

8th International Workshop on
Radiation Safety at Synchrotron Radiation Sources

DESY Hamburg, 3 – 5 June 2015

*Proposed material release plan for
The decommissioning of the ESRF storage ring*

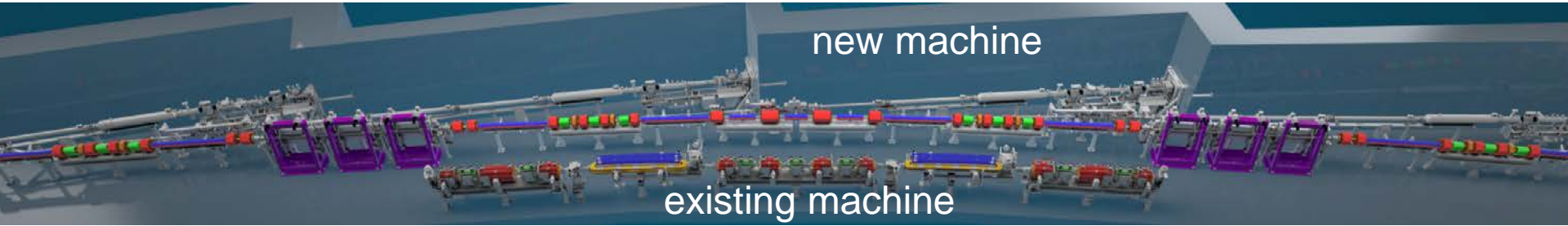
Paul Berkvens



| The European Synchrotron



DECOMMISSIONING OF EXISTING STORAGE RING



	#/cell	magnet		cell	
		iron (kg)	copper (kg)	iron (kg)	copper (kg)
quadrupole 40 cm	4	580	70	2,320	280
quadrupole 50 cm	4	615	85	2,460	340
quadrupole 90 cm	2	1,065	135	2,130	270
sextupole	7	410	40	2,870	280
dipole	2	3,100	700	6,200	1,400

total cell 19
 storage ring 608

15,980	2,570
511,360	82,240

	stainless steel (kg)	aluminium (kg)
vacuum vessels		
cell	300	25
storage ring	9,600	800

supports
 ≠ km cables

DEFINITION OF RADIOACTIVE WASTE IN FRENCH LEGISLATION

Article L542-1-1 of French Environmental Act → definition of radioactive waste

“A radioactive material is a material containing radionuclides, natural or artificial, whose activity or concentration justify radiation protection control measures.

Radioactive waste is a radioactive material for which no further use is foreseen or envisaged.

Table A, Part 1 of annex VII of the 2013/59/EURATOM Directive defines clearance levels for radioactive waste.

H ³	Cr ⁵¹	Mn ⁵²	Mn ⁵⁴	Fe ⁵⁵	Co ⁵⁶	Co ⁵⁷	Co ⁵⁸	Co ⁶⁰	Ni ⁶³
100	100	1	0.1	1000	0.1	1	1	0.1	100

Clearance levels (Bq/g) defined in the 2013/59/EURATOM Directive

French legislation however does not define clearance levels.

Discussions between ESRF and the French Nuclear Safety Authority (ASN) started several years ago.

A formal meeting with the ASN took place on 13 April 2013.

Following several exchanges it was decided that ESRF should carry out a technical study and propose a methodology for the possible clearance of certain accelerator components.

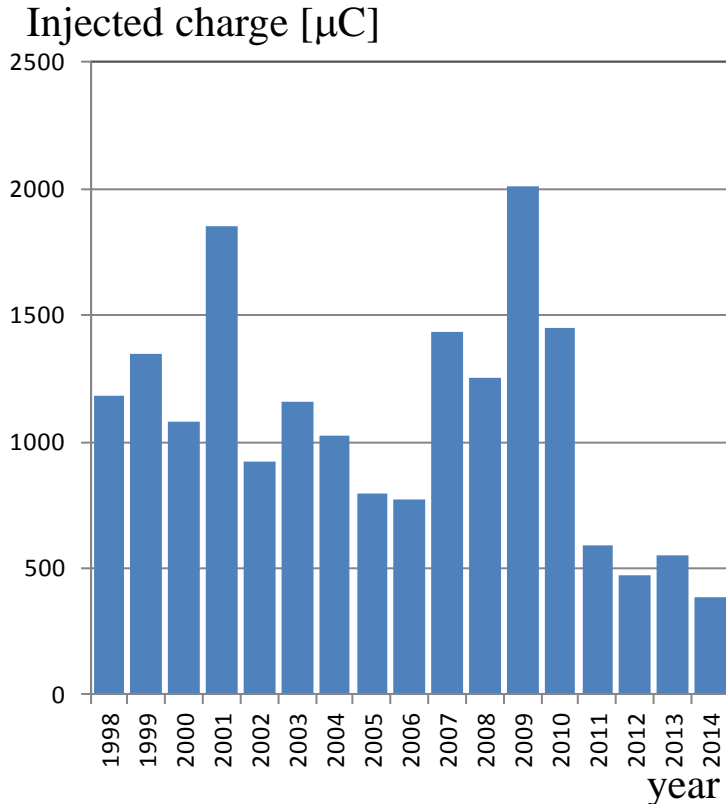
The design study should be based, in particular, on 3D Monte Carlo calculations, and special attention should be placed on the presence of possible activation hot spots.

A first technical study should be submitted to ASN beginning of 2015.

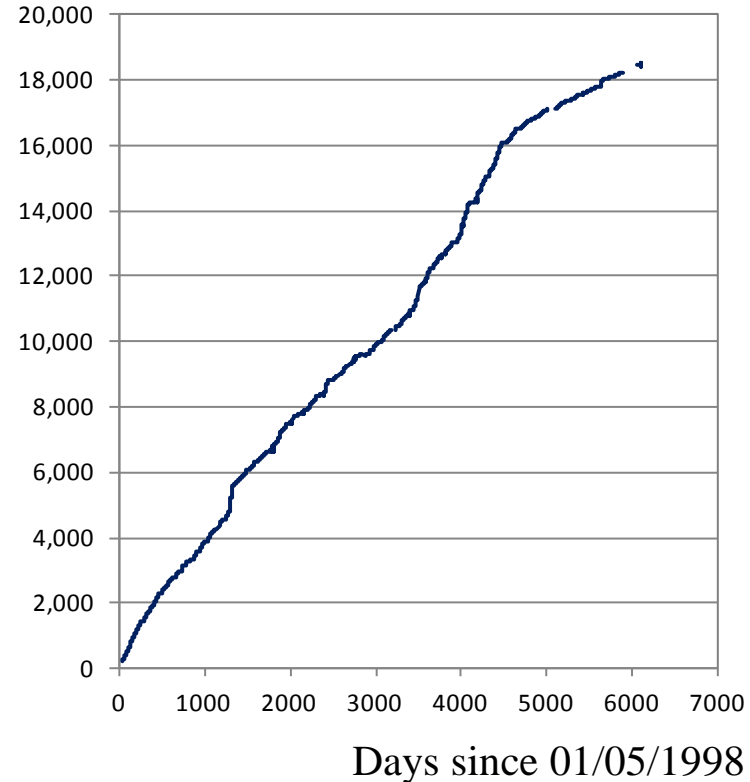
PROCESS KNOWLEDGE: BEAM LOSSES

Injected electron charge recorded

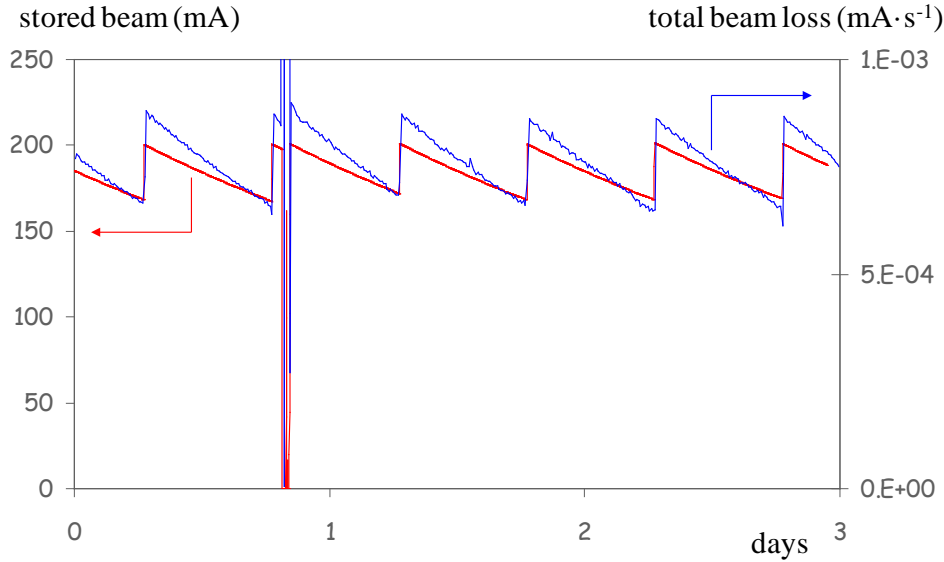
Presently: 400 $\mu\text{C}/\text{year}$ \rightarrow small beam loss power



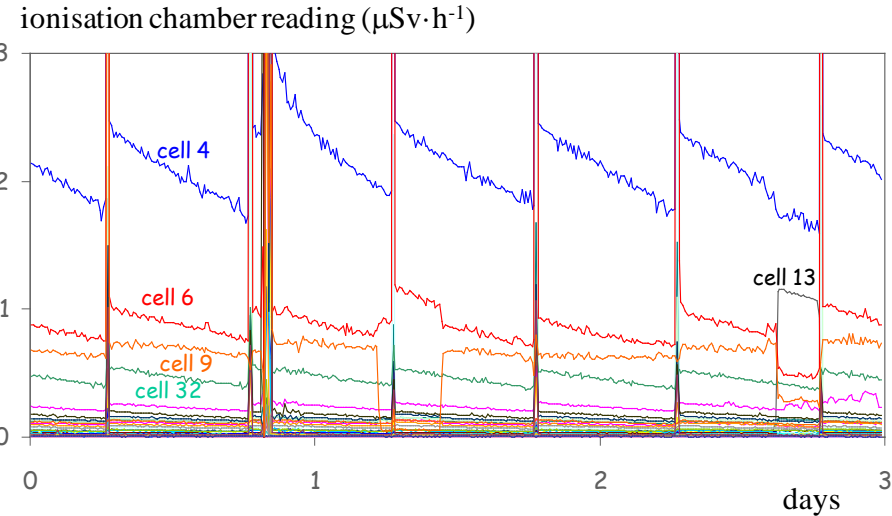
Injected charge [μC]



Ionisation chambers beamloss monitors



Typical stored beam decay in uniform filling mode. Red curve: stored beam intensity; blue curve: corresponding total beam losses



Readings from the 32 beam loss ionisation chambers, during the same period

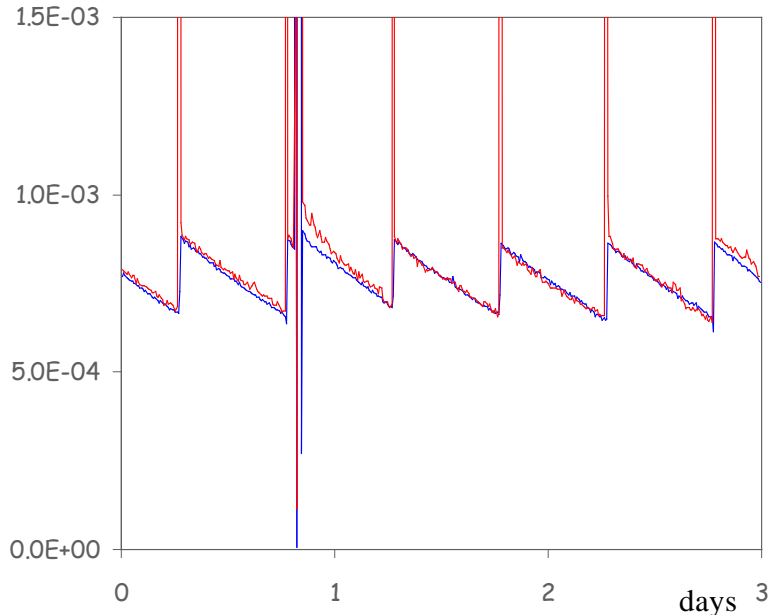
PROCESS KNOWLEDGE: BEAM LOSSES

$$\sum_{i=1}^5 (\textit{ionisation chamber})_i + 2.5 \times (\textit{ionisation chamber})_6 + \sum_{i=7}^{32} (\textit{ionisation chamber})_i$$

$$\textit{beam loss power} [mA \cdot s^{-1}] = 1.1 \cdot 10^{-4} \cdot \textit{weighted sum} [\mu Sv \cdot h^{-1}]$$



total beam loss (mA·s⁻¹)



Reproduction of the total beam loss power via the weighted sum of the readings of the 32 beam loss ionisation chambers.

Blue curve: total beam loss power

Red curve: weighted sum of ionisation chamber readings

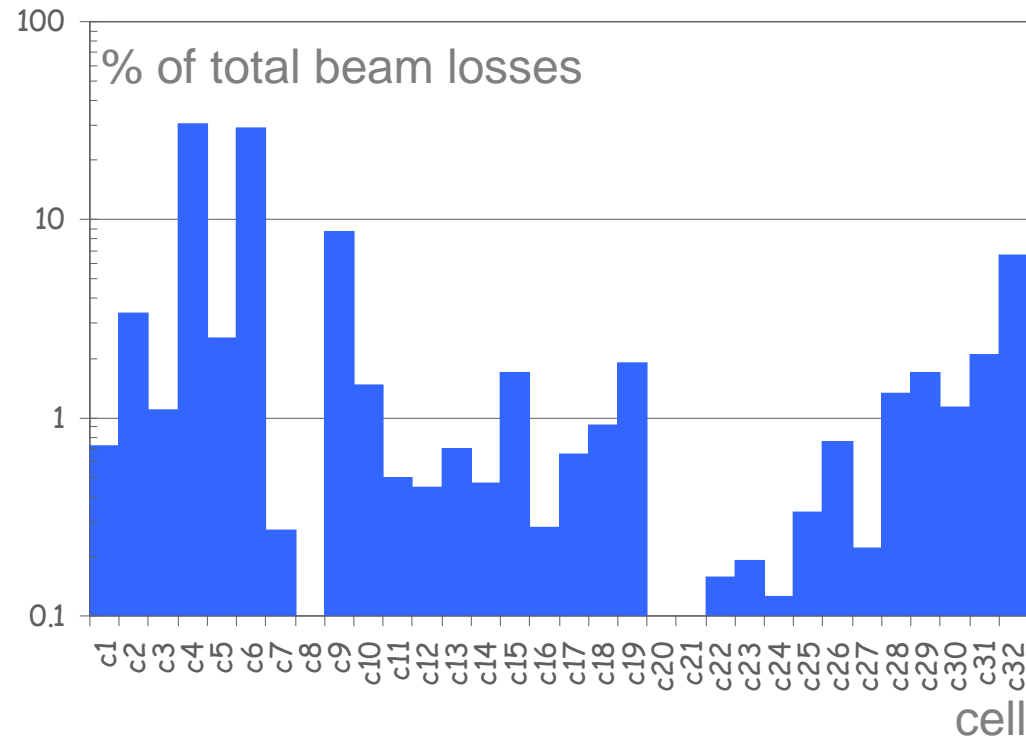
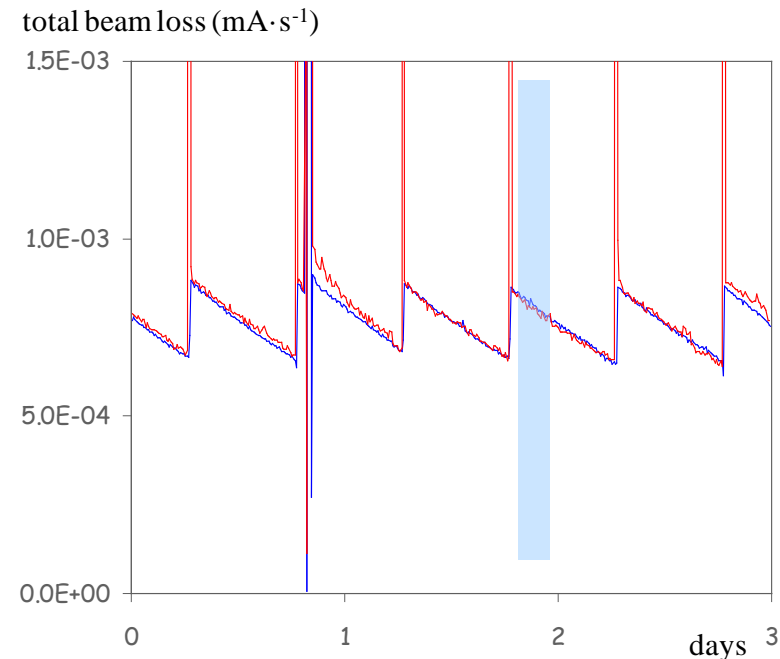
PROCESS KNOWLEDGE: BEAM LOSSES

Standard cells: losses $\leq 1\%$ of total losses

400 $\mu\text{C}/\text{year} \rightarrow \leq 0.76 \text{ mW per cell}$

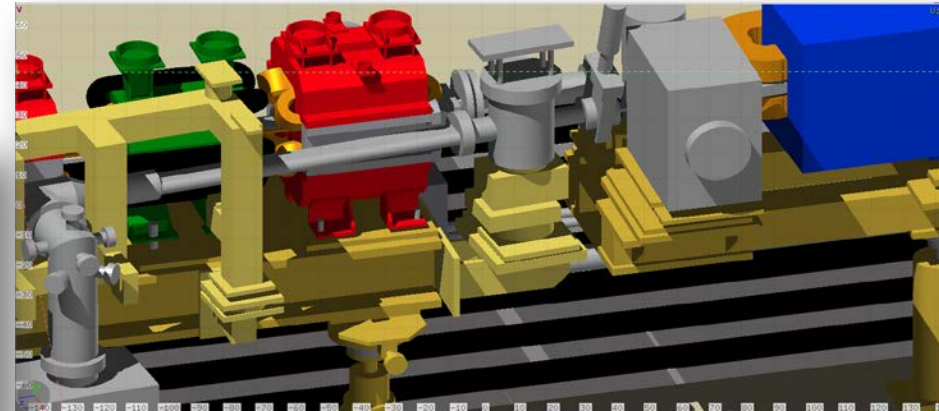
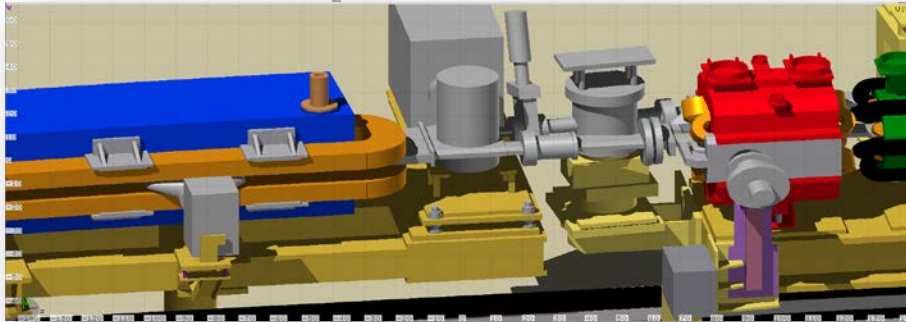
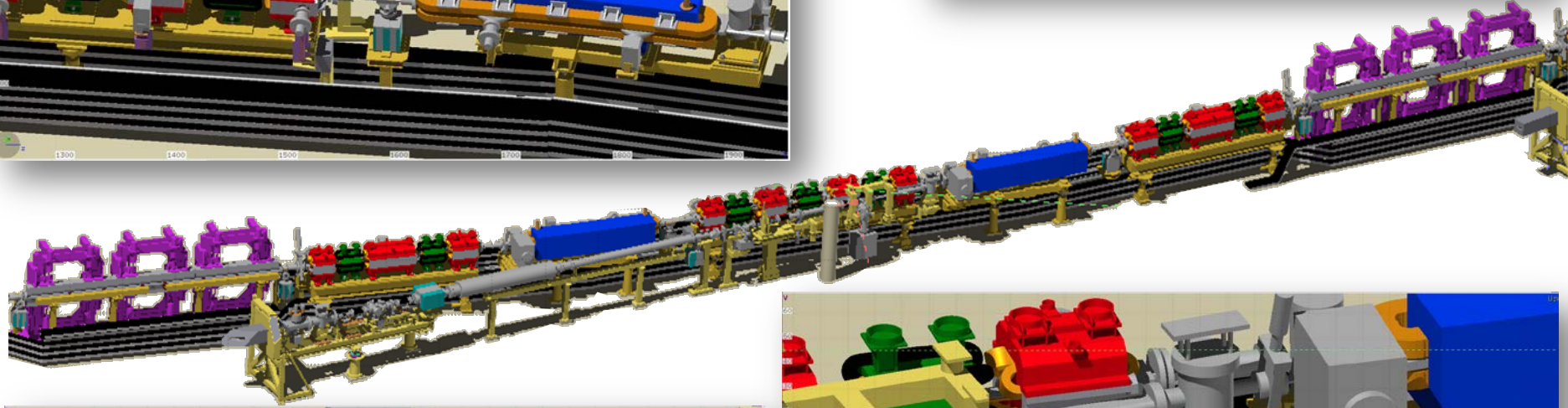
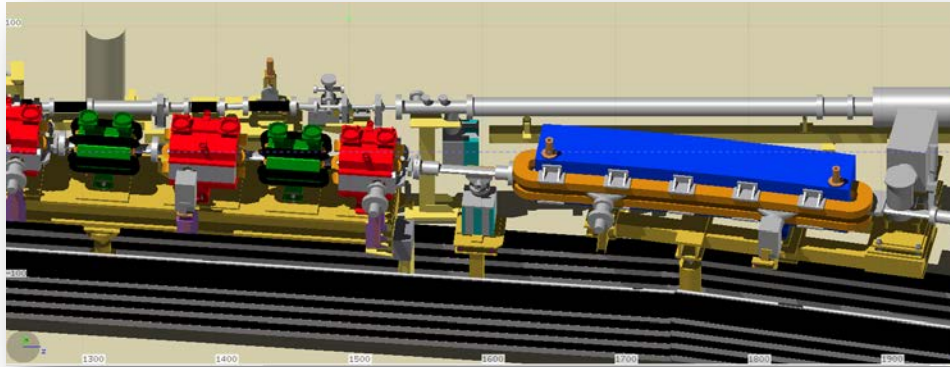
A few cells $\leq 10\%$ of total losses

400 $\mu\text{C}/\text{year} \rightarrow \leq 7.6 \text{ mW per cell}$

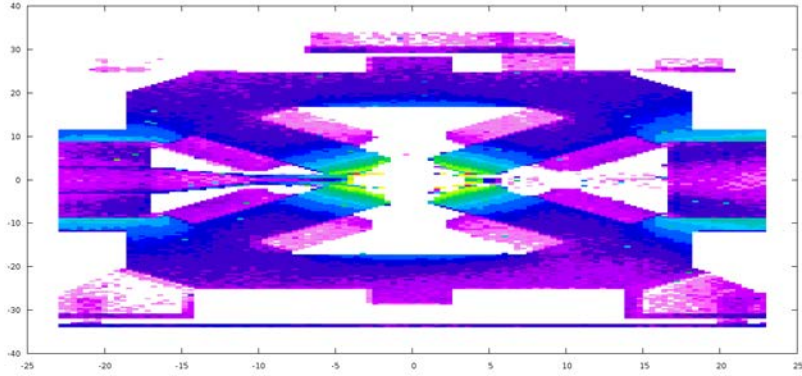


Typical beam loss distribution along storage ring

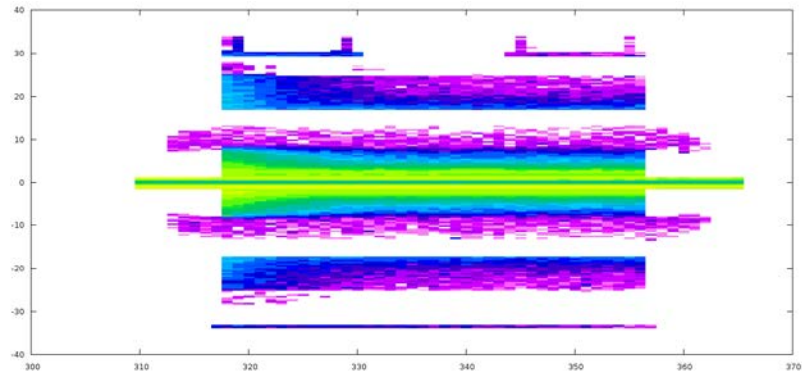
MONTE CARLO CALCULATIONS: FLUKA



FLUKA ACTIVATION CALCULATIONS: EXAMPLES

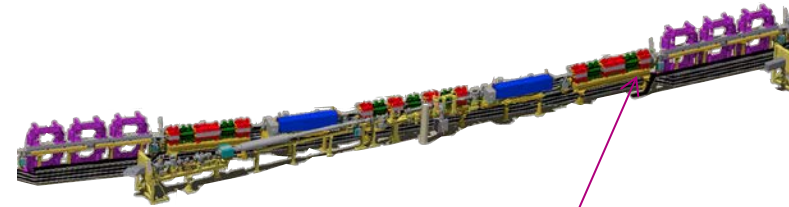
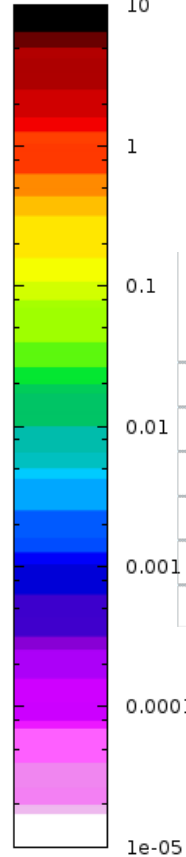


Total specific activity (all isotopes), integrated over all z

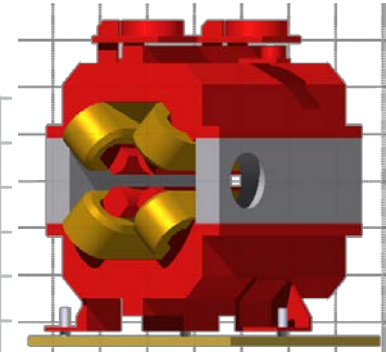
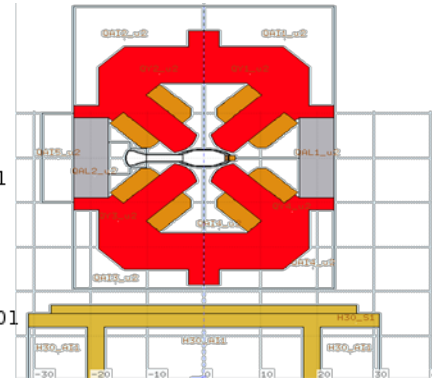


Total specific activity (all isotopes), integrated over $x = [2.6 \text{ cm}, 3.8 \text{ cm}]$

Bq/g



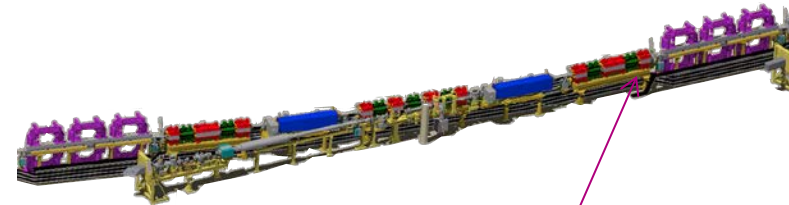
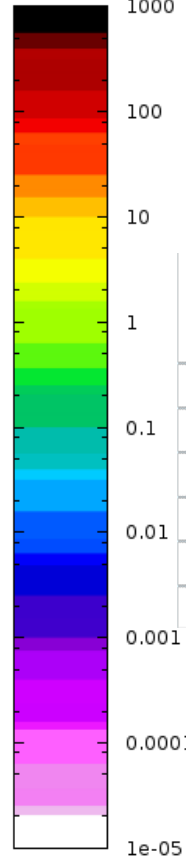
Quadrupole 1



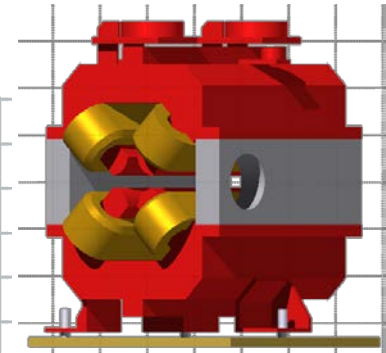
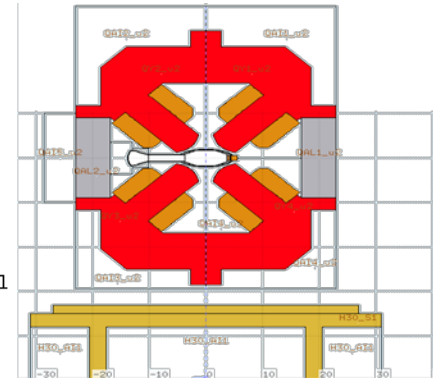
Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

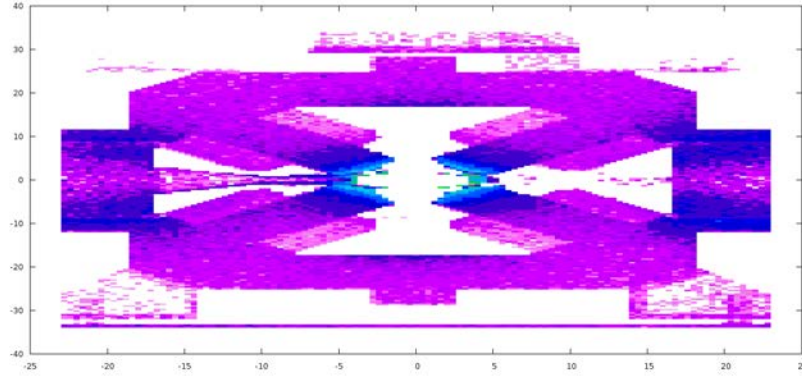
$$\Sigma_i(AS_i/SE_i)$$



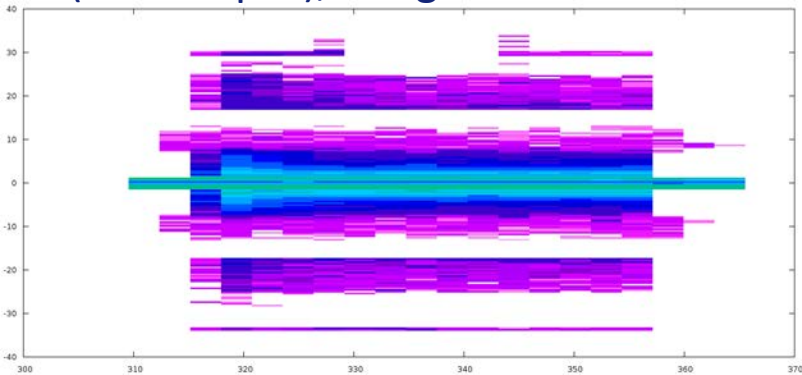
Quadrupole 1



Cooling down time = 1 month
1 % local losses

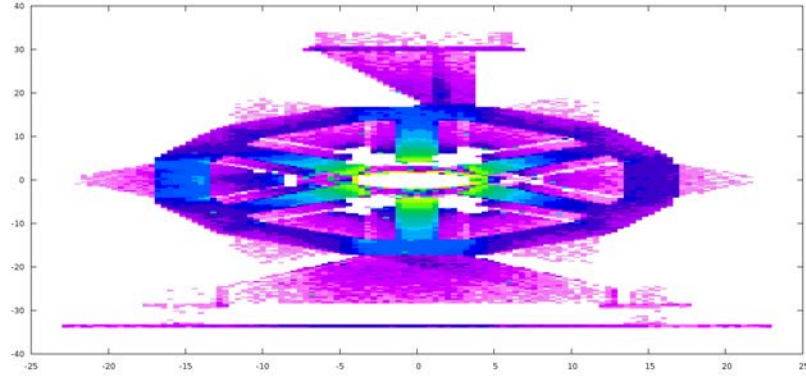


Sum specific activities/clearance levels
(all isotopes), integrated over all z

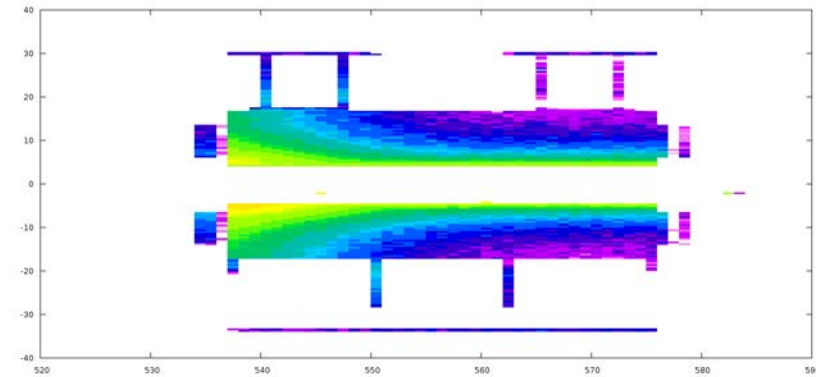


Sum specific activities/clearance levels(all
isotopes), integrated over x = [2.6 – 3.8 cm]

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

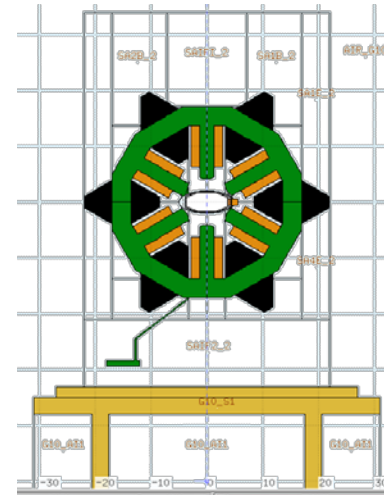
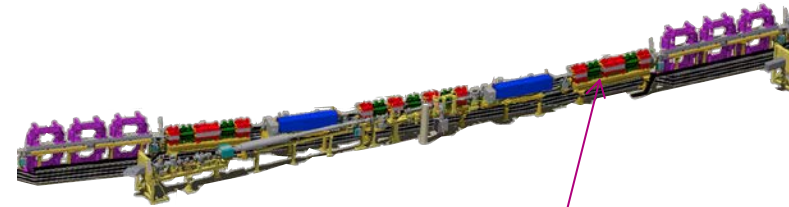
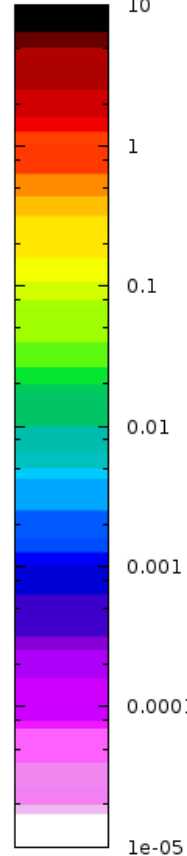


Total specific activity (all isotopes), integrated over all z

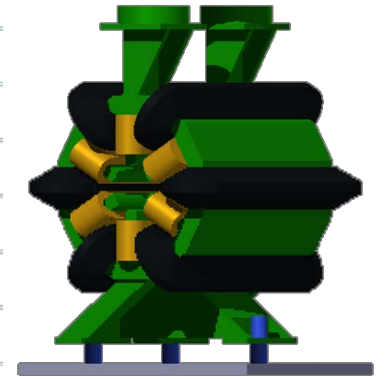


Total specific activity (all isotopes), integrated over $x = [-1 \text{ cm}, 1 \text{ cm}]$

Bq/g

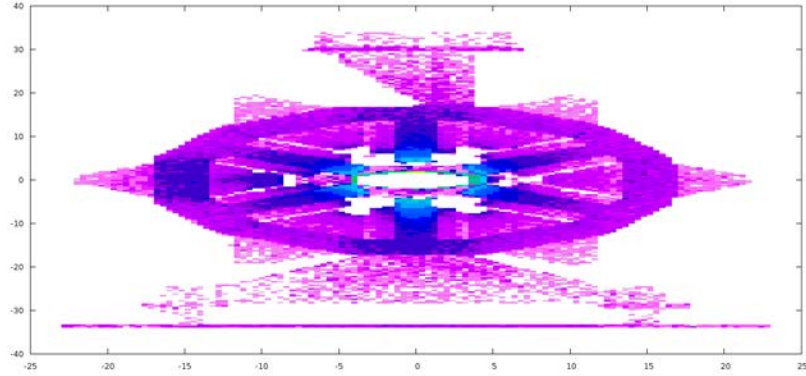


Sextupole 2

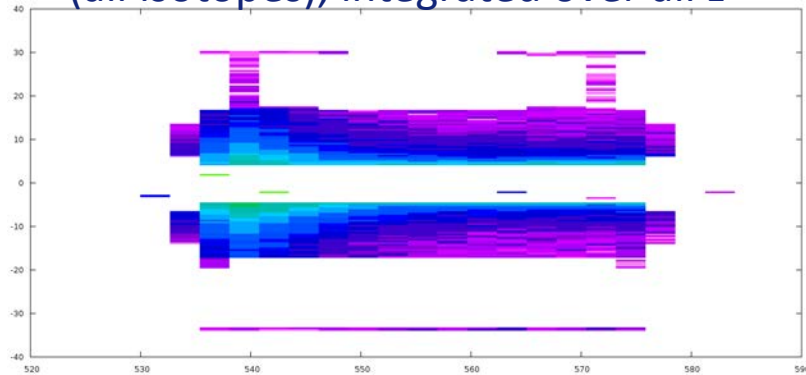


Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

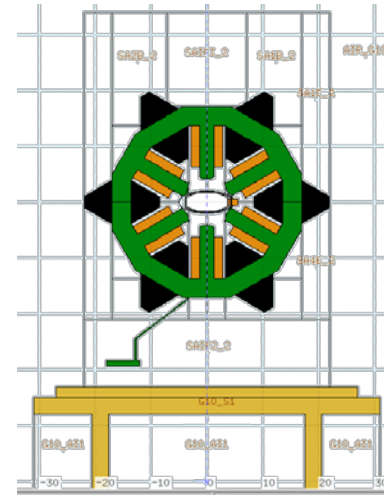
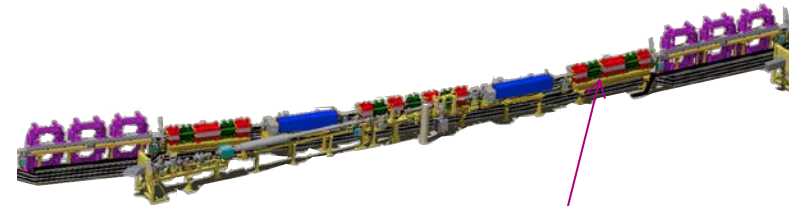
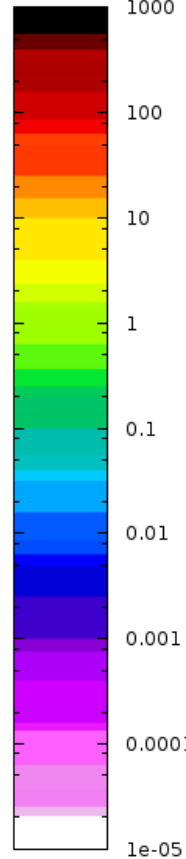


Sum specific activities/clearance levels (all isotopes), integrated over all z

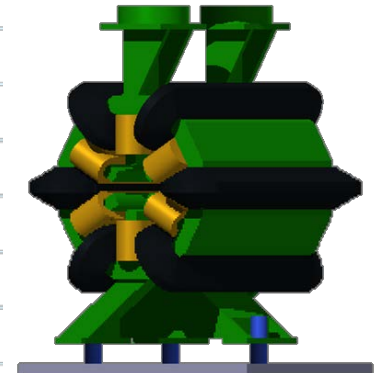


Sum specific activities/clearance levels (all isotopes), integrated over x = [-1 - 1 cm]

$$\Sigma_i(AS_i/SE_i)$$

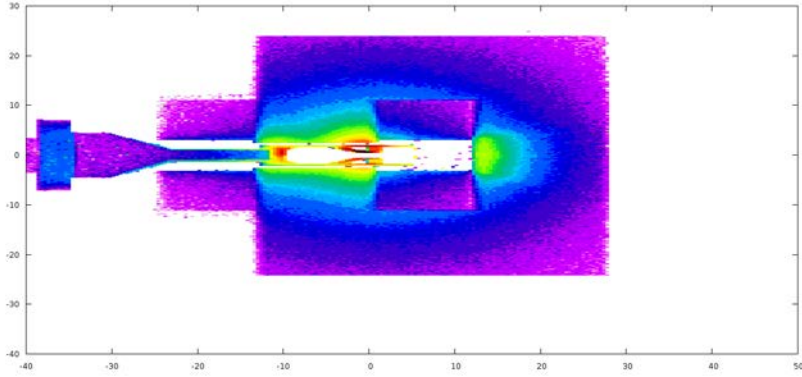


Sextupole 2

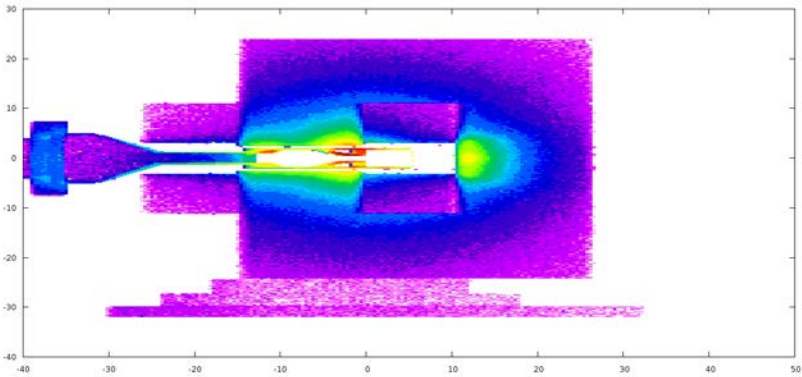


Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

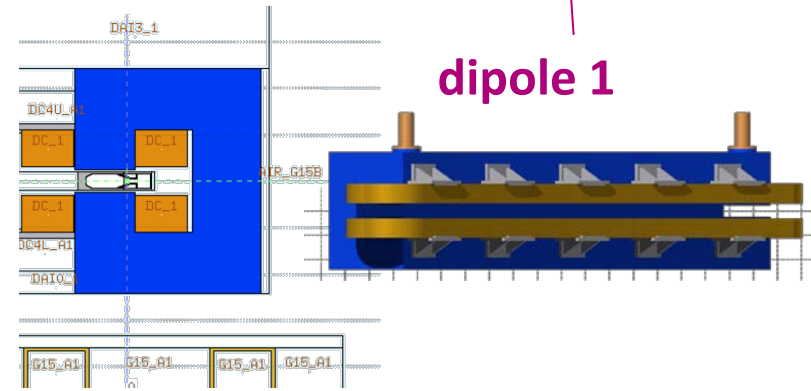
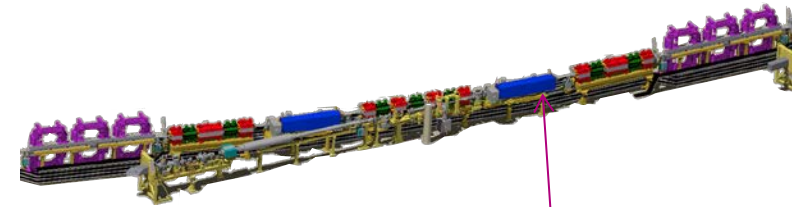
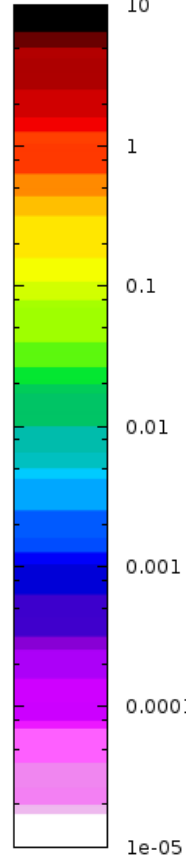


Total specific activity (all isotopes),
integrated over $z = [910 \text{ cm}, 930 \text{ cm}]$



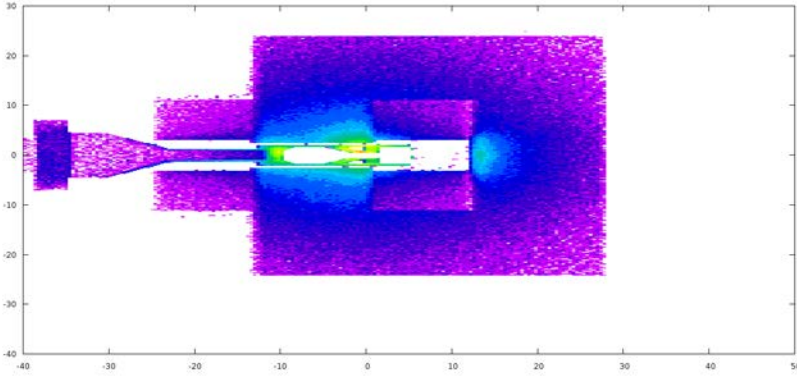
Total specific activity (all isotopes),
integrated over $z = [930 \text{ cm}, 950 \text{ cm}]$

Bq/g

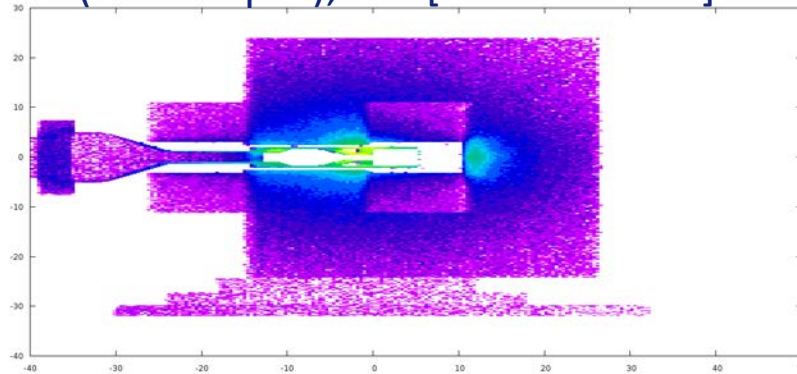


Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

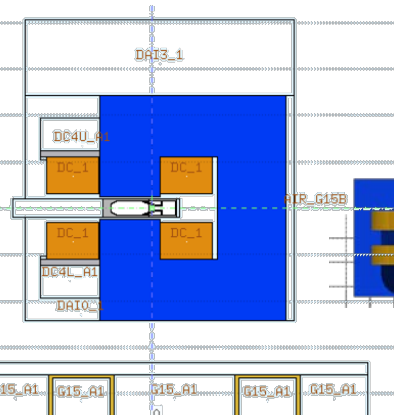
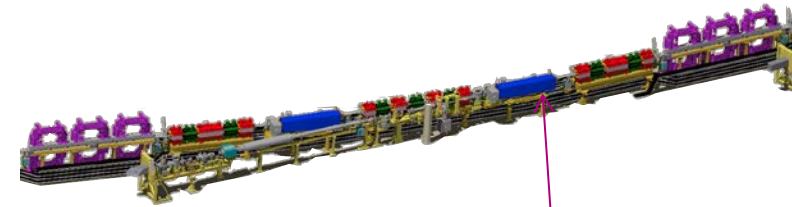
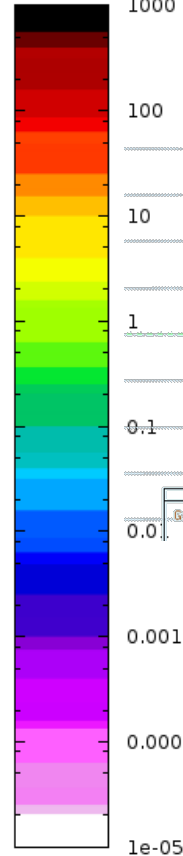


Sum specific activities/clearance levels
(all isotopes), $z = [910 - 930 \text{ cm}]$

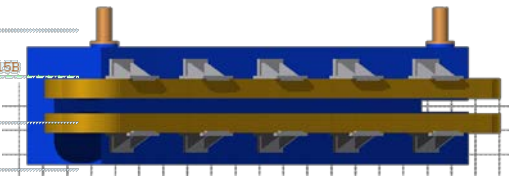


Sum specific activities/clearance levels
(all isotopes), $z = [930 - 950 \text{ cm}]$

$$\Sigma_i(AS_i/SE_i)$$

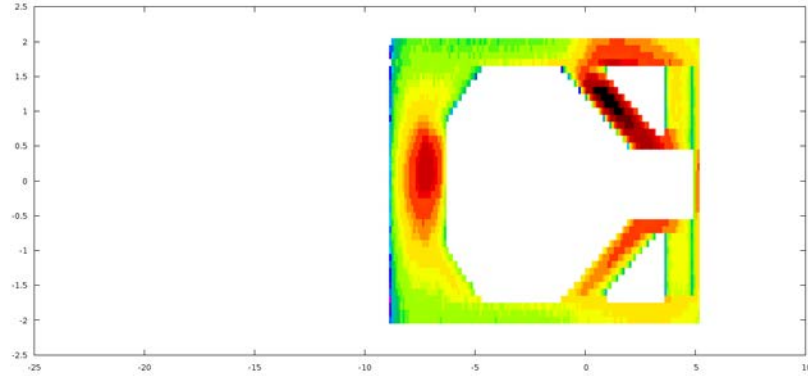


dipole 1

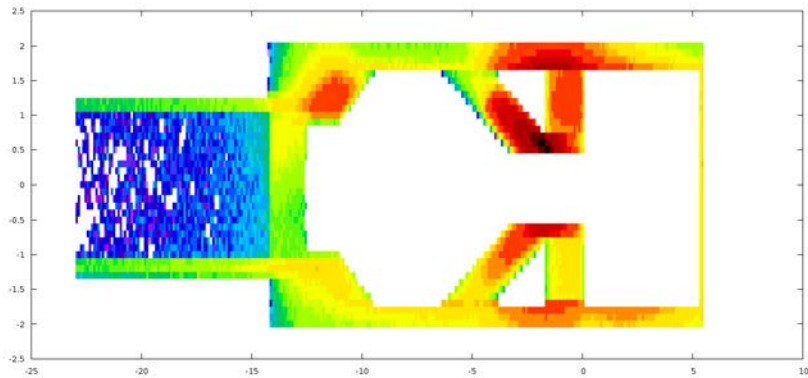


Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

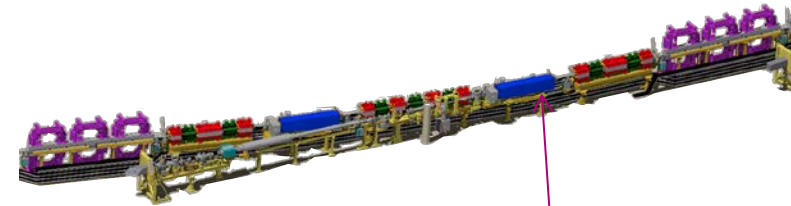
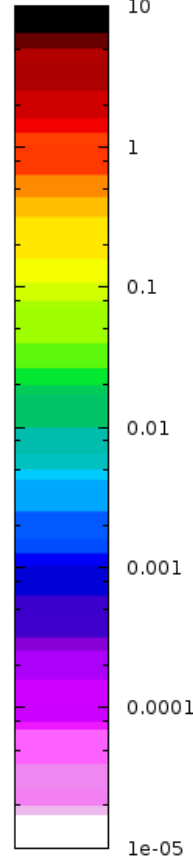


Total specific activity (all isotopes),
integrated over $z = [851 \text{ cm}, 871 \text{ cm}]$

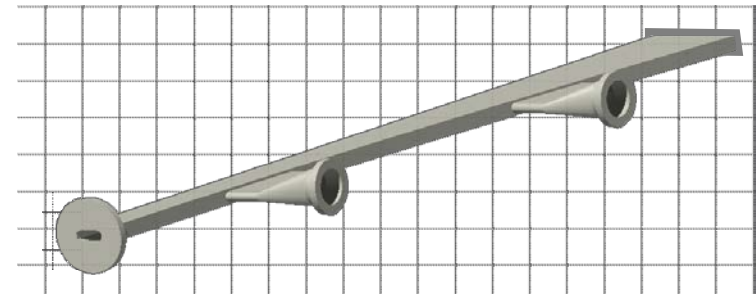


Total specific activity (all isotopes),
integrated over $z = [931 \text{ cm}, 951 \text{ cm}]$

Bq/g

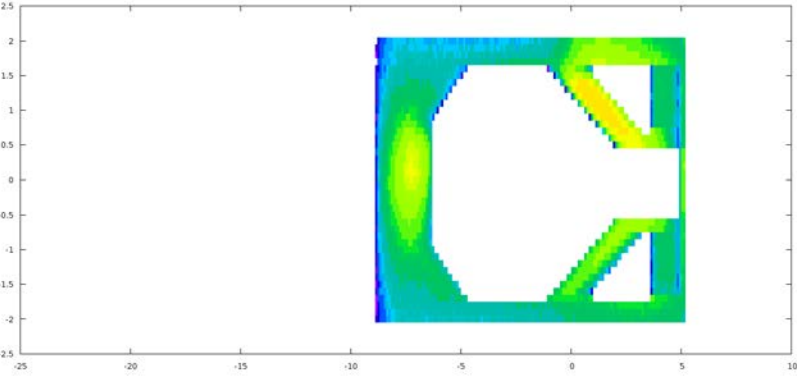


dipole vessel 1

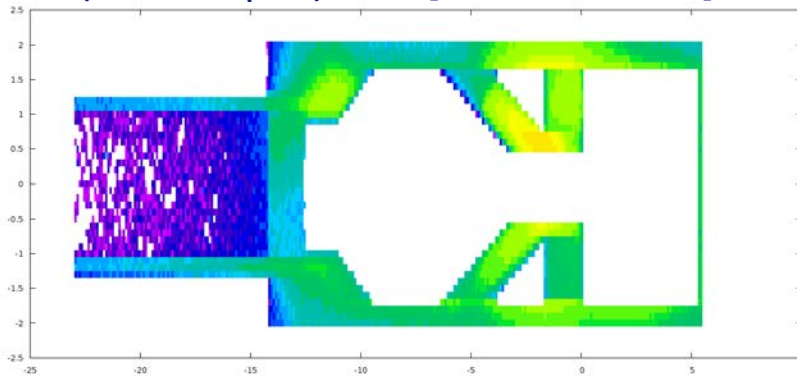


Cooling down time = 1 month
1 % local losses

FLUKA ACTIVATION CALCULATIONS: EXAMPLES

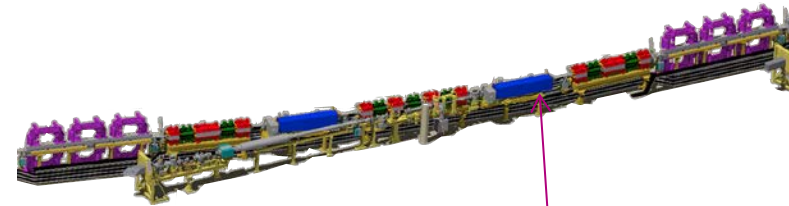
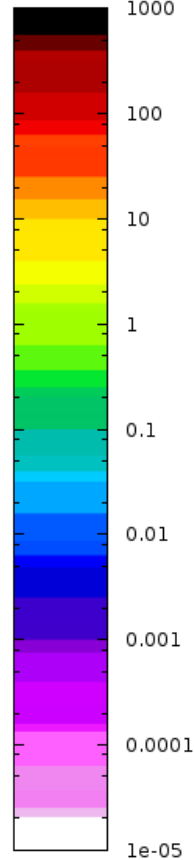


Sum specific activities/clearance levels
(all isotopes), $z = [851 - 871 \text{ cm}]$

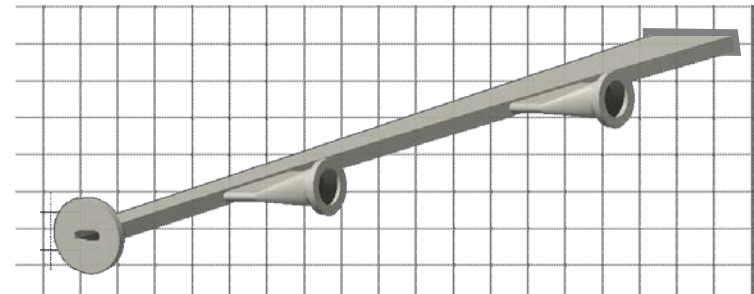


Sum specific activities/clearance levels
(all isotopes), $z = [931 - 951 \text{ cm}]$

$$\Sigma_i(AS_i/SE_i)$$



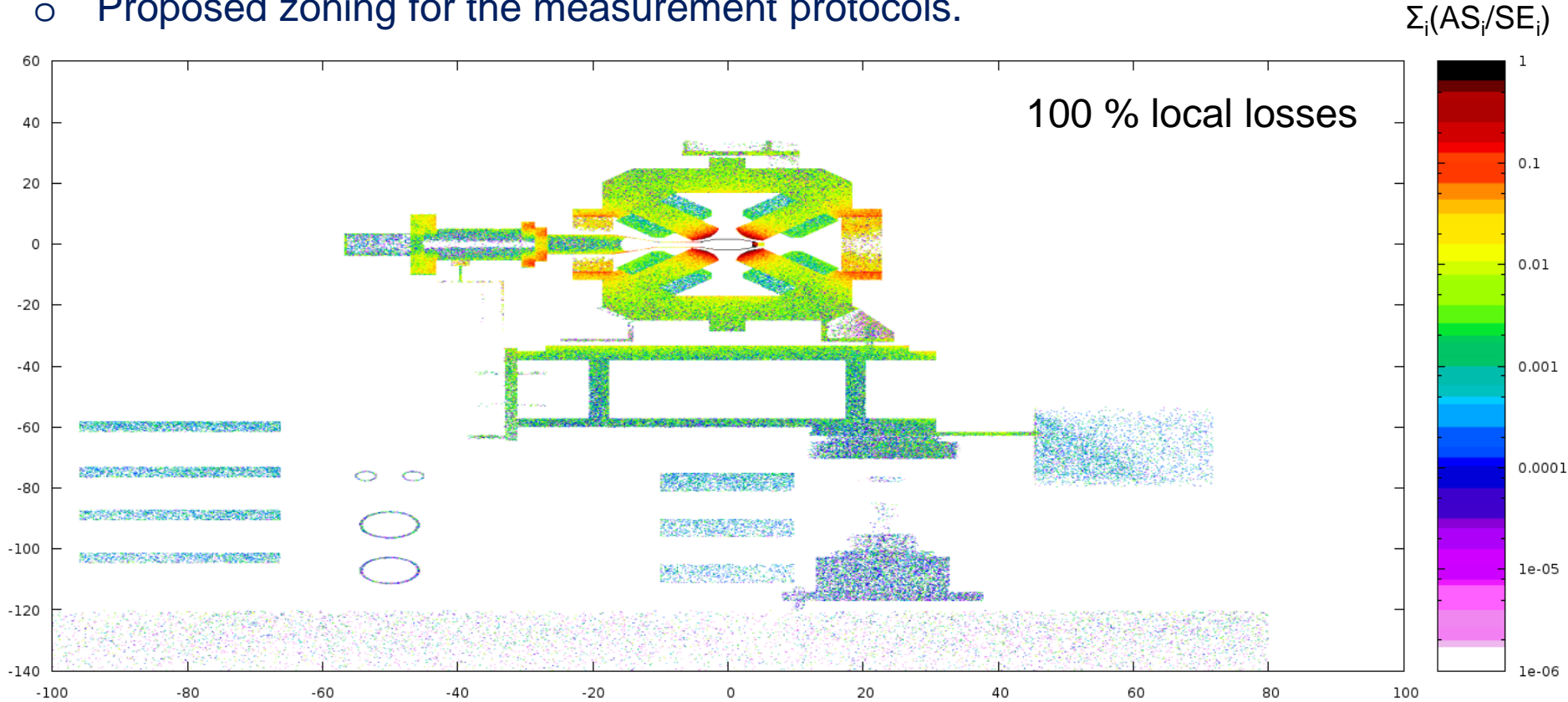
dipole vessel 1



Cooling down time = 1 month
1 % local losses

Proposed material release plan

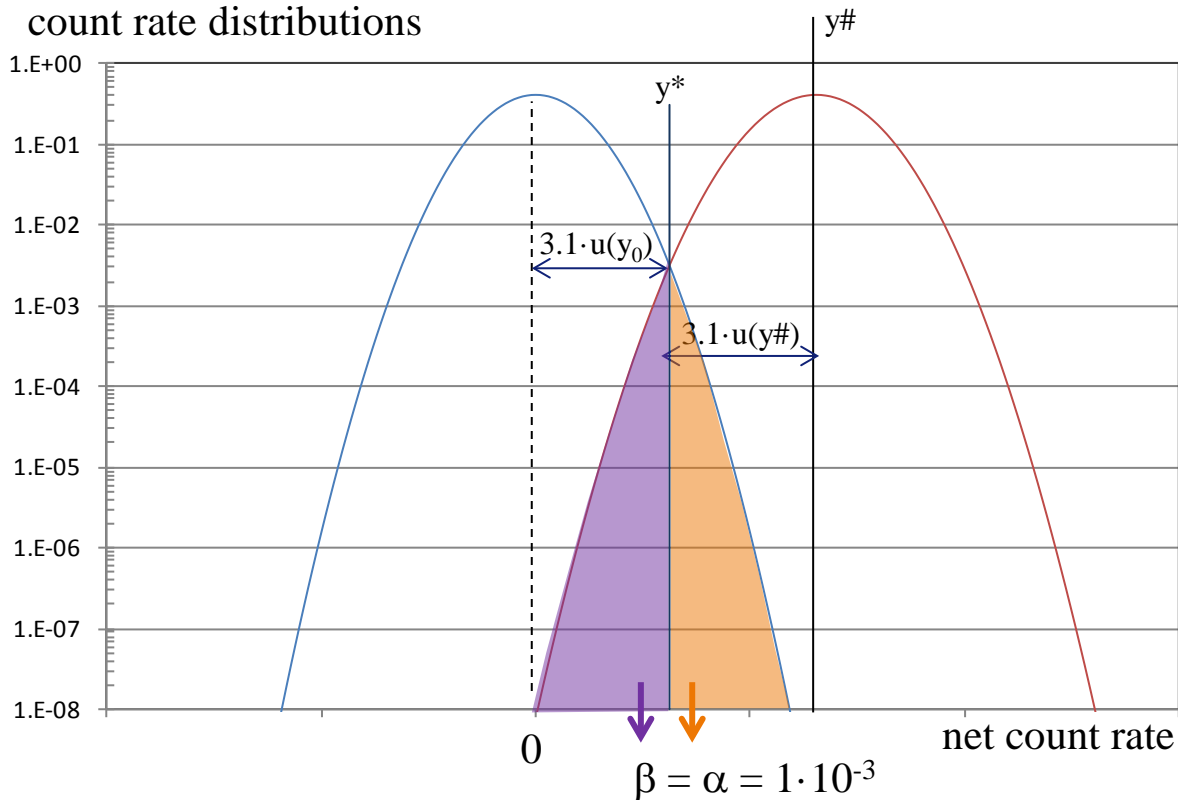
- Proposed zoning for the measurement protocols.



INDISTINGUISHABLE FROM BACKGROUND

Proposed criterion for definition of non-radioactive material

- **Surface dose measurements: indistinguishable from background**



ISO 11929 standard, May 2010

Detector

Exploranium Gr-130 miniSPEC
(1.5" x 1.5" x 2" NaI(Tl)
scintillator)

(count rate: 1.37 cps per nSv/h)

1 minute integration time:

Decision threshold: 3.62 cps

Detection limit: 7.4 cps

(for 30 nSv/h background)

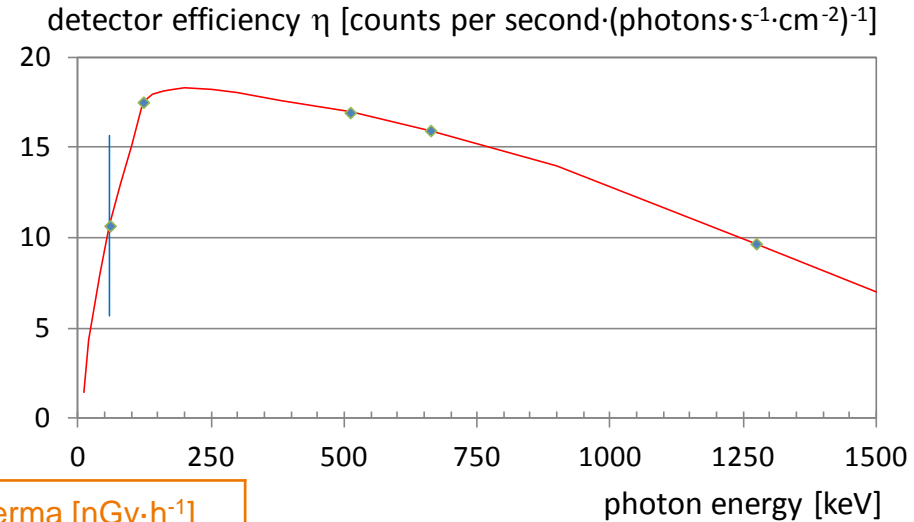
INDISTINGUISHABLE FROM BACKGROUND AND EURATOM CLEARANCE LEVELS

Exploranium Gr-130 calibrated in terms of air kerma between 60 keV and 3 MeV.
 Relate detection threshold (cps) to residual ambient dose equivalent rates obtained from FLUKA.

$$\Phi_E [ph \cdot s^{-1} \cdot cm^{-2}] = \frac{1}{(K_a/\Phi)_E [pGy \cdot cm^2] \cdot 3.6} \times (\dot{K}_a)_E [nSv \cdot h^{-1}]$$

$(K_a/\Phi)_E [pGy \cdot cm^2]$: table A.21, ICRU Report 57

$$\eta [counts \ per \ second \cdot (ph \cdot s^{-1} \cdot cm^{-2})^{-1}] = \frac{\dot{C}_E}{\Phi_E}$$



	Count rate [counts per second]	Air kerma [nGy·h ⁻¹]
Cs ¹³⁷ 662 keV	530.60 ± 3.32	372.00 ± 5.52
Na ²² 511 keV	255.77 ± 1.41	116.58 ± 1.67
1274 keV	42.63 ± 0.23	143.82 ± 0.28
Am ²⁴¹ 59.54 keV	28.40 ± 1.64	2.80 ± 1.30
Co ⁵⁷ 122 keV	55267.60 ± 40.75	5366. ± 10.

Measured net count rates
 and net air kerma rates



INDISTINGUISHABLE FROM BACKGROUND AND EURATOM CLEARANCE LEVELS

ratio κ between the ambient dose equivalent rate and the count rate for a given spectrum.

$$\kappa = \frac{\sum_{\text{all bins } i} (H^*(10)/\Phi)_{E_i} [pSv \cdot cm^2] \times 3.6 \times [photons \cdot bin^{-1}]_i}{\sum_{\text{all bins } i} \eta_{E_i} [cps \cdot (ph \cdot s^{-1} \cdot cm^{-2})^{-1}] \times [photons \cdot bin^{-1}]_i}$$

$H^*(10)/\Phi$: table A.21, ICRU Report 57

κ [nSv·h⁻¹·cps⁻¹]

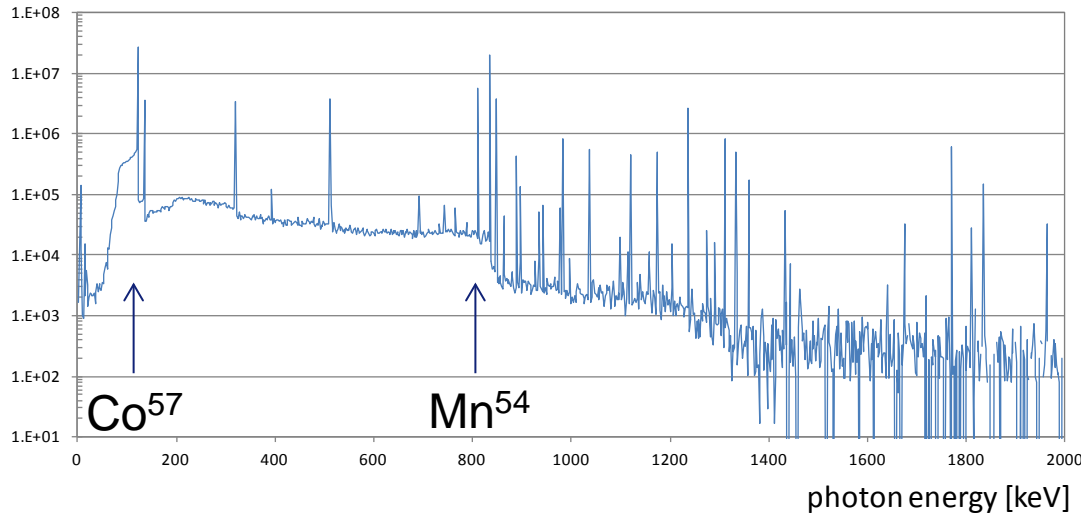
Background spectrum: 0.748

Stainless steel: 0.620

Magnet yoke: 0.789



photons per bin [relative units]



Detection limit

Stainless steel: **4.5 nSv/h**

Magnet yoke: **5.8 nSv/h**

(for 30 nSv/h background)

Spectrum calculated with FLUKA
for stainless steel vessel

INDISTINGUISHABLE FROM BACKGROUND AND EURATOM CLEARANCE LEVELS

Compliance with clearance levels defined in Council Directive 2013/59/EURATOM

Surface dose measurements
(indistinguishable from background)



$$\sum_{all\ isotopes} \frac{AS_i}{SE_i} \leq 1$$

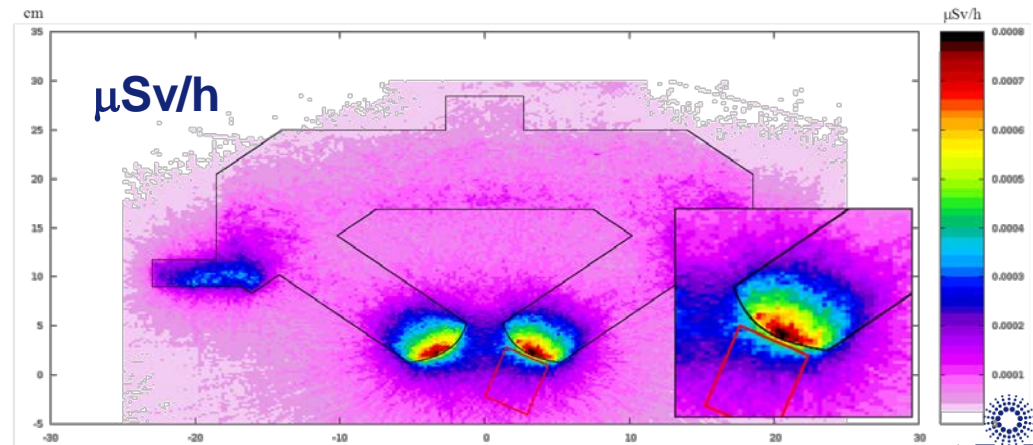
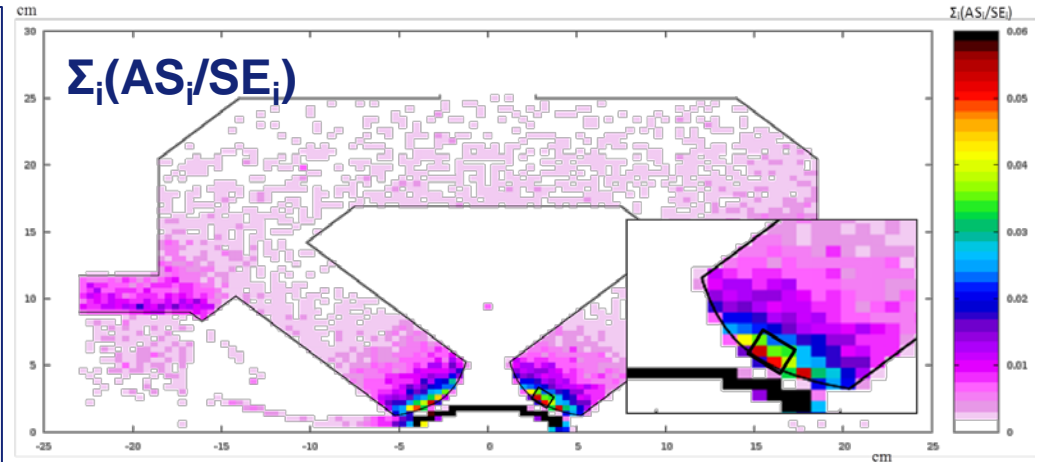
guaranteed for 1 cm³ hotspots.

Detection limit of 5.8 nSv·h⁻¹



1 cm³ hotspots with

$$\sum_{all\ isotopes} \frac{AS_i}{SE_i} \geq 0.7$$



INDISTINGUISHABLE FROM BACKGROUND AND EURATOM CLEARANCE LEVELS

Compliance with clearance levels defined in Council Directive 2013/59/EURATOM

Surface dose measurements
(indistinguishable from background)



$$\sum_{all\ isotopes} \frac{AS_i}{SE_i} \leq 1$$

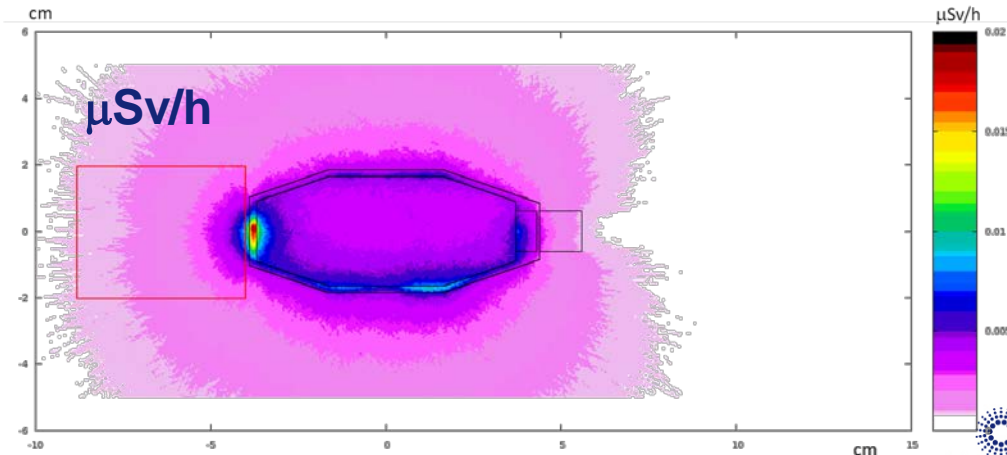
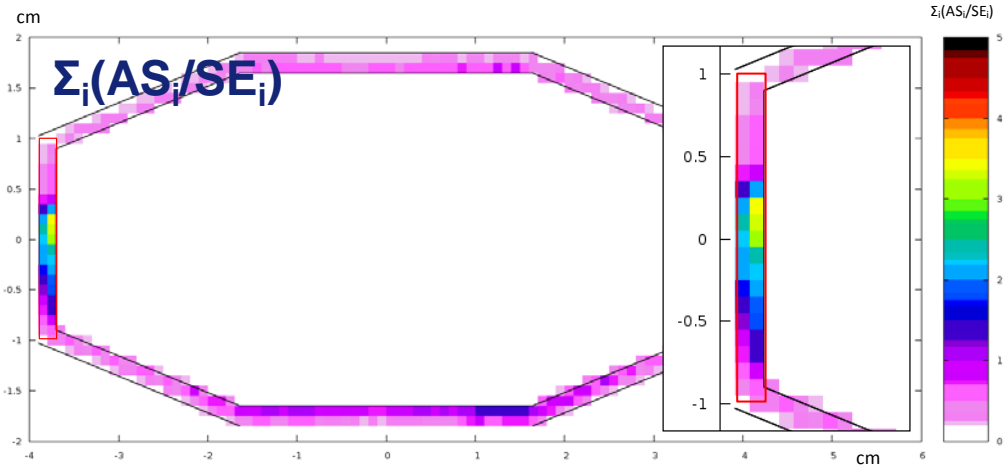
guaranteed for 1 cm³ hotspots.

Detection limit of 4.5 nSv·h⁻¹



1 cm³ hotspots with

$$\sum_{all\ isotopes} \frac{AS_i}{SE_i} \geq 0.8$$



INDISTINGUISHABLE FROM BACKGROUND AND EURATOM CLEARANCE LEVELS

Compliance with clearance levels defined in Council Directive 2013/59/EURATOM

Surface dose measurements
(indistinguishable from background)



$$\sum_{all\ isotopes} \frac{AS_i}{SE_i} \leq 1$$

guaranteed for 1 cm³ hotspots.

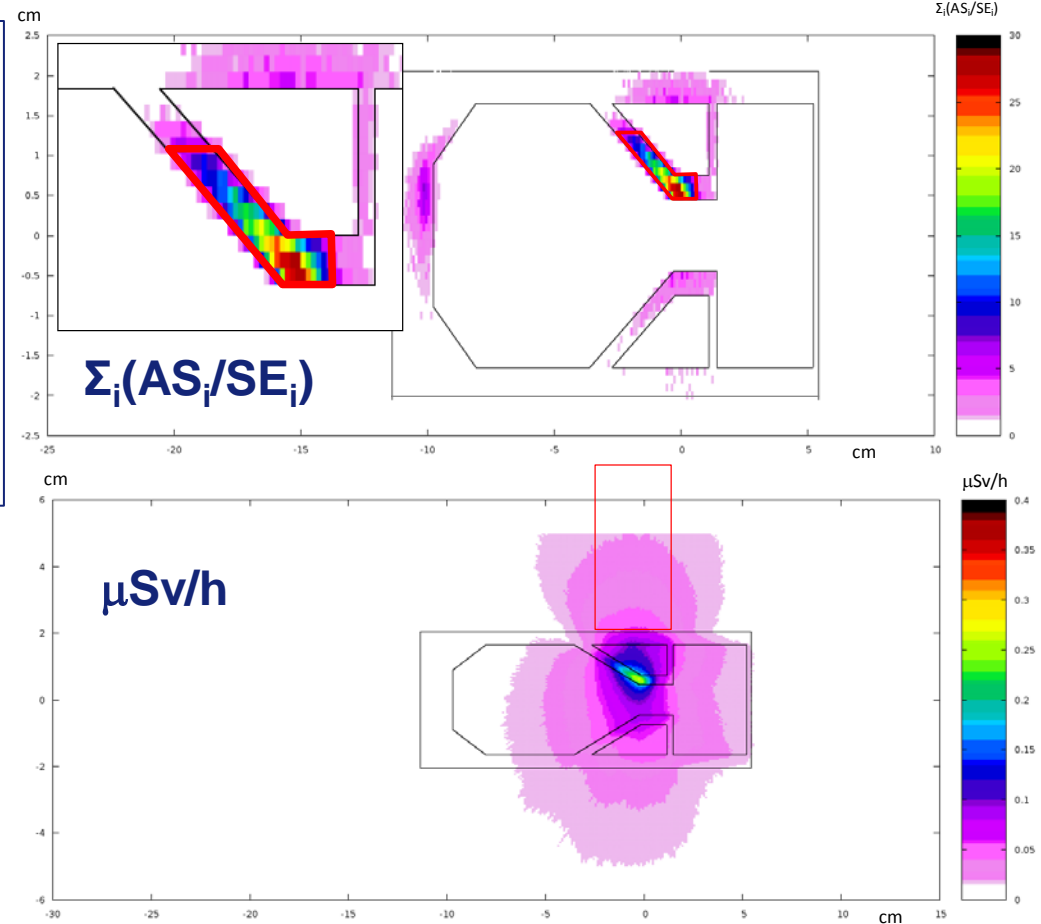
Detection limit of 3.2 nSv·h⁻¹



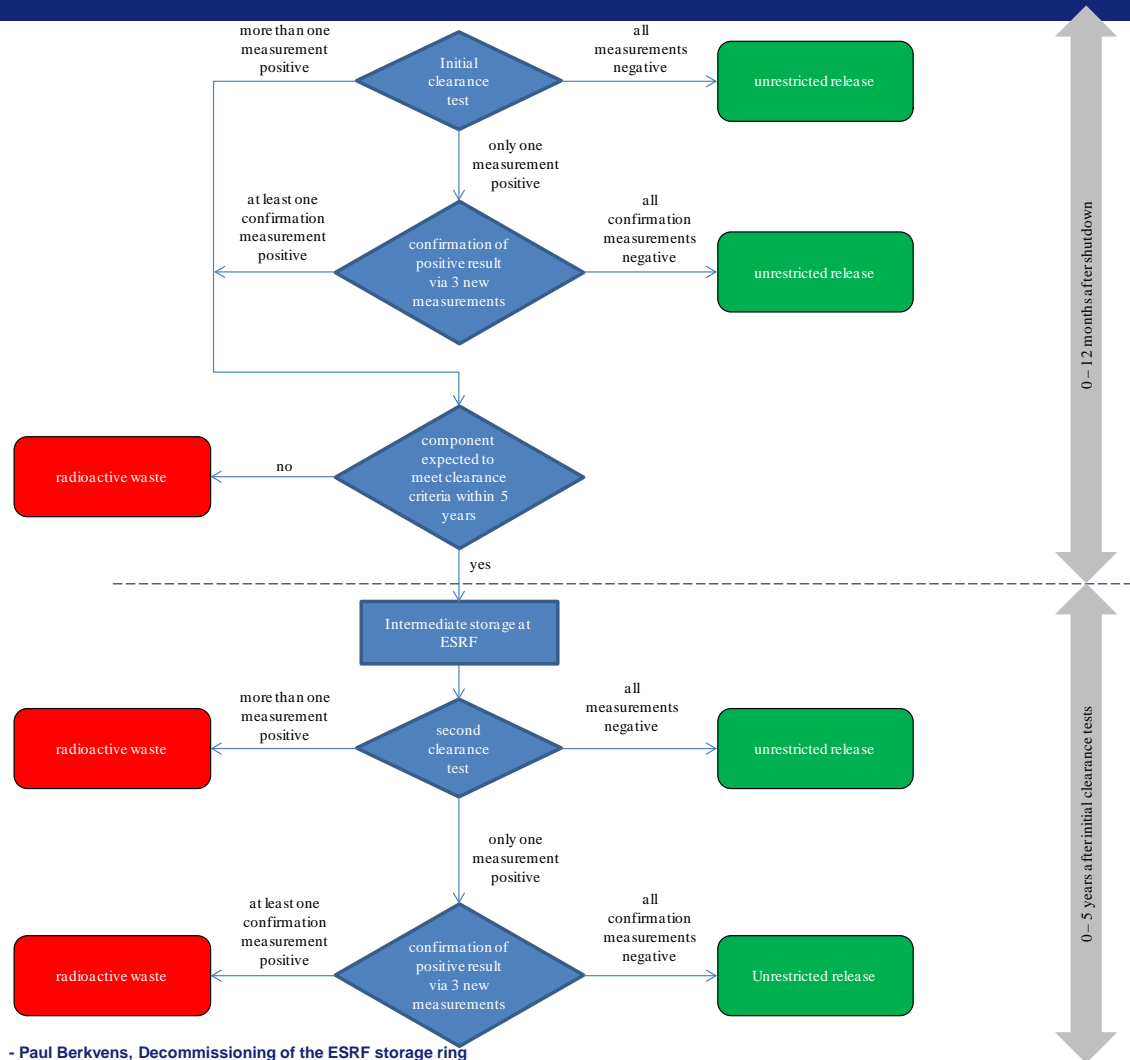
1 cm³ hotspots with

$$\sum_i (AS/SE)_i \geq 0.96$$

(for 15 nS/h background)



PROPOSED MEASUREMENT PROTOCOL



Technical study sent to ASN on 25 February 2015

- Proposed material release plan
- Detailed activation calculations of standard cell

Meeting with ASN on 22 May 2015

- Outcome of meeting: yes, but
 - ESRF should rephrase criteria to make it criteria for radiological zoning.

Next steps

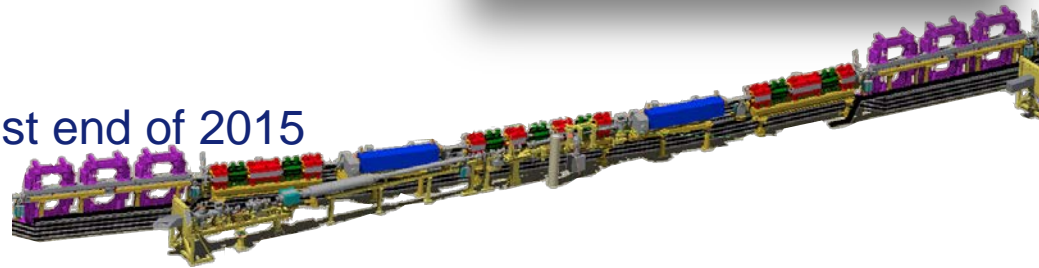
- Submit formal authorisation request end of 2015
- Public hearing beginning 2016
- Authorisation expected 2017



**Proposed material release plan for the
decommissioning of the ESRF storage ring**

P. Berkvens, P. Colomp
25 February 2015

Reference : ESRF/SGRP/ASN/rapport/decomm/2015-len



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