Cable radiation quality control: why and how?

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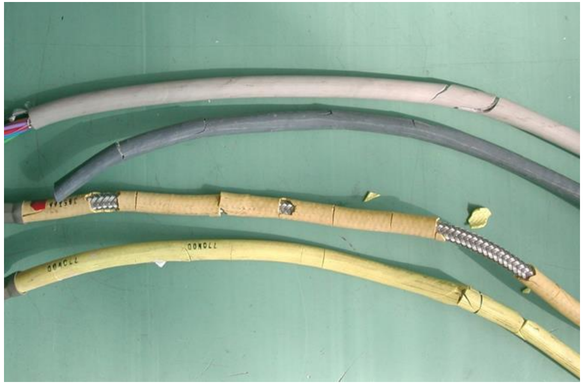
https://indico.cern.ch/event/958625/



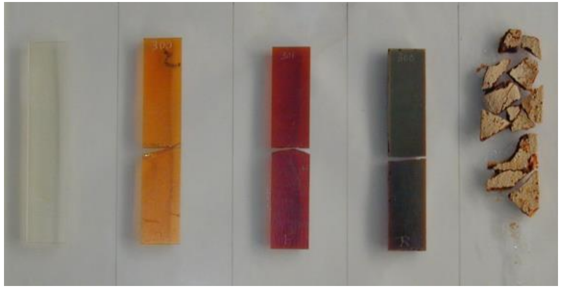
Why is radiation quality control for cables important?

- Insulating materials degrade due to radiation, up to a point in which the insulating properties are lost

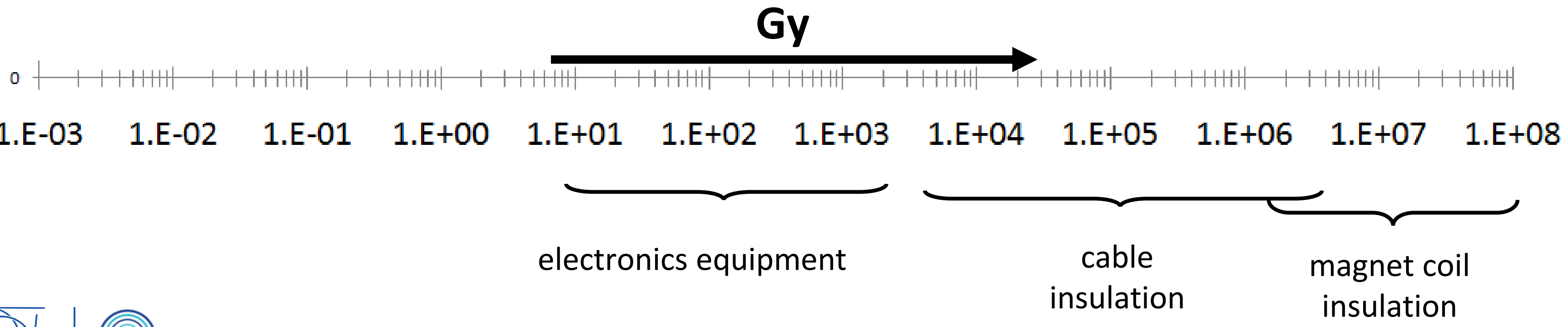
Input by Helmut Vincke, linked to high-level dosimetry activity

D (Gy)

0 $5x10^6$ 10^7 $2.5x10^7$ $5x10^7$



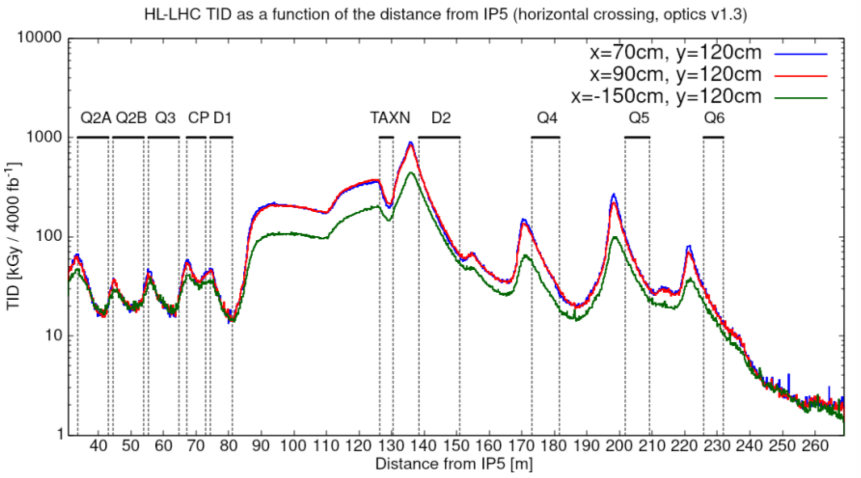
Dose levels above which permanent material/equipment damage is expected

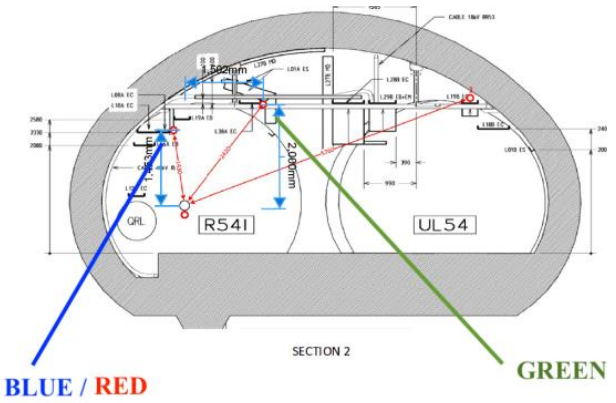


Why is radiation quality control for cables important? (II)

Giuseppe Lerner, HL-LHC annual meeting (2019)

- In HL-LHC, significant portions of the LHC tunnel (notably near IP1 and IP5) will be exposed to radiation levels that pose a threat to cable insulating materials
- Radiation values shown for cable tray location – can be significantly larger closer to beamline/equipment





How can cable radiation quality control be performed?

Procurement specifications

- Presently, this is **specified via IS23 Safety Instruction**, with two possible radiation tolerance categories:
  - General purpose: up to 500 kGy
  - Radiation resistant: up to 10 MGy (significantly more expensive)
- Radiation tolerances are specified as demonstrated in **accelerated irradiation**. At lower dose rates (i.e. dose absorbed in operation), radiation damage can be significantly worst due to synergies with other environmental strains
- Therefore, a **factor 5** applies to convert from demonstrated dose tolerance in accelerated tests to actual levels in operation (as per *“Clarification for referencing to IS23 Rev3 and IS41 when writing technical specifications for cable purchasing”*, EDMS 1495561)
- **According to the categorization above, a significant fraction of HL-LHC LSS1 and LSS5 cables would need to be radiation resistant**

How can cable radiation quality control be performed? (II)

Radiation testing

- It is very difficult to know *a priori* whether a certain insulating material will be compliant with the specified radiation tolerance (e.g. 10 MGy), mainly due to:
  - The lack of recent systematic testing of such materials;
  - The strong dependence of the radiation response to the detailed material composition (e.g. additives, etc.) which is typically not disclosed by the manufacturers.
- Therefore, at least in first instance, **radiation testing** would be needed performed. As cable manufacturers do not have experience in materials irradiation (nor access to facilities), this would need to be performed by CERN.
- Key ingredients for testing:
  - Well established and systematic test procedure
  - Regular access to a suitable irradiation facility
  - Resources (instrumentation, person-power) and know-how for post irradiation analysis
  - Guarantee that irradiated samples are representative of what is installed in the machines

How can cable radiation quality control be performed? (III)

- Key ingredients for testing:
  - **Well established and systematic test procedure**
  - Regular access to a suitable irradiation facility
  - Resources (instrumentation, person-power) and know-how for post irradiation analysis
  - Guarantee that irradiated samples are representative of what is installed in the machines

- Main solution: **IEC 60544 international standard**
  - Scope: *"This part of IEC 60544 provides a classification system that serves as a guide for the selection and indexing of insulating materials intended to serve in the radiation environment of nuclear reactor facilities, reactor fuel-processing facilities, irradiation facilities, particle accelerators, and X-ray apparatus."*


IEC

IEC 60544-2

Edition 3.0 2012-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Electrical insulating materials – Determination of the effects of ionizing radiation on insulating materials –
Part 2: Procedures for irradiation and test

Matériaux isolants électriques – détermination des effets des rayonnements Ionisants sur les matériaux isolants –
Partie 2: Méthodes d'irradiation et d'essai

How can cable radiation quality control be performed? (IV)

- Example of cable irradiation (and importance of **end point criterion** and **dose rate**)

"Absorbed doses and radiation damage during the 11 years of LEP operation"
H. Schonbacher (CERN), M. Tavlet(CERN)
Published in: Nucl.Instrum.Meth.B 217 (2004) 77-96

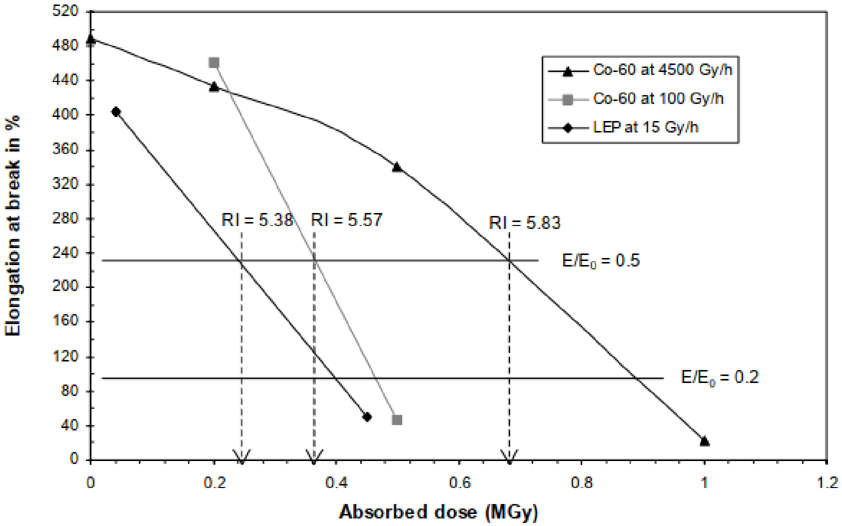
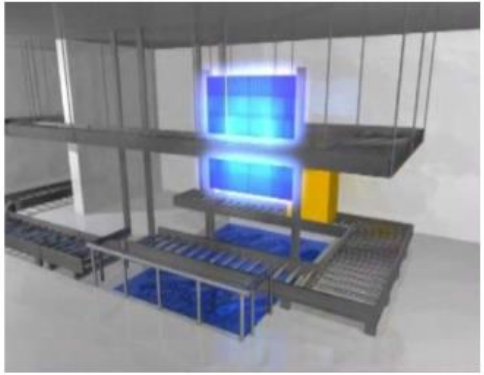


Fig. 4: Decrease of elongation at break of a cable sheathing VAC material C 995, as a function of the absorbed dose, at different dose rates.

How can cable radiation quality control be performed? (V)

- Key ingredients for testing:
  - Well established and systematic test procedure
  - **Regular access to a suitable irradiation facility**
  - Resources (instrumentation, person-power) and know-how for post irradiation analysis
  - Guarantee that irradiated samples are representative of what is installed in the machines

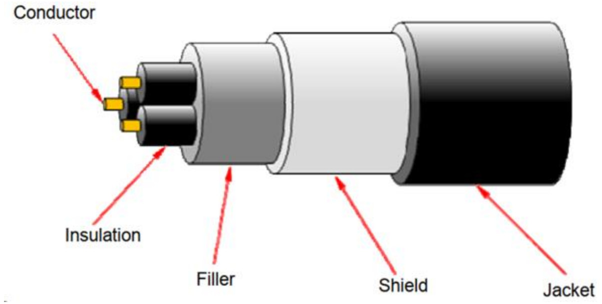


BGS conveyor

- CERN has access to **high dose rate (~30 kGy/h) gamma irradiation facilities** through contract B1642/EN ("Supply of Irradiation Tests")
- At CERN, the activity is coordinated through the R2M work package of the R2E project. The technical responsible is Matteo.Ferrari.2@cern.ch.

How can cable radiation quality control be performed? (VI)

- Key ingredients for testing:
  - Well established and systematic test procedure
  - Regular access to a suitable irradiation facility
  - **Resources (instrumentation, person-power) and know-how for post irradiation analysis**
  - **Guarantee that irradiated samples are representative of what is installed in the machines**



- Cable post (and pre) irradiation testing performed by **CARE project** (responsible: José Gascón), not only in scope of radiation damage, but as more general quality control
- For representativeness of irradiation samples, traceability needs to be ensured by manufacturer/distributor of cables

Summary

- Radiation damage in cables is a **risk** for HL-LHC operation, owing to:
  - The large radiation and levels and;
  - The lack of knowledge of the response of cable insulating materials presently available on the market to such radiation levels.
- Not much can be done about the first point, but for the second, **systematic radiation testing** is the only solution to select suitable materials, and discard weak ones
- Systematic radiation testing needs to be traded off against the **risk acceptance** of installing non-tested cables, and the related consequences (e.g. need of replacing cables in non-programmed or highly conservative time intervals, etc.)
  - Indeed, we can hope to “be lucky” and not experience significant degradation of cables in HL-LHC, but this would (to my knowledge) be more “wishful thinking” than a well-based expectation
  - An intermediate solution could be to monitor the radiation damage in situ, and plan cable replacement accordingly
- If systematic radiation tests are to be implement, CERN has the necessary ingredients in place: available test standard, access to irradiation facilities and related service, and post-irradiation cable testing

Some references (procedural, mainly from RIAC)

- SAFETY INSTRUCTION NORDM; 23 (IS 23 REV. 3)
- REVISED SAFETY INSTRUCTION 41 (IS41 REV.)
- “Clarification for referencing to IS23 Rev3 and IS41 when writing technical specifications for cable purchasing” (guideline)
- “Working Group on the Replacement of Irradiated and Ageing Cables” (final report)
- “LHC & SPS Cable Samples/Sampling Procedure”
- « Processus de décision du remplacement des câbles irradiés »
- IEC 60544 Part 2: Electrical insulating materials - Procedures for irradiation and test
- IEC 60544 Part 4: Electrical insulating materials - Classification system for service in radiation environments
- IEC 61244 Technical Report: Effects of different temperatures and dose rates under radiation conditions

Some references (technical/scientific)

- Tavlet, Marc. "Effects of ageing of electrical insulators after exposure for 11 years in the large electron–positron collider at CERN." Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 208 (2003): 476-479.
- Schönbacher, H., and M. Tavlet. "Absorbed doses and radiation damage during the 11 years of LEP operation." Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 217.1 (2004): 77-96.
- Chapiro, A., et al. "What is ageing? Are there still problems to be solved?." *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 131.1-4 (1997): x-xii.
- Perrin, Sh, et al. "Evaluation of the radiation resistance of electrical insulation materials." *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 198.1-2 (2002): 77-82.
- Plaček, V., et al. "Dose rate effects in radiation degradation of polymer-based cable materials." *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 208 (2003): 448-453.
- Radiation Damage to Organic Materials in Nuclear Reactors and Radiation Environments (Proceedings of a Final Research Co-ordination Meeting, Takasaki, Japan, 17-20 July 1989)
- Clough, Roger L., and Shalaby W. Shalaby. "Radiation effects on polymers." (1991).