Experience with the ageing of organic insulators at CERN

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History

- CERN has been building high-energy proton accelerators for about 40 years
- Radiation-damage problems have been addressed since the design of the ISR (60's)
- The Large Electron-Positron collider (LEP) was designed in the 80's. Radiation-damage problems were a major concern.

Remind : sources of radiation

- In the hadron machines :

  beam losses, beam interaction with residual gas and surrounding materials

  → hadronic cascades

- In the lepton machine :

  synchrotron radiation

  → electro-magnetic cascades

Possible shielding

- In the hadron machines ;

  almost impossible

  best shielding = concrete

- In the lepton machine :

  lead is effective

Sensitive components

In the accelerators, from beam to walls :

- Metallic vacuum chamber, scrapers, absorbers, septa… ; no problem
- Thermal insulation ; mineral - no problem

  polymer (Kapton)
- Electrical insulation of magnet coils ;

  polymer = GFRP

Sensitive components

In the accelerators, cntd :

- Insulation of electrical cables ;

  mineral - no problem

  polymers (plastics, rubbers)

- Various (structural) components, hoses…
- Mineral and organic fluids (coolants)
- Electronic components

Sensitive components

In the particle detectors :

- Electronic components, silicon detectors,
- Organic scintillators and optical fibres,
- Insulation of electrical cables,
- Structural components (GFRP, CFRP),
- Adhesives, hoses, o-rings…
- Mineral and organic fluids (coolants)

Annual radiation levels in the CERN accelerators

- At the vacuum chamber : $10^5 - 10^7$ Gy
- Magnet coils insulations : $10^4 - 10^6$ Gy
- Cable insulations : $10^3 - 10^5$ Gy
- Ancillary equipment : $10^3 - 10^6$ Gy
- Electronic : $1 - 10^3$ Gy

Critical dose levels

• Metals and ceramics :	> 10^{10} Gy + 10^{20} n.cm^{-2}
• GFR-epoxies :	10^7 – 10^8 Gy
• Rubber cable-insulations :	10^6 – $3x10^6$ Gy
• Plastic cable-insulations :	10^5 – $3x10^5$ Gy
• Organic optical-components :	100 – 10^5 Gy
• Electronic components :	10 – 10^4 Gy + 10^{12} n.cm^{-2}

Mechanisms of radiation damage

Polymers = long chains with + covalent liaisons,
mainly between carbon atoms

semi-crystalline

low sensitivity to atomic displacements

sensitive to ionisation;

undergo degradation via radical propagation

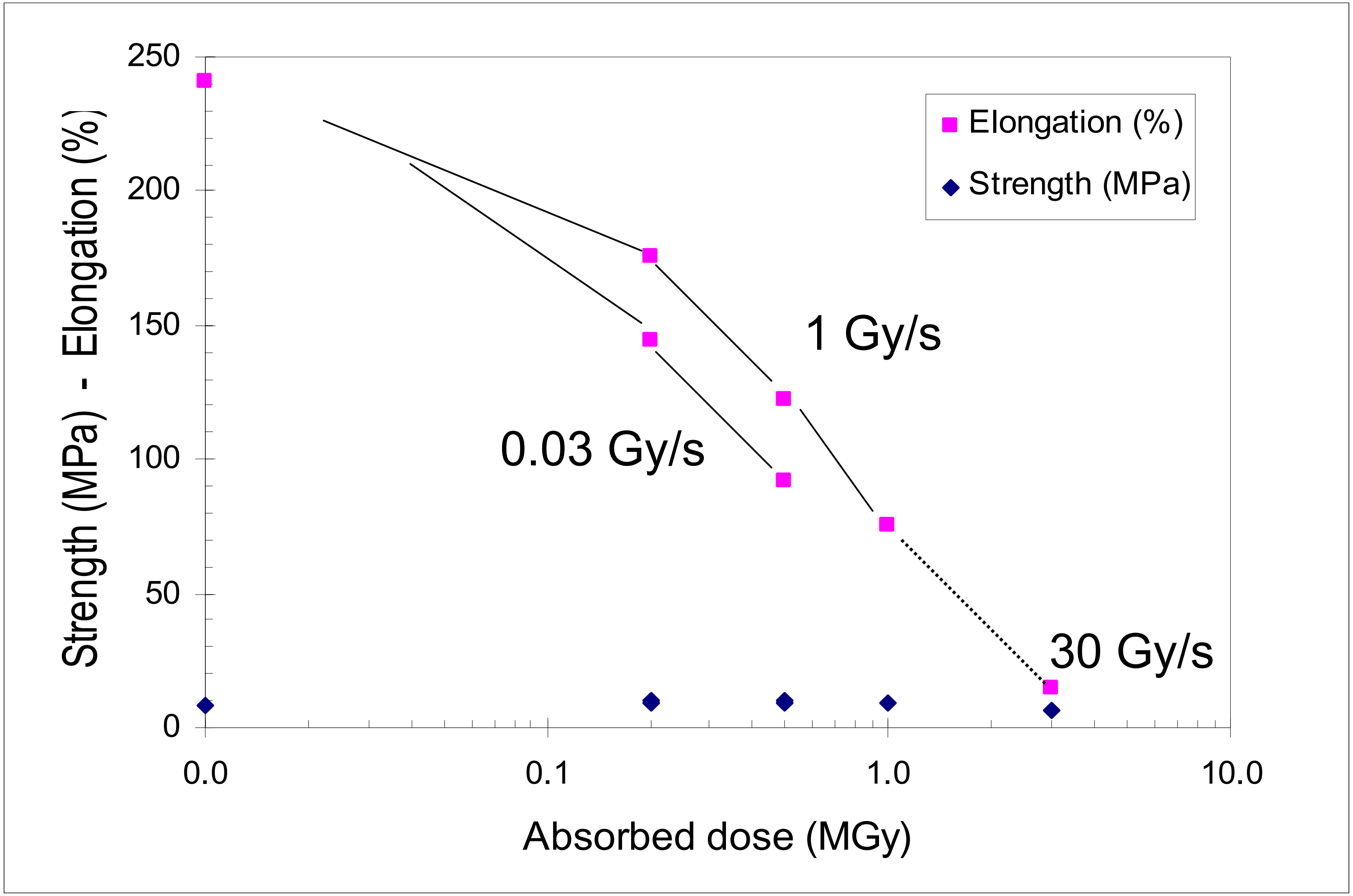
+ «radio-oxidation» !

Consequences of radiation damage on the mechanical properties

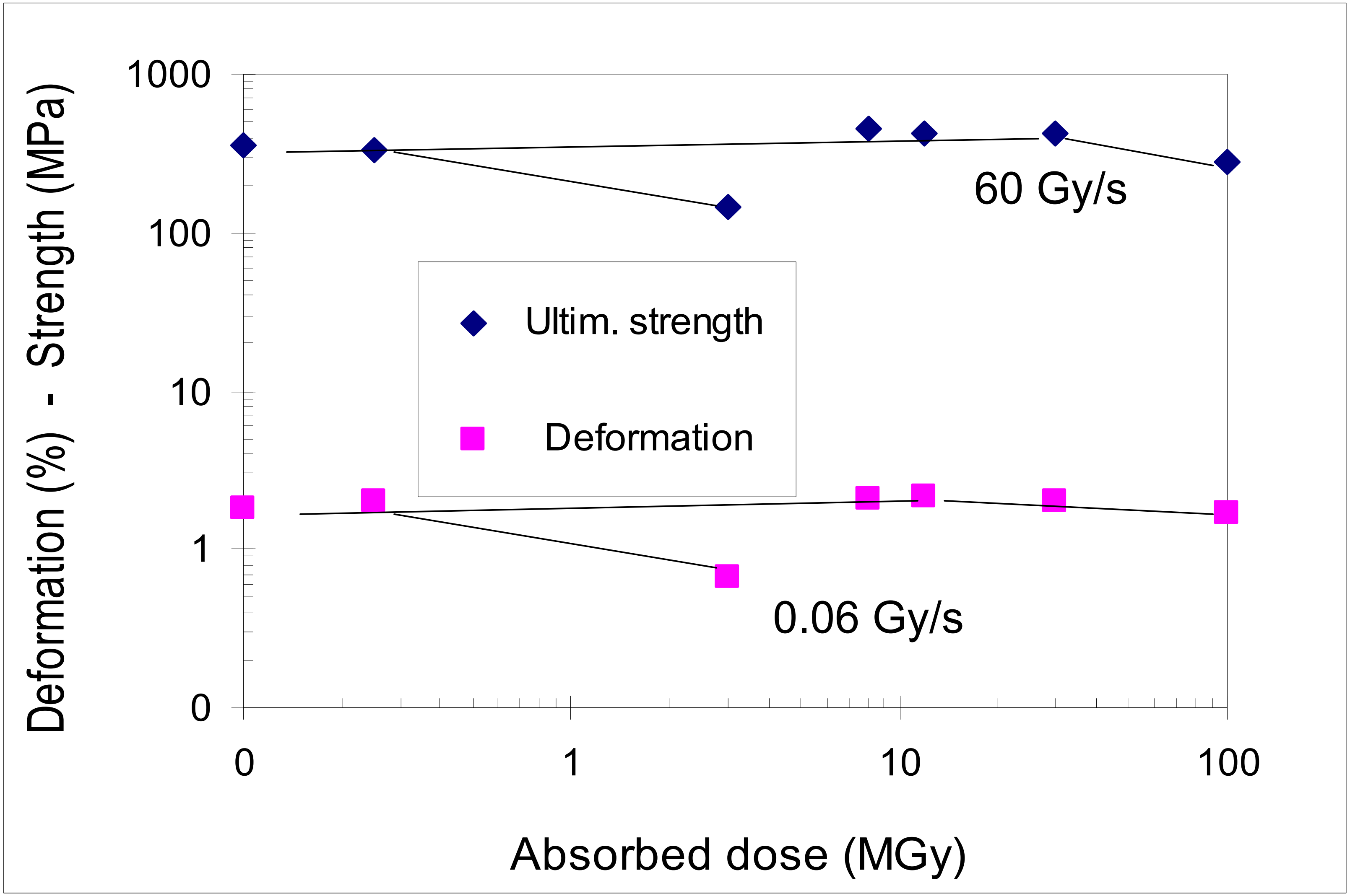
If the polymer chains mainly undergo

then	scission	or cross-linking
- mechanical strength	□	□
- deformation at break	□	□
- modulus of elasticity	□	□
- resilience	□	□

Example : radiation damage to a cable insulting polyolefin



Example : radiation damage to a GF-epoxy



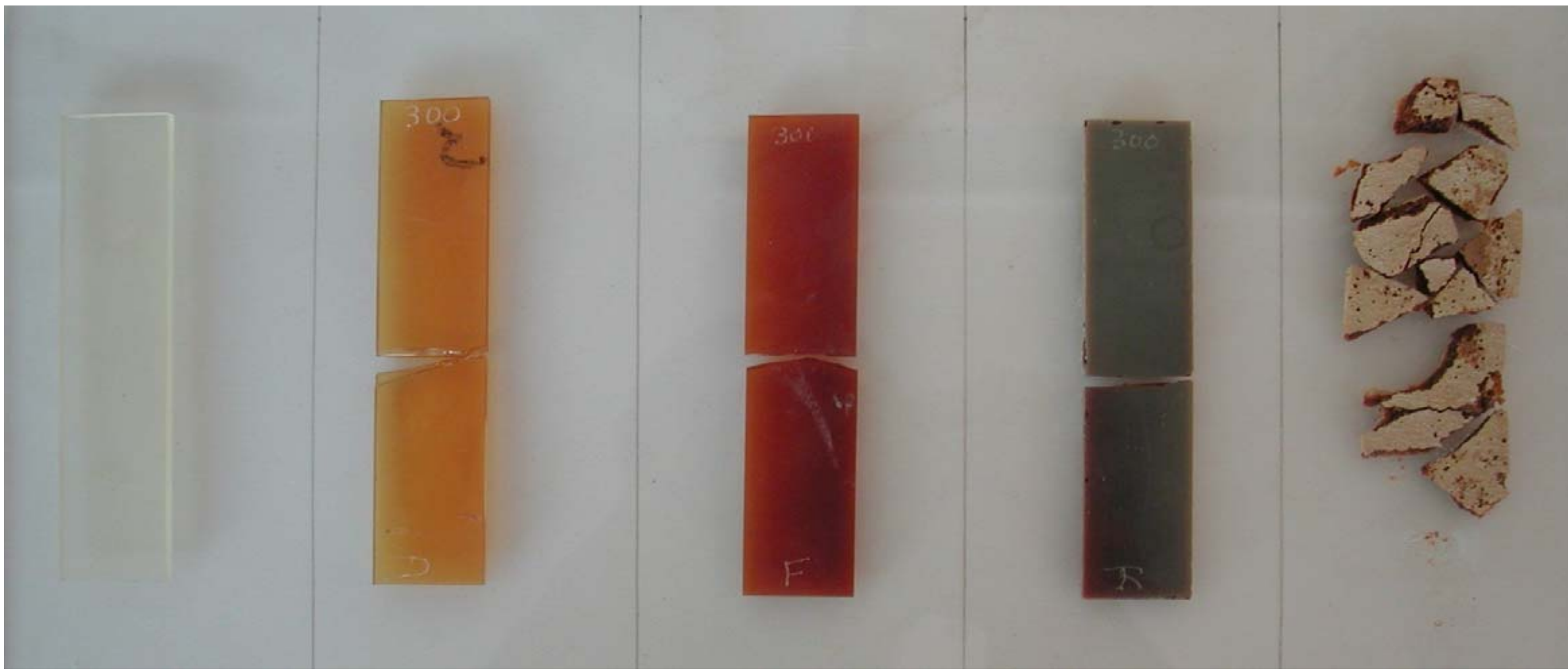
Consequences of radiation damage on other properties

- Unsaturations → stiffness, colour centres…
- Gas evolution → swelling, crazing, ….
- Evolution of low molecular weight products
- Weakening of fibre-matrix interface
- Polymerisation of liquid insulators and lubricants

- No significant change of electrical properties

- No significant change of fire behaviour

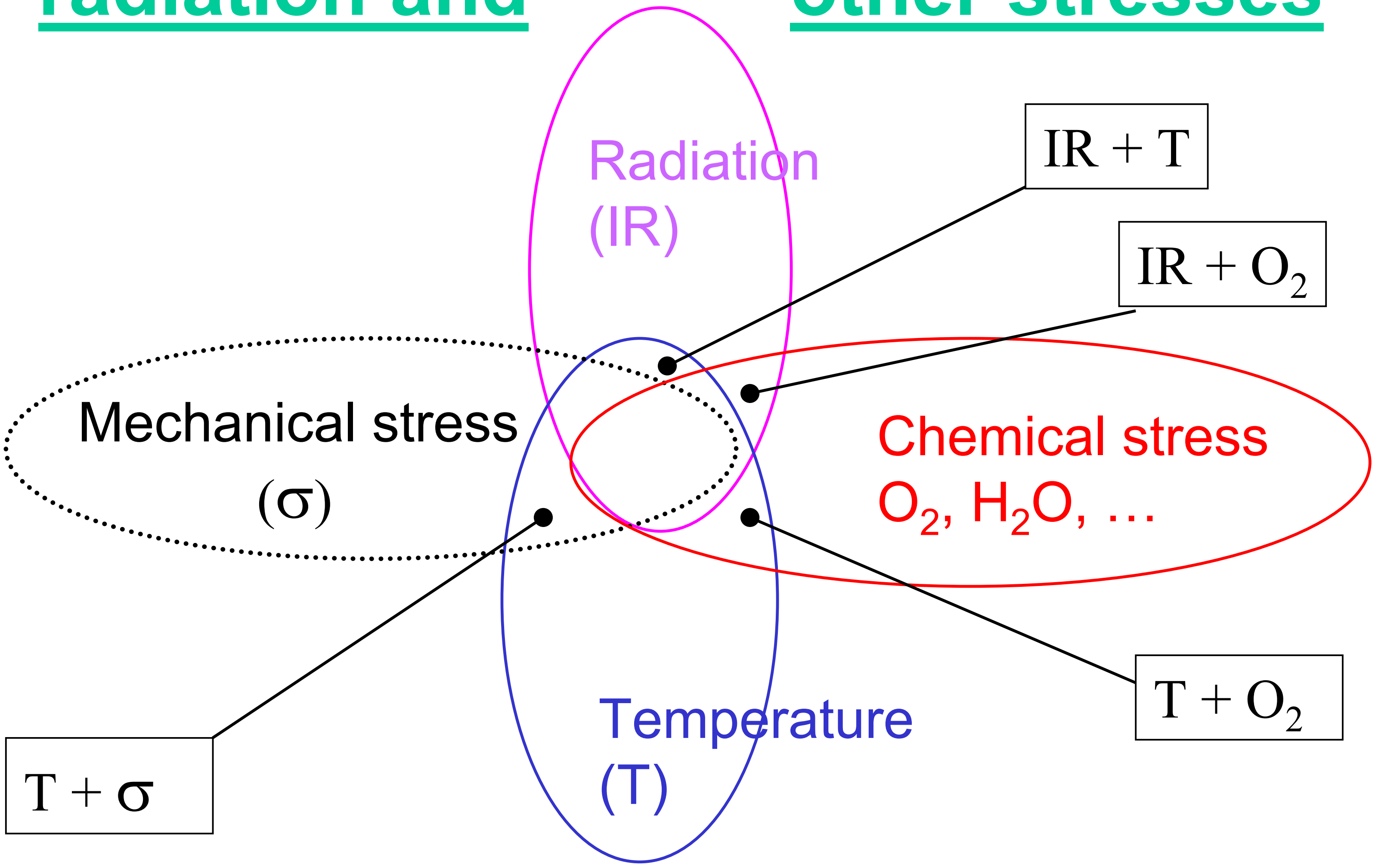
Example of radiation damage on a thermosetting resin



Dose 0 | 5 MGy | 10 MGy | 30 MGy | 100 MGy

Example of radiation damage on two organic oils

Synergistic effects between radiation and other stresses



Synergistic effects between radiation and other stresses

+ Oxygen, oxidant	→	radio-oxidation,
		"dose-rate effect" in air
		effect of humidity
		effect of ozone
+ Mechan. Stress	→	lower fatigue limit
		increase fragility
		(squeezed and hoses)

Synergistic effects between radiation and other stresses

+ ‘High’ temperature → almost no effect below Tg

but effects depend on sequence

+ ‘Cryo’ temperature → no oxidation in cryo gas

Conclusions

The level of radiation damage

- depends on the material type
- depends on the additives
- depends on the dose and on the dose-rate
- does not depend on the irradiation type
- depends on other stresses (synergy)

References ; CERN "catalogues"

H. Schönbacher, M. Tavlet et al.:
Compilation of radiation damage test data ;

- Part 1, 2nd ed.: Halogen free cable-insulating materials, CERN 89-12 (1989)
- Part 2, 2nd ed.: Thermosets and thermoplastic resins, composite materials, CERN 98-01 (1998)
- Part 3 : Materials used around high-energy accelerators, CERN 82-10 (1982) (sold-out)
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All of the CERN reports on

http://preprints.cern.ch/cernrep/Welcome.html

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- P. Maier and A. Stolarz : Long-term radiation effects on commercial cable-insulating materials, CERN 83-08 (1983)
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More refs ; some CERN "publications"

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CERN Academic Training Lecture (4-8/02/02) on

Reliability issues at the LHC

by P. Kafka (RelConsult, Grunwald, D)

- Reliability engineering, from components up to the system and the plant, common cause failures and human factor issues, needs for training.
- Interrelations of Reliability & Safety (R&S), reliability and risk informed approach, living models, risk monitoring.
- The ideal R&S process for large scale systems, from R&S goals via the implementation into the system to the proof of the compliance.
- Applications of R&S on LHC: master logic, anatomy of risk, cause - consequence diagram, decomposition and aggregation of the system.
- Lessons learned from R&S application in various technologies, success, pitfalls, constrains in data and methods, limitations...