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Induced Radioactivity in the Elettra Storage Ring

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Contents

- Introduction
- Simulation studies
- Experimental activities
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Elettra parameters

Elettra Parameters	
Storage ring circumference	259.2 m
Number of achromats	12 (long straight section + short section)
Years of activity	30 (since October 1993)

Operating Conditions	
User Operating Energy	2.0 GeV (75% of user time) 2.4 GeV (25% of user time)
Operating mode	Top-up
Operating current (user request)	300 mA at 2.0 GeV 140 mA at 2.4 GeV
Operating time	5000 h (divided in five cycles)
Beam lifetime	~100 h

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Introduction

- Elettra storage ring will be upgraded to a new generation machine
- The new storage ring will be installed in the existing tunnel:
  - Dismantling of almost all components of the present accelerator

284 magnets	~ 8.5 tons of steel and copper
84 supports	~ 11 tons of concrete
260m vacuum vessel	~ 1 tons of stainless-steel
A large number of cable trays and several kilometres of cables	

- The Italian law D.lgs. 101/2020, art. 54, regulates the release of radioactive materials:
  - Radiological non-relevance criterion (the 10 uSv/y concept)
  - Accurate prediction of induced radioactivity essential for the decommissioning
  - Simulations by FLUKA Monte Carlo code

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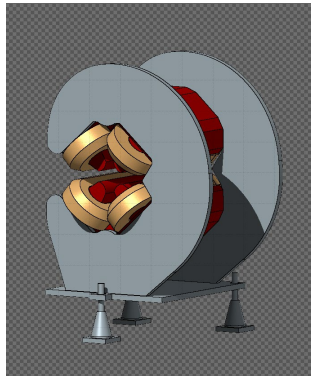
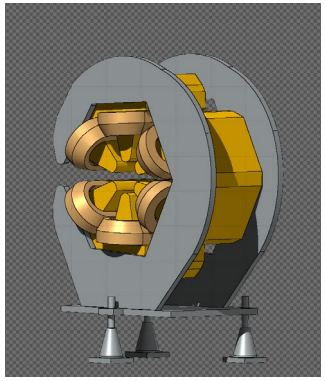
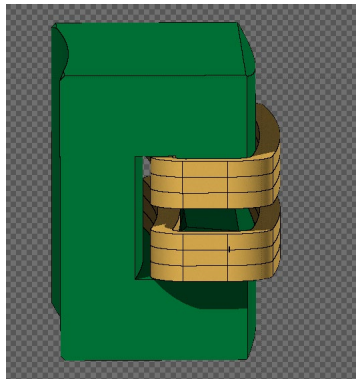
Simulation studies

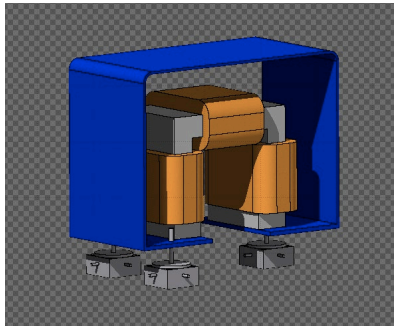
Storage ring modelling

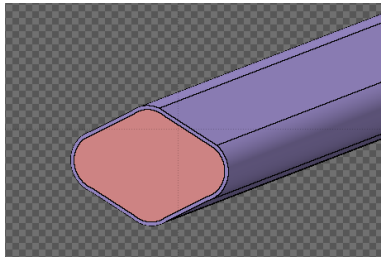
- **FLUKA ACCELERATOR COMPONENTS MODELLING**
  based on manufacturing drawings and detailed in geometry and elemental composition


Quadrupole - QBC


Sextupole - SBC


Dipole - BAC


Corrector - CAC


Vacuum vessel

Storage ring modelling

- **FLUKA ACHROMAT MODELLING**
  section 3 - standard achromat

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Beam losses scenario

- Three types of beam losses occur:
  1) Losses during **injection**
  2) Losses during **stored beam** (RF cavities or magnets stop)
  3) Losses during **beam dumps** (wanted or unwanted)

- Fluka simulations:
  - 2 GeV, 310 mA, losses due to bremsstrahlung photons and injection losses

- No record of electron losses tracks:
  - Conservative assumptions for activation studies:
    charge lost in a single location, perpendicular to the surface, no significant divergence

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Beam losses scenario

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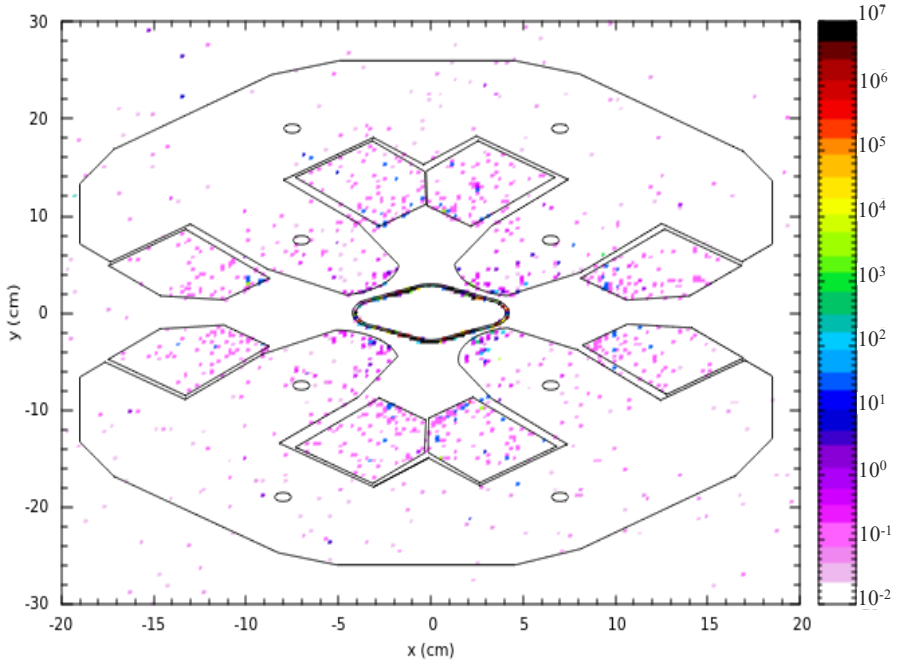
Activation maps

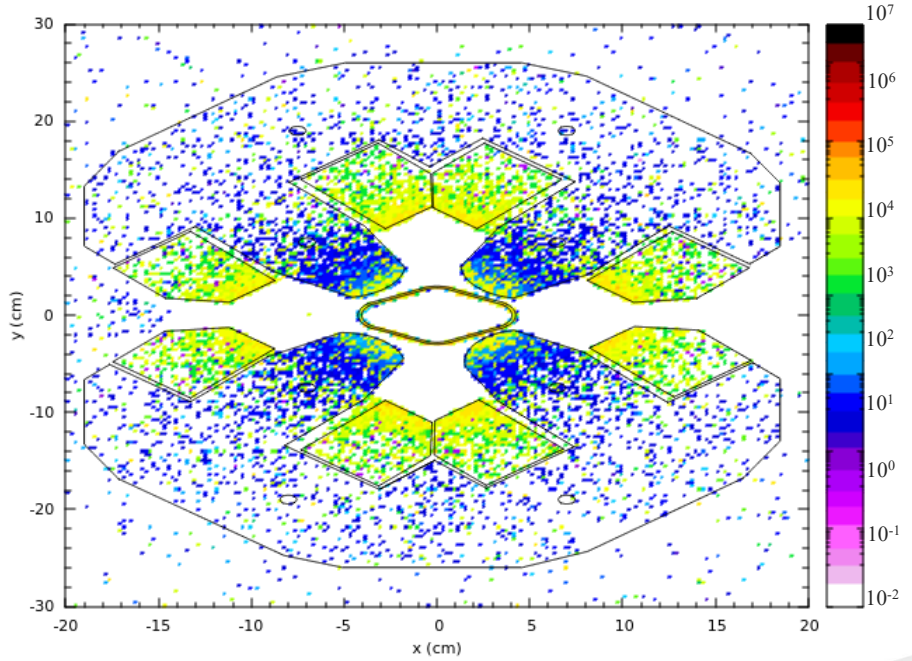
Activation maps calculated for the different accelerator components

1) NO LOSSES (Bremsstrahlung photons)

2) CONSERVATIVE INJECTION LOSSES

Activity (all isotopes) per unit volume integrated over all z axis for the quadrupole Q3_S3.1 at 2 GeV, 310 mA. Cooling time t = 0s.





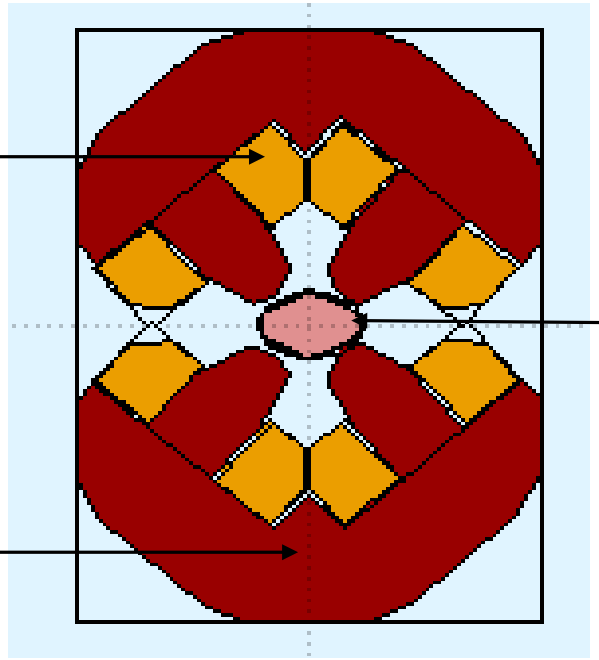
Shorted Nuclide Vector

COILS*
Copper

^{63}Ni
^{60}Co
^{58}Co
^{55}Fe

YOKE*
AISI 1018

^{56}Co
^{55}Fe
^{54}Mn
^{51}Cr
^{49}V
^{48}V



VACCUM VESSEL**
AISI 316LN

^{99}Mo, ^{93}Mo
^{63}Ni, ^{59}Ni
^{58}Co, ^{57}Co, ^{56}Co
^{55}Fe
^{54}Mn
^{51}Cr
^{49}V, ^{48}V

In agreement with similar studies in literature:

* Brugger M, et al. *Activation benchmark study at a 2.5 GeV electron accelerator.* Progress in Nuclear science and Technology, Vol. 4 (2014)
** Berkvens P. *Induced radioactivity in the ESRF storage ring. Radiation protection Dosimetry*, Vol. 115, No. 1-4 (2005)

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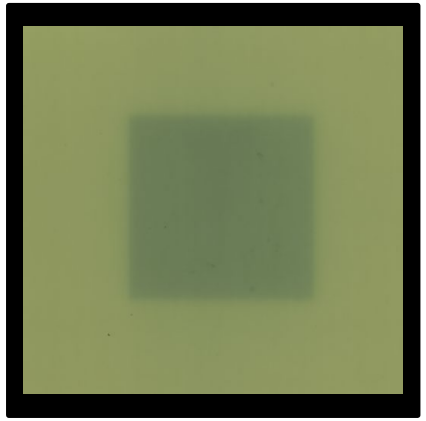
Experimental activities

Radiochromic films – GafChromic EBT3

- The EBT3 films were used to map the storage ring in order to locate the machine hotspots
- These films are designed for the measurement of absorbed doses of ionizing radiation
  - The blackening is proportional to the absorbed dose



Technical features:

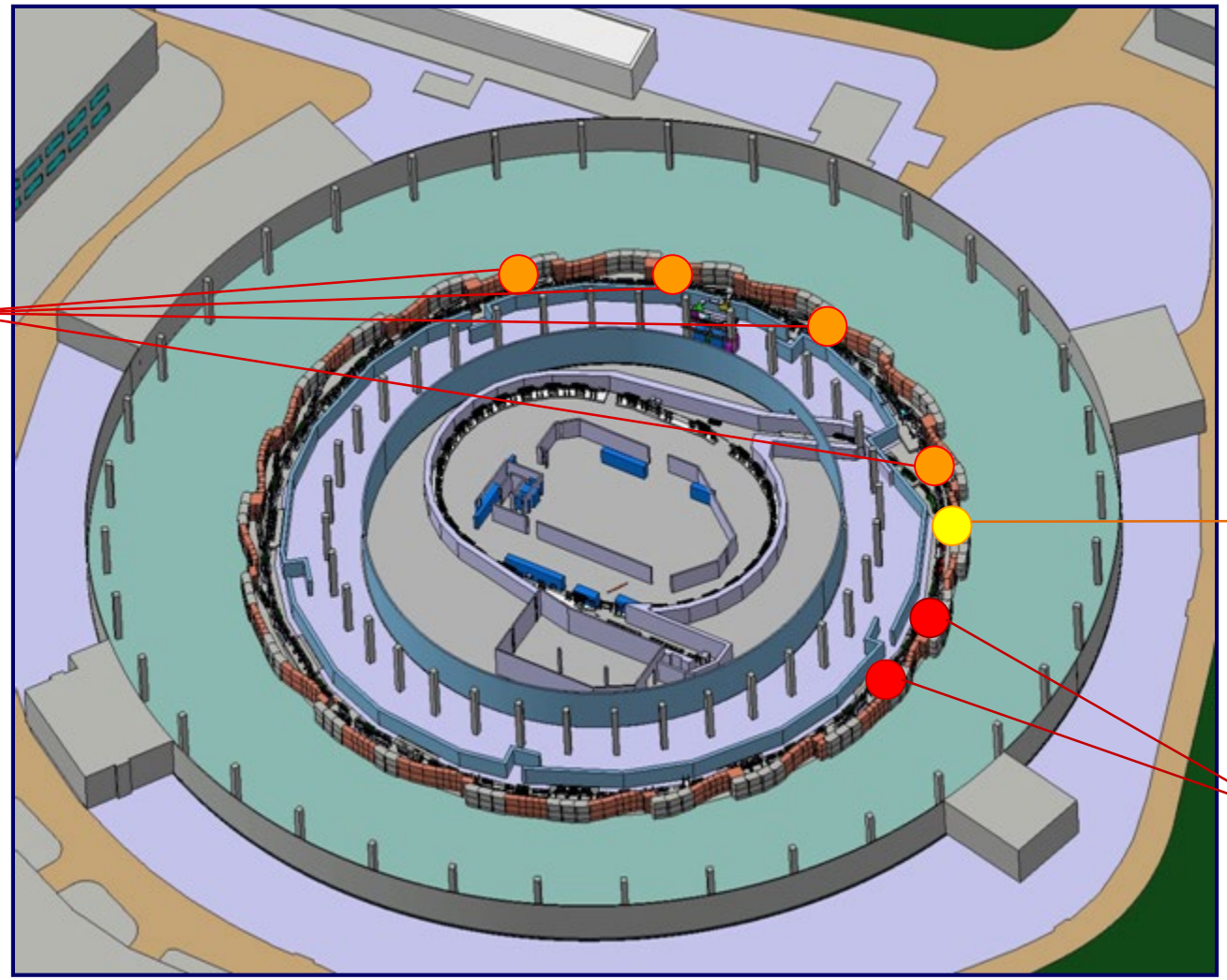
- ✓ Dose range: (0-90) Gy
- ✓ Energy independent
- ✓ High spatial resolution (25 um)
- ✓ Self developing
- ✓ Accuracy: 5%

- EBT3 measures during last year for three machine cycles, for an average period of eight weeks per cycle
  - Every cycle end, films were analysed and new ones were replaced before the start of the next cycle

Machine Hotspots' Map

SECTION 8-9-10-11:
Doses ~ 60 Gy per cycle

No significant doses were recorded in the other sections

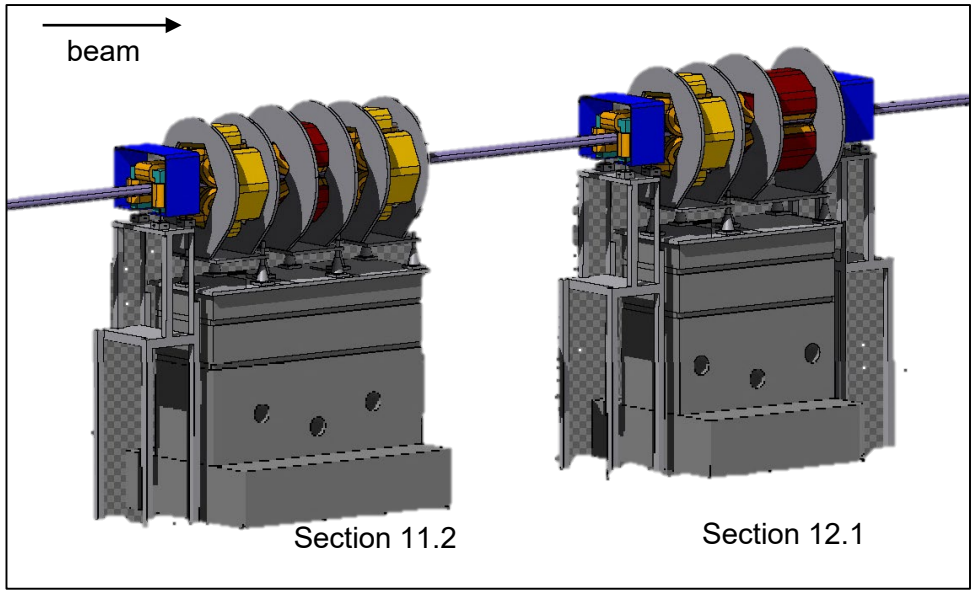


SECTION 12:
Doses ~ 5 Gy per cycle

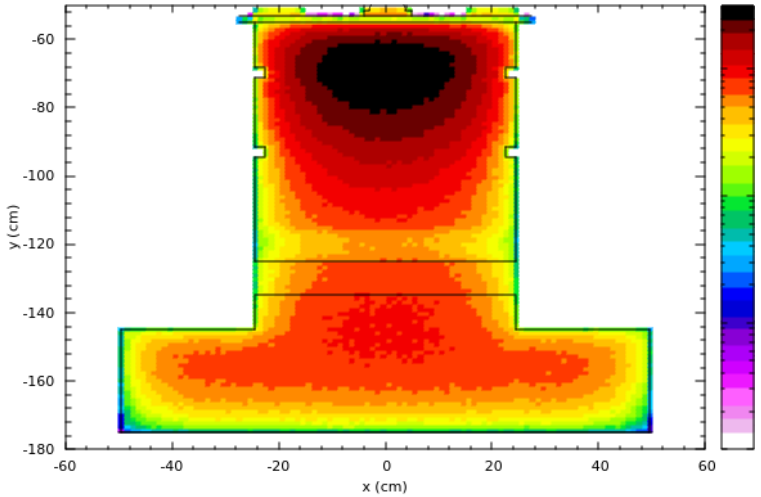
SECTION 1:
Doses > 90 Gy per cycle

Magnets support in section 12.1

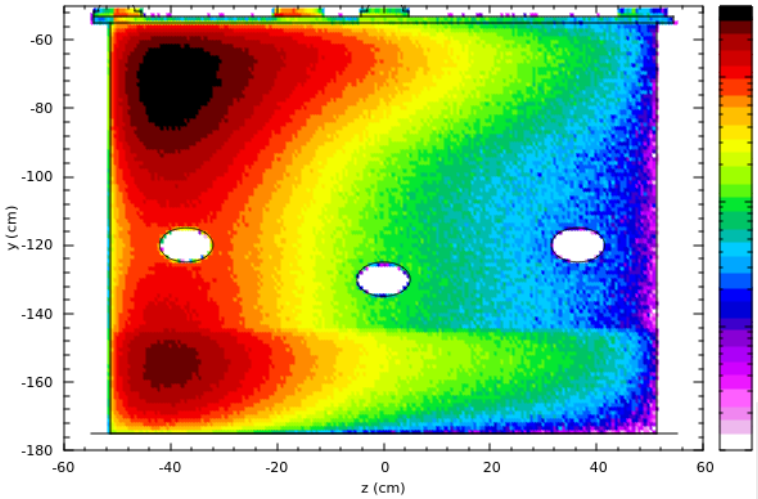
FLUKA model



Activity integrated over all z axis for the first support in sec 12.1 at 2 GeV, 310 mA. Cooling time t = 24h. Conservative injection losses.



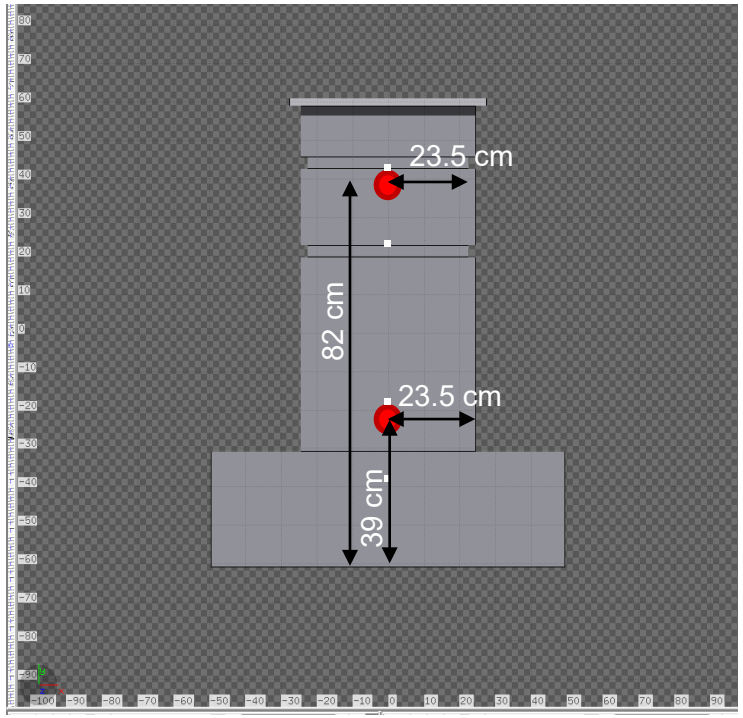
Front view



Lateral view

Magnets support in section 12.1

Two corings: 4 cm diameter, 40 cm depth



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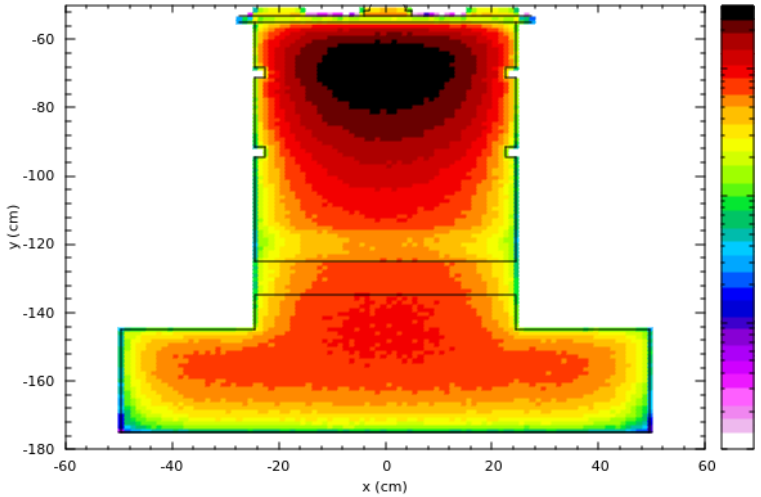
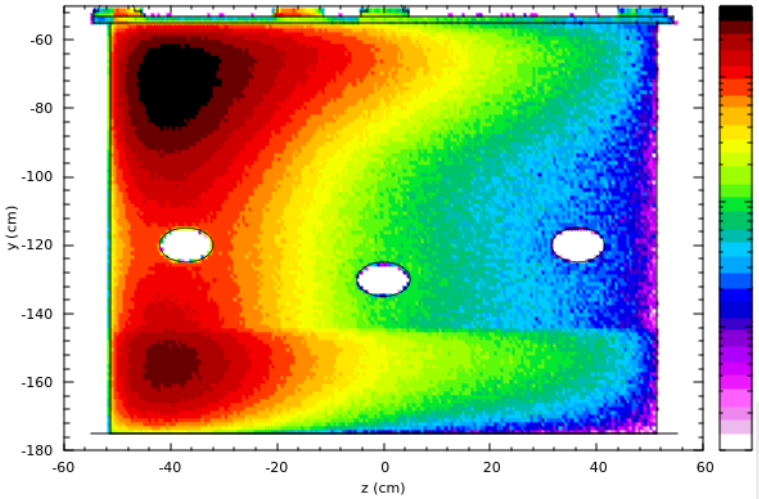


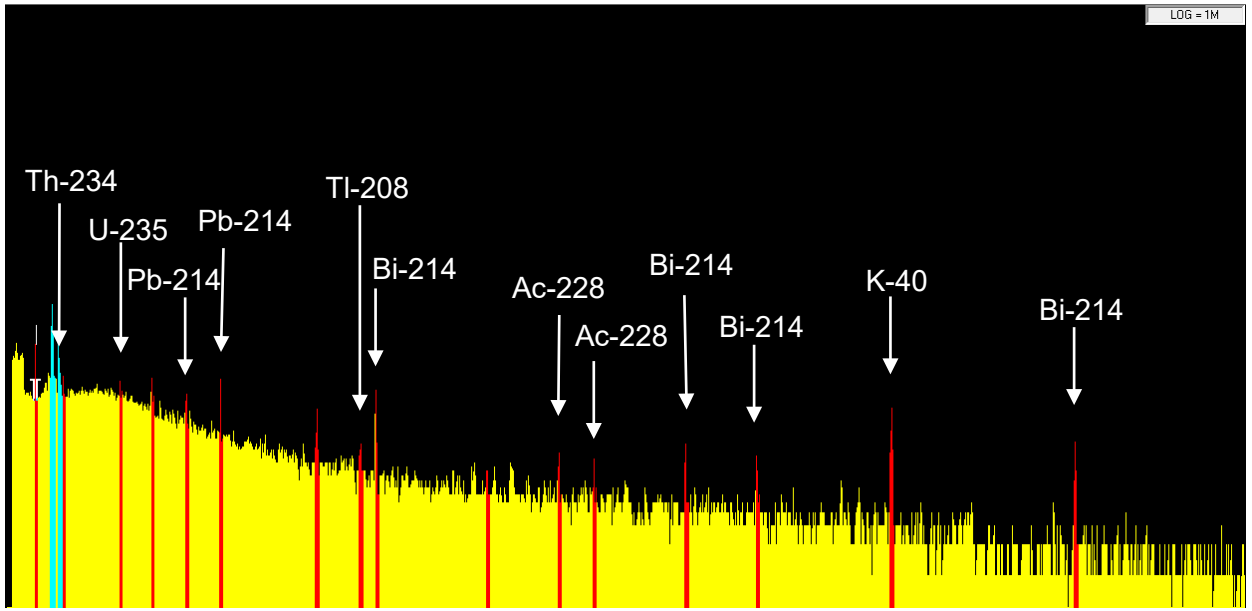
Front view



Lateral view

Gamma spectrometry and Beta analysis

Gamma spectrometry. Upper coring, sample number 7. Acquiring time: 7200 s. Log scale.



Beta analysis on H-3, C-14, Ca-45, Total beta.
Upper coring, sample number 7. Acquiring time: 24000 s.

RISULTATI DELLE PROVE EFFETTUATE

PARAMETRO	METODO DI PROVA	RISULTATO E INCERTEZZA	UNITÀ DI MISURA	MAR [1]
^{3}H – Trizio	ISO 19361:2017	< MAR	Bq/kg	5,8
^{14}C – Carbonio 14	ISO 19361:2017	< MAR	Bq/kg	7,0
^{45}Ca – Calcio 45	ISO 19361:2017	< MAR	Bq/kg	7,1
β totale – Attività beta totale	Metodo interno [3]	133 ± 18	Bq/kg	6,1

Annotazioni

ISO 19361:2017 "Determinazione delle attività dei Beta emettitori mediante Scintillazione Liquida".
Determinazione eseguita mediante Scintillazione Liquida (LSC) previa preparativa radiochimica.
[3] Metodo interno basato su UNI EN ISO 11704:2019 "Qualità dell'acqua – Misura della concentrazione di attività alfa e beta totale in acque non saline – Metodo del conteggio per scintillazione liquida".
Attività Beta totale ottenuta con efficienza relativa a Sr/Y-90.

Pareri e interpretazioni – non oggetto di accreditamento ACCREDIA

n.n.

FINE RAPPORTO

Data di emissione: 11/05/2023

L'addetto alla prova:
Dott. Andrea Iannarone

Il responsabile:
Dott. Giacomo Zambelli

Note:
[1] MAR – Minima Attività Rilevabile; [2] Radionuclide naturale.
* Prova non accreditata da ACCREDIA; ** Prova eseguita presso laboratorio esterno.
- Il presente rapporto di prova può essere riprodotto parzialmente solo col permesso scritto di Protex Italia Srl.
- I risultati si riferiscono unicamente al campione analizzato.
- Le attività specifiche rilevate si riferiscono alla data di analisi del campione.
- L'incertezza di misura è espressa con un livello di fiducia del 95% e fattore di copertura k=2.
- Si declina ogni responsabilità per modalità di campionamento, prelievo, trasporto e consegna del campione fino all'arrivo in laboratorio quando effettuati dal committente.
- Le informazioni fornite dal committente sono riportate in colore blu.
- In caso di riemissione del rapporto di prova le informazioni modificate e corrette in fase di revisione saranno evidenziate in grassetto e corsivo.
- Al termine dell'analisi un'aliquota residua di campione, se non deperibile o esaurito durante le prove, sarà conservata presso il nostro laboratorio per 30 giorni dalla data di emissione del rapporto di prova.

No radionuclides from activation were found in the two corings

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Work in progress

- More coring samples on the magnets supports during next shutdowns
- *In-situ* gamma spectrometry measurements
- Comparison of simulations with experimental data
- Development of the measurement protocols for the decommissioning
- To decode beam loss monitor data for evaluating the beam losses distribution in comparison with radiochromic films readings

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Thank you!

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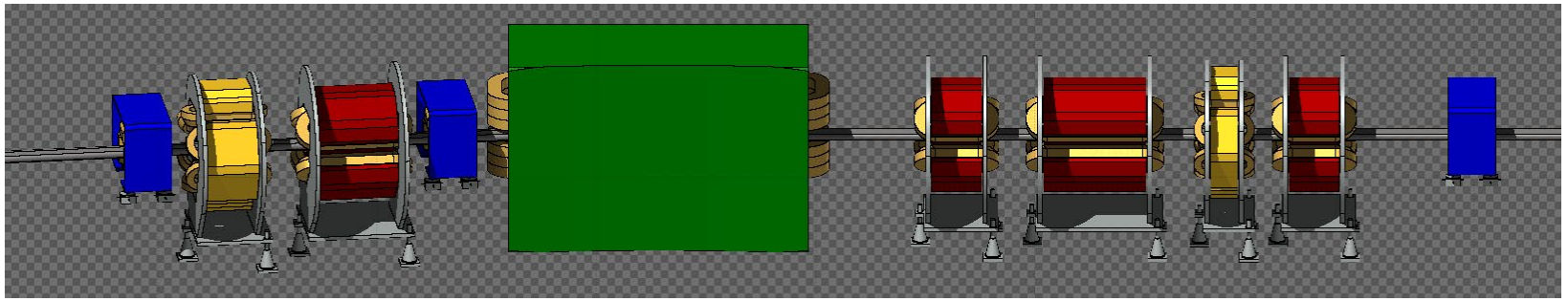
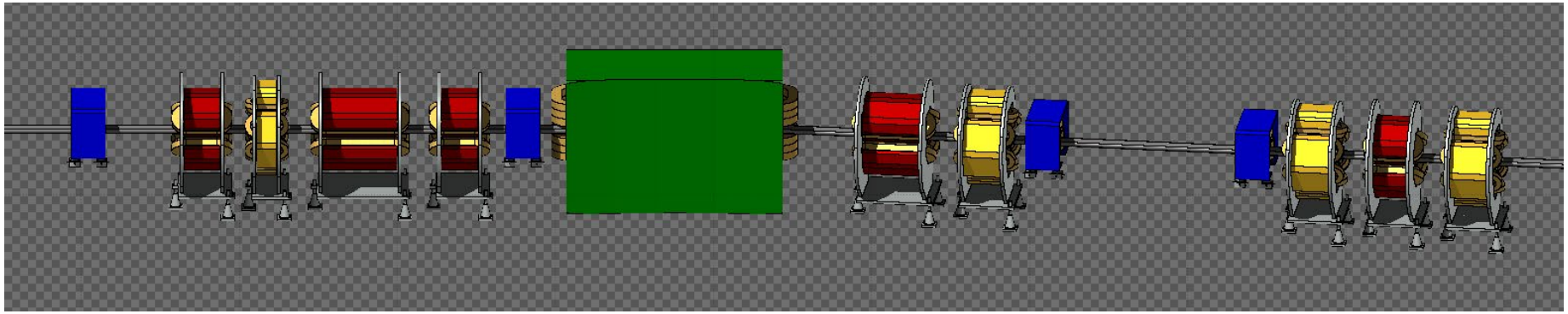
Storage ring modelling

- **FLUKA ACHROMAT MODELLING**



Sec. 3 – maglia bending



Sec. 3 – maglia ID + short part

Elemental composition accelerator components

MAGNETS			
yoke material:			AISI 1018
elemento	% massa	g/cm^3	g/cm^3 *f
C	0,2	3,51	0,00702
Mn	0,9	7,20	0,0648
P	0,04	1,82	0,000728
S	0,05	2,07	0,001035
Fe	98,81	7,87	7,78030
		TOT	7,854

materiale tiranti yoke:			AISI 1040
elemento	% massa	g/cm^3	g/cm^3 *f
C	0,44	3,51	0,015444
Mn	0,90	7,20	0,0648
P	0,04	1,82	0,000728
S	0,05	2,07	0,001035
Fe	98,57	7,87	7,76140

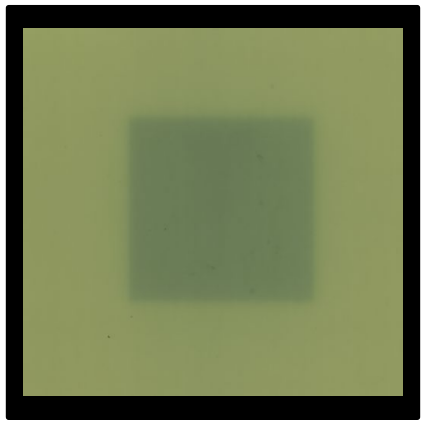
materiale supporto:			AISI 304L
elemento	% massa	g/cm^3	g/cm^3 *f
C	0,03	3,51	0,001053
Si	1,00	2,33	0,0233
Mn	2,00	7,20	0,144
P	0,045	1,82	0,000819
S	0,015	2,07	0,0003105
Cr	19,50	7,14	1,3923
Ni	10,50	8,80	0,924
N	0,11	0,00125	1,375E-06
Fe	66,80	7,87	5,259832
		TOT	7,746

materiale bobina:			COPPER
elemento	% massa	g/cm^3	g/cm^3 *f
Cu	100	8,96	8,96

VACUUM VESSEL			
material:	AISI 316LN		
element	% massa	g/cm^3	g/cm^3 *f
C	0,04	3,51	0,001404
Si	0,75	2,33	0,017475
Mn	2,00	7,20	0,144
P	0,035	1,82	0,000637
S	0,015	2,07	0,0003105
Cr	18,00	7,14	1,2852
Mo	3,00	10,28	0,3084
Ni	14,00	8,80	1,232
N	0,18	0,00125	0,00000225
B	0,005	2,34000	0,000117
Fe	61,975	7,87	4,8799115
		TOT	7,869

GafChromic EBT3 films

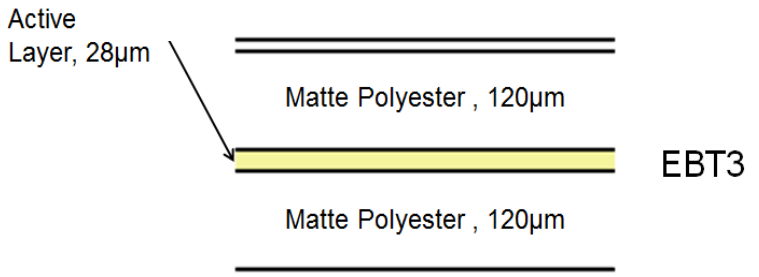
GAFChromic EBT-3 is designed for the measurement of absorbed doses of ionizing radiation.



Technical features:

- ✓ Dose range: (0-90) Gy
- ✓ Energy independent
- ✓ High spatial resolution (25 um)
- ✓ Self developing
- ✓ Accuracy: 5%

The structure:



The film is comprised of an active layer, nominally 28 μm thick, sandwiched between two 120 μm matte-polyester substrates. The active layer contains the active component, a marker dye, stabilizers and other components giving the film its near energy-independent response.

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GafChromic EBT3 films – support sec 12.1

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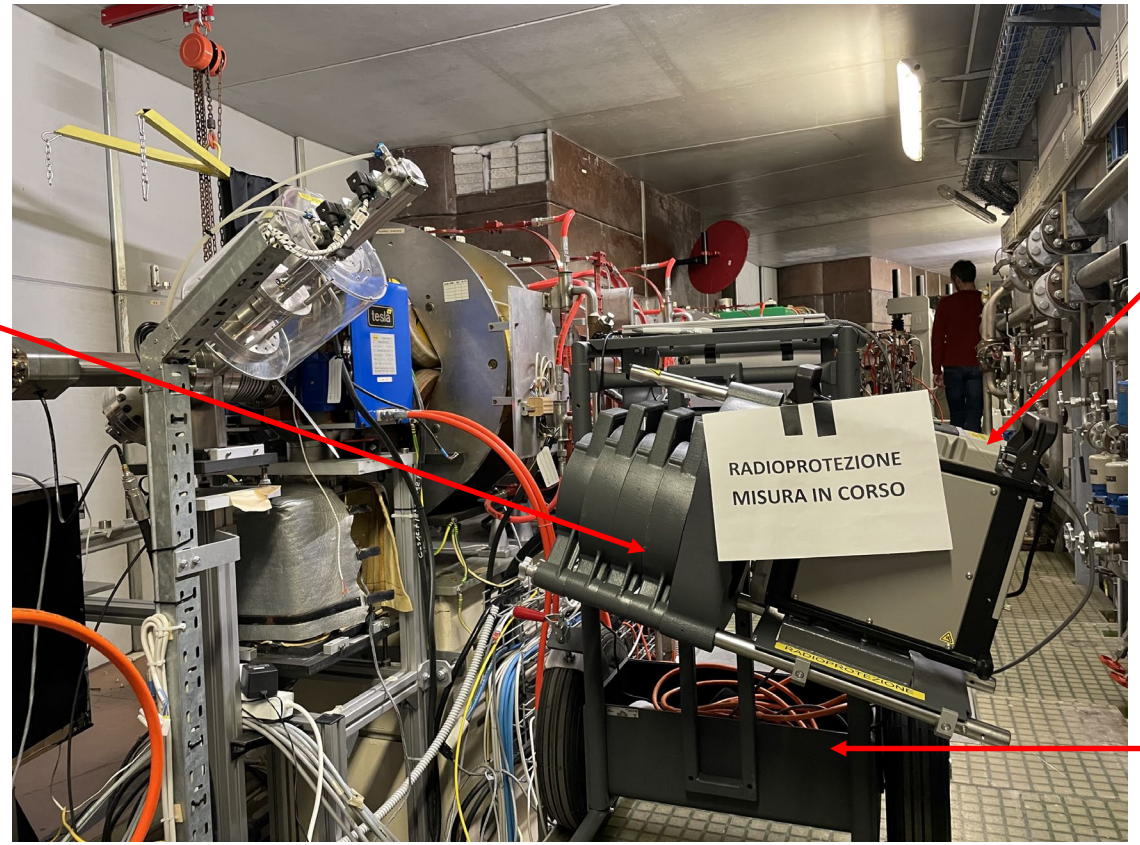
In-situ gamma spectrometry



Lead shields

Portable detector for gamma spectrometry (Ge Crystal)

Model: AEGIS-BE5030
Detector S/N: 13794Portable detector

Trolley!