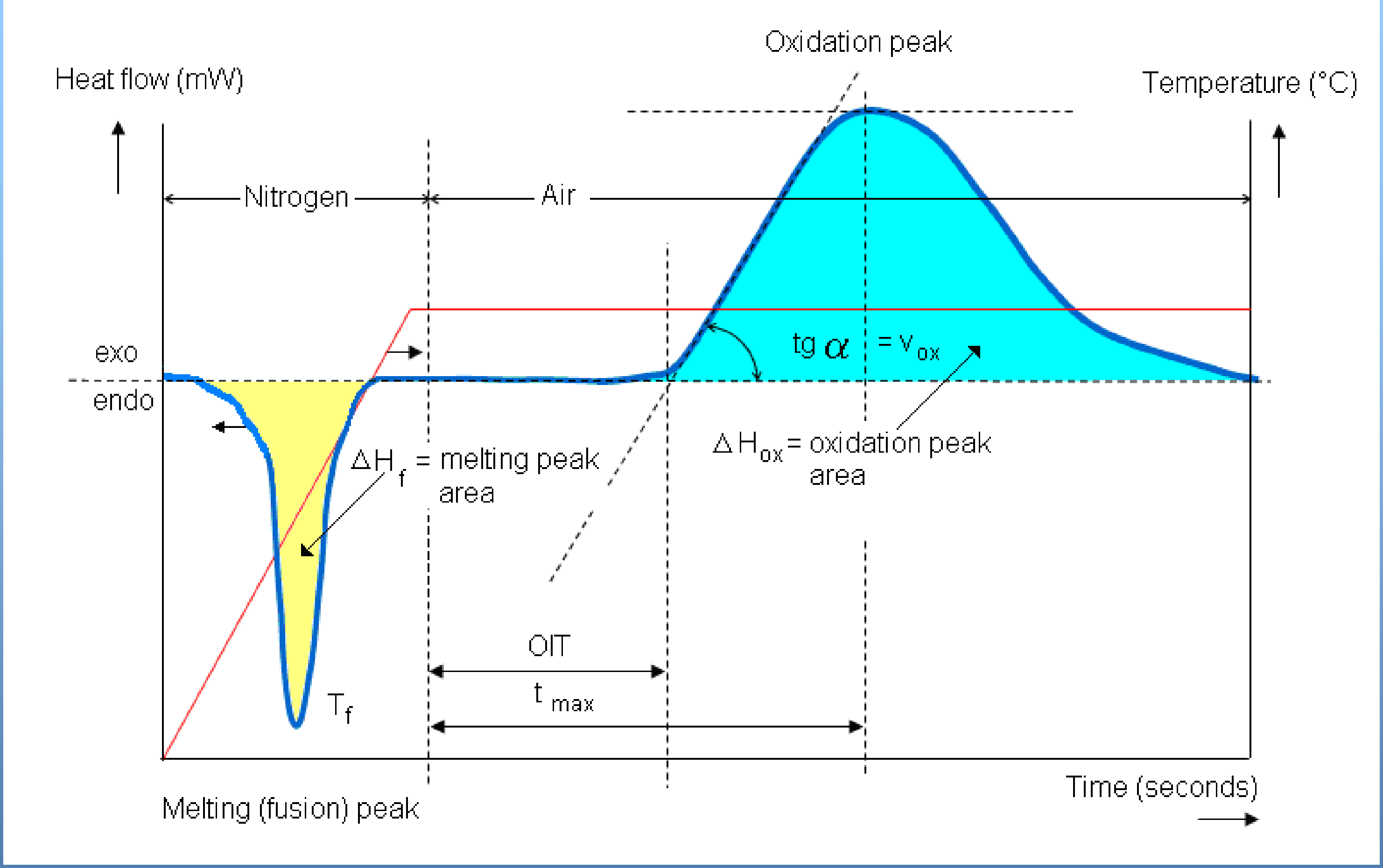
Methods recommended for cables ageing monitoring - small amounts of sample material available (IEC 60544)

- **Indenter** (mechanical test) - non destructive (cable sheaths measurements; difficult to correlate the values of indenter modulus to the ageing state, in some cases
- **Thermal analysis:**
  - Oxidation Induction Time (OIT) - isothermal
  - Oxidation Onset Temperature (OOT) - non-isothermal
    - measured by Chemiluminescence (CL), Differential Scanning Calorimetry (DSC); sample size: 2-3 mg;
  - TGA
- **Density measurements** - density gradient columns; sample size: 2-3 mg

DSC in ageing characterization of the cable polymeric insulating materials ageing

Generalities on the method (typical DSC curves and parameters)

Examples of application on CERN cables and results



OIT (oxidation induction time) is the time interval to onset of exothermic oxidation of a material at a specified temperature in an oxygen containing atmosphere (ASTM 3895-07). OIT can be measured by isothermal **CL** or **DSC**

OIT ~ Antioxidant concentration → → life-time evaluation

From the work carried out, the **isothermal DSC method** can be applied to the following types of polymeric insulators:

- Polyethylene:
  LDPE; XLPE, PE cell; MDPE; HDPE; LLDPE

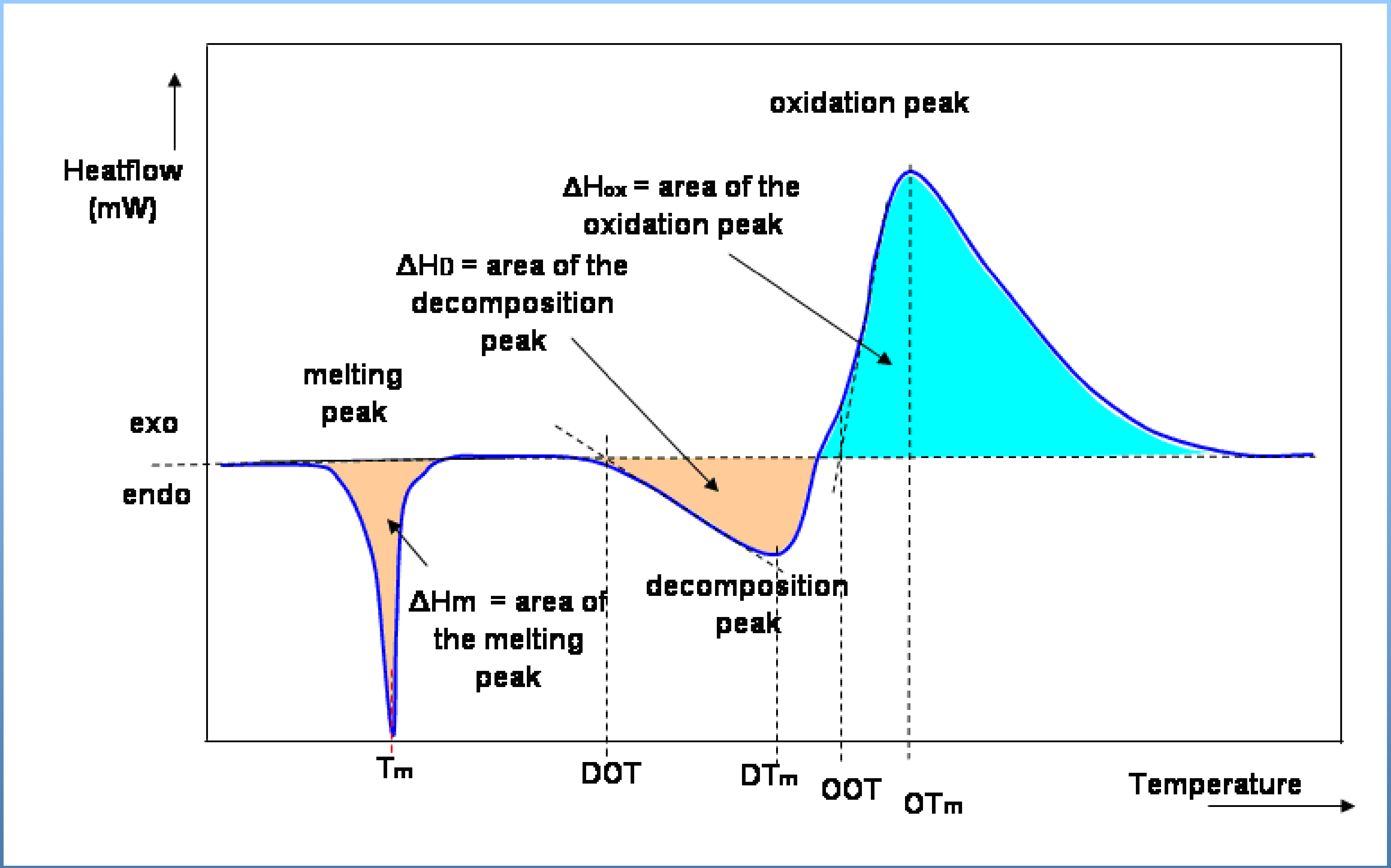
- Ethylene-propylene copolymers

- Natural and synthetic polyisoprene rubbers

- Some ethylene-vinyl acetate copolymers - limited applicability to copolymers with less (< 30 %?) vinyl acetate content - "EVA type I materials"

CERN TE/VSC/CSA-Chemistry Laboratory, Standard Operating Procedure:

SOP-DSC-01/ 2009:
Measurement of the Oxidation Induction Time (OIT) in cable polymeric insulating materials using isothermal Differential Scanning Calorimetry (DSC)



OOT (oxidation onset temperature) is determined from the data recorded during a DSC non-isothermal test, as the temperature corresponding to the oxidation onset.

OOT ~ Antioxidant concentration → → OIT → life-time evaluation

Calculation of OIT from OOT data

Method:
I determination of OOT at 4 different heating rates (e.g. 2.5, 5.0, 10.0 and 15.0 K/min.)
II determination of the activation energy (E_a/R) of the oxidation process:

$$ln\frac{OOT^2}{\beta} = \frac{E_a}{R \cdot OOT} + C$$

β = heating rate;
E_a = activation energy;
R = the gas constant

III determination of OIT from the equation:

$$OIT = \frac{1}{\beta} \cdot \frac{\int_{T_0}^{OOT} e^{-\frac{E_a}{R}dT}}{e^{-\frac{E_a}{RT_{iso}}}}$$

E_a = activation energy, T = temperature;
T_0 = *starting temperature of non-isothermal test*
T_{iso} = the temperature of an isothermal experiment;
OOT = oxidation onset temperature
R = gas constant;
t = time;

The OIT calculated from OOT is equivalent to the OIT measured in isothermal DSC mode

Non-isothermal testing is convenient if:
- the material cannot be measured in isothermal (OIT not evident or too long)
- the thermal effect of isothermal oxidation is weak

From the work carried out, the **non-isothermal DSC method** **(and subsequent OIT calculation)** is more generally applicable;

- High stability EVA copolymers - "EVA type II materials"

- it can be useful for OIT determination in high stability polymers and/or in those presenting weak oxidation heat, e.g.
    - PE cell insulation
    - EPR insulation or jacketing material

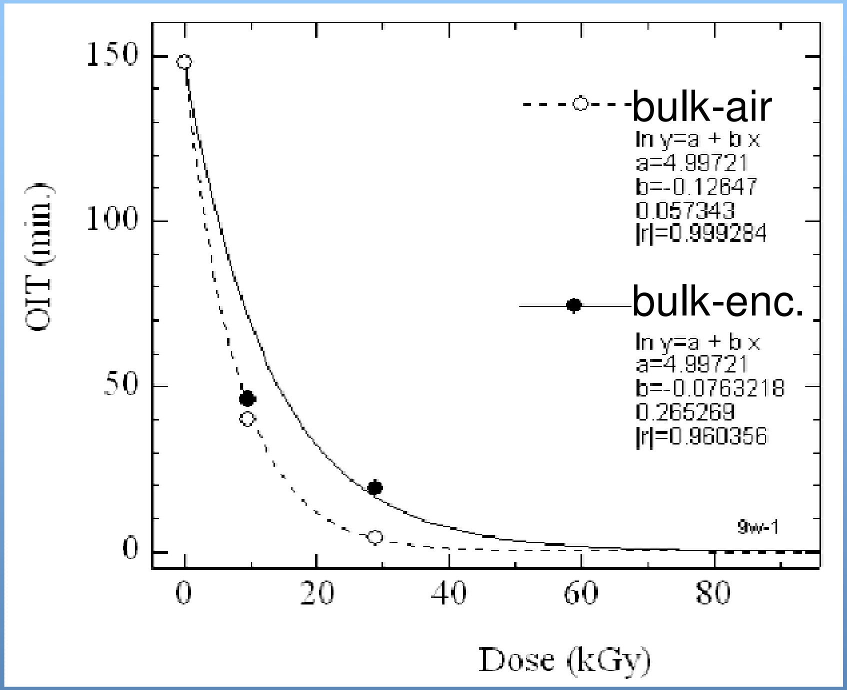
CERN TE/VSC/CSA-Chemistry Laboratory, Standard Operating Procedure:

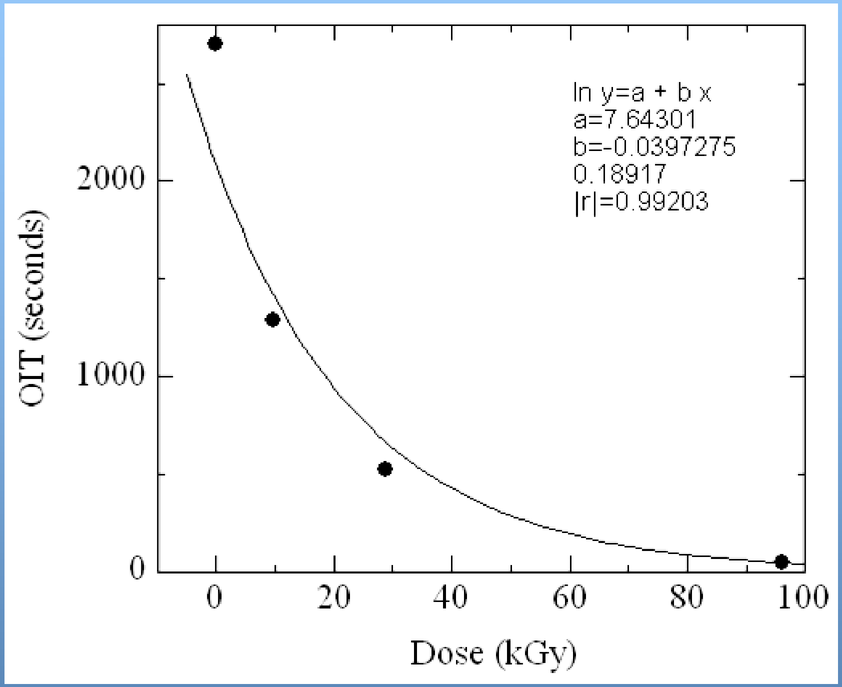
SOP-DSC-02:
Measurement of the Oxidation Onset Temperature (OOT) in cable polymeric insulating materials using non-isothermal Differential Scanning Calorimetry (DSC) and calculation of Oxidation Induction Time (OIT) from OOT data

Cables aging in ionizing radiation fields

- DSC and FTIR measurements on CERN cables (materials identification);
- irradiation ageing characterization (DSC, CL, FTIR, Shore D...):
  - irradiation in controlled conditions:
    - γ^{137} Cs, D_r = 0.4 kGy/h, at ICPE-CA Bucharest, Ro
    - γ^{60} Cs, D_r = 1.5 kGy/h, at Ionisos Dagneaux, Fr
    - γ^{60} Cs, D_r = 21.1 kGy/h, at BGS, Wiehl, De
  - CERN irradiated - witness and service aged (used cables);
- degradation kinetic model, based on OIT, for life-time & maximum supportable dose estimations
- applicability of the isothermal DSC method as a function of the chemical nature of polymeric materials used as cable insulators
- reports and testing procedures

OIT and OOT values decreases as the ageing time (or the dose) increases.
The life-time evaluation using the decrease of OIT is possible





The OIT exponential decrease for some irradiated (γ ^{137}Cs, D_r = 400 Gy/h) cable insulating materials:

(1) - NG-18, LDPE insulation (white material), irradiated as bulk

(2) - Silec cable, LDPE insulation, irradiated as strap

DSC: isothermal, 190 ℃

The exponential degradation models

(a) Time based model

$$OIT_{t_1} = OIT_{t_2} \cdot \frac{e^{-kt_1}}{e^{-kt_2}}$$

where:
$OIT_{ti} = OIT$ *at the ageing time* t_i; i = 1, 2
$k =$ the rate constant; dependent on material and irradiation conditions

the rate constant (k):

$$k = \frac{1}{t_2 - t_1} ln \frac{OIT_{t_1}}{OIT_{t_2}}$$

the end-life criterion (OIT ≈ 0)

$$OIT_{t_x} = 0.2\, min.$$

the life-time (t_x):

$$t_x = t_1 + \frac{1}{k} ln \frac{OIT_{t_1}}{OIT_{t_x}}$$

the residual life-time (rt_x)

$$rt_x = t_x - t_2$$

The exponential degradation models

(b) Dose based model

$$OIT_{D_1} = OIT_{D_2} \cdot \frac{e^{-k' D_1}}{e^{-k' D_2}}$$

where:
OIT_{Di} = *OIT at dose* D_i; i = 1, 2
k' = the rate constant; specific and dependent of irradiation conditions

the rate constant (k'):

$$k = \frac{1}{D_2 - D_1} ln \frac{OIT_{D_1}}{OIT_{D_2}}$$

the end-life criterion (OIT ≈ 0)

$$OIT_{t_x} = 0.2\, min.$$

the maximum supportable dose (D_x):

$$D_x = D_1 + \frac{1}{k'} ln \frac{OIT_{D_1}}{OIT_{D_x}}$$

the residual supportable dose (rD_x)

$$rD_x = D_x - D_2$$

the radiation index (RI)

$$RI = log_{10}[D_x (Gy)]$$

The relation between the dose and time:

$$D_r = \frac{D}{t}$$

CERN TE/VSC/CSA-Chemistry Laboratory, Standard Operating Procedure:

SOP-DSC-03:
Evaluation of The Life-Time of Cable Polymeric Materials using the Oxidation Induction Time (OIT) from DSC Measurements.

Summary of the life-time (D_x) values found for the insulation and the jacket materials in NG-18 cable

Material	Irradiation conditions	OIT_0 (min.)	k (kGy^{-1})	D_x (kGy)	RI	Remarks
white insulation (LDPE)	0.4 kGy/h, bulk-air	148*	0.127	53	4.7	
	0.4 kGy/h, bulk-enc.		0.0763	89	4.9	D_x = 84 kGy by CL
	1.5 kGy/h		-	< 300	-	
brown insulation (LDPE)	0.4 kGy/h bulk-air	157*	0.153	45	4.7	
	0.4 kGy/h bulk-enc.		0.0846	81	4.9	D_x = 85 kGy by CL
	1.5 kGy/h		-	< 300	-	
jacket (EVA copolymer, type I)	0.4 kGy/h	343**	0.0106	720	5.9	D_x = 642 kGy by CL
	1.5 kGy/h		0.0094	811	5.9	

*measured at 190 °C, in air; **measured at 210 °C, in air

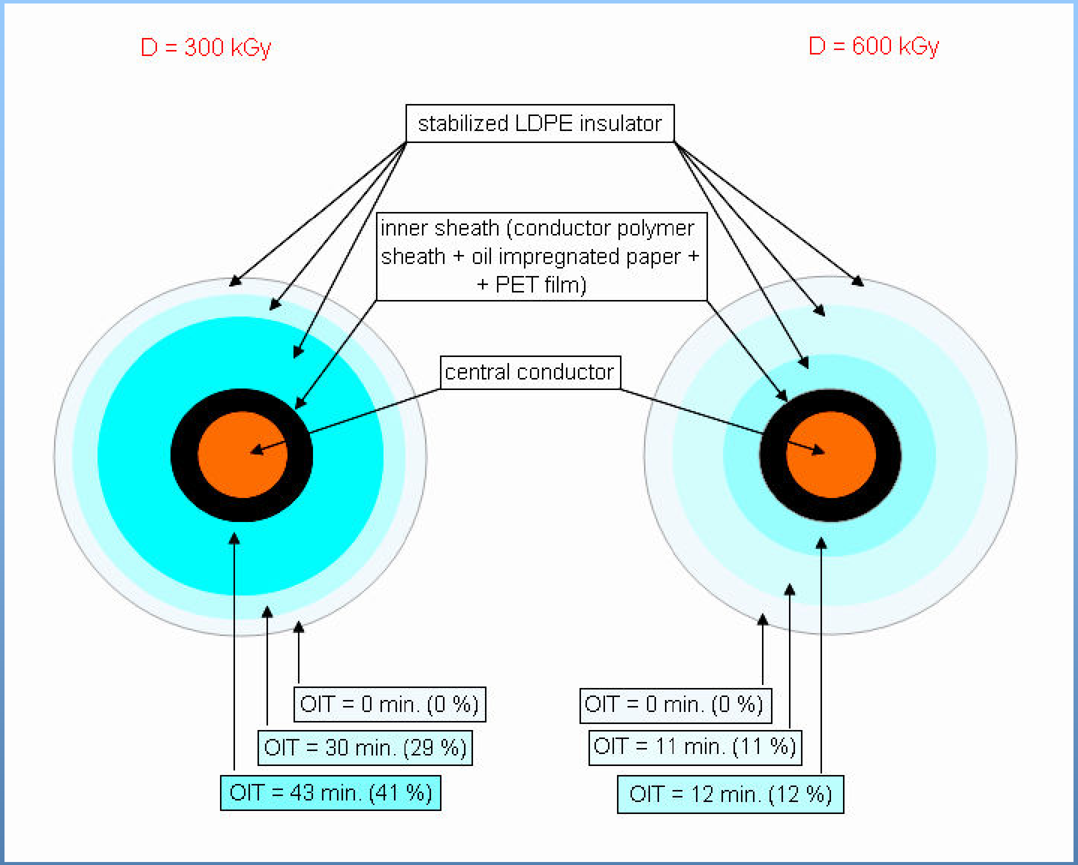


Illustration of the oxidation profiles in the PE insulator of a cable **PB-300** (insulation thickness ~ 7 mm);
OIT measured by DSC in isothermal mode (T = 190 °C).
The values in brackets indicate the OIT decrease induced by irradiation (in percents).

Technical Reports and Seminars on radiation induced ageing of cables polymeric insulating materials

S. Ilie, R. Setnescu, "*Compilation of the DSC and ATR-FTIR data on irradiated CERN cables*", November 2009, in print

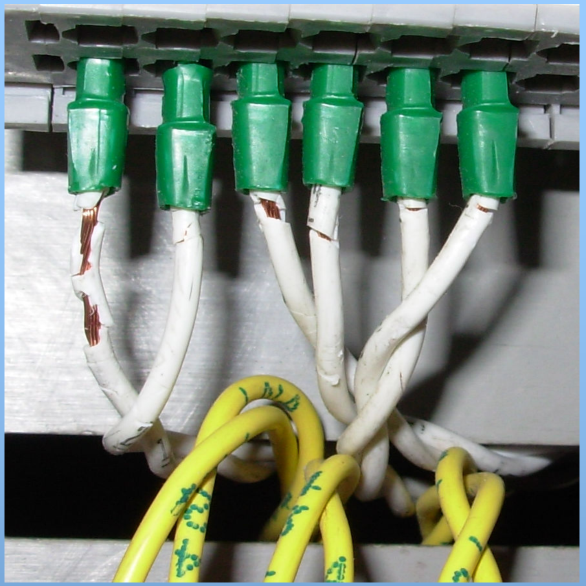
S. Ilie, R. Setnescu, "*Radiation Induced Aging Effects in Polymeric Cable Insulators at CERN",* TE-VSC Technical note, October 2009, in print

S. Ilie, R. Setnescu, *Polymeric Materials Review on Oxidation, "Stabilization and Evaluation using CL and DSC Methods",* TE-VSC Technical note, September 2009

S. Ilie, R. Setnescu "*Aging effects induced by ionizing radiations and/or normal environments on some CERN electrical cables insulations: ongoing works in Chemistry Laboratory",* RIAC-WG 04 June 2009, EDMS 1013644

S. Ilie, R. Setnescu, "*DSC tests on LSS-2 Cable materials". Note for AB-ABP,* March 2008

S. Ilie, R. Setnescu, "*Oxidative degradation and stabilization of polymeric materials, principles and methods of their life-time evaluation"*
CERN TS Seminar 29 Aug. 2007, EDMS 905340



Cables ageing in CERN non-radiative environments

- investigation of abnormal degradation of some CERN cables

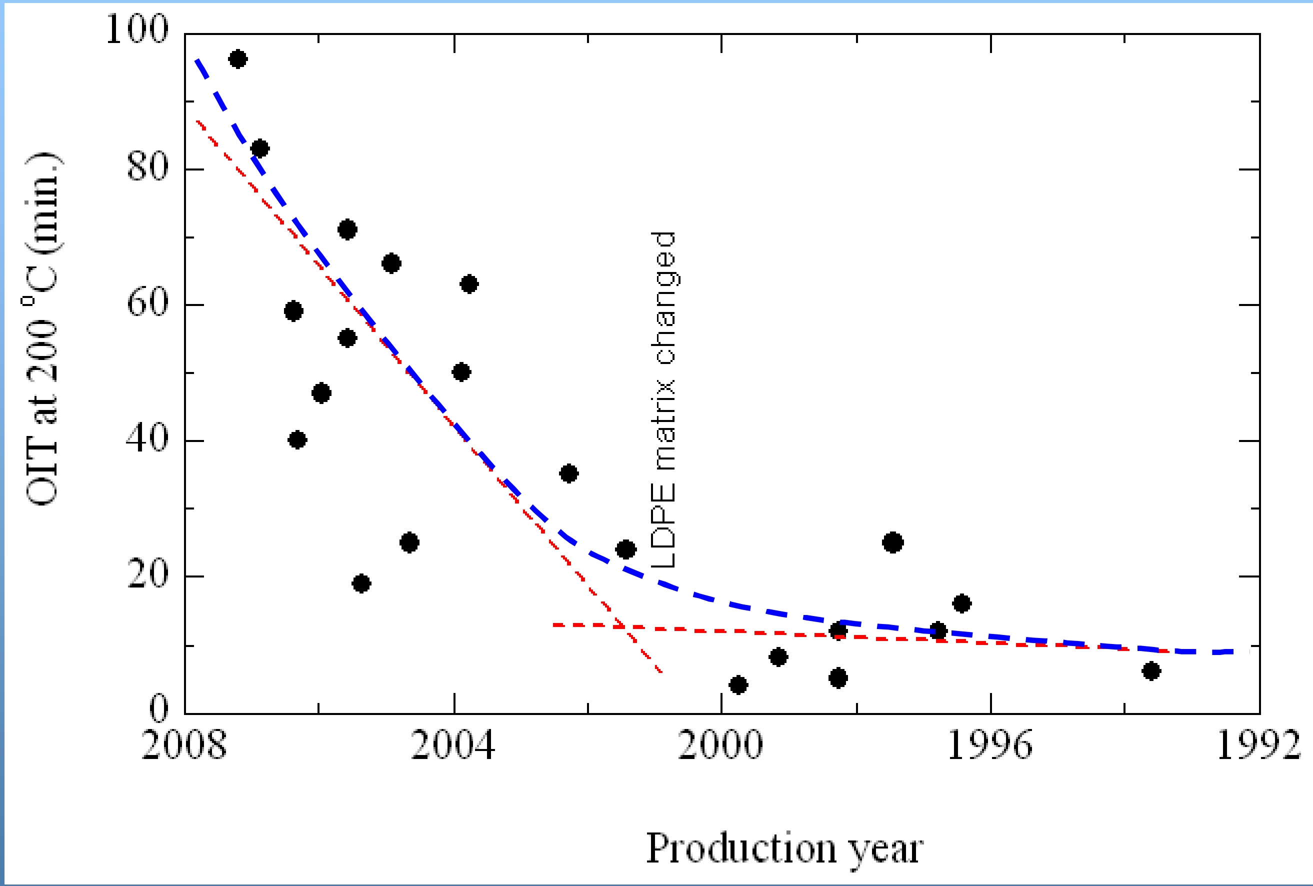
- common work with the producers to improve the quality of the cables supplied to CERN

- proposals for introduction of quality control tests on the as received cables

S. Ilie, R. Setnescu "*Draka Cable ageing*" October 2007 CERN EDMS 873423

S. Ilie, R. Setnescu "*Tentative explanation of the unexpected ageing of NG 18 and of similar cables in indoor conditions Part two: tests on raw materials*" CERN/Draka Seminar 14 Feb. 2008

S. Ilie, R. Setnescu, "*Results on DSC and FTIR Investigation of Insulation Materials Aged in non-Radiative Environments*" - TE/VSC Note 2009, in print



Comparative characterization by isothermal DSC of the stability at 200 ℃ (OIT values) in air of LDPE white insulation of NX-YZ type cables as a function of the production year

Conclusions

- The present work confirms the Differential Scanning Calorimetry (DSC) as an appropriate method to evaluate the aging state, hence the life-time, of most of the polymeric materials in irradiated cable polymeric insulating materials used in CERN accelerators.

- The DSC method can evaluate the antioxidative protection (quality and uniformity) in the as received or the stored cable polymeric insulating materials cable insulators.

- The isothermal DSC method is more rapid and cost effective as compared to the classical electrical and mechanical tests, but the electrical and mechanical tests constitute the true reference tests.

- A kinetic model, based on the exponential decrease of the OIT's as a function of the irradiation time (t), or the irradiation dose (D), is proposed, checked and developed within the project work.

-The maximum supportable dose Dx values found for the PE insulating materials irradiated with gammas ^{137}Cs are not within the limits of the CERN specifications for the general purpose cables.
Note: the radiation aging of PE based insulators are strongly dose rate dependent; the dose rate imposed by IS 23 (higher as 1 Gy/s) for the radiation resistance tests must be revised.

- The maximum supportable dose Dx values found for the EVA jacketing materials irradiated with gammas ^{137}Cs are in the limits of the CERN specifications for the general purpose cables and in concordance to the RI values found in CERN by Schönbacher, Tavlet et al. using mechanical tests.

- Following the rapid and unexpected aging of some cables for CERN general use from DRAKA, our measurements revealed large non-uniformities and cables without sufficient antioxidative protection; we contacted the supplier experts and demonstrated the causes; following his recent information, the supplier produced and is able now to offer better protected cables.

Thank you for your attention!

I'm waiting for yours questions

Reserve

One of the ultimate aims of polymer degradation studies is the ability to predict material life-times via a detailed understanding of the degradation mechanism and the controlling parameters involved. Despite the wealth of information currently available describing the various aspects of polymer degradation, both in chemical and physical terms, lifetime prediction remains very much an art plagued by the intrinsic dilemma of the need to extrapolate data from accelerated experiments (primarily at elevated environmental stress levels, e.g. higher temperatures, dose rates, etc.) to ambient conditions.

M. Celina, K. T. Gillen, J. Wise and R. L. Clough - "Anomalous Aging Phenomena in a Crosslinked Polyolefin Cable Insulation"
Radiat. Phys. Chem. Vol. 48, No. 5, pp. 613-626, 1996

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Ageing of Cables: Principles and Characterization Techniques

Authors	Title	Publication	Investigation methods
M. van de Voorde (Ed.)	Low-temperature irradiation effects on materials and components for superconducting magnets for high-energy physics applications	CERN 77-03 (Yellow Reports)	Mechanical properties (flexural tests), specific heat, thermal conductivity
H. Schönbacher and A. Stolarz-Izicka	Compilation of radiation damage test data, Part I: Cable insulating materials	CERN 79–04 (Yellow Report).	Mechanical properties (tensile and Shore hardness), oxygen index
P. Beynel, M. Tavlet, H. Schonbacher	Compilation of radiation damage data: materials used around high-energy accelerators	CERN 82-10 (Yellow Report)	Mechanical properties (tensile, Shore hardness), oxygen index
P. Maier, A Stolarz	Long-term radiation effects on commercial cable-insulating materials irradiated at CERN	CERN 83-08 (Yellow Report)	Mechanical properties
P. Beynel, M. Tavlet, G.P. Tartaglia	Rapport des tests d'irradiation des matériaux utilisés dans l'anneau du LEP	LEP Note 581; TIS-RP/TM/87-19, 12 May 1987	Mechanical properties (tensile and Shore hardness)
M. Tavlet, H. Schönbacher	Compilation of radiation damage test data, pt.1 1 : Halogen-free cable-insulating materials	CERN-89-12 (Yellow Report)	Mechanical properties (tensile, Shore hardness), oxygen index
H. Schönbacher, B. Szeless, M. Tavlet, K Humer, W. Weber	Results of radiation tests at cryogenic temperature on some selected organic materials for the LHC	CERN 96-05 (Yellow Report)	Mechanical properties (tensile)
H. Schönbacher, M. Tavlet	Absorbed doses and radiation damage during the 11 years of LEP operation	CERN–TIS–2002–010–DI–PP	Mechanical properties (tensile)

Applicable standards:

- ASTM D 3895-07: Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential scanning Calorimetry

- ASTM E 2009-02: Standard Test Method for Oxidation Onset Temperature of Hydrocarbons by Differential Scanning Calorimetry

- ISO 11357-6-08: Plastics - Differential scanning calorimetry (DSC) Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT)

- ISO 60544:Electrical insulating materials – Determination of the effects of ionizing radiation. Part 5 Procedures for assessment of ageing in service

- IEC 60811 Second ed. 2004-5: Insulating and Sheathing Materials of Electric and Optical Cables - Common Test Methods. Part 4.2: Methods Specific to Polyethylene and Polypropylene Compounds. Annex B: Test Method for Cooper-Catalyzed Oxidative Degradation of Polyolefin Insulated Conductors (OIT test)

Comments on DSC and CL isothermal methods

The DSC and CL in isothermal mode provide similar information about the oxidation state of a sample and require similar low sample amounts (few milligrams).

For both methods the life-time evaluation procedure requires an initial, as received sample and an aged sample from the same material, having the aging time known.

For further practical application of the life-time value the complete knowledge of the "ageing history" of the sample (e.g. temperature, visible or UV light presence, dose, dose - rate, etc.) is required.

DSC method appeared more convenient than CL method for the investigation of CERN cable materials:

- the heat flow signal is not influenced by the optical properties of the sample.
- evidences the thermal transition zones characteristic for a polymer matrix and enables the polymer identification.

Applicable standards:

- IEC 60811 Common test methods for insulating and sheathing materials of electric cables

Part 4-2: Methods specific to polyethylene and polypropylene compounds. Section two: Elongation at break after preconditioning - Wrapping test after thermal ageing in air - Measurement of mass increase

Appendix A: Long term stability test

Appendix B: Test method for cooper-catalyzed oxidative degradation

- IEC 60544 Electrical insulating materials. Determination of the effects of ionizing radiation:

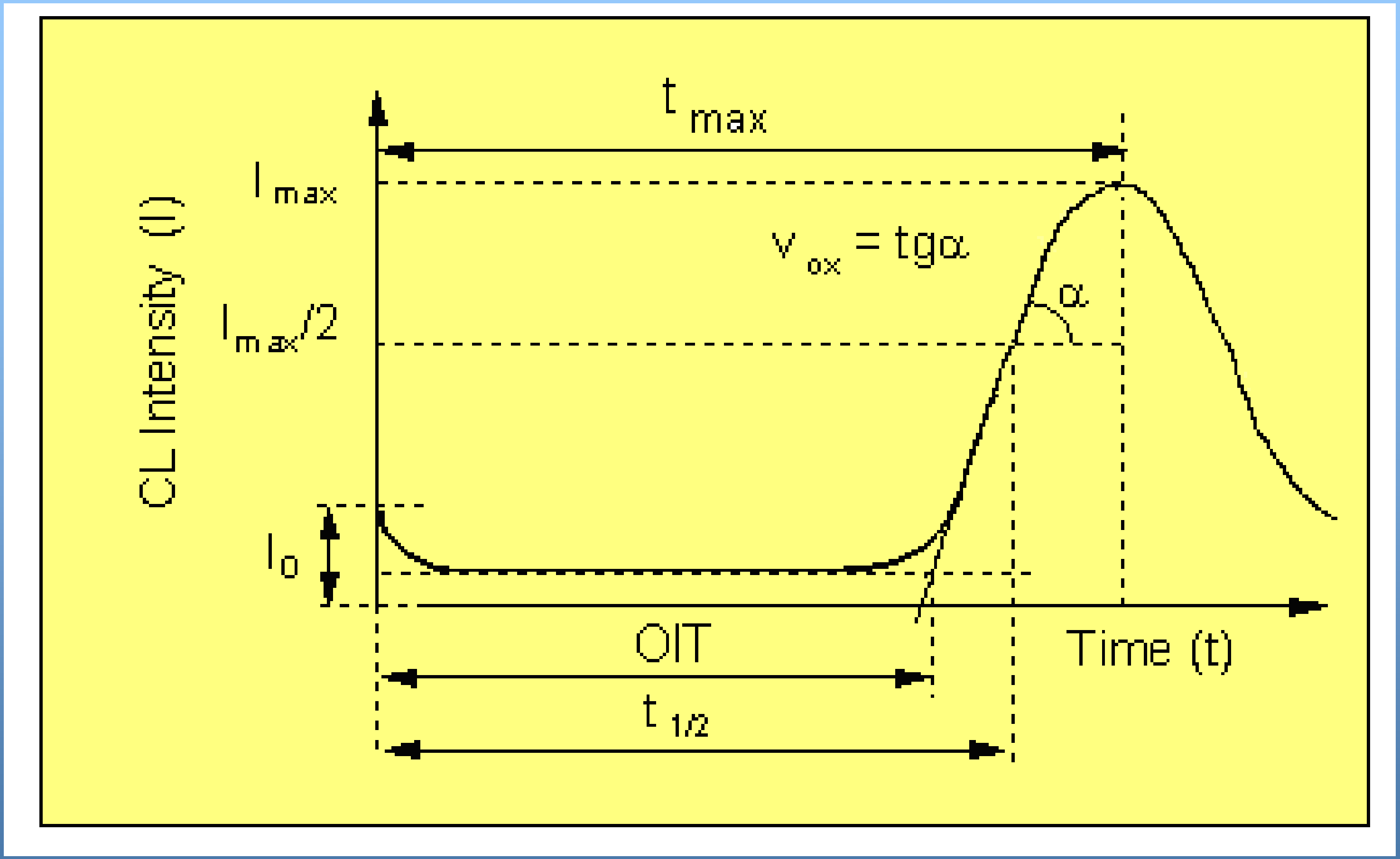
Part 1: Radiation interaction and dosimetry

Part 2: Procedures for irradiation and test

Part 3: (now incorporated into Part 2)

Part 4: Classification system for service in radiation environments

Part 5: Procedures for assessment of ageing in service



An ideal chemiluminescence (CL) curve in isothermal mode and its parameters

The ***indenter*** is an instrument that determines a parameter related to the compressive modulus of a polymer.
The probe shape is a truncated cone, whose tip diameter shall be stated in the test report.

The indenter modulus (IM) is defined for a specific force range as:

$$IM = (F1 - F2)/(d1 - d2)$$

where $F1$ and $F2$ are the force values and $d1$ and $d2$ are the corresponding displacement values over a force range covering the initial linear part of the force-displacement curve.

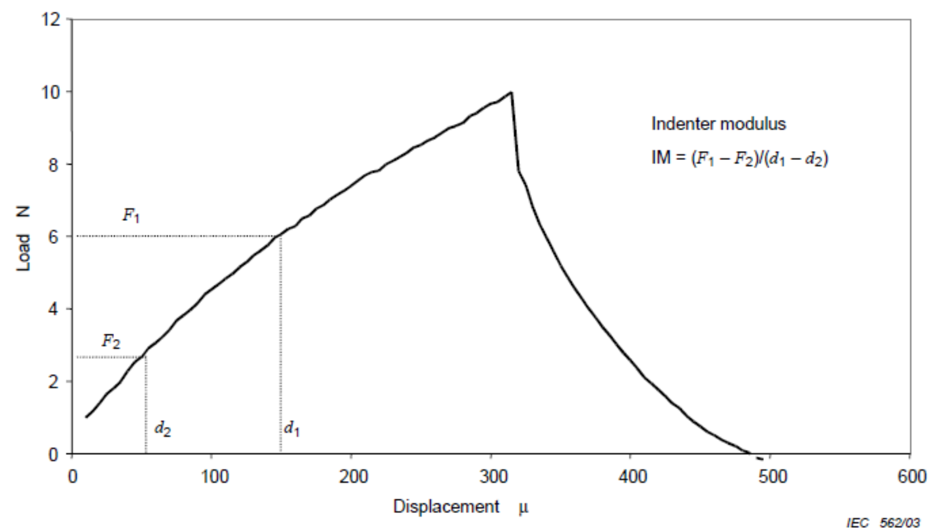


Figure 4 – Typical force – Displacement curve from indenter measurements, showing definition of indenter modulus

Reproducibility

Typically, IM values can be measured within ± 5 % to ±10 % of the mean value, depending on the material.
The IM values can be affected by the ambient testing temperature: important for PVC, EVA and CSPE; less important for EPR, EPDM, XLPE and PE (T in the range 16 °C to 24 °C).

Limitations

Good correlation data have been demonstrated for EPR, EPDM, CSPE, PVC, EVA and neoprene-based cable materials; does not work well for XLPE-based cable materials

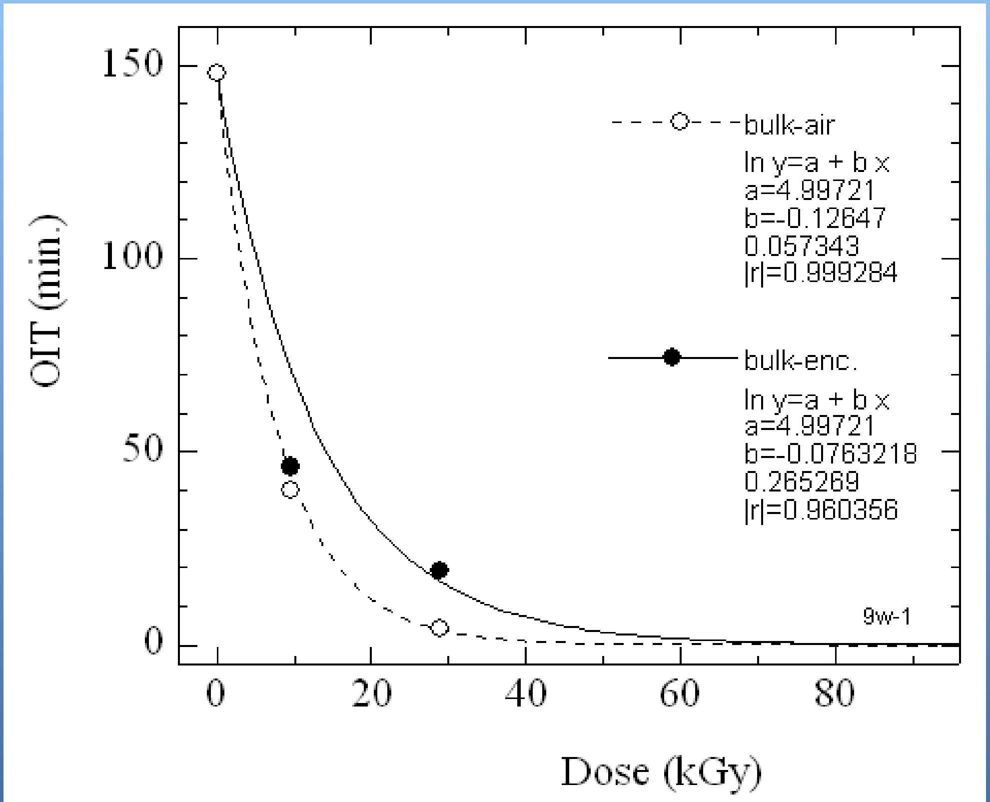
Suitable for cables and components with a cylindrical geometry with diameters in the range of 5 mm to 30 mm; wires as small as 3 mm in diameter can be measured but the variability in modulus values tends to be higher than in the larger diameters.

Normally only the jacket material is accessible for testing. It is not always possible to infer the degradation state of the insulation from the measured degradation of the jacket material. For many cables, there is little correlation between the degradation of insulation and jacket materials [2] ("Management of ageing of in-containment I&C cables: Final report of the phase II IAEA, coordinated research programme", AEAT-6577 (2000), ed. S.G. BURNAY, cit. in IEC 60544-5)

OIT and OOT values decreases as the ageing time (or the dose) increases. Life-time evaluation using the decrease of OIT is possible

Oxidation induction tests utilize micro-samples of material which can be taken from the component (for example, cable jacket material) without affecting functionality (ICE 60544-5).

Sample weight: 2 - 3 mg
Reproducibility:
- OIT measurements: ± 5 % - 10 % of the average value
- OOT measurements: ± 2 °C



Technical Reports and Seminars

S. Ilie, R. Setnescu, *Compilation of the DSC and ATR-FTIR data on irradiated CERN cables*, November 2009, in print

S. Ilie, R. Setnescu, *Radiation Induced Aging Effects in Polymeric Cable Insulators at CERN,* TE-VSC Technical note, October 2009, in print

S. Ilie, R. Setnescu, *Polymeric Materials Review on Oxidation, Stabilization and Evaluation using CL and DSC Methods,* TE-VSC Technical note, September 2009

S. Ilie, R. Setnescu *Aging effects induced by ionizing radiations and/or normal environments on some CERN electrical cables insulations: ongoing works in Chemistry Laboratory,* RIAC-WG 04 June 2009, EDMS 1013644

S. Ilie, R. Setnescu, *DSC tests on LSS-2 Cable materials. Note for AB-ABP (in attn. of Mr. Baird)* March 2008

S. Ilie, R. Setnescu *Tentative explanation of the unexpected ageing of NG 18 and of similar cables in indoor conditions* Part two: tests on raw materials CERN/Draka Seminar 14 Feb. 2008

S. Ilie, R. Setnescu Draka *Cable ageing* October 2007 CERN EDMS 873423

S. Ilie, R. Setnescu *Oxidative degradation and stabilization of polymeric materials, principles and methods of their lifetime evaluation*
CERN TS Seminar 29 Aug. 2007, EDMS 905340

Consequences of this work:

- establishing the causes of the unexpected cracking of insulation in NX-YZ cables;

- the possibility of checking of cable polymeric materials in the as received state (reproducibility of polymeric matrix and stabilization level;

- rapid ageing tests to check the ageing behavior of the new or as received materials;

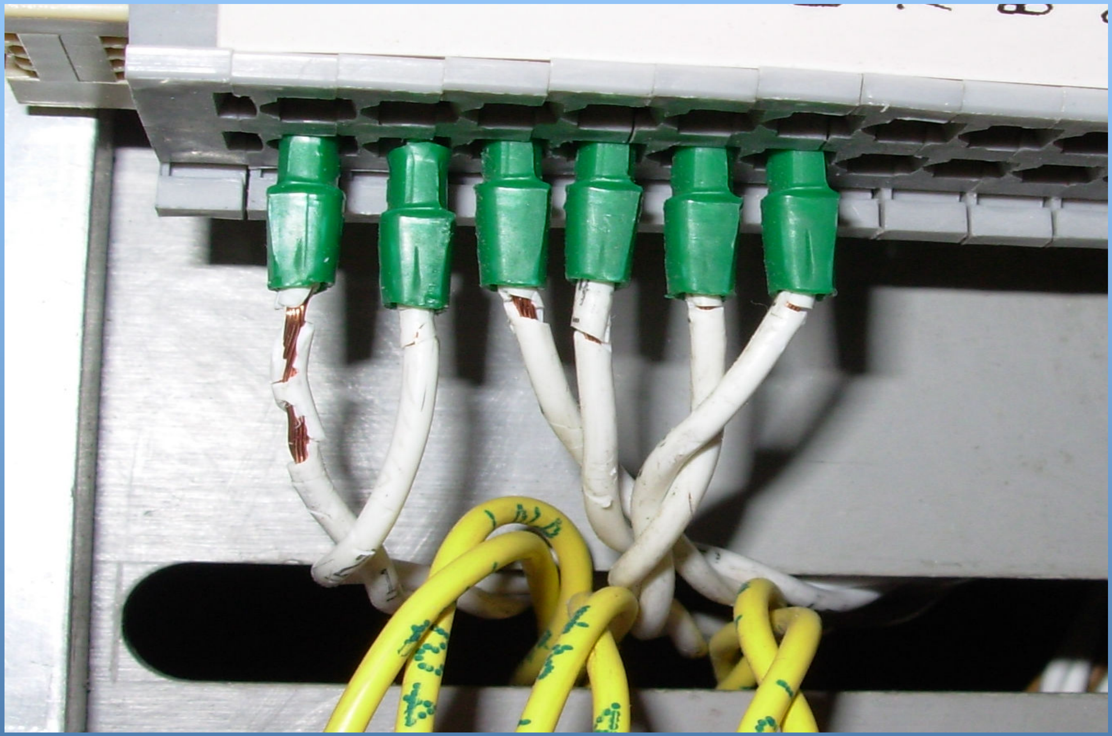
- improving the stabilization level and changing of some additives (white masterbatch) at Draka;

- Draka introduced the ageing test specified in IEC 60811 and based on OIT measurements, for the CERN cables;

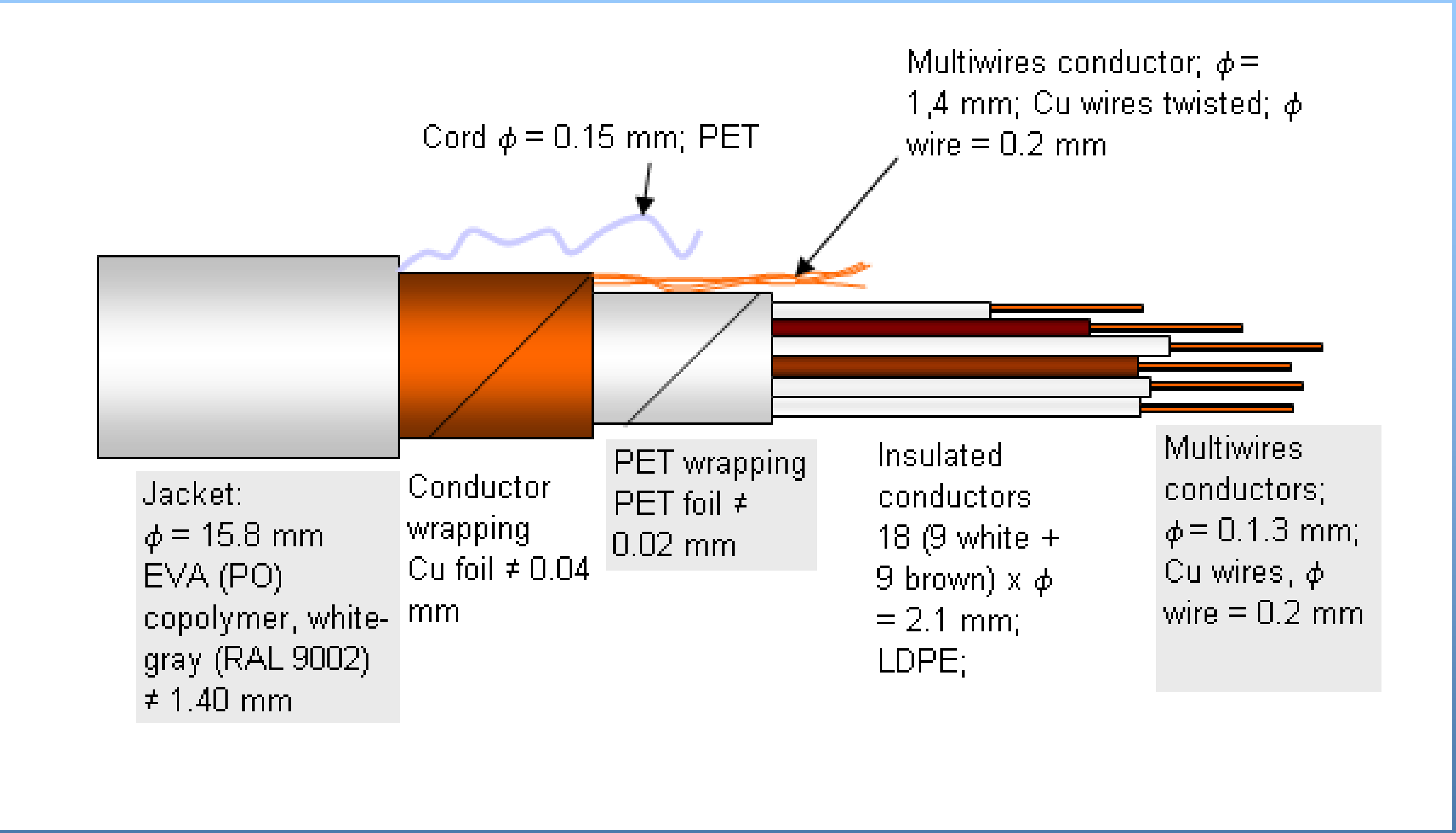
- the necessity of improvement of CERN specifications.

Examples of application and results

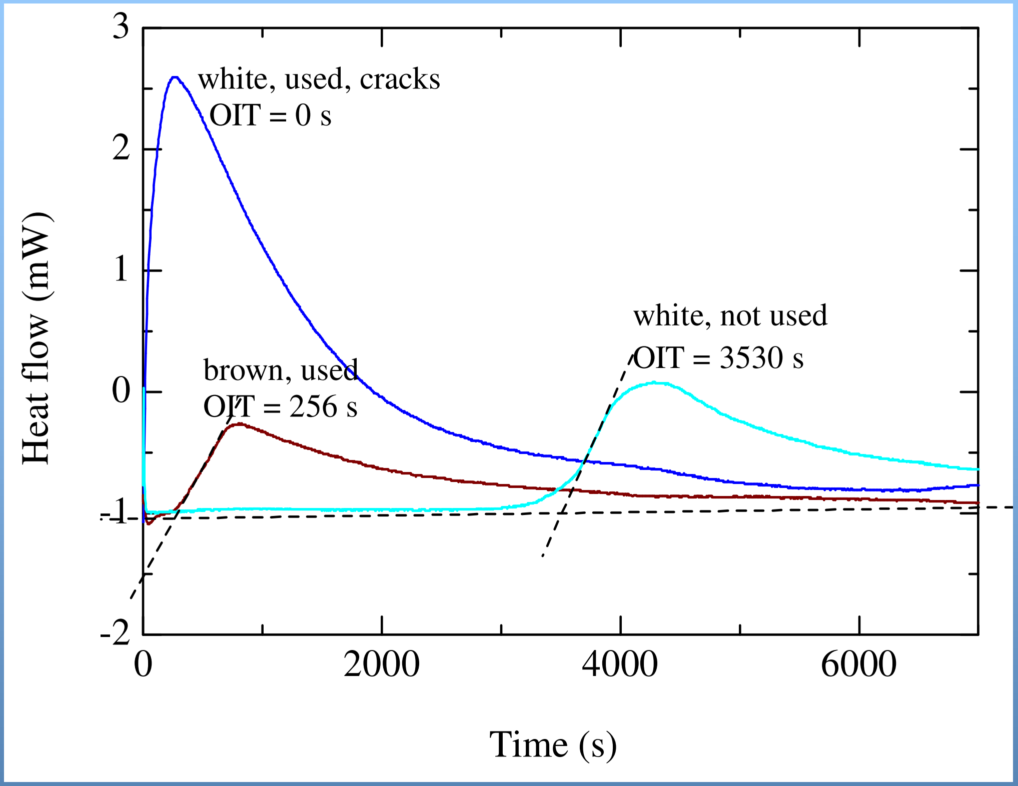
Non-radiation environment, indoor aging.
Case study: DRAKA NX-YZ type cables



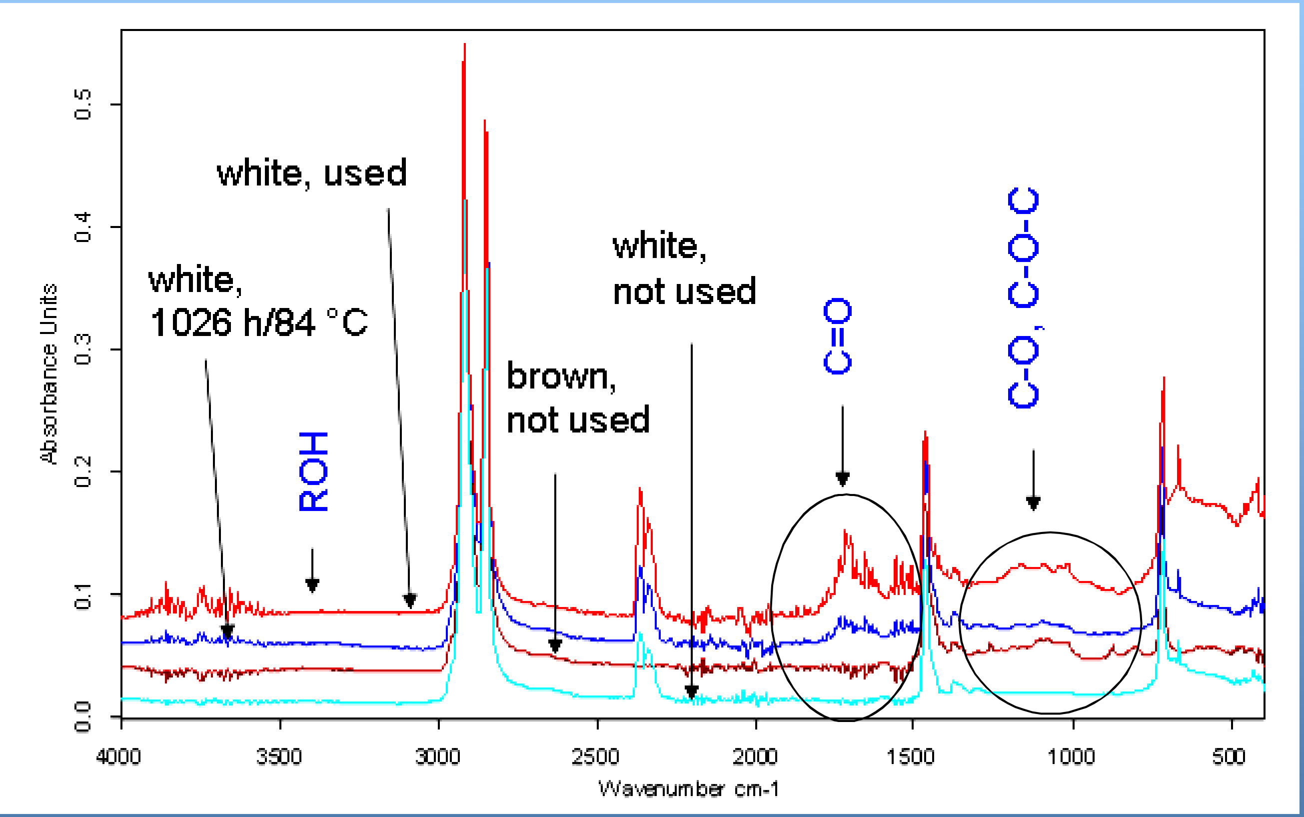
- Degradation and cracks were observed on instrumentation and control cables in indoor, at r.t. conditions after 5-7 years of service; only the white ones!
- Absence of ionizing radiations, UV light or ozone;
- Air flow or visible light were occasionally present.



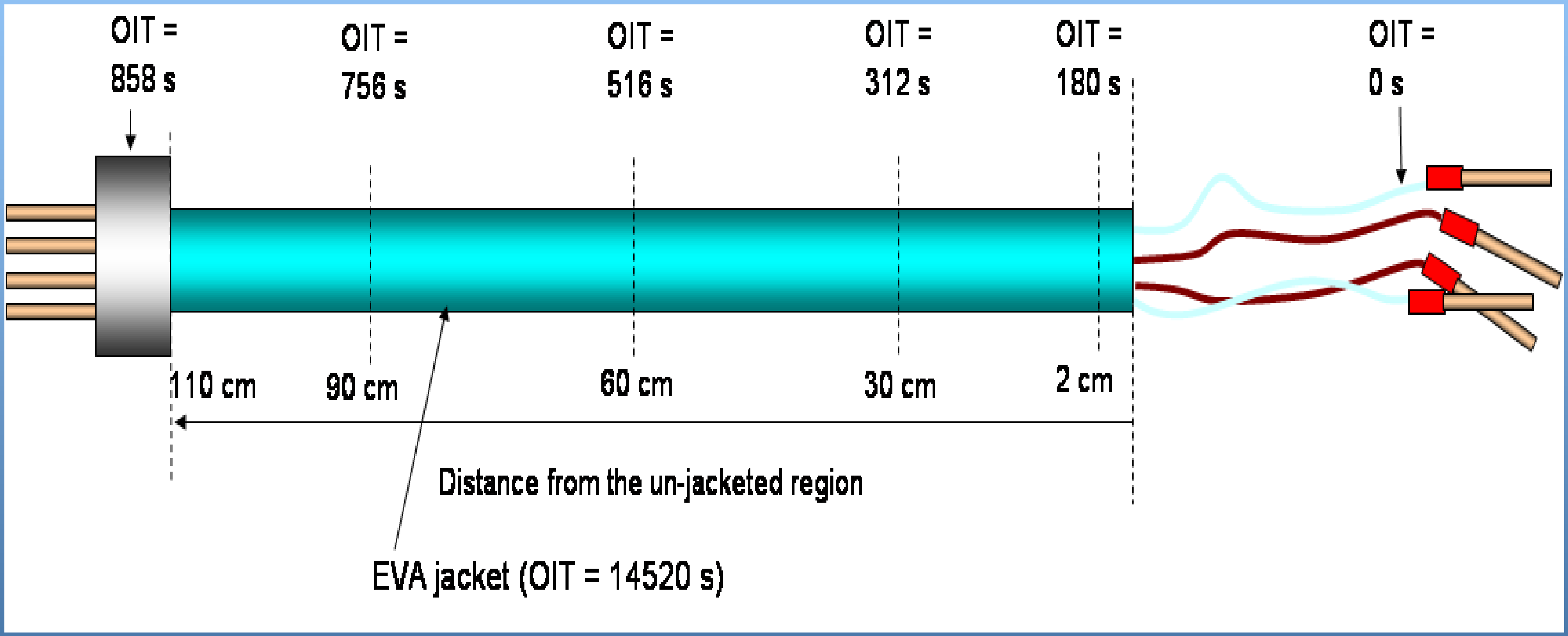
Other cables (e.g. NE-26 or NE-48) can contain differently colored insulation together white and brown: red, yellow, orange... but always the same cracking phenomena of white insulation only



DSC curves (isothermal, 200 ℃, in air) from the initial and the aged conductors insulating materials in NG-18 cable



ATR-FTIR spectra of conductors insulating materials of NG-18 cables in initial and aged states


OIT =
858 s
OIT =
756 s
OIT =
516 s
OIT =
312 s
OIT =
180 s
OIT =
0 s
110 cm
90 cm
60 cm
30 cm
2 cm
Distance from the un-jacketed region
EVA jacket (OIT = 14520 s)

Ageing in non - radiation environments

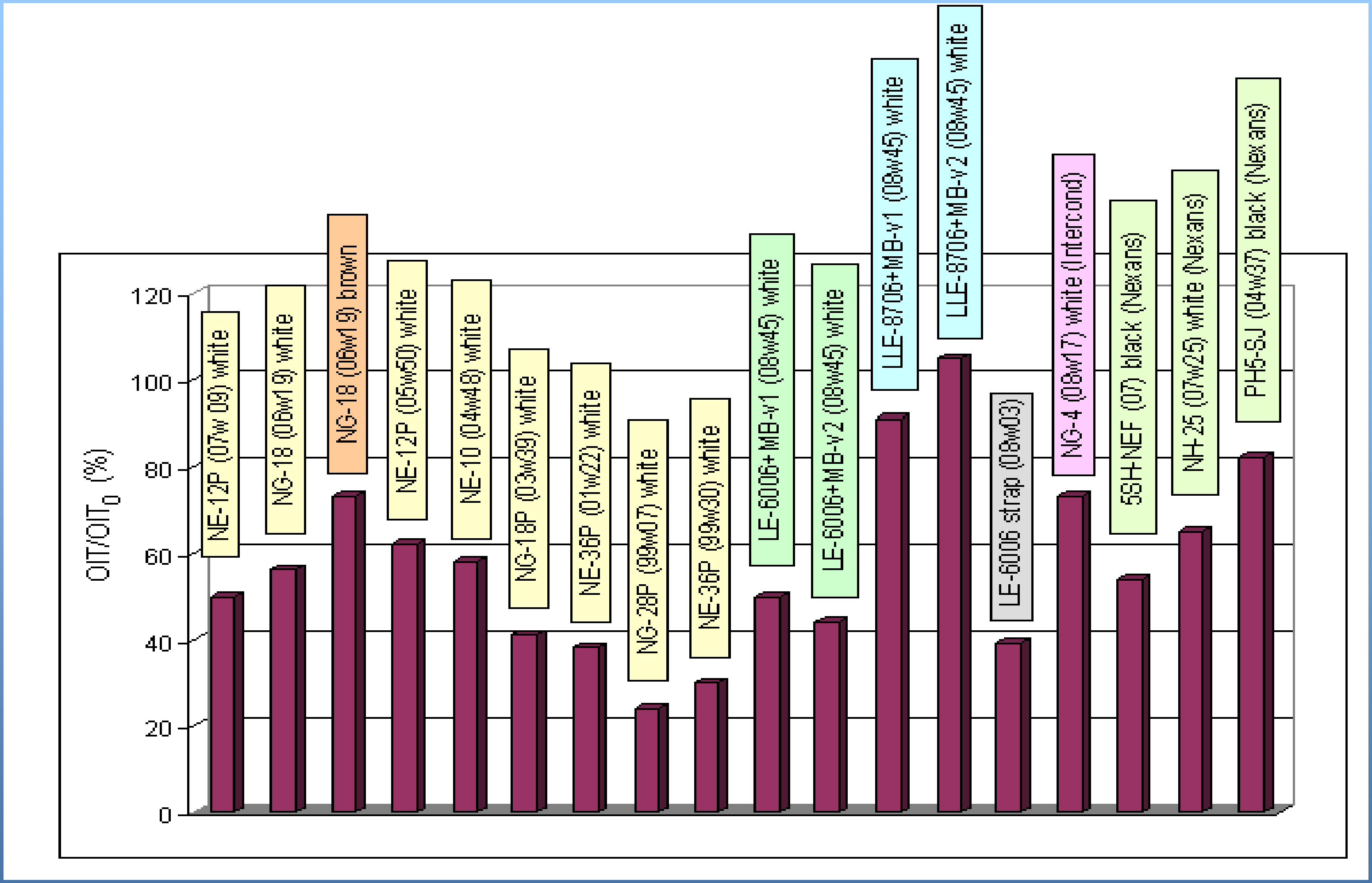
Non-radiation environments

Controlled (laboratory)

- **thermo-oxidative, different temperatures (60 - 105 °C);**
- **standard thermooxidative test 42 d/100 °C (ISO 60811-4-2);**
- **air flow, dark r.t.**
- **air flow, visible light, r.t.**

CERN aged cables

- **service aged in PCR, dry type transformers boxes (LHC surface, SPS)**



The effect of visible light and air flow (aging time = 170 h) on various insulation materials from OIT measurements (DSC, isothermal, 200 °C, air)

Examples of application and results

Ageing in radiation environments

Ageing conditions in radiation environments

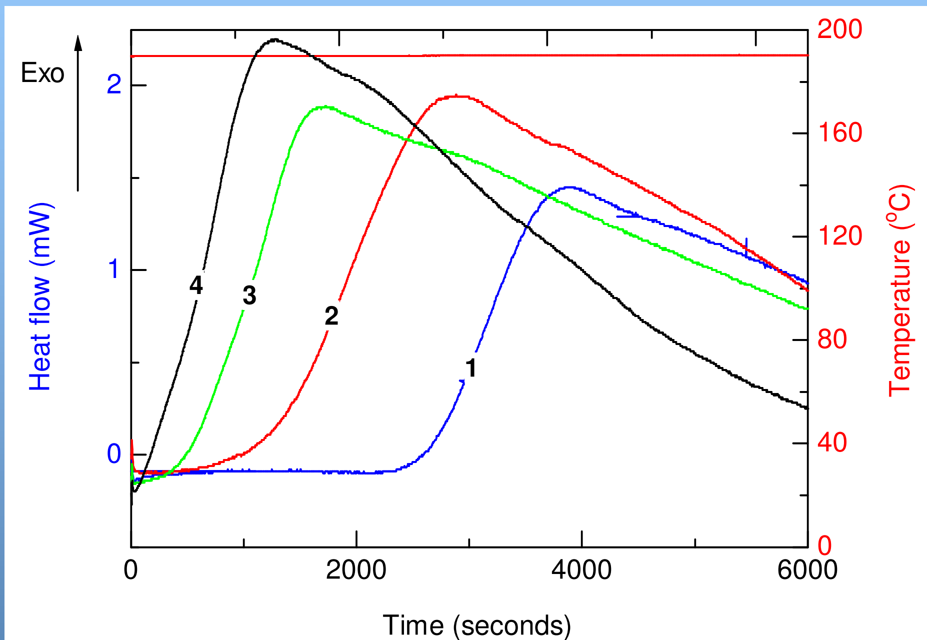
Controlled irradiation

- **γ ^{137}Cs, D_r = 0.4 kGy/h (ICPE-CA Bucharest, RO);**
- **γ ^{60}Co, D_r = 1.5 kGy/h (Ionisos, Dagneaux, FR);**
- **γ ^{60}Co, D_r = 21.1 kGy/h (BGS, Wiehl, DE)**

CERN aged cables

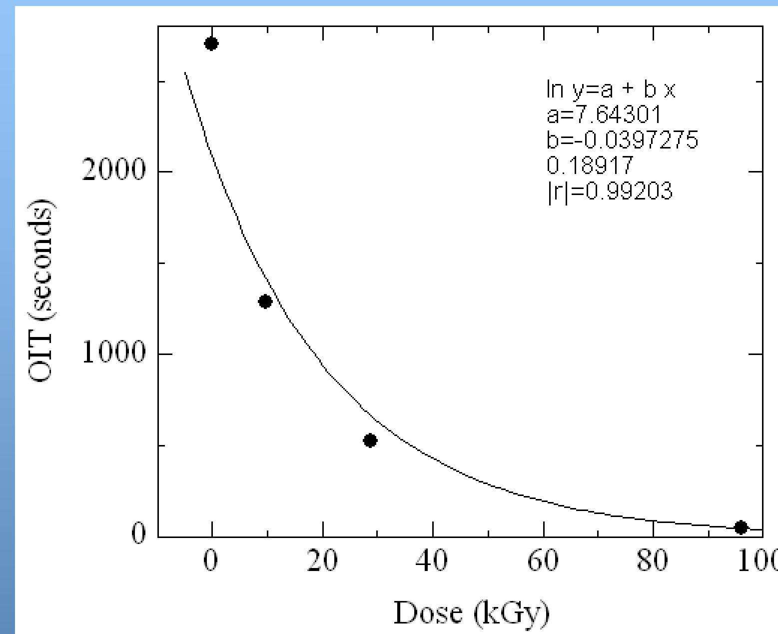
- witness aged in SPS, PS, LSS-2..
- service aged in PS, LLS-2

Irradiation effects evidenced by DSC method



The effect of γ[137]Cs irradiation on the oxidation stability at 190 ℃ in air of the PE insulation in cable **Silec,** irradiated as strap:

1 - 0 kGy (as received);
2 - 9.6 kGy;
3 - 28.8 kGy;
4 - 96 kGy



The OIT variation as a function of dose from the left figure data (exponential decrease)

Work objectives

I - CERN electrical cables

- actual CERN specifications;
- existing CERN works & data on cable polymeric insulating materials;
- applicable standards;
- collection of CERN representative cables (more than 40 cables and more than 150 cable polymeric insulating materials, and raw materials)

S. Ilie, R. Setnescu, *Radiation Induced Aging Effects in Polymeric Cable Insulators at CERN,* TE-VSC Technical note, October 2009, in print

II - Basic overview on polymers aging and on DSC method

S. Ilie, R. Setnescu, *Polymeric Materials Review on Oxidation, Stabilization and Evaluation using CL and DSC Methods,* CERN-TE-Note-2009-004. - 2009. - 62 p.