Introduction

• We present a strategy for the definition of HL-LHC radiation level specifications on cables based on FLUKA simulations by M. Sabaté Gilarte, using HL-LHC optics v1.5 with hor/ver crossing in P1/P5 and TCL4-5-6 at $14\sigma$, referring to the ultimate luminosity scenario (4000 fb$^{-1}$).

• The approach consists in defining categories of cables qualified up to a given radiation threshold (e.g. 500 kGy for ‘standard’ ones).

• Important: the qualification thresholds refer to accelerated test conditions → according to EDMS 1495561 (IS23 safety instruction), at low dose rate the degradation is faster and a factor 5 margin is required.

• Consequence: cables qualified up to a given dose can only be used in areas where 5 times less dose is expected.
IS23 safety instructions and radiation level categories

- The original approach included only two categories of cables based on the IS23 safety instructions:
  - ‘standard’ cables qualified up to 500 kGy (i.e. to be exposed up to 100 kGy in operation, taking into account the 5x safety margin)
  - ‘rad-hard’ cables qualified up to 10 MGy (i.e. ok up to 2 MGy in operation)
- Two categories are not enough because the TID limit of standard cables is exceeded over large portions of the cable trays in the tunnel, but rad-hard cables would be over-qualified (see 2nd meeting on the topic, April 7th).
- We propose to introduce a third ‘intermediate’ category, with qualification threshold around 3.5 MGy* (i.e. 700 kGy* in operation), to be used on all cable trays by the wall and possibly also to connect to some beamline elements (e.g. magnets, to be checked on a case-by-case basis).

*the exact threshold can be optimised - see next slides
‘Standard’ and ‘intermediate’ cable categories in P1

based on FLUKA simulations by M. Sabaté Gilarte

(‘rad-hard’ cable category not shown - to be used in radiation hot-spots close to the beam, e.g. collimators, absorbers…)
By the wall the 700 kGy threshold of intermediate cables is (almost) always met at beam height, which represents a worst-case for cable trays.
Cable categories for 4000 fb\(^{-1}\) - right of P1 (side view)

By the ceiling the 700 kGy threshold of intermediate cables is comfortably met everywhere in the tunnel.
Cable categories for 4000 fb\(^{-1}\) - section view before TAXN in P1

- The highest dose is reached upstream of the TAXN - see below a transverse view with category thresholds and full TID (in linear scale)
- The 700 kGy threshold is narrowly exceeded by the wall at beam height or below. A slightly higher threshold would solve the issue, but cables may be more expensive (more on this later)
‘Standard’ and ‘intermediate’ cable categories in P5

based on FLUKA simulations by M. Sabaté Gilarte

(‘rad-hard’ cable category not shown - to be used in radiation hot-spots close to the beam, e.g. collimators, absorbers…)

By the wall the 700 kGy threshold of intermediate cables is (almost) always met at beam height, which represents a worst-case for cable trays. In P5 the 700 kGy threshold at beam height by the wall is exceeded over a slightly longer z range compared to P1.
Cable categories for 4000 fb\(^{-1}\) - right of P5 (side view)

By the ceiling the 700 kGy threshold of intermediate cables is comfortably met, as it was in P1.
• As in P1, the TID threshold upstream of the TAXN of 700 kGy is moderately exceeded by the wall at beam height or below
• A slightly higher threshold (e.g. 1 MGy) would improve the situation, but it requires to qualify the cables up to higher TID (5 MGy)
General arguments
Benefits of the intermediate cable category

- The intermediate cable category is designed to be used everywhere along the cable trays on the walls in the LSS of P1-P5.

- The 3.5 MGy threshold (i.e. 700 kGy in operation) is defined accordingly, and it is only partially exceeded upstream of the TAXN at beam height or below.

- The market offers options between 3 MGy and 5 MGy: the former is a bit tight, the latter would be safer but probably more expensive.

- As usual, it’s a tradeoff between different considerations - see safety margin arguments in the next slides.

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<table>
<thead>
<tr>
<th>Cables in Radiation Environment Air (standard atmosphere)</th>
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<tbody>
<tr>
<td><strong>Some typical numbers from suppliers:</strong></td>
</tr>
<tr>
<td>Lapp-Kabel (PU)</td>
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<tr>
<td>Lapp-Kabel (EPR)</td>
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<tr>
<td>Helukabel (PU, HM2, TM7)</td>
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<tr>
<td>Huber+Suhner RADOX® (RX125-XLPolyolefin Copolymer)</td>
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<tr>
<td>Marmon (XLPE + CSPE, certified to Class 1E, IEEE-323)</td>
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<tr>
<td>Habiatrion (XL Polyolefin, certified IEEE-323 + 383)</td>
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<tr>
<td>Axon (Polax®-PEI)</td>
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<tr>
<td>Huber+Suhner RADOX® (TPU)</td>
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<td>Axon (Neutrax®-PEEK)</td>
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<td>Axon (Kapton®-Polymide)</td>
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From H. Garcia Gavela’s talk

G. Lerner - 25/06/21
Are 3 MGy enough for intermediate cables, or shall we go to 5 MGy to have more margin?
FLUKA studies by M. Sabaté Gilarte compared the TID deposition in air (used in FLUKA to define the specification) to the TID in cable insulators and jackets.

Simplified material models (based on input from A. Danyluk):

- Material 1 (insulators): containing just C and H
- Material 2 (jackets): C, H, O, Al

The dose in these materials is found to be slightly lower than in air (~20%) near the highest peak before the TAXN → effectively a safety margin.
Other considerations

- The cable trays above the beam height are generally a bit less exposed compared to the reference values that I have shown at beam height.
- The plots in this presentation are all referred to the full ultimate scenario of 4000 fb\(^{-1}\), which is also a conservative assumption.
- In the present study we neglected any possible mitigation measure that could have an impact on the radiation levels (e.g. shielding).
Conclusions
Summary of the proposed cable categories

- We propose to move forward with 3 radiation level categories:
  - **Standard cables**, qualified up to 500 kGy (to be used up to 100 kGy)
  - **Intermediate cables**, ideally qualified up to 3.5 MGy (ok up to 700 kGy)
    Here one can possibly consider options in the 3MGy-5MGy range based on the considerations outlined in this presentation
  - **Rad-hard cables**, qualified up to 10 MGy (ok up to 2 MGy)