Cable Irradiation Activity

J. Gascon for CARE project

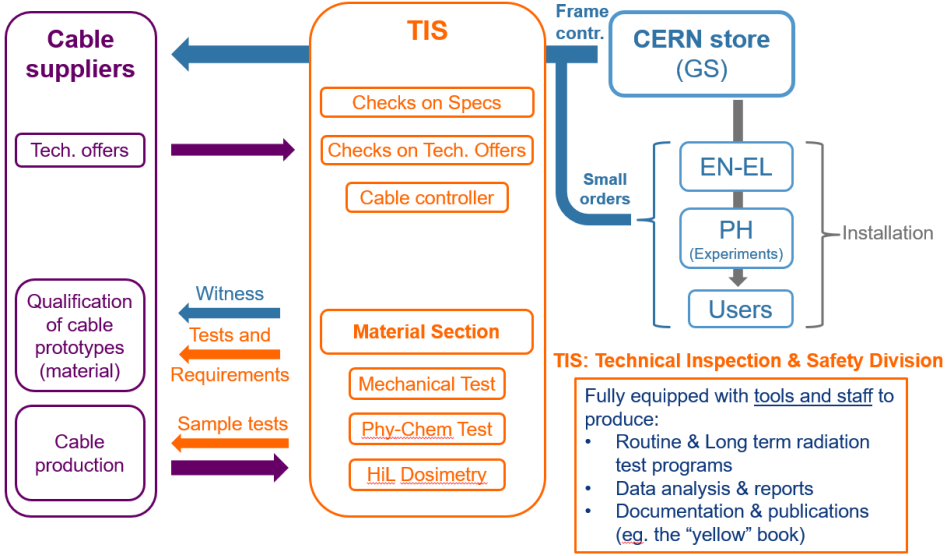
Special thanks to I. Aviles Santillana, M. Ferrari, H. Garcia Gavela, R. Garcia Alia, C. Garino, G. Lerner, S. Sgobba, M. Taborelli & CARE team

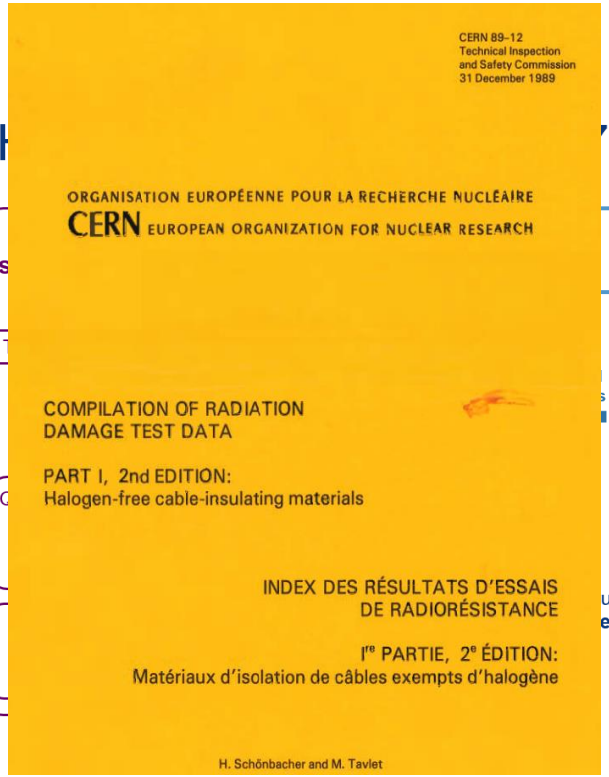
Introduction

History

Source: RIACWG

Historical perspective (until 1997)

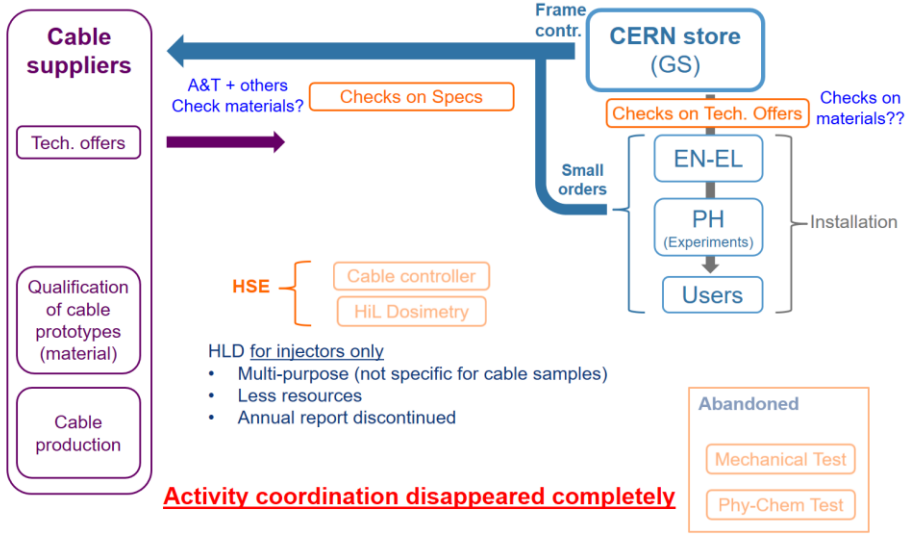




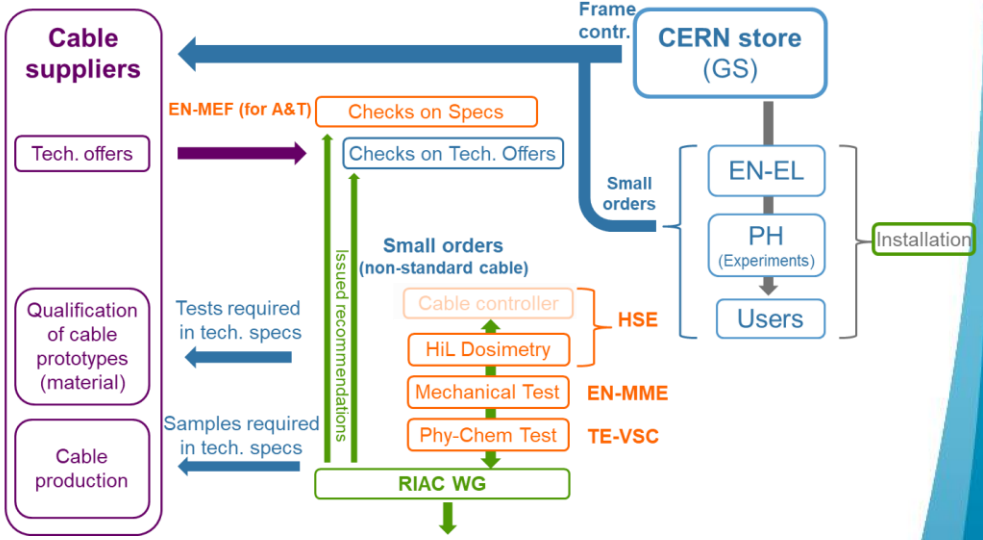
History

Source: RIACWG

Historical perspective (after 2002)



Historical perspective (2010-2015)



History

- **CARE Working Group 2016-2019**
  - Activity taken by HSE unit
  - Followed recommendation proposed by RIACWG
- **CARE Project 2019-**
  - **Leader:** J. Gascon
  - **Team members:**

Berta
RUIZ PALENZUELA
Materials Eng.

Federica
BORTOLETTO
Materials Eng.

Dr. Marija
KRANJCEVIC
PhD in Computing

Cable Ageing Research (CARE) Project

- Long-lead Research programme on cable ageing
- Focussed to Rad-Hard cables
- Oriented mainly on new cables procurement
- Seeking predictive maintenance oriented to reduce cable replacements
- Enhancing decision making process in terms of expected cables lifetime

Main Objective: extend cable lifetime procuring the most appropriate cables for CERN operations

- Determining cable “weathering” installation & operation conditions *(cable stressors)*
- Defining appropriate technical requirements and tests procedures in cable procurement bids
- Providing Quality control & acceptance criteria on cable procurement
- Assessing cable degradation during beam operation (condition monitoring)
- Tracing logbook during all cable lifecycle (complete cable life data over years)
- Establishing lifetime models for cables from cable life data analysis

Cable design considerations

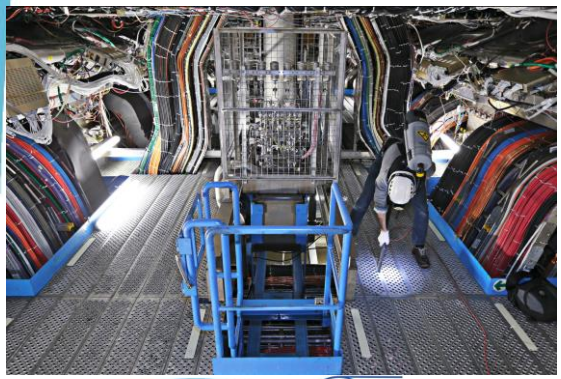
Cable Design

➢ 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 (commercial products)*
- *Grounding*

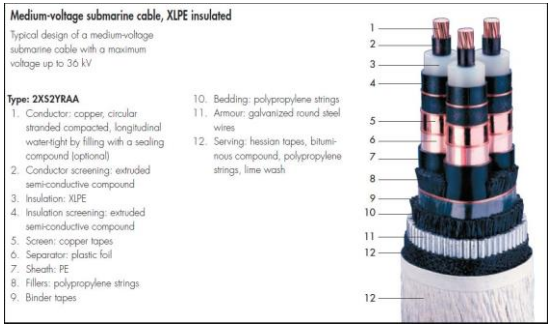
➢ Cable Stressors

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



Cable Design

- **Cable main components**
  - Conductors (electrical): *copper, aluminium*
  - Insulation (electrical): *polymers*
  - Shielding (electrical): *foil and/or braided wires (Al, Cu)*
  - Jacket (mechanical, chemical, fire): *polymers*
- **Additional components**
  - Fillers, binder or bedding: *mechanical stability*
  - Tapes, semiconductors: *electrical, mechanical or fire*
  - Armouring: *mechanical protection*

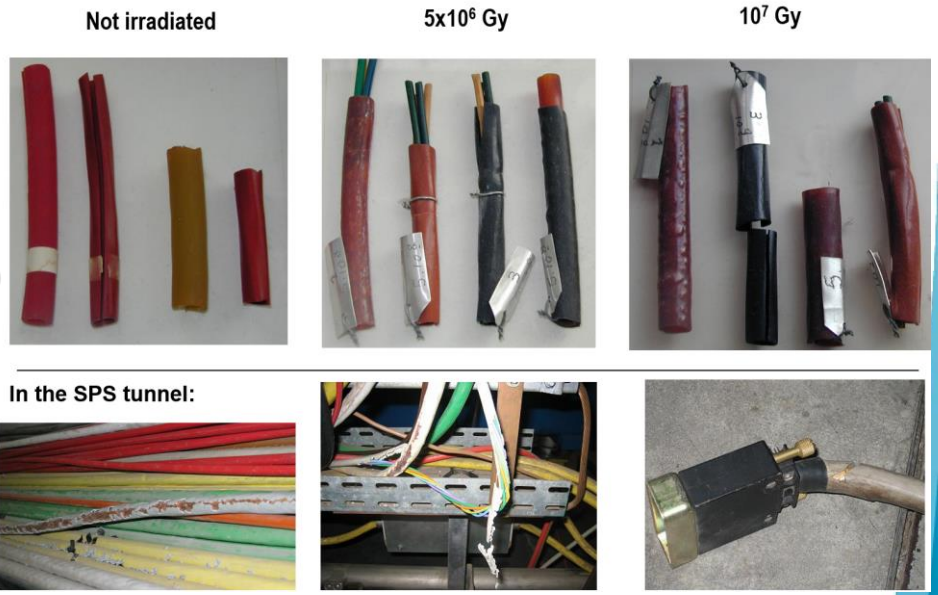


- **Typical Polymers cable Industry**
  (halogen free)
  - Ethylene vinyl acetate (EVA)
  - Cross-linked polyethylene/polyolefin (XLPE / XLPO)
  - Low and High density polyethylene (LDPE / HDPE)
  - Ethylene propylene based elastomers (EPR / EPDM)
  - Polypropylene (PP)
  - Polyphenylene oxide (PPO)
  - Polyphenylene ether (PPE)
  - Butyl rubber (BR)
  - Polyimide (Kapton®)
  - Silicone rubber (SiR)
  - Polyether ether ketone (PEEK)
  - Polyurethane rubber (PUR)
- **Additives** ***(antioxidants, flame retardant, stabilizers)***

Radiation effects

➢ Ionizing radiation effects on Polymers

- Formation of free radicals: depending on chemical structure, crystallinity, dose rate, solvent content, additives, plasticizer, stabilizers, temperature, oxygen levels, humidity.
- Formation of hydrogen & light hydrocarbon
- Formation of C-C bonds between molecules (crosslinking)
- Rupture of C-C bond (chain scission)
- Increase in unsaturation
- Breakdown of crystalline structure
- Discoloration
- Oxidation



➢ Synergistic effect

- Simultaneous stressors damage higher than sequential equivalent stressor damage separately:
  Temperature & radiation more damage than temperature and after radiation for same quantities

CARE activities for HL-LHC Project

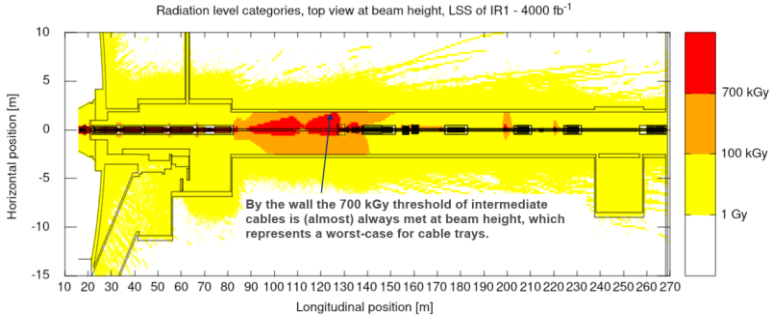
Performed activities

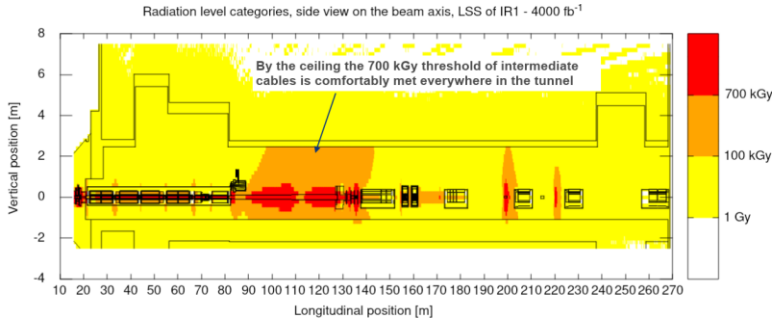
- **Preparation of cable qualification process for HL-LHC cables procurement**
  - **Strategy**
    - ✓ Inputs from R2E for cable radiation levels expected in HL-LHC areas
    - ✓ Preparation of Procurement documents for Rad-tolerant cables (new 3.5MGy cable category)
    - ✓ Establishing qualification criteria and acceptance criteria for cables on ageing (radiation)
  - **Tests procedures**
    - ✓ Tests techniques for cable assessment reviewed
    - ✓ Test techniques fully defined particularly on test parameters not defined by standards
    - ✓ Ageing radiation methods definition according to expected cable radiation levels in HL-LHC areas
  - **Tests execution**
    - ✓ Ageing samples at CERN & in external facilities
    - ✓ Specimen preparation for testing after ageing
    - ✓ Testing in CERN labs
    - ✓ Tracking data results in database
    - ✓ Qualification practice campaigns on available cables at CERN
  - **Analysis**
    - ✓ Technical report from test results
    - ✓ Statistical studies improving reliability of tests

R2E inputs for HL-LHC cables

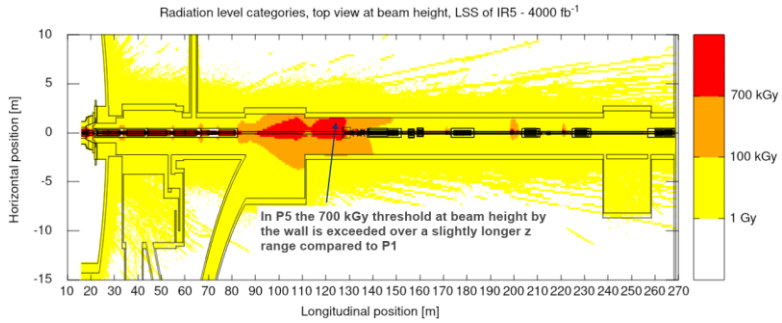
- **R2E WG FLUKA simulations** *(June 2021)*

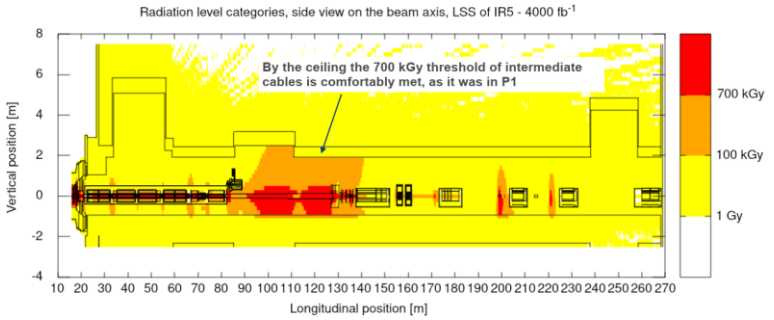
IR1





IR5





Courtesy of G. Lerner, SY-STI

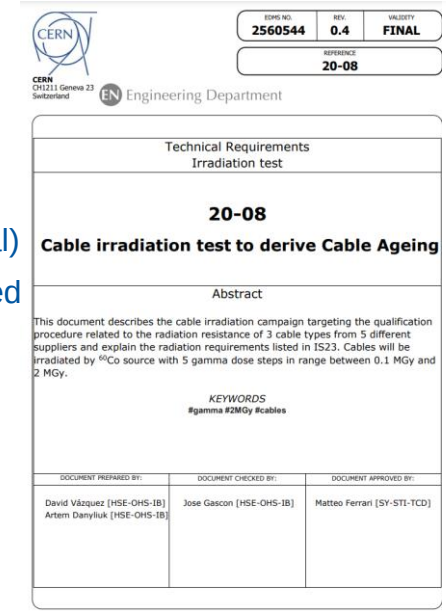
Qualification Criteria

- **Testing methods & acceptance criteria**

	ageing Method	Source ageing method	Acceptance criteria	International standards
Reference Stage		IEC 60502	• EaB ≥ 125% (sheath) • EaB ≥ 200 % (insulation) • Tensile strength ≥ 9MPa	According to IEC 60502 **sheath LSZH** • EaB ≥ 125% • Tensile strength ≥ 9MPa **insulation XLPE** • EaB ≥ 200% • Tensile strength ≥ 12MPa
Thermal Ageing Stage	Thermal ageing 42 days at 100°C	Temperature, time and oven requirements are taken from IEC 60811-408	• Residual EaB ≥ 70% • OIT > 2 minutes	According to IEC 60811-408 Applicable for wires, materials to be rolled into coils, no cracks to be obtained after the thermal ageing
Radiation Resistance Stage	Gamma Irradiation Dose 3.5 MGy (dose rate 1Gy/s)	IEC 60544-2	• EaB ≥ 100 % (sheath) • Residual EaB ≥ 50% (insulation) • Residual Tensile strength ≥ 50%	According to IEC 60544-2 • Residual EaB ≥ 50% • Residual Tensile strength ≥ 50%

Irradiation ageing experience

- **Artificial irradiation with cable bundles**
  - ✓ R2M framework contract used for 2 campaigns
  - ✓ Facility for 1st campaign Germany
  - ✓ Facility for 2nd campaign France
  - ✓ Difficulties due to COVID (facilities overbooked for medical)
  - ✓ 1st campaign sent out in May 2021- Cable bundles received in September 2021
  - ✓ 2nd campaign sent out in October 2021- Cable bundles received in May 2022
  - ✓ Technical report on 1st campaign released
  - ✓ Tests on 2nd campaign ongoing



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EDMS NO. 2560544 | REV. 0.4 | VALIDITY FINAL
REFERENCE 20-08

EN Engineering Department

Technical Requirements
Irradiation test

20-08

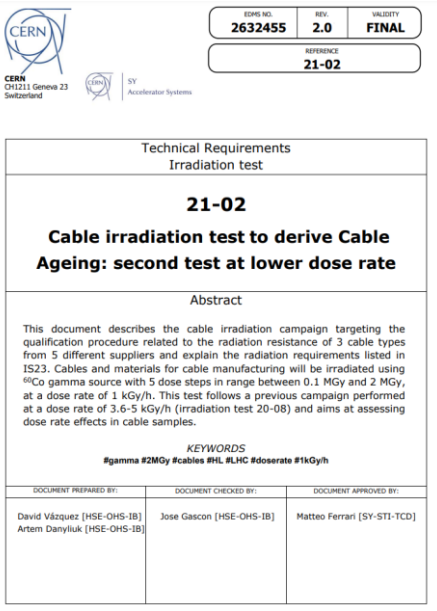
Cable irradiation test to derive Cable Ageing

Abstract

This document describes the cable irradiation campaign targeting the qualification procedure related to the radiation resistance of 3 cable types from 5 different suppliers and explain the radiation requirements listed in IS23. Cables will be irradiated by ^{60}Co source with 5 gamma dose steps in range between 0.1 MGy and 2 MGy.

KEYWORDS
#gamma #2MGy #cables

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
David Vázquez [HSE-OHS-IB] Artem Danyliuk [HSE-OHS-IB]	Jose Gascon [HSE-OHS-IB]	Matteo Ferrari [SY-STI-TCD]



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CH1211 Geneva 23
Switzerland

SY Accelerator Systems

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REFERENCE 21-02

Technical Requirements
Irradiation test

21-02

Cable irradiation test to derive Cable Ageing: second test at lower dose rate

Abstract

This document describes the cable irradiation campaign targeting the qualification procedure related to the radiation resistance of 3 cable types from 5 different suppliers and explain the radiation requirements listed in IS23. Cables and materials for cable manufacturing will be irradiated using ^{60}Co gamma source with 5 dose steps in range between 0.1 MGy and 2 MGy, at a dose rate of 1 kGy/h. This test follows a previous campaign performed at a dose rate of 3.6-5 kGy/h (irradiation test 20-08) and aims at assessing dose rate effects in cable samples.

KEYWORDS
#gamma #2MGy #cables #HL #LHC #doserate #1kGy/h

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
David Vázquez [HSE-OHS-IB] Artem Danyliuk [HSE-OHS-IB]	Jose Gascon [HSE-OHS-IB]	Matteo Ferrari [SY-STI-TCD]

Irradiation ageing experience #1

➢ **1st Irradiation campaign objectives** *(bundles received in September 2021)*

- **Type of cables & manufacturers**
  - ✓ NE8 & NE48 types selected as most used type in HL-LHC project *(source EN-EL Group)* & cables available in CERN stores
  - ✓ NE48 type includes 2 different manufacturers to assess influence of manufacturer
  - ✓ PH3SJ type from Polycab manufacturer (contract signed by CERN stores) to assess radiation hardness
  - ✓ CGN50 type produced with popular Megolon S304 (radiation resistant)

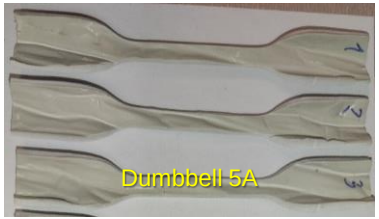
- **Dose rate influence 1Gy/s** *(~3.6kGy/h)*
  - ✓ 5 Dose steps 0.1 - 0.2 - 0.5 - 1 - 2 MGy increase data
  - ✓ Confirm degradation trend of each cable type & manufacturer
  - ✓ Confirm cable degradation around 500kGy
- **Ageing methods**
  - ✓ 3 Combinations: Radiation only , Thermal ageing & radiation later, Radiation & thermal ageing later
  - ✓ Thermal ageing 168h as requested in IEC-60502
  - ✓ Assess influence of cable stressors and combination of them

- **Pilot campaign #1**
  - ✓ Bundles dosimetry (3 dosimeters per bundle) & dose from facility
  - ✓ Get experience from irradiation facility for cable qualification

Testing

➢ Tensile Tests (TT)

- **Procedure**
  - ✓ CARE procedure (EDMS no 2705496) for specimens preparation and test
  - ✓ Dumbbell specimens type 5A & 5B from jackets



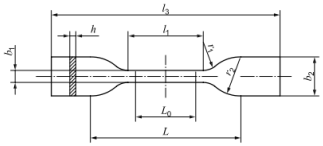
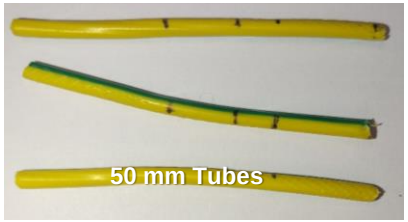
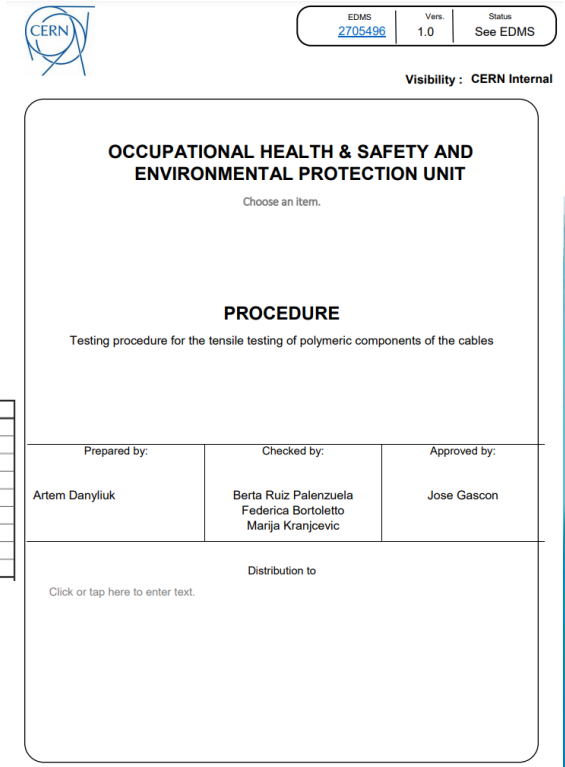


Figure A.2 — Type 5A and 5B test specimens

	Specimen type	5A	5B
l_3	Overall length	≥75	≥35
b_2	Width at ends	12,5 ± 1	6 ± 0,5
l_1	Length of narrow parallel-sided portion	25 ± 1	12 ± 0,5
b_1	Width at narrow portion	4 ± 0,1	2 ± 0,1
r_1	Small radius	8 ± 0,5	3 ± 0,1
r_2	Large radius	12,5 ± 1	3 ± 0,1
L	Initial distance between grips	50 ± 2	20 ± 2
L_0	Gauge length	20 ± 0,5	10 ± 0,2
h	Thickness	2 ± 0,2	1 ± 0,1

  - ✓ 50 mm tubes from insulation (L0=10 mm)





EDMS 2705496 | Vers. 1.0 | Status See EDMS

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PROCEDURE

Testing procedure for the tensile testing of polymeric components of the cables

Prepared by:	Checked by:	Approved by:
Artem Danyliuk	Berta Ruiz Palenzuela Federica Bortoletto Marija Kranjcevic	Jose Gascon

Distribution to

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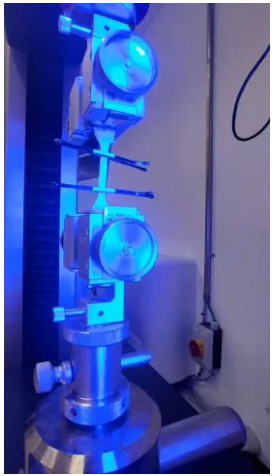
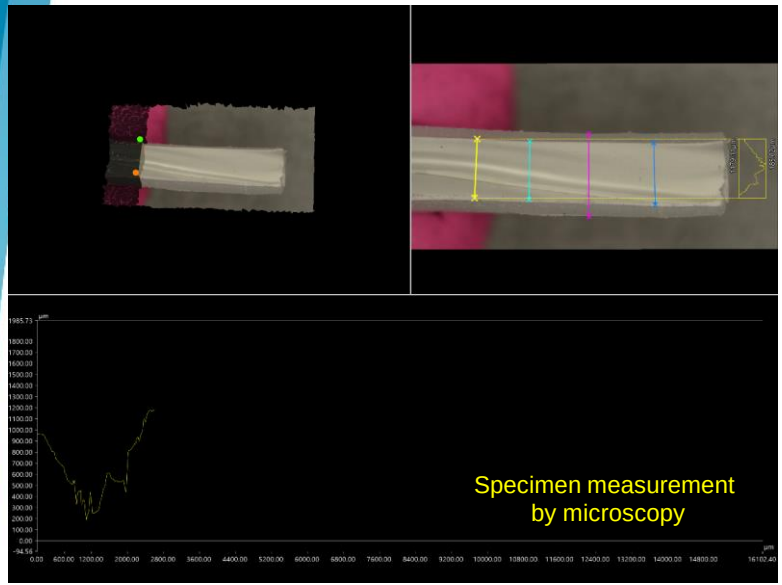
Testing

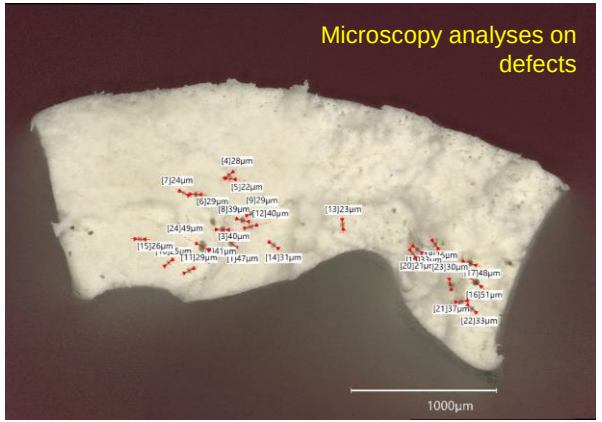
- **Tensile Tests (TT)**
  - **Equipment (MME lab)**
    - ✓ Machine Zwick/Roell Z010
    - ✓ Grips 8106 500N
    - ✓ 2 different jaws
    - ✓ Limmes video-extensometer
  - **Test**

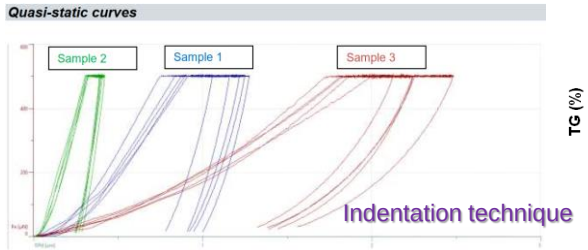


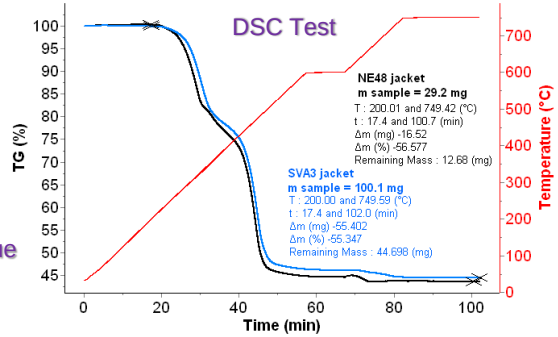
Testing

- **Other performed test techniques**







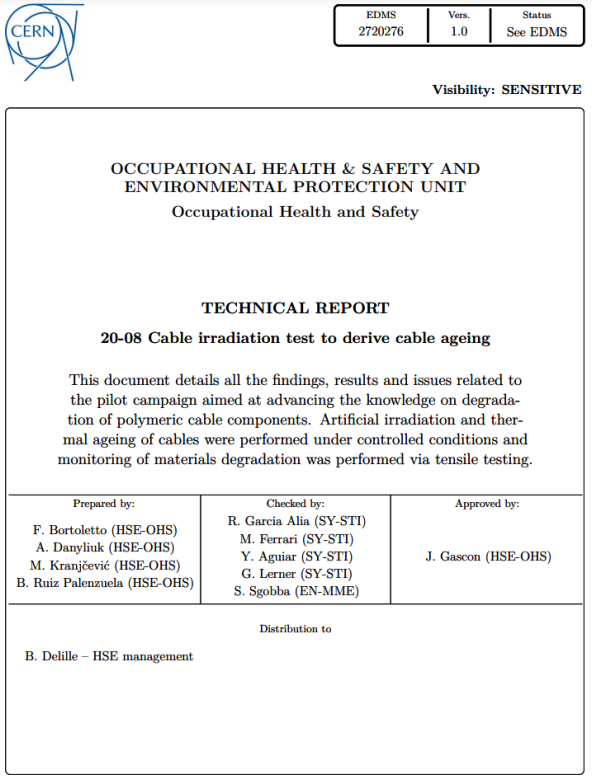


Tests results

- **Tensile tests performed on 1st irradiation samples**

Cable Type	Manufacturer	Number of tested specimens					
		Jackets			Insulation		
		Total	Valid	Share of valid [%]	Total	Valid	Share of valid [%]
NE8	NOVACAVI	275	184	67	22	15	68
NE48	DRAKA	463	337	73	114	67	59
NE48	2M KABLO	492	408	83	341	225	66
CGN50	RFS	37	32	86	-	-	-
HCA78	RFS	36	33	92	-	-	-
PH3SJ	POLYCAB	41	38	93	112	65	58

Most expected cable types (33%) in HL-LHC Project



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EDMS	Vers.	Status
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TECHNICAL REPORT

20-08 Cable irradiation test to derive cable ageing

This document details all the findings, results and issues related to the pilot campaign aimed at advancing the knowledge on degradation of polymeric cable components. Artificial irradiation and thermal ageing of cables were performed under controlled conditions and monitoring of materials degradation was performed via tensile testing.

Prepared by:	Checked by:	Approved by:
F. Bortoletto (HSE-OHS) A. Danyliuk (HSE-OHS) M. Kranjčević (HSE-OHS) B. Ruiz Palenzuela (HSE-OHS)	R. Garcia Alia (SY-STI) M. Ferrari (SY-STI) Y. Aguiar (SY-STI) G. Lerner (SY-STI) S. Sgobba (EN-MME)	J. Gascon (HSE-OHS)

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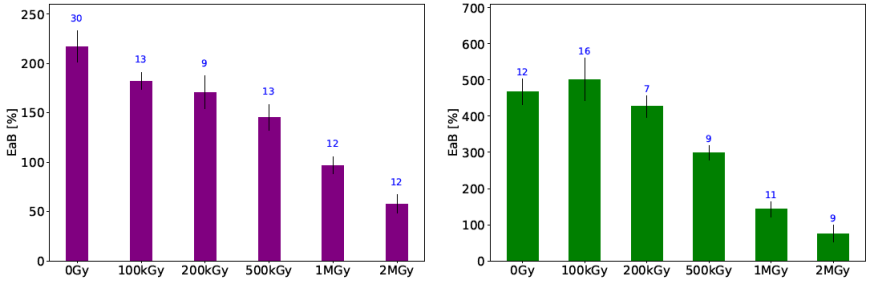
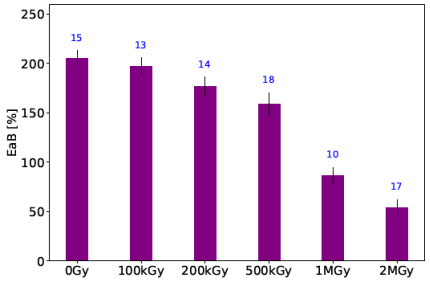
Tests results

- **Results trend on cable degradation**

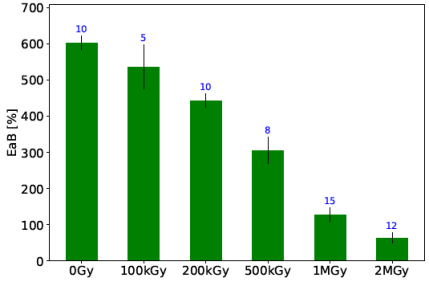


(a) Draka NE48 jacket.

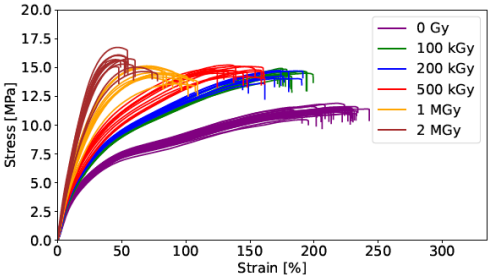
(b) Draka NE48 insulation.



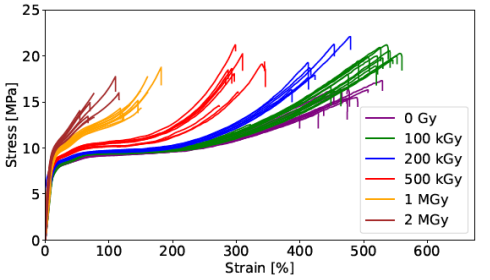
(c) 2M Kablo NE48 jacket.



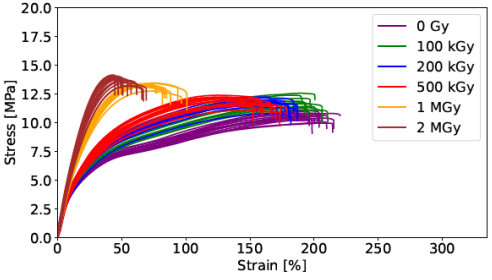
(d) 2M Kablo NE48 insulations.



(a) Draka NE48 jacket.



(b) Draka NE48 insulation.



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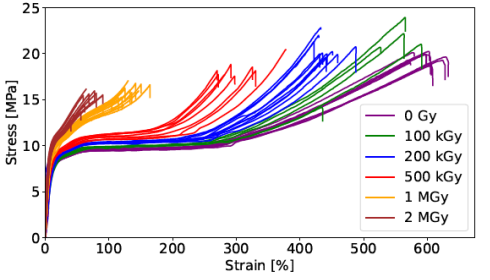

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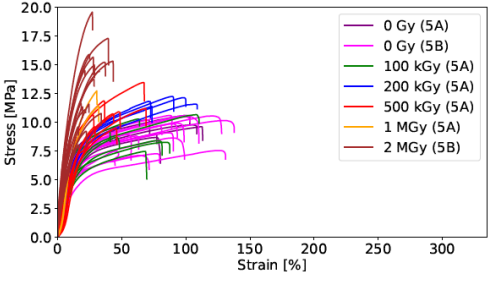
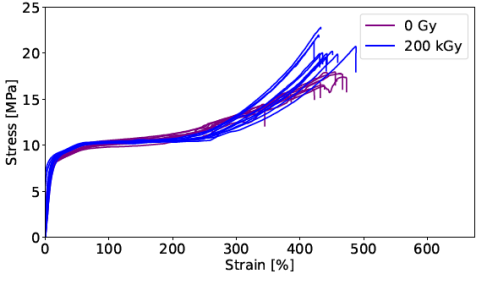


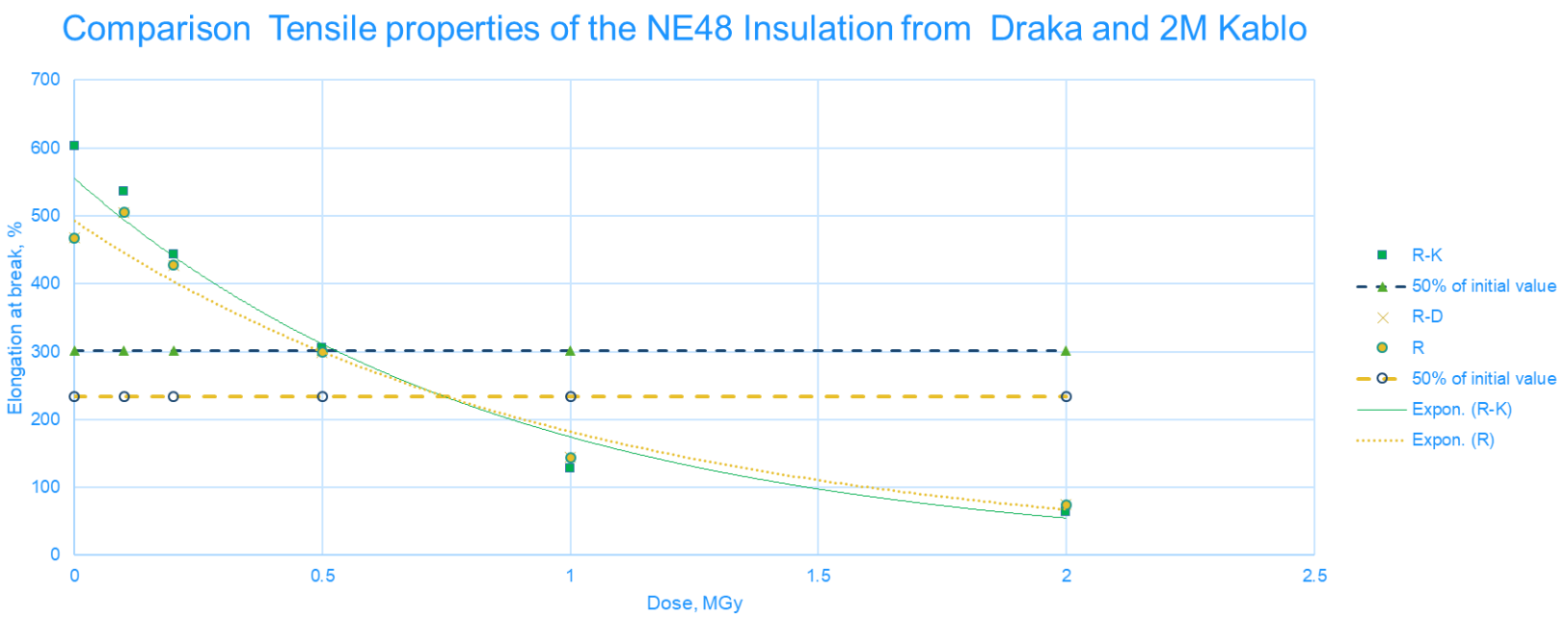
(e) Novacavi NE8 jacket.



(f) Novacavi NE8 insulation.

Tests results

- **Results comparison per manufacturer**

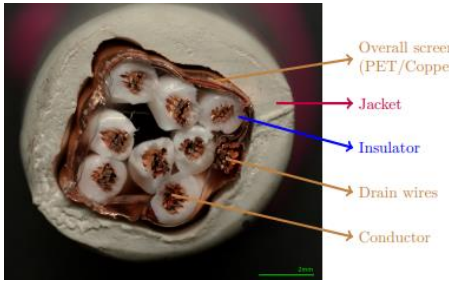


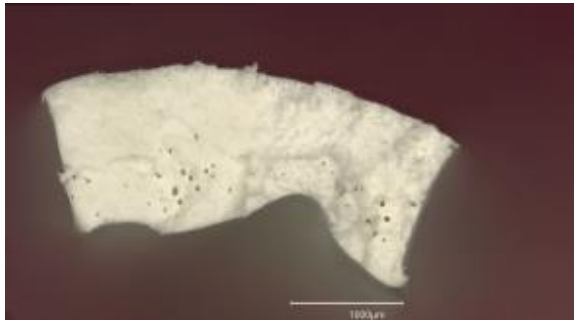
Tests results

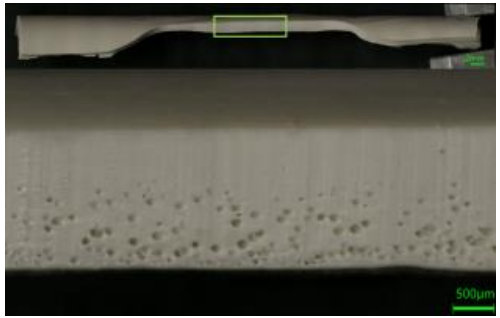
- **Acceptance criteria results**

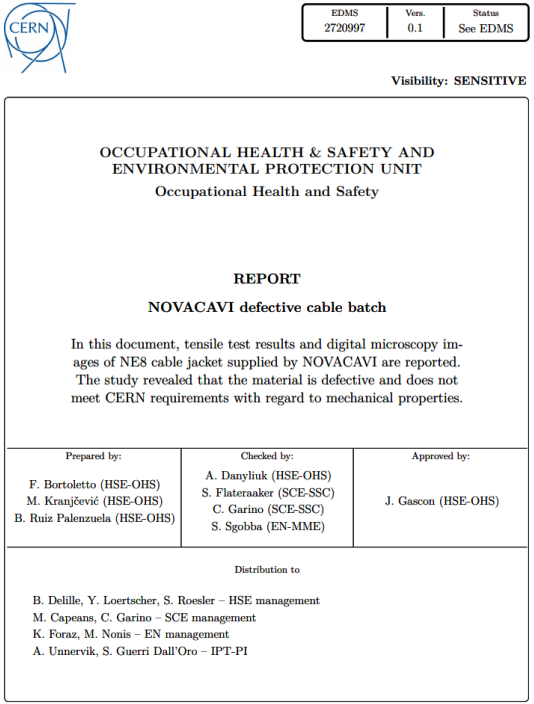
Cable	Cable component	500kGy Facility
NE8 NV	sheath	do not pass*
NE48 DR	sheath	pass
NE48 DR	insulation	pass
NE48 2M	sheath	pass
NE48 2M	insulation	pass
PH3SJ Polycab	sheath	pass
PH3SJ Polycab	insulation	do not pass

Production defect discovered in NV cable sheath









CERN

EDMS	Vers.	Status
2720997	0.1	See EDMS

Visibility: SENSITIVE

OCCUPATIONAL HEALTH & SAFETY AND ENVIRONMENTAL PROTECTION UNIT

Occupational Health and Safety

REPORT

NOVACAVI defective cable batch

In this document, tensile test results and digital microscopy images of NE8 cable jacket supplied by NOVACAVI are reported. The study revealed that the material is defective and does not meet CERN requirements with regard to mechanical properties.

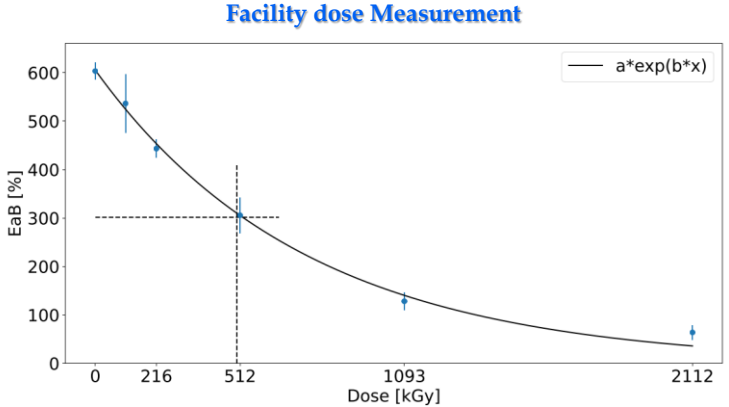
Prepared by:	Checked by:	Approved by:
F. Bortoletto (HSE-OHS) M. Kranjčević (HSE-OHS) B. Ruiz Palenzuela (HSE-OHS)	A. Danyliuk (HSE-OHS) S. Flateraaker (SCE-SSC) C. Garino (SCE-SSC) S. Sgobba (EN-MME)	J. Gascon (HSE-OHS)

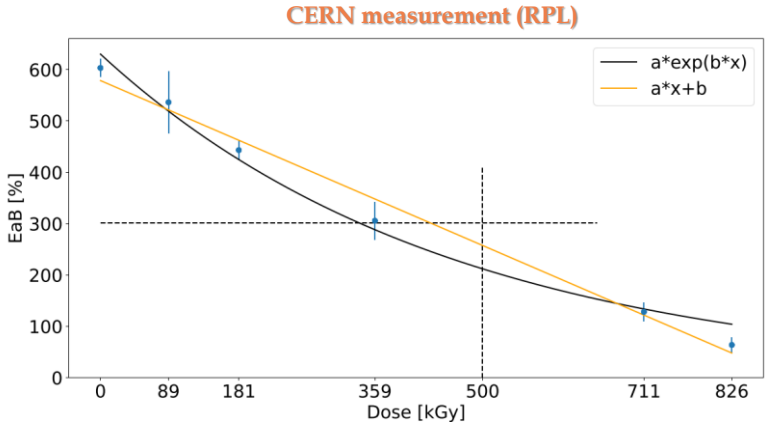
Distribution to

B. Delille, Y. Loertscher, S. Roesler – HSE management
M. Capeans, C. Garino – SCE management
K. Foraz, M. Nonis – EN management
A. Unnervik, S. Guerri Dall'Oro – IPT-PI

Tests results

- **Dosimetry findings**





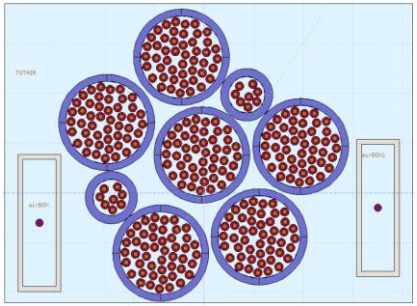
Target Dose [kGy]	Dose Facility [kGy][4]	R2E		
		Dosimeter	Dose [kGy][5]	Error
100	107	D1-0.1	78	27 %
		D2-0.1	89	17 %
		D3-0.1	88	18 %
200	216	D1-0.2	171	21 %
		D2-0.2	181	16 %
		D3-0.2	176	19 %
500	512	D1-0.5	270	47 %
		D2-0.5	359	30 %
		D3-0.5	359	30 %
1000	1093	D1-1	681	38 %
		D2-1	711	35 %
		D3-1	641	41 %
2000	2112	D1-2	754	64 %
		D2-2	826	61 %
		D3-2	730	65 %

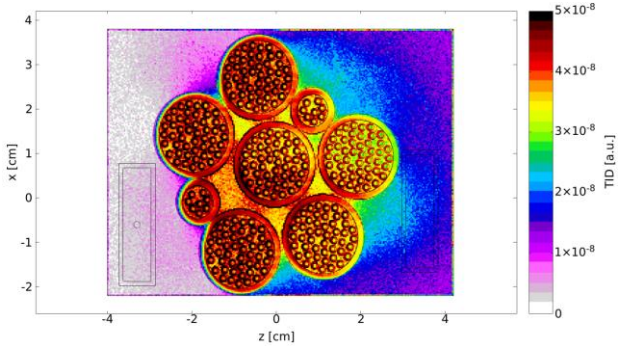
(4) Dose calculated by facility via 2 alanine dosimeters (2 positions)
(5) Measured by R2E at CERN after an ultrasonic bath

Tests results

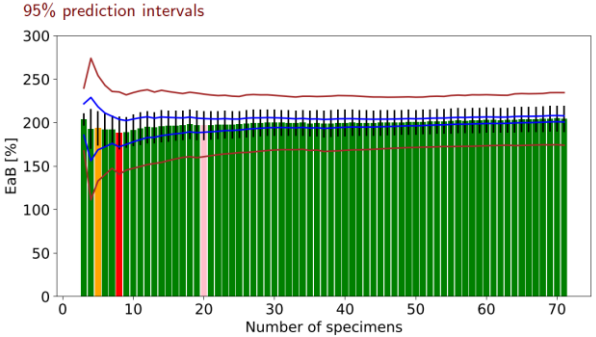
➢ Other analysis performed

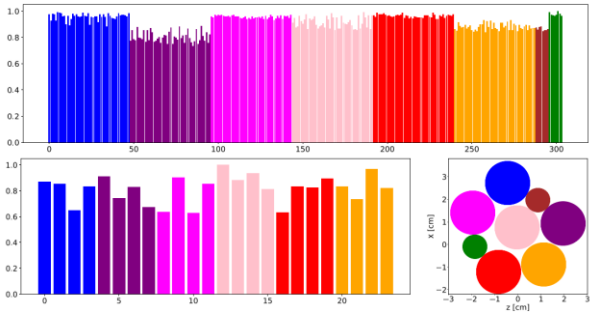
- **Working closely with R2E group on dosimetry & FLUKA for artificial irradiation**





- **Math analysis: statistics, data correlation, models**

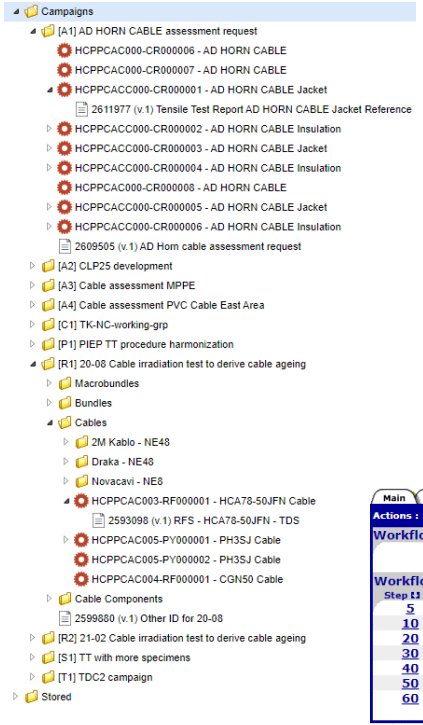


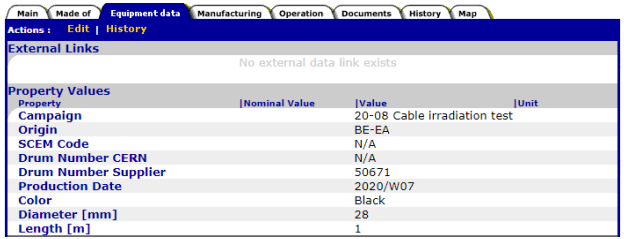


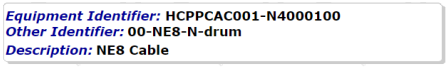
Tests results

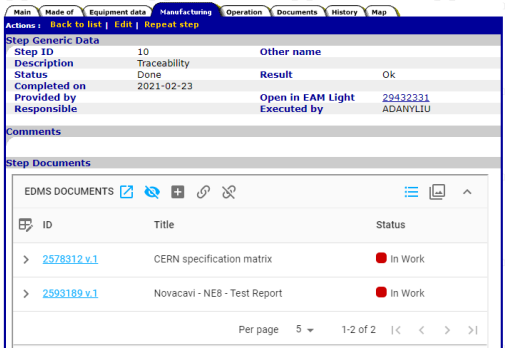
Results tracked in CARE Database

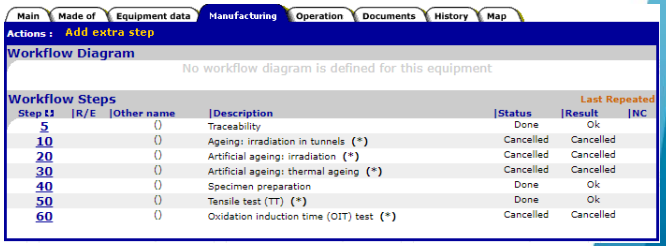
- **Created with the guidance of the HL-LHC quality control group**
- **Tracking CARE elements**
  - ✓ Cables and cable components (jacket & insulation)
  - ✓ Cable bundles
  - ✓ Dosimeters
  - ✓ Raw Materials
- **EDMS Node**
  - ✓ Items & assets (cables, materials, etc.)
  - ✓ Documents (specifications, test reports, etc.)
  - ✓ Projects (campaigns, documentation, etc.)
- **Infor, MTF, EAM Light**
  - ✓ Asset properties
  - ✓ Steps
- **EAM store representing the physical storage space**
- **Labels with a QR code**









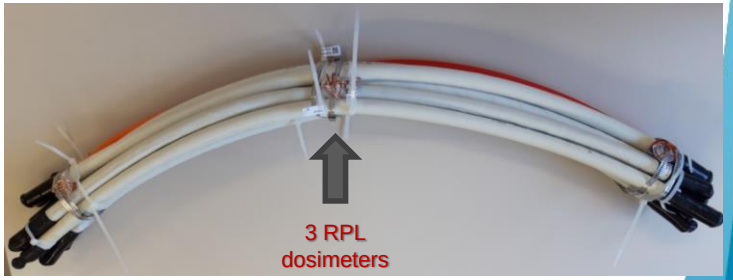


1st irradiation experience summary

- **Irradiation facility** (R2M framework contract)
  - ✓ Shipping going and back should be improved (samples stacked, packing inadequate, time delays, weathering)
  - ✓ Packing from CERN to be improved in terms of dimensions
  - ✓ Difficulties to obtain clear information from facility (subcontractor)
  - ✓ Samples irradiation monitoring to be improved
- **Dosimetry**
  - ✓ Mismatching between dosimeters measurements and facility dose calculation
  - ✓ Bundles arrangement to be optimised to reduce shielding effect during irradiation
  - ✓ Expected shielding effect on bundles mismatching with dosimeters measurements
- **Testing**
  - ✓ Extremely difficult to prepare tubes for small cable insulations
  - ✓ Slipping prepared insulation tubes in TT machine grips
  - ✓ Number of Tensile test should be 10 valid ones per component to obtain reasonable standard deviation in results (<10%)
  - ✓ DSC tests on cable insulation were not performed due to machine breakdown
- **Qualification exercise**
  - ✓ 2 manufacturers will pass qualification (facility dose measurement)
  - ✓ Qualification process allowed detect defective cable batch
  - ✓ Applicable CPR class Cca fire requirement might disqualify cables in terms of radiation (Polycab manufacturer)

Radiation ageing experience #2

- **2nd irradiation campaign objectives** *(bundles received in May 2022)*
  - **Type of cables & manufacturers**
    - ✓ NE8 & NE48 types from same batch than 1st campaign
    - ✓ NF12, SVA3 & TFA3 type included as samples irradiated naturally in TS1+ & TDC2 tunnels
  - **Dose rate lower ~1kGy/h**
    - ✓ Same dose steps 0.1 - 0.2 - 0.5 - 1 - 2 MGy
    - ✓ Confirm cable degradation around 500kGy is independently of dose rate
  - **Ageing methods**
    - ✓ Same as 1st campaign
  - **Dosimetry**
    - ✓ 2 extra RPL dosimeters per bundle + 2 RPLs for facility measurement
  - **Pilot campaign #2**
    - ✓ Dose rate effect
    - ✓ Fix parameters to be retained for HL-LHC qualification
    - ✓ Confirm shielding effect and dosimetry
    - ✓ Correlate all results with 1st campaign ones



2nd Irradiation experience situation

- **Irradiation facility** (R2M framework contract)
  - ✓ Packing was improved delays shorter
  - ✓ Detailed information about radiation but partially clear information from facility (subcontractor)
  - ✓ Maintenance stop cut irradiation during around 10 days
- **Dosimetry**
  - ✓ Confirmed mismatching between dosimeters measurements and facility dose calculation
  - ✓ R2E is looking for an appropriate solution for future
- **Testing**
  - ✓ Tensile tests for cable sheath performed
  - ✓ Insulation cable specimen tubes are prepared awaiting new upgrade of Tensile Test machine
  - ✓ DSC machine repaired tests for 1st and 2nd on cable insulation are ongoing at this time
- **Reporting**
  - ✓ Analysing tests results from cable sheath on 2nd campaign
  - ✓ Correlation with 1st campaign ongoing
  - ✓ Drafting report

CARE Roadmap

- **Complete 2nd campaign**
  - ✓ DSC & TTs on cable insulation by January 23
  - ✓ Correlation between both campaign by February 23
  - ✓ Technical report by March 23
- **Prepare 3rd campaign**
  - ✓ More Cables & compounds sent to facility by December 22
  - ✓ Ageing & Testing by May 23
  - ✓ Analyses & report by July 23
- **HL-LHC cable procurement**
  - ✓ Market Survey by October 22
  - ✓ Qualification process from manufacturers starting June 23
  - ✓ Irradiation ageing by November 23
  - ✓ Testing & qualification process by January 24
  - ✓ Technical specification by June 24

Summary

- Radiation tolerant cables aim reduce cable replacement campaigns
- Qualification process will identify best cable manufacturers
- Work started on preparing qualification for HL-LHC
  - ✓ Development of qualification procedures
  - ✓ Defining acceptance criteria
  - ✓ Getting experience with pilots campaigns on existing cables at CERN
- Short term objectives
  - ✓ Supporting HL-LHC cable procurement
  - ✓ Technical exchange with cable manufacturers
  - ✓ Research on testing and ageing methods
  - ✓ More accurate thresholds based on tests results and correlations

Thank you for your attention!