
CERN
HSE
Occupational Health & Safety
and Environmental Protection unit

Cable strategy proposal HL-LHC

CARE Project

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EDMS no. 2425714

Introduction

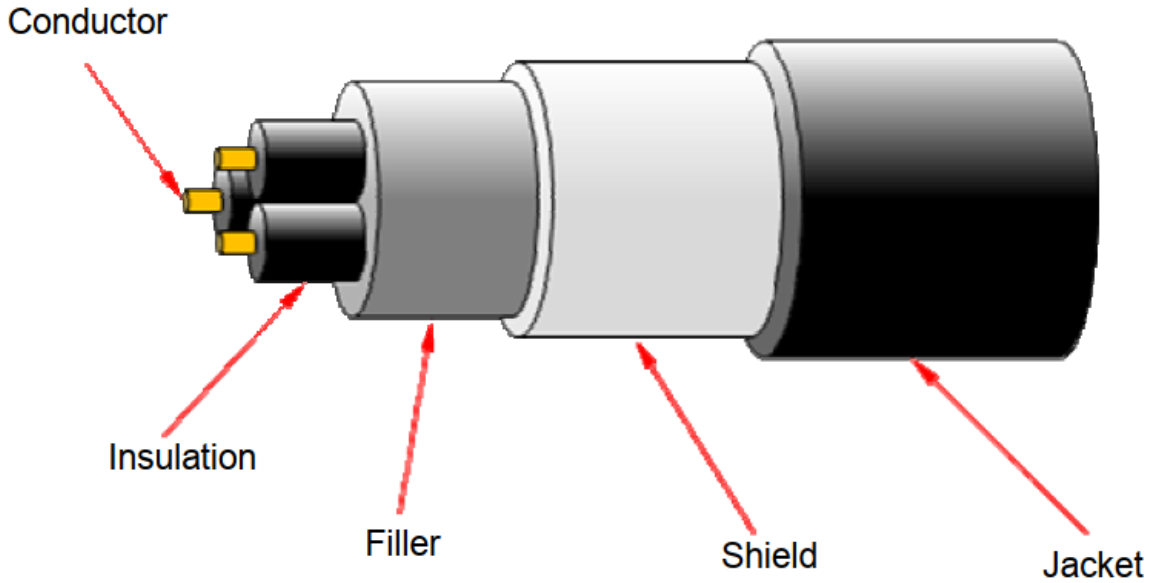
Cable applications at CERN

- HV power
- LV power
- DC power *(Power converters & magnets)*
- Instrumentation & Control
- Speciality *(RF, experimental areas, others)*
- Safety *(lighting, monitoring, safety systems)*
- IT & office *(IEC/EU compliant)*
- Grounding

Introduction

Cable main components

- Conductors: *copper, aluminium*
- Insulation: *polymers (XLPE, PVC, EVA, etc.)*
- Shielding: *foil (Al) or braided (Cu, Al)*
- Jacket: *similar materials to insulation*



Structural components

- Fillers or bedding: *mechanical stability*
- Tape wraps: *electrical, mechanical, fire or identification*
- Armouring: *mechanical protection*

Introduction

Common polymeric cable materials

(halogen free)

- Ethylene vinyl acetate (EVA)
- Cross-linked polyethylene/polyolefin (XLPE / XLPO)
- Low and High density polyethylene (LDPE / HDPE)
- Ethylene propylene based elastomers (EPR / EPDM)
- Polyphenylene oxide (PPO known as Noryl®)
- Butyl rubber (BR)
- Polyimide (known as Kapton®)
- Silicone rubber (SiR)
- Polyether ether ketone (PEEK)
- Polyurethane

Additives (anti-oxidants) & stabilizers: how-know of cable manufacturers !!!

Introduction

Cable Stressors

(ageing and degradation)

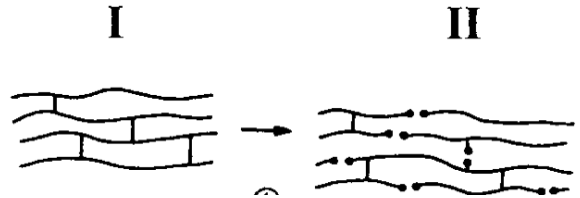
- **Temperature**
- **Humidity**
- **Chemicals** (oxygen, ozone, lubricants)
- **Ionising radiation** *(UV included)*
- **Electrical** *(ohmic heating)*
- **Mechanical** *(bending, squeezing, vibration)*

Cable degradation is a combination of stressors effects !!!!

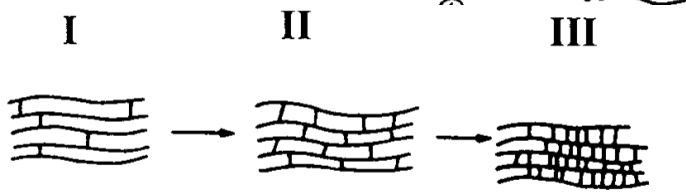
Introduction

Chemistry of ageing

- **Scission of molecular chains:** typically alkoxyl or peroxide radicals



- **Cross-linking reactions:** formation of new molecular links



- **Oxidation process**

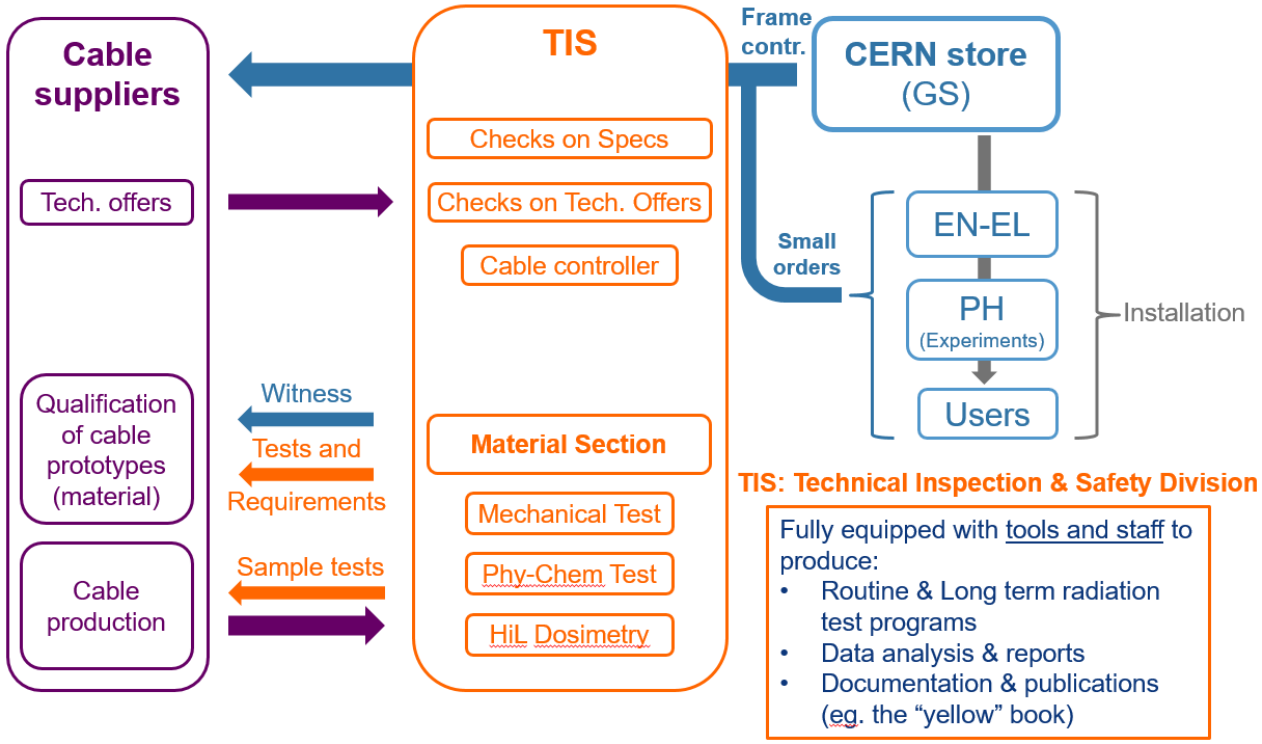
1. Initiation: formation of free radicals
2. Propagation: formation of peroxy radicals and hydroperoxide
3. Chain branching: decomposition of hydroperoxide
4. Termination: deactivation of radicals in inert products (alcohol, acid ...)

- **Synergistic effect**: combined stressors effects higher than stressors effects separately (e.g. temperature + radiation)

Background

Source: RIACWG

Historical perspective (until 1997)

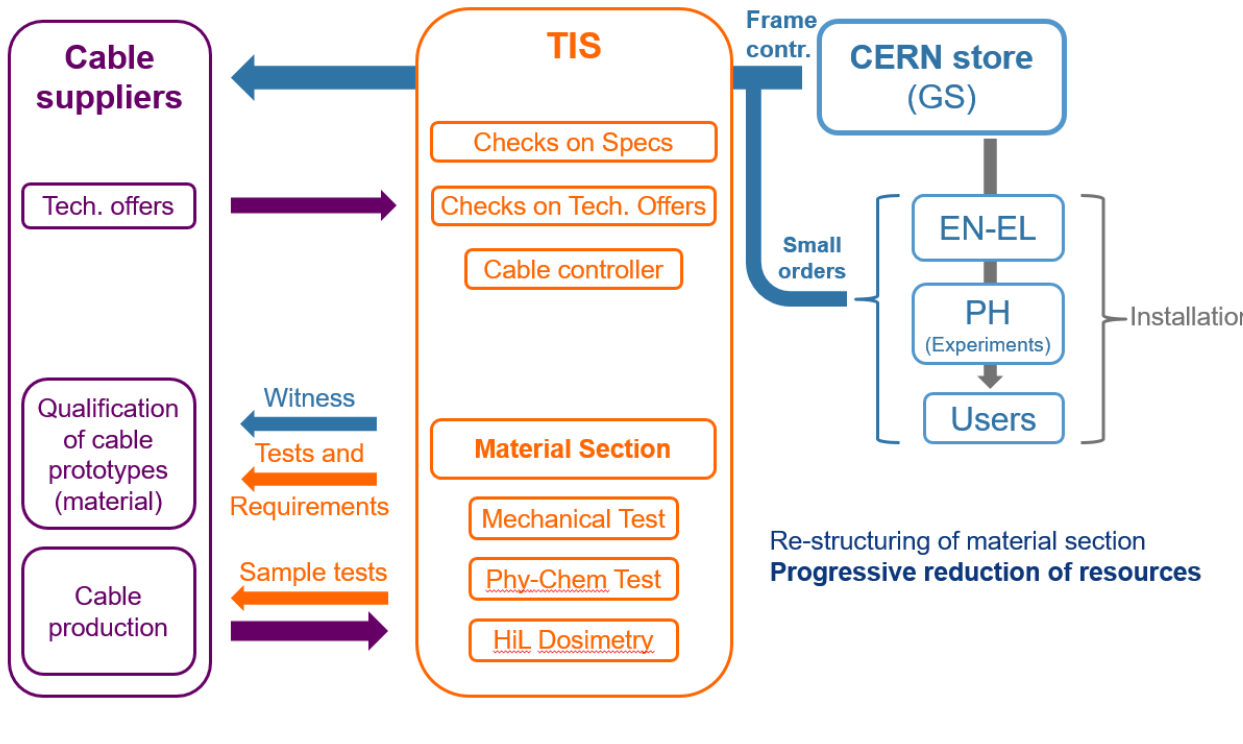


TIS: Technical Inspection & Safety Division

Fully equipped with tools and staff to produce:

- Routine & Long term radiation test programs
- Data analysis & reports
- Documentation & publications (eg. the "yellow" book)

Historical perspective (1997-2002)

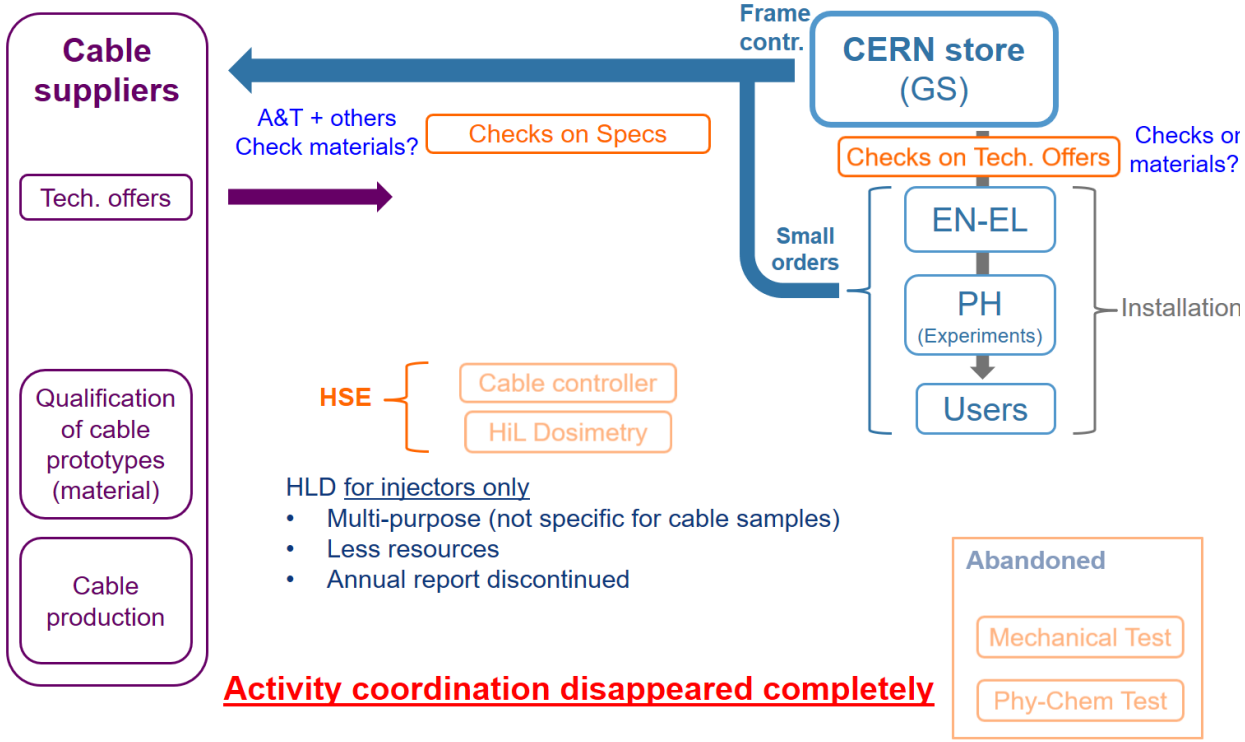


Re-structuring of material section
Progressive reduction of resources

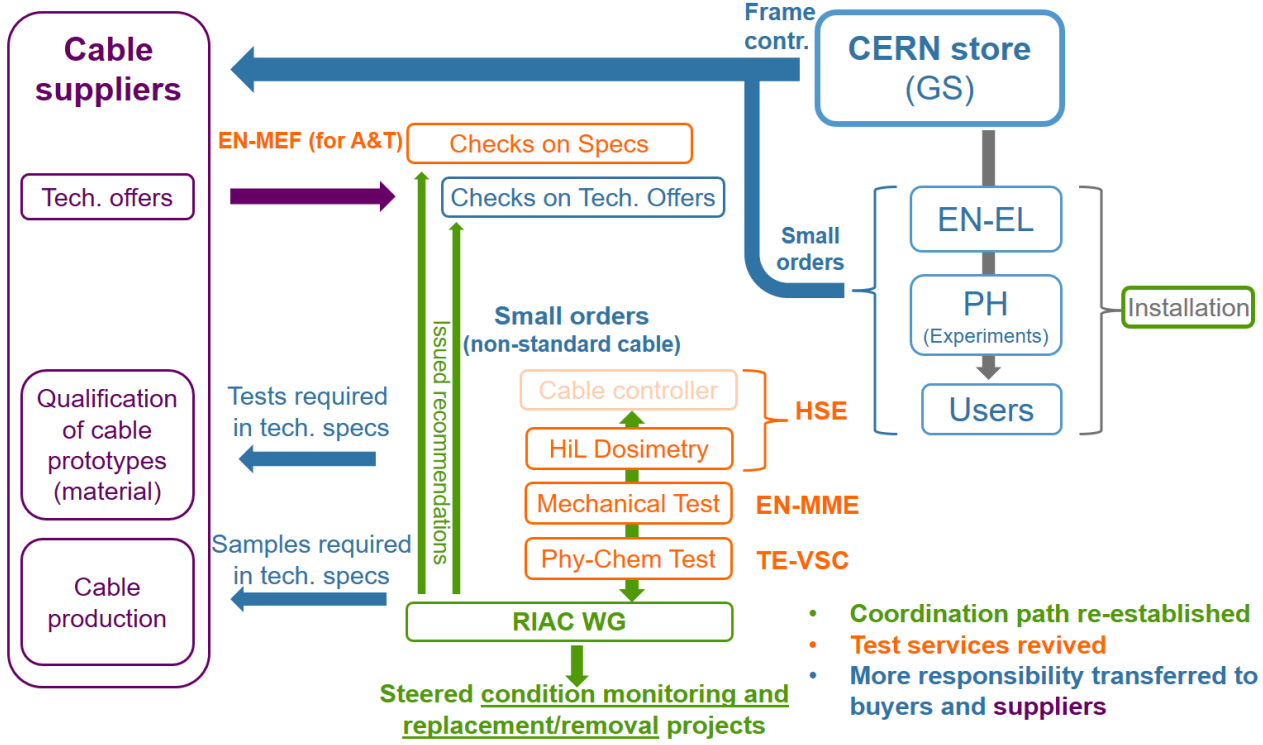
Background

Source: RIACWG

Historical perspective (after 2002)



Historical perspective (Today: 2015)



Background

CARE Working Group 2016-2019

- Problems with samples placed in tunnels from RIAC WG *(length shorter, not end-caps, displaced from original place, dosimeters solid state)*
- Test results not conclusive and sometimes erratic (inconsistency)
- Budget contribution from departments reduced

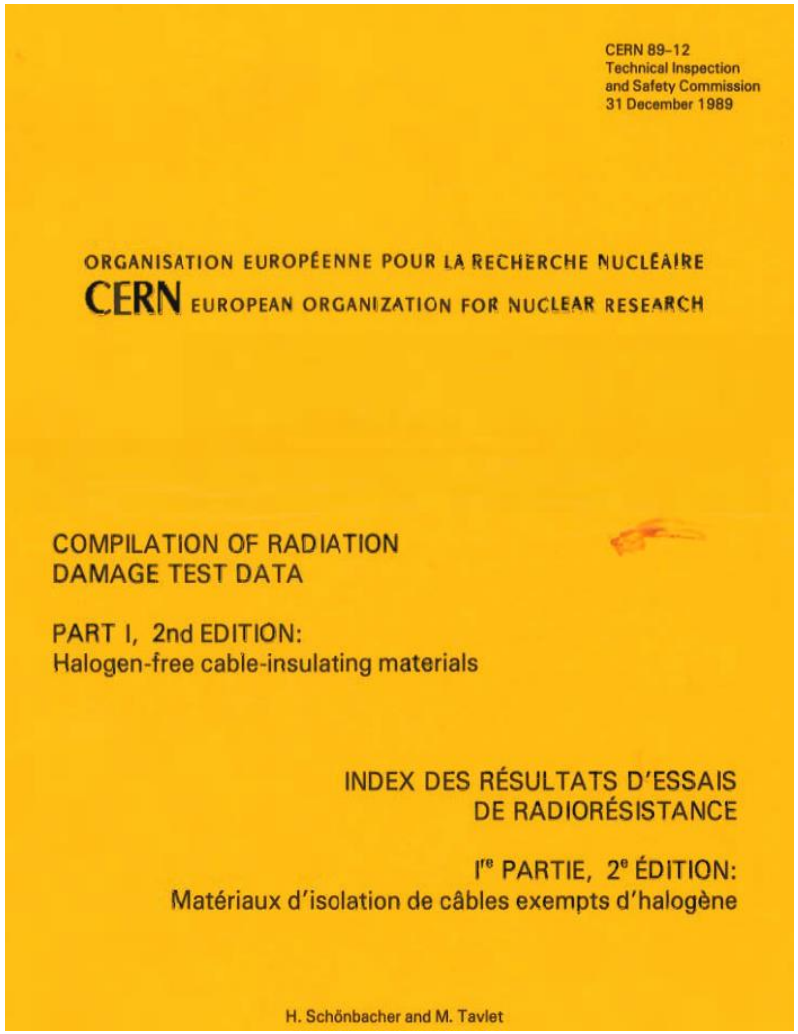
CARE Project 2019-

- Conversion into a formal research project
- Implementing lessons learned
- Reviewing test procedures and samples management
- Focusing in cable purchasing and quality control for radiation resistant cables
- Provide technical support to CERN cable users on demand
- Project funded by HSE

CARE motivations

CERN's motivations for the CARE project are *still endorsed*

- **Cable procurement cost**: cable price, quality control & storage requirements *(now based on IS23)*
- **Replacement cost**: manpower for removing and pulling
- **Personnel safety cost**: more workers in radiation areas *(Limited Stay and High Radiation Areas)*
- **Time schedule**: time required during LS & TS *(radiation cooling limits time for works)*
- **Waste cost**: irradiated cables are radioactive waste and require treatment expenses



CARE Objectives

- Enhanced decision making process in terms of expected cables lifetime
- Improvement in cable quality control
- Condition monitoring of “sensitive” installed cables
- Reference database for new “sensitive” cables
- Improve knowledge on cable ageing mechanisms
- Develop lifetime models on ageing cables
- Expertise on cable ageing testing techniques
- Expertise on polymers behavior under radiation and other cable stressors

CARE proposal to HL-LHC project

Limited only to “sensitive” cables

- Technical support in cable ageing during purchasing process
- Condition Monitoring of HL-LHC cables in collaboration with **R2E/R2M**
- Artificial irradiation of cable samples&compounds in collaboration with **R2E/R2M**
- Cable tests and analysis for cable ageing
- Product Lifecycle Management according to HL-LHC quality plan
- Predictive maintenance oriented (estimate lifetime)
- Waste RP characterization

Technical support during purchasing

✓ Cable design

- **Technical requirements:** define cable requirements appropriated to cable stressors presents in HL-LHC
- **Polymer selection:** propose the most appropriated polymer according to cable stressors
- **Test techniques:** establish type and routine tests to be performed by cable manufacturer
- **Documentation:** identify technical documentation to be delivered with cable supply (data sheet, test records, cable composition, additives, etc)

✓ Acceptance criteria

- **Prototypes:** provide technical support to select the most convenient cable among manufacturers proposals
- **FAT:** routine tests criteria for acceptance
- **SAT:** criteria for CERN site acceptance

✓ Manufacturing process

- **Audit:** technical support on manufacturing quality control
- **Witnessing:** participation on FAT and SAT

Condition Monitoring

✓ Sensitive areas definition (R2E/R2M)

- **Identification:** identify the most appropriated areas to place samples by stressors expected values
- **Placement:** accurate spot in the zone for the samples
- **Geometry:** position and conditioning of samples
- **Equipment:** define the most appropriated sensors to measure real stressor values

✓ Samples management

- **Installation:** put in place samples in the identified areas
- **Stressor follow-up:** follow-up sensors and measurements obtained from sample area
- **Extraction:** collect samples
- **Data:** database all measurements data obtained
- **Extraction:** collect samples

Cable testing

✓ Samples conditioning

- **Preparation:** sample handling for testing according to defined procedures and standards
- **Measurements:** inputs in database on measurements of specimens prepared (codification, shape, weight, etc)

✓ Testing

- **Ageing test techniques:** determine appropriated tests technique by cable stressor and type of polymer
- **Artificial irradiation:** define tests parameters, facility required at CERN or externally **(collaboration R2E)**
- **Tests:** perform all tests techniques in prepared specimens according to defined procedures
- **Tests records:** introducing in database obtained results and managing tests

PLM & Lifetime models

✓ Database

- **Cable codification:** cable codification per batch (drum codification) where attach all cable data information
- **Cable data sheet:** cable parameters (electrical & mechanical) and drums length
- **Tests records:** prototype tests records, FAT, SAT, samples tests performed
- **Samples codification:** codification of cable samples to be placed in targeted areas
- **Specification stressors:** technical requirements and location stressors

✓ Mathematical statistics

- **Correlation:** statistic models to compare testing results among test techniques
- **Models:** research on mathematical models to predict lifetime of cable

HSE-RP Considerations for HL-LHC

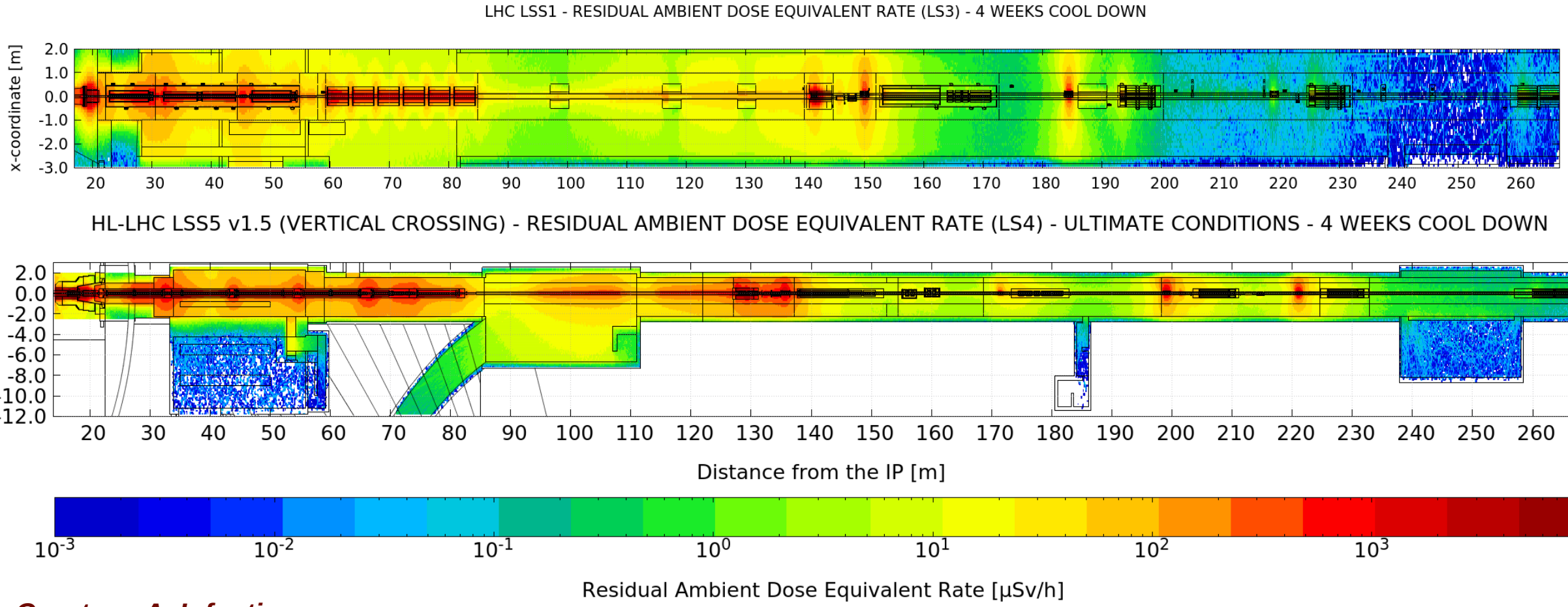
Radiation levels in HL-LHC era significantly higher than LHC impacting directly on

- Cumulated (collective/individual) dose during intervention
- Waste management for future decommissioning

Regarding the HL-LHC cables

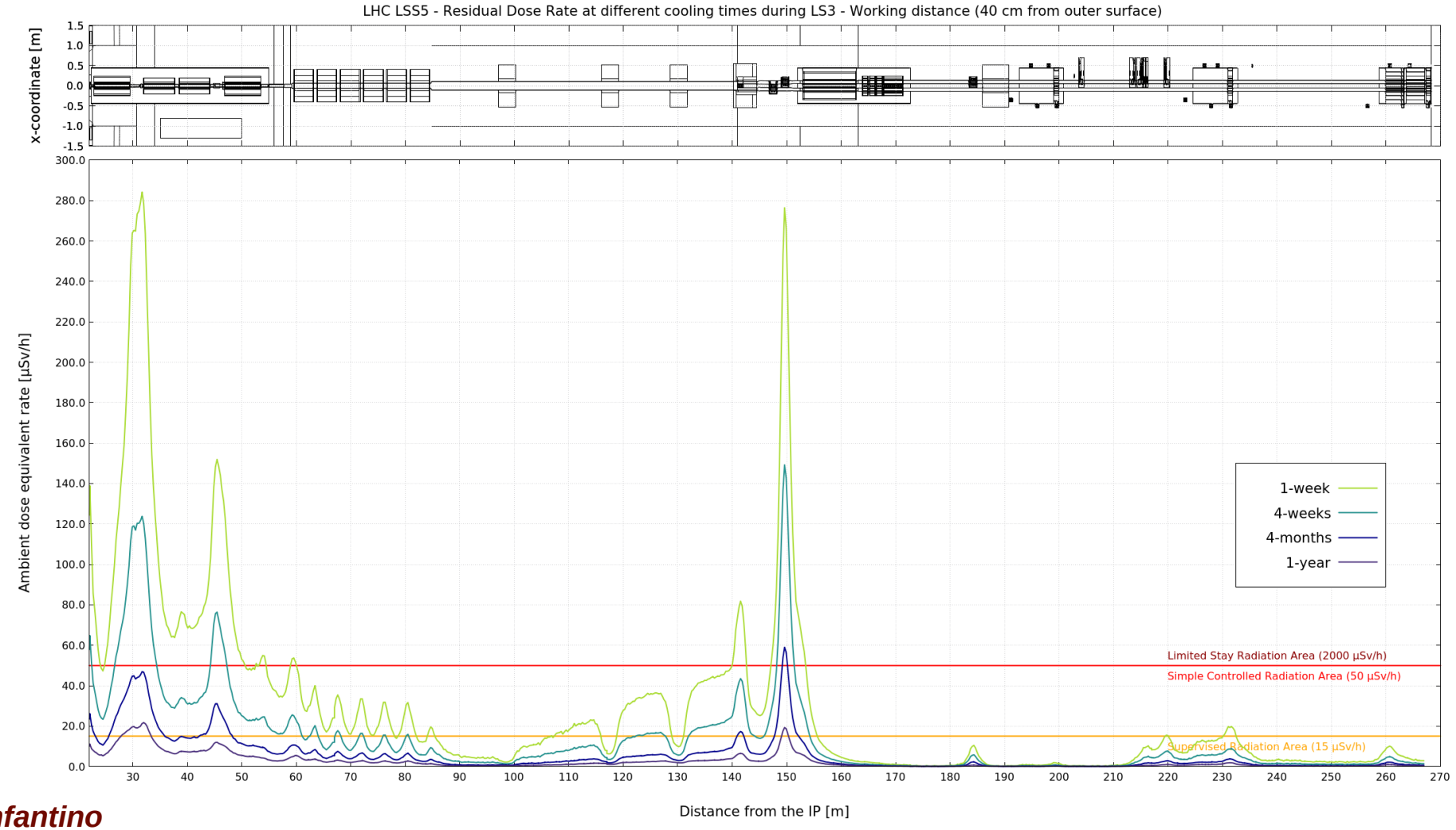
- LS3 will face a major de-cabling campaign and large fraction of the cables will be activated → to be treated as radioactive waste
- Estimates via FLUKA simulations ongoing but experimental validation of the cables activation in collaboration with R2E is crucial for accurate evaluation/characterization of cable waste
- Cable bundles placed at LHC during RUN3 can be measured in gamma-ray spectrometry (non-destructive analysis) to characterize the radionuclide inventory and benchmark FLUKA activation studies
- More radiation-resistant cables will reduce the need of cable-replacement during HL-LHC era, and consequently avoiding long interventions in highly activated environments.
- Sinergy between **CARE, R2E and RP groups** can lead to an extremely valuable scientific outcome with a significant beneficial impact to the organization's future projects/activities.

Radiation levels in LHC/HL-LHC LSS1/5



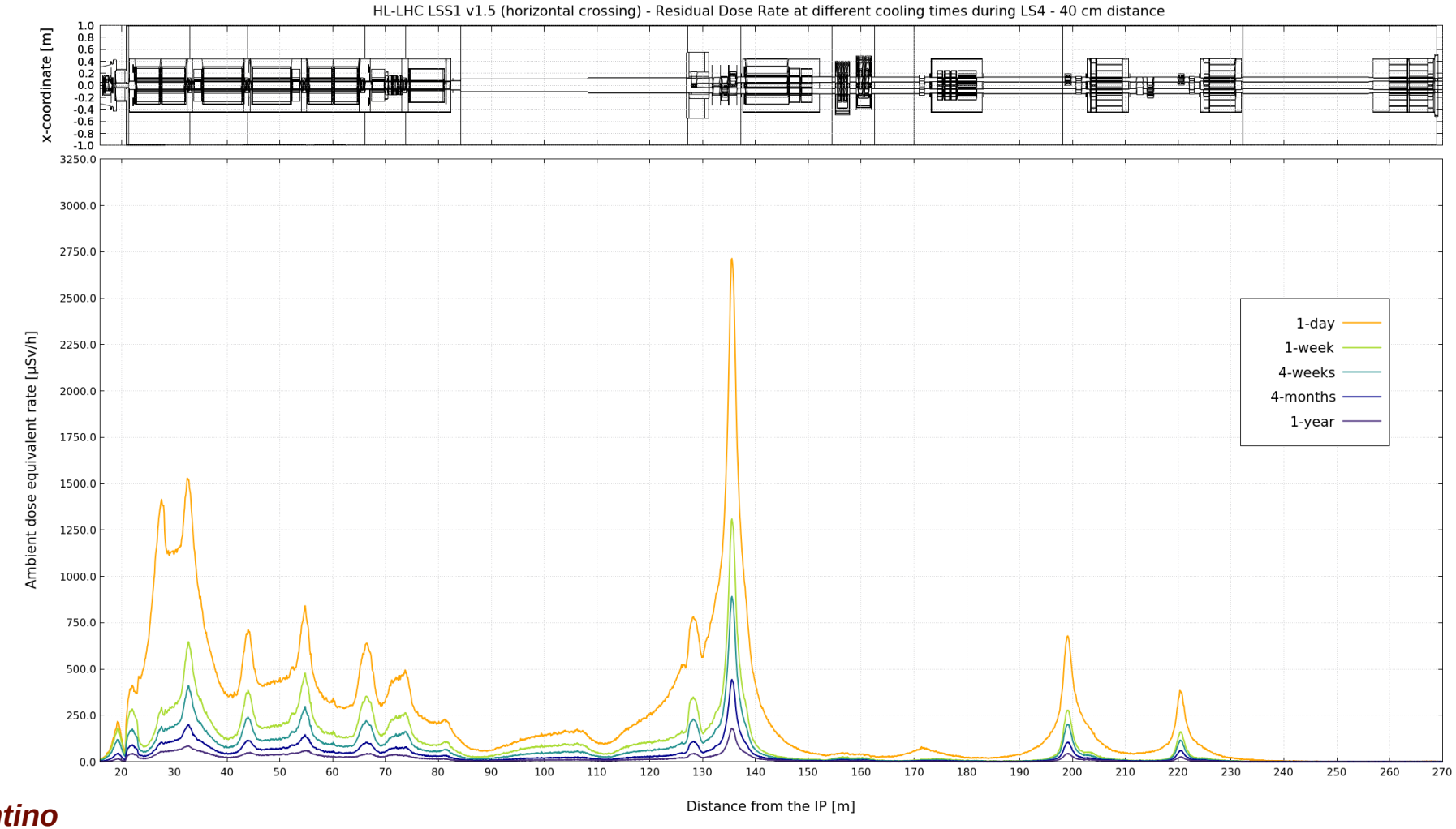
Courtesy A. Infantino

Radiation levels in LHC LSS5 (V. crossing)



Courtesy A. Infantino

Radiation levels in HL-LHC LSS1 (V. Crossing)



Courtesy A. Infantino

Conclusions

- CARE & R2E can contribute efficiently in HL-LHC cable purchasing
  - Choosing suitable cable for HL-LHC requirements
  - Increasing quality control and traceability of cable batches
- During HL-LHC operation, CARE, R2E and RP can monitor cable condition
  - Cable Samples in sensitives areas
  - Complete information on cable characterization
  - Ageing estimation of installed cables
- Benefits
  - Cable purchasing cost optimized: recent materials and production cables
  - Optimization on cable replacement campaigns: cable condition monitoring
  - Reduction on cable waste expenses

QUESTIONS?