RADIATION PROTECTION maintenance considerations for SPES

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PROJECT CONSTRAINTS: max. 5 mSv/y to exposed workers

Maintenances at SPES

Plan design

Constraints in the dose rate for maintenance proposes

Exposed workers- Year workload 2000h

Frequency of intervention	Maximum dose rate
Low < 5 times/y	100 μSv h^{-1} (5 h total) 10 μSv h^{-1} (30 h total)
Medium > 5 times < 20 /y	6.0 μSv h^{-1} (15 h) 2.5 μSv h^{-1} (50 h)
High > 20 times <35/y	2.5 μSv h^{-1} (15 h) 1.0 μSv h^{-1} (80 h)

Radiation field in the cyclotron vault

Dose (γ), cooling: 1 sec
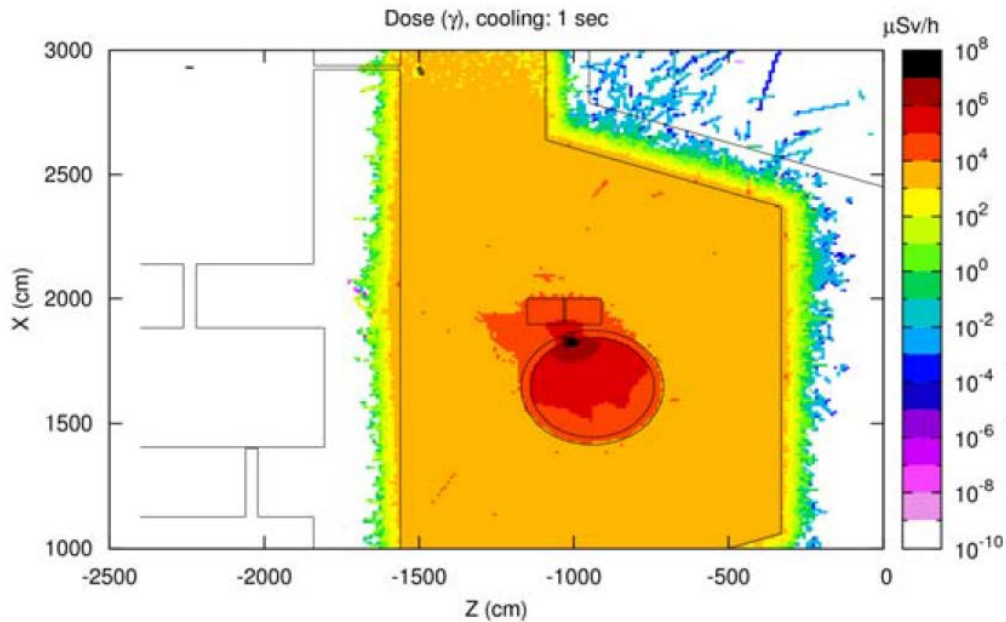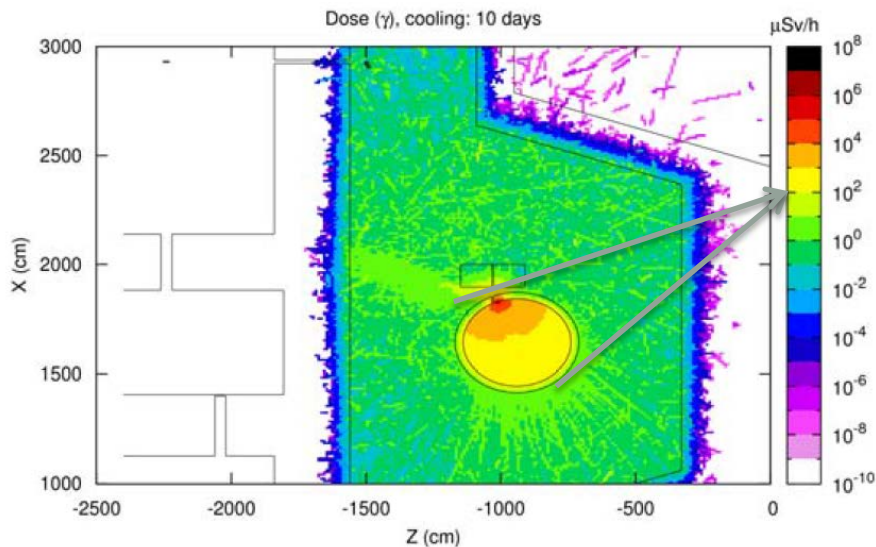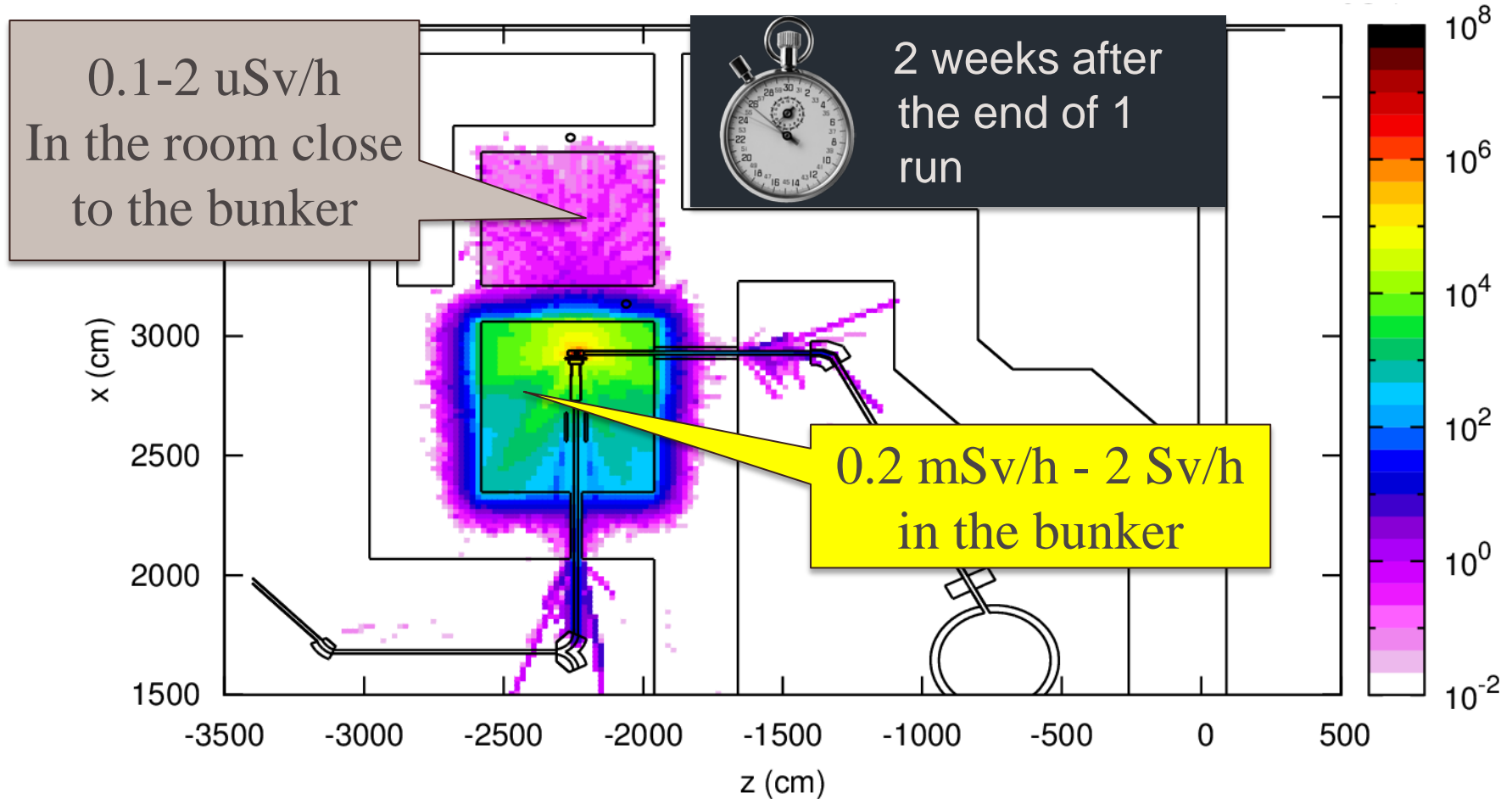

Dose (γ), cooling: 10 days

Tabella 6. Perdite di corrente del fascio nel ciclotrone, nei magneti e nelle linee di fascio

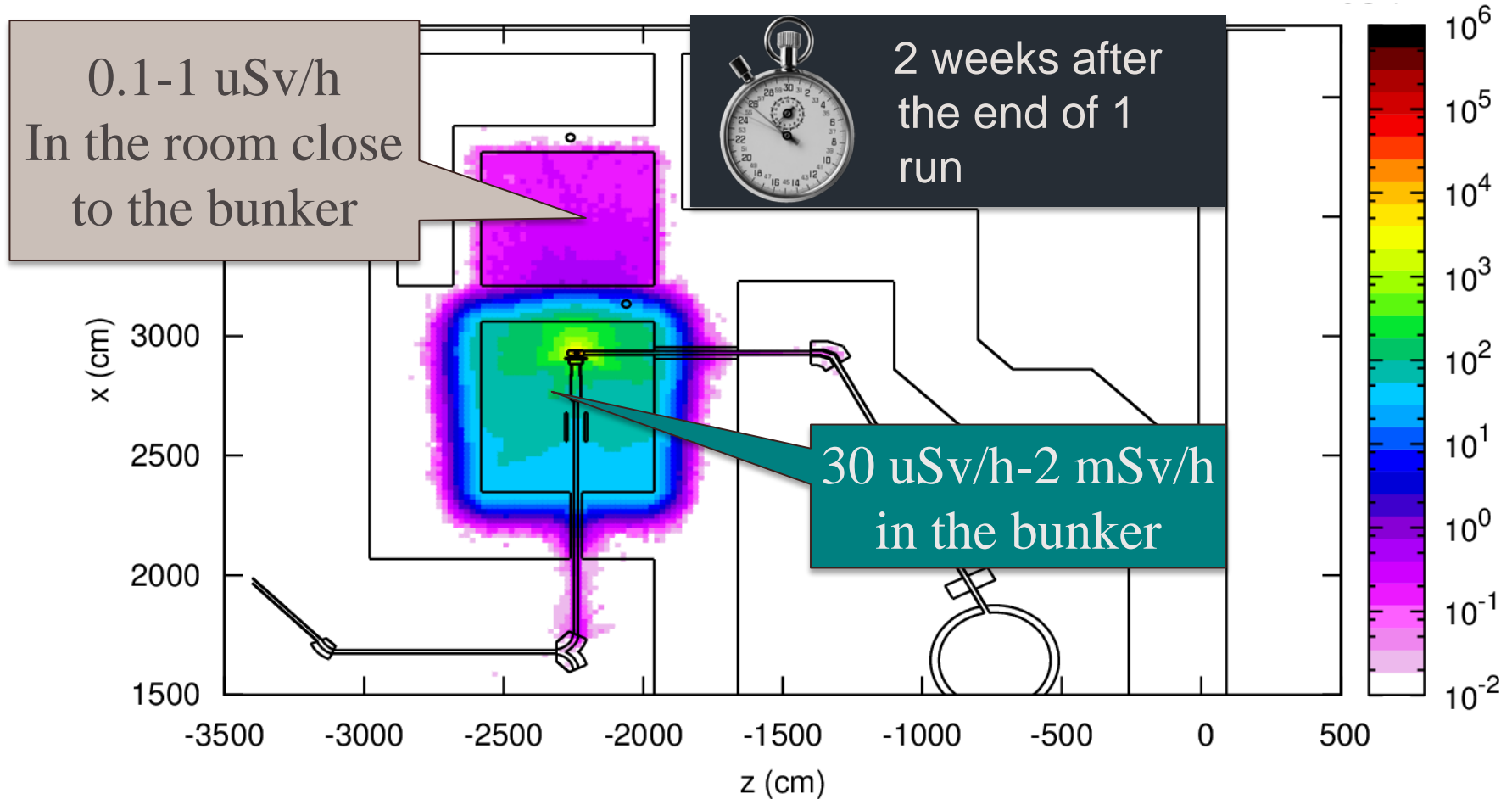| Perdite di fascio	Energia [MeV]	%	di 750 µA
Nel ciclotrone	30	3%	22.5 µA
	40	3%	22.5 µA
	50	1.5%	11.25 µA
	60	1.5%	11.25 µA
	70	6%	45 µA
Nei dipoli		0.6%	3 µA (1 tgt) - 4.5 µA (2 tgt)
Nei quadrupoli			
	70	3%	15 µA (1 tgt) - 22.5 µA (2 tgt)
Linea di fascio			
		0.3%	1.5 µA (1 tgt) – 2.25 µA (2 tgt)

After 10 days of cooling time, 1 run, there are zones very closed and around the cyclotron where maintenance operations can be done with a gamma a.d.e.r of 100 µSv/h

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Radiation field in the irradiation bunker

0.1-2 uSv/h
In the room close
to the bunker

2 weeks after
the end of 1
run

0.2 mSv/h - 2 Sv/h
in the bunker

The target is in place in the irradiation

Radiation field in the irradiation bunker

0.1-1 uSv/h
In the room close
to the bunker

2 weeks after
the end of 1
run

30 uSv/h-2 mSv/h
in the bunker

The target has been removed from the irradiation

Wien Filter

Z\A	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142
42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.005E+00	
44	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
45	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
46	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
47	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
48	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
49	3.60E+09	2.52E+09	4.20E+09	3.85E+09	4.19E+09	2.98E+09	2.52E+09	1.72E+09	1.26E+09	3.03E+08	1.73E+08	9.94E+07	2.31E+07	1.93E+06	1.96E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
50	9.96E+09	1.84E+10	1.29E+10	2.10E+10	1.57E+10	2.36E+10	1.85E+10	2.42E+10	2.03E+10	2.43E+10	1.63E+10	1.30E+10	2.60E+09	2.52E+09	1.25E+10	2.09E+08	2.79E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
52	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
53	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
54	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
55	0.00E+00	3.15E+06	1.95E+07	2.23E+07	1.24E+08	1.88E+08	5.05E+08	7.47E+08	1.40													09
56	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E+06	1.51E+06	1.66E+07	6.34E+07	1.0													09
57	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.7													09
58	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00														
59	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00														
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00														
61	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00														

Z Atomic number

Mass number

TRACEWIN calculations, L. Bellan
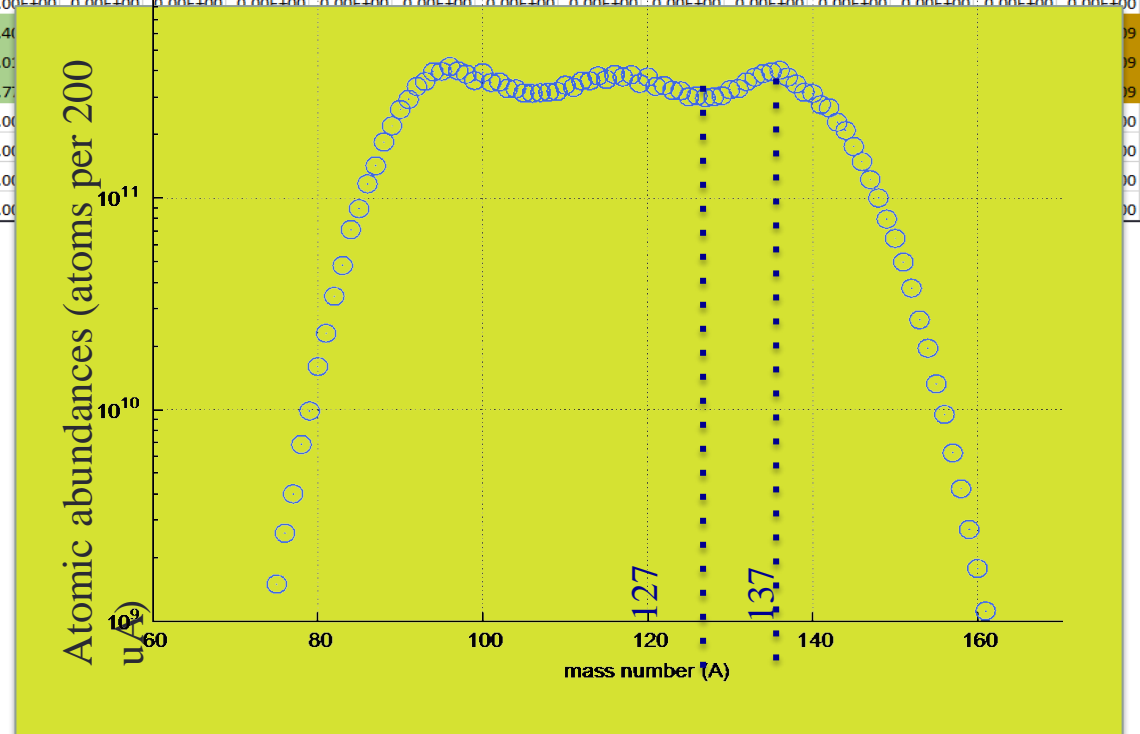
Pre-separator:
$|\Delta p/p| > 2\%$

For a ^{132}Sn beam:
$127 \leq A \leq 137$

Atomic abundances (atoms per 200 u/A) vs mass number (A)

Wien filter

Mass number

Z: Atomic number
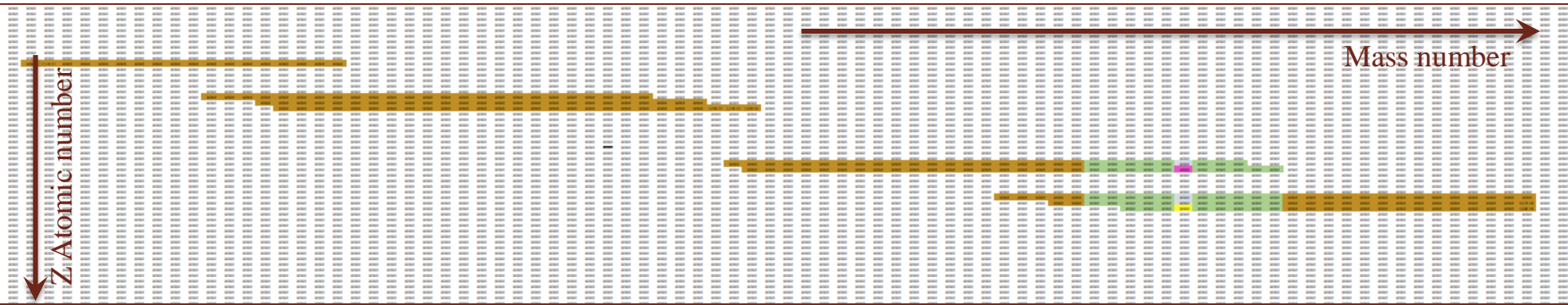
- Hundreds of species potential radioactive sources on the WF
- After 2-3 years of operation maintenance needed
- Non urgent maintenance: before touching the element it is allowed to wait months
- Reasonably, species with half lives longer than 2 weeks will be worth of consideration
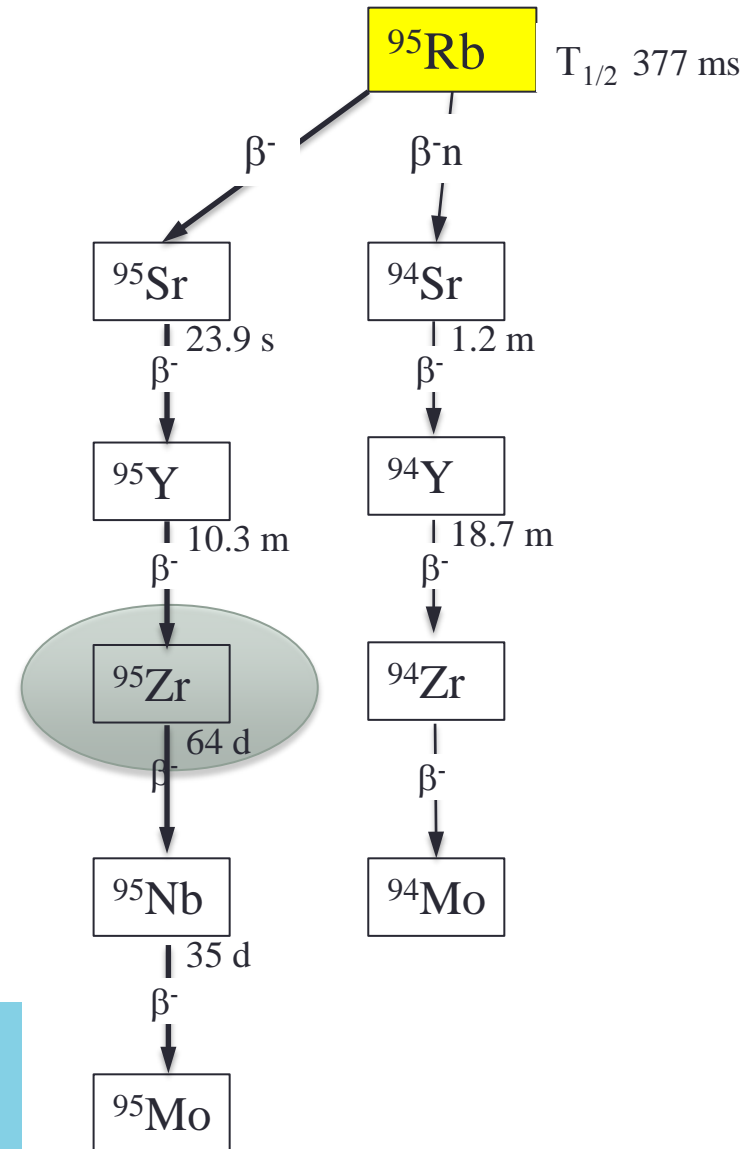- Reduction to about 50 species

Wien filter

Decay chain for each radionuclide

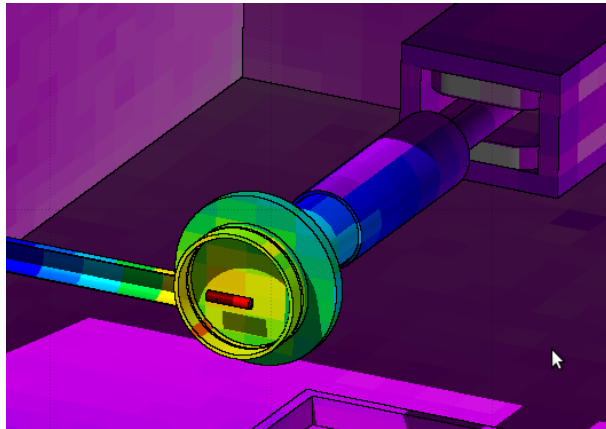Half life longer than 2 weeks are selected

If the half life is 2 weeks, after 6 months (12 half lives) the remaining activity is 0.02%

Specific gamma, mSv/h/1 MBq @ 1 meter

Dose rate @ 1 meter from the Wien filter after ^{132}Sn extraction, **3 mSv/h**

^{95}Rb $T_{1/2}$ 377 ms

β^- $\beta^- n$

^{95}Sr ^{94}Sr

23.9 s β^- 1.2 m β^-

^{95}Y ^{94}Y

10.3 m β^- 18.7 m β^-

^{95}Zr ^{94}Zr

64 d β^- β^-
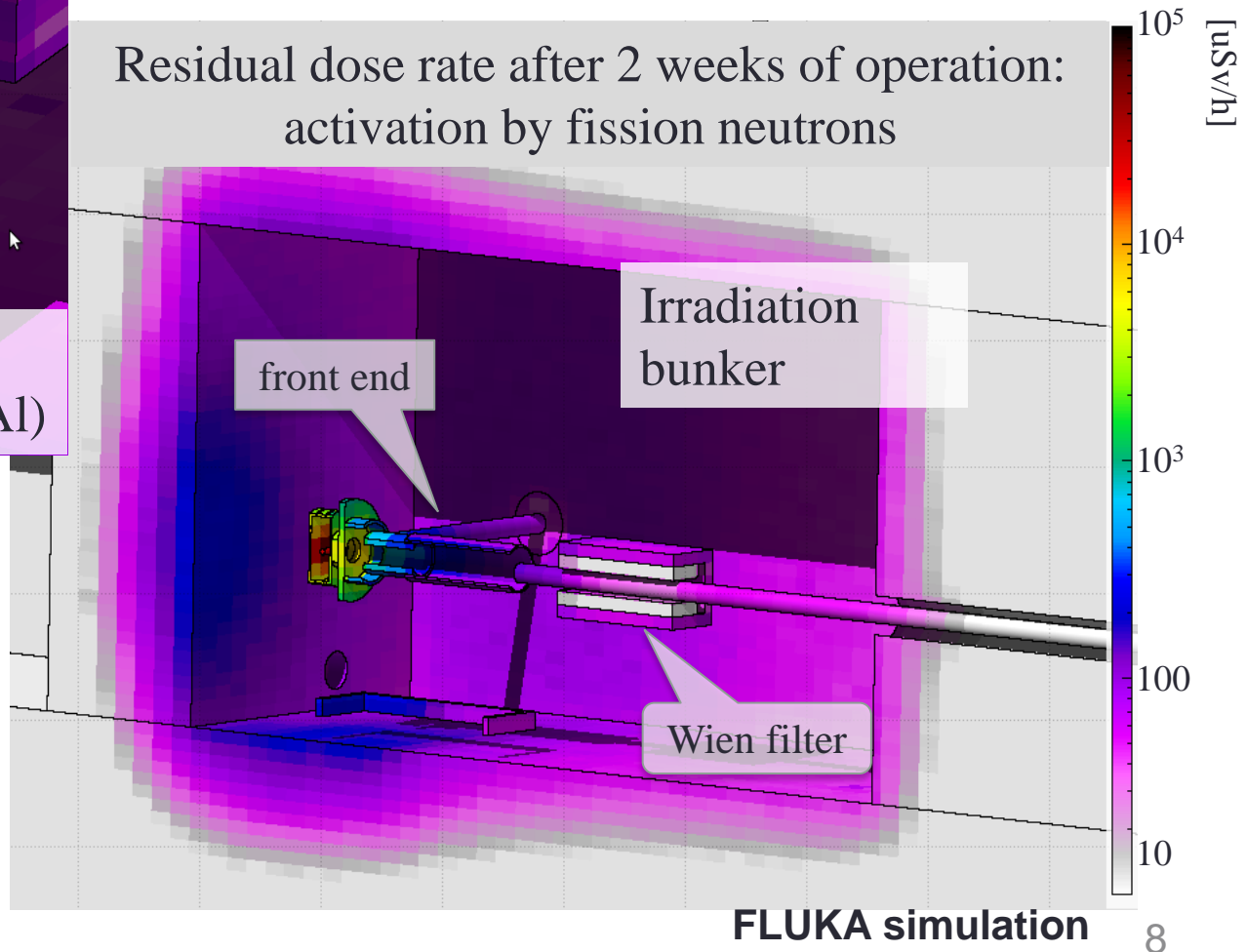
^{95}Nb ^{94}Mo

35 d β^-

^{95}Mo

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Wien filter

Front end with target container (graphite and Al)

About **100 uSv/h** from the activation due to fission neutrons (negligible compared to **3 mSv/h** from the radioactivity of the unselected RIB
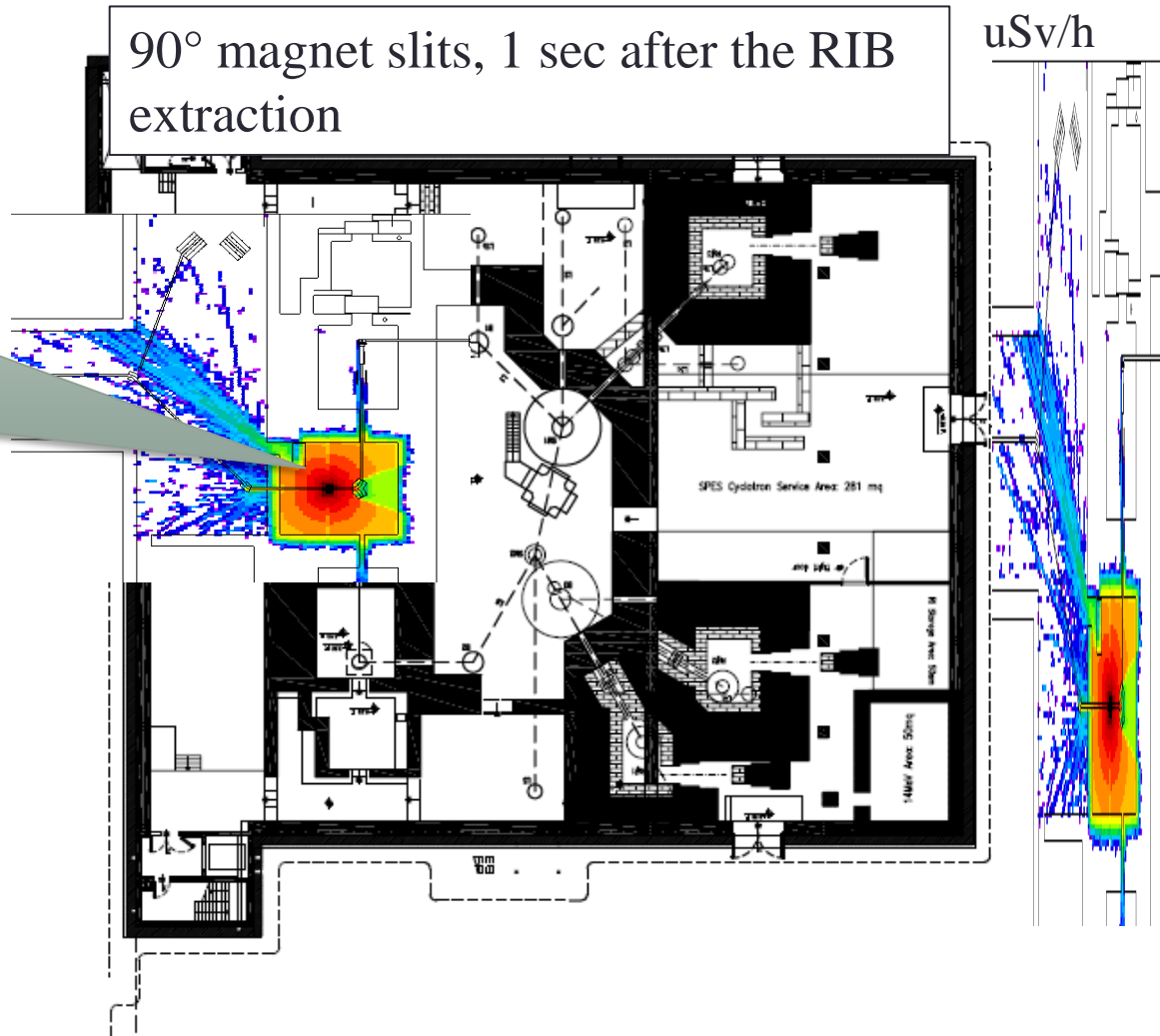

Residual dose rate after 2 weeks of operation: activation by fission neutrons

Irradiation bunker

front end

Wien filter

[uSv/h]

10^5

10^4

10^3

100

10

FLUKA simulation

90° magnet

During the extraction 40 mSv/h

After 2 weeks < 2 mSv/h

Pre-separator: |ΔM/M| > 1/200

For a ^{132}Sn beam: 132 isobars resolved

90° magnet slits, 1 sec after the RIB extraction

uSv/h

High Resolution Mass Spectrometer

HRMS slits, 1 sec after the RIB extraction

During the extraction 0.6 mSv/h

After 2 weeks < 0.2 mSv/h

At this stage the ^{132}Sn beam si completely resolved

uSv/h

Charge Breeder

+n RIB

+1 RIB
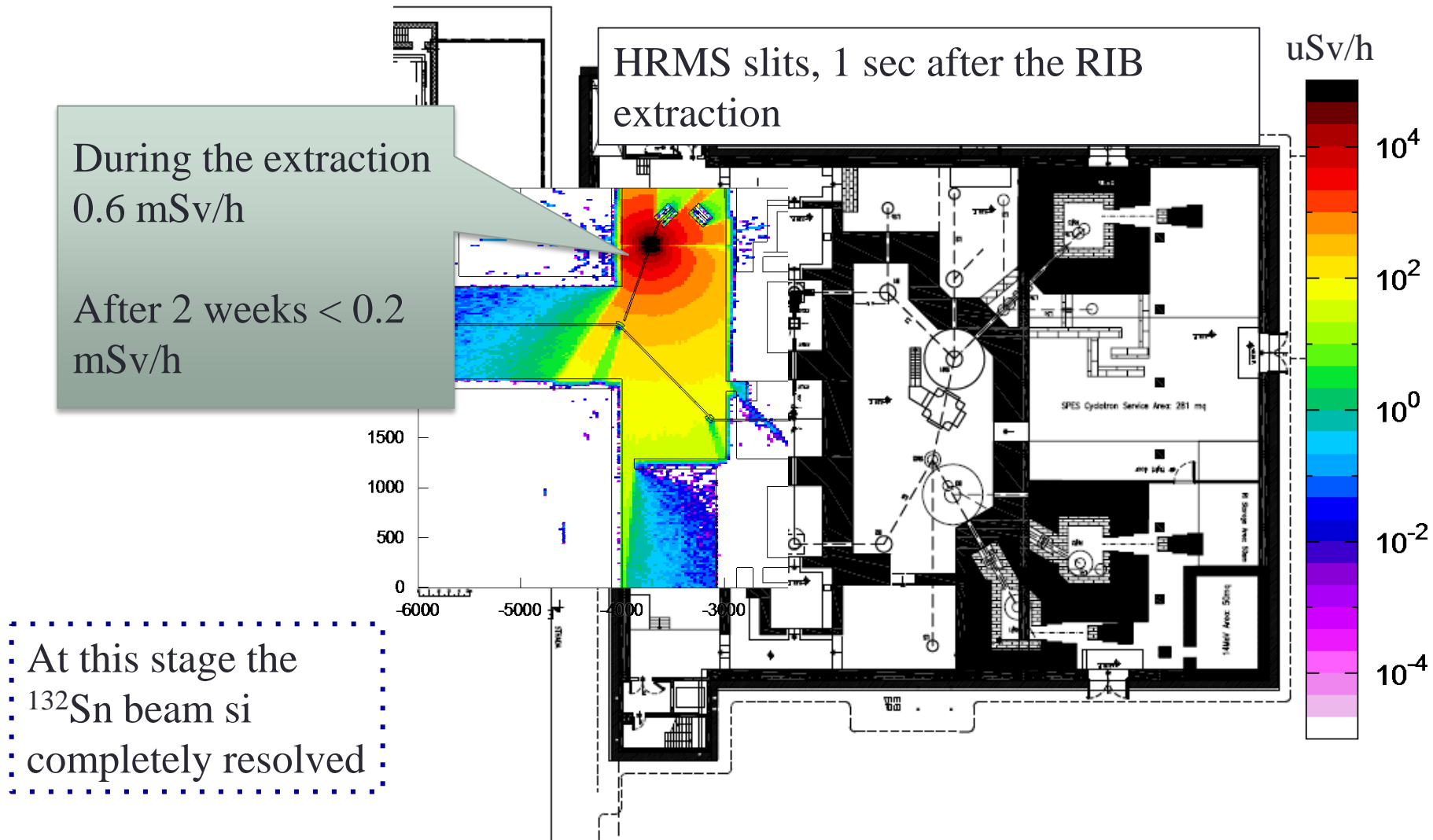
Interaction with plasma inside the plasma chamber
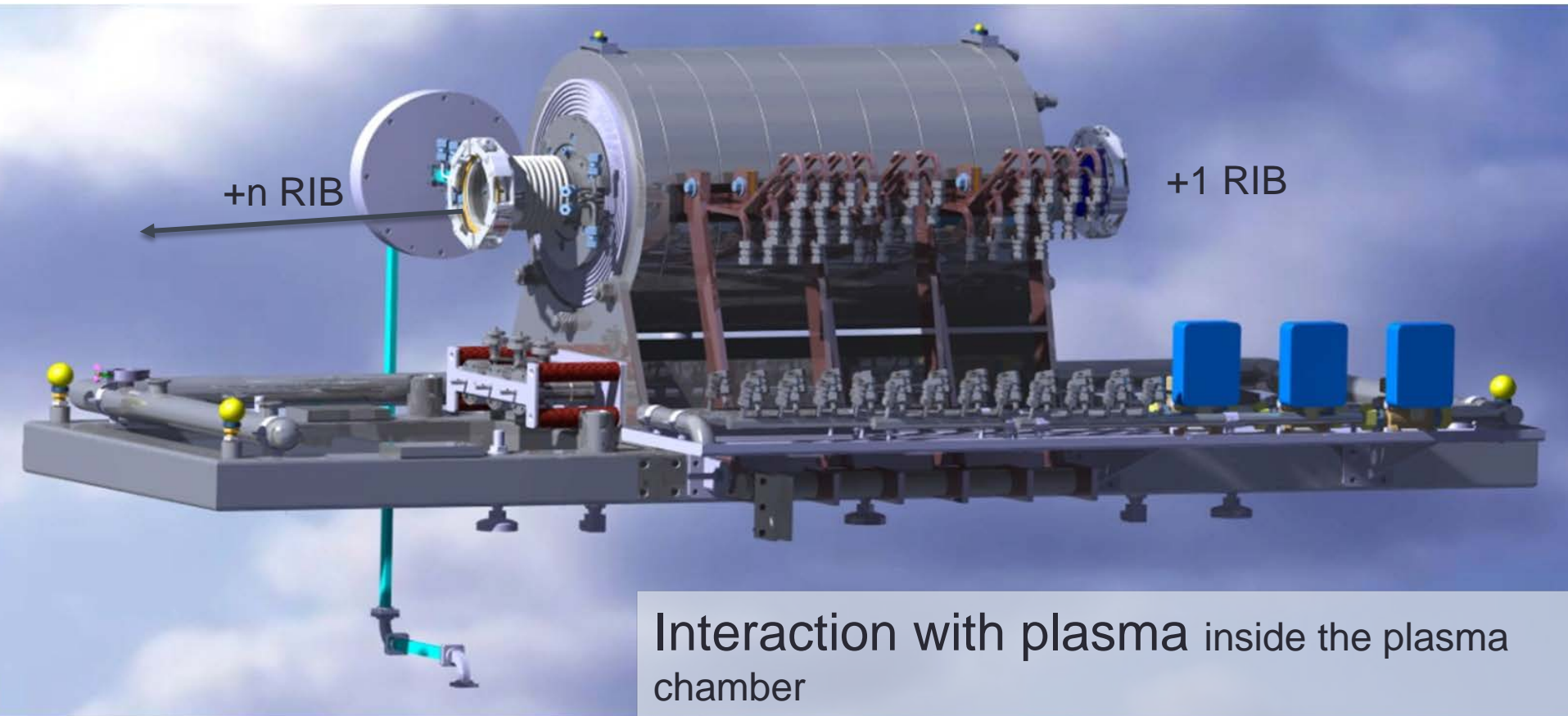
Maintenance on the charge breeder: possible removal of the plasma chamber for cleaning

Charge Breeder

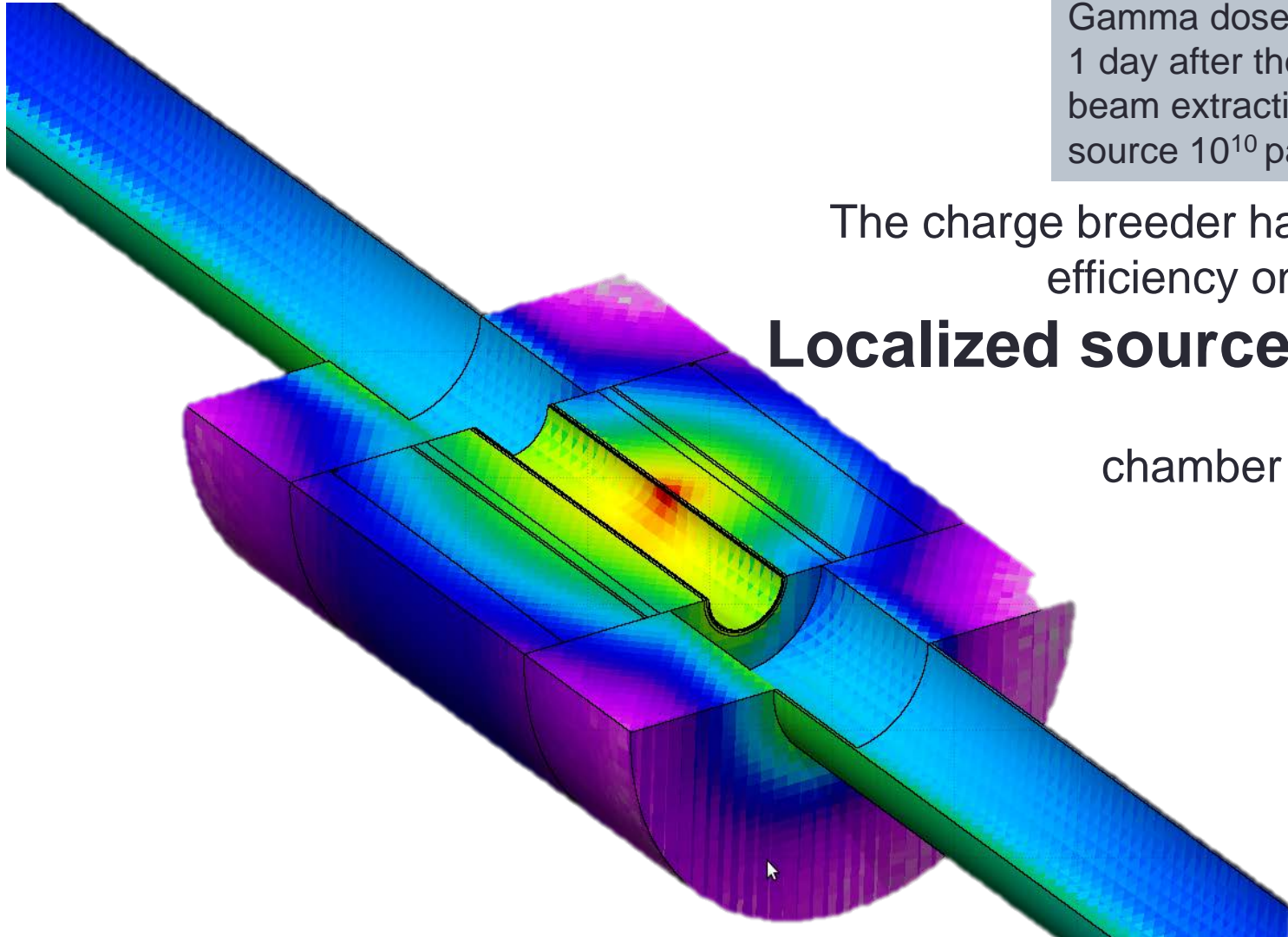10^{10} 10^9 10^8 10^7 10^6 10^5 10^4 10^3 10^2 10 1 0.1
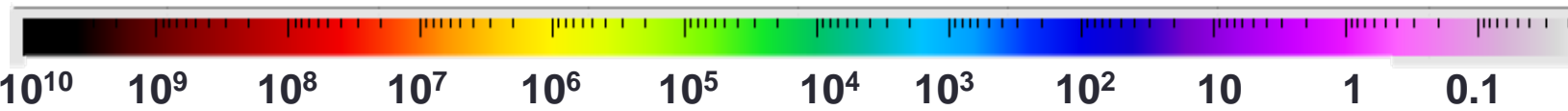
Gamma dose rate (uSv/h) 1 day after the end of beam extraction, ^{132}Sn source 10^{10} part/sec

The charge breeder has limited efficiency on the RIB

Localized sources on the plasma chamber surfaces

Charge Breeder

Beams considered: ^{90}Rb, ^{135}I, ^{137}Te, ^{94}Kr, ^{138}Xe, ^{132}Sn, ^{134}Sn

External gamma dose rate:

^{90}Rb - After 1 day everywhere < 1 μSv/h

^{135}I -   After 1 week for distances > 30 cm < 1 μSv/h

^{137}Te – After 1 h the dose rate is < 1 uSv/h for distances > 30 cm; at contact with the surface of CB max. rate of 100 uSv/h. The presence of ^{137}Cs in the decay chain of ^{137}Te keeps the dose rates further costant.

^{94}Kr - After 1 day the dose rate is < 1 uSv/h for distances > 30 cm; at contact with the surface of CB max. rate of 100 uSv/h. After a week everywhere < of 1 uSv/h

^{138}Xe - After 1 day everywhere < 1 μSv/h

^{134}Sn – After 3-4 days max. rate 1 uSv/h for distances > 30 cm; at contact with the surface of CB max. rate of 100 uSv/h.

^{132}Sn – After 10 days dose rate still high; close to the surface rates near to 1 mSv/h.

Charge Breeder

Gamma dose rate (uSv/h) 1 day after the end of beam, ^{132}Sn source 1.8×10^{10} part/sec
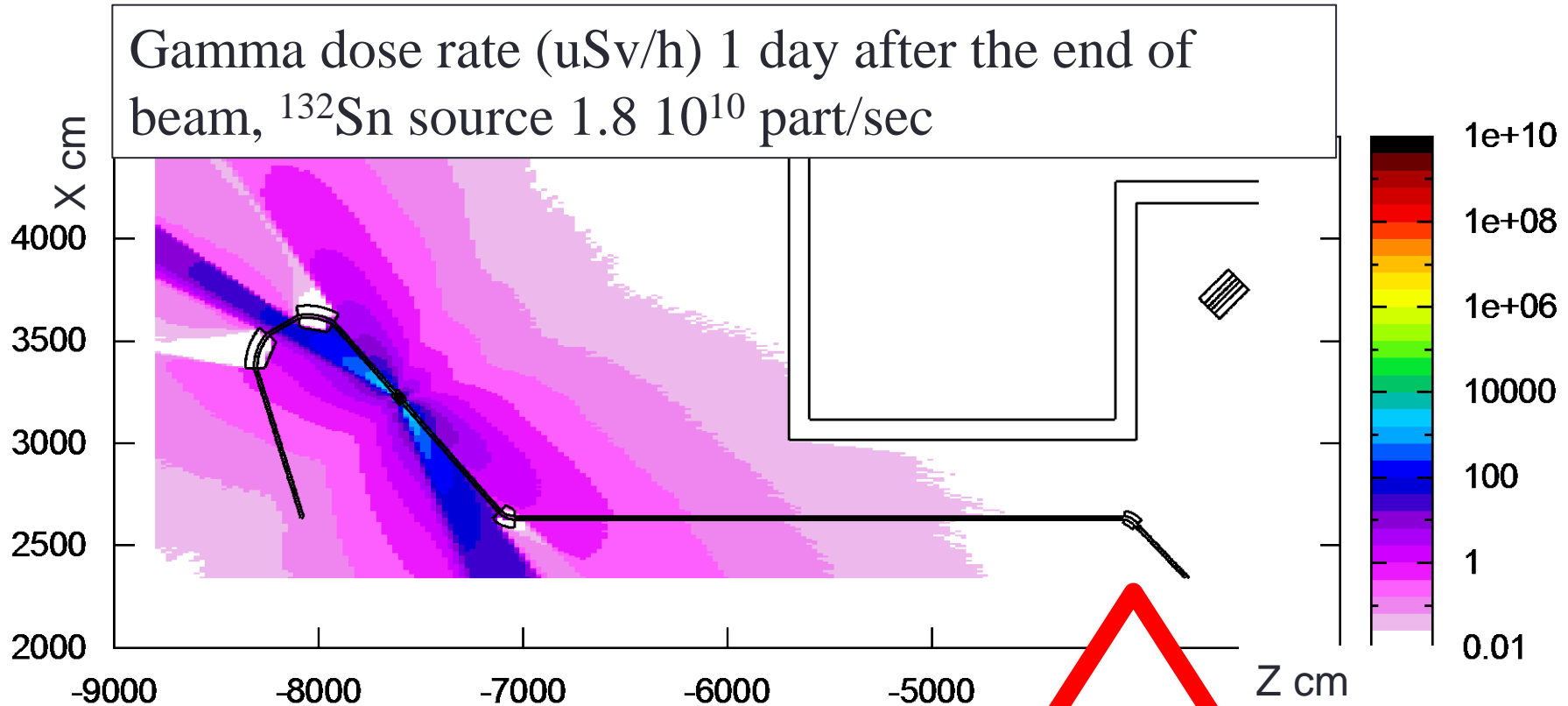
10 days after the end of beam the dose rate is higher than 1 mSv/h in contact with the CB surface

Caution in maintenance operations!

Charge Breeder

Internal dose:

^{90}Rb - No contaminated beams are present e none gaseous element present
  ^{90}Rb → ^{90}Sr → ^{90}Y → ^{90}Zr

^{135}I – Gaseous elements ^{135}I e ^{135}Xe. After 2 weeks total radioactivity present equal a 1 Bq.

^{137}Te - Gaseous elements ^{137}I e ^{137}Xe. After 2 weeks the total radioactivity present is less than 1 Bq.

^{94}Kr – After 10 seconds is compleed decay.

^{138}Xe – After 2 weeks less than 1 Bq.

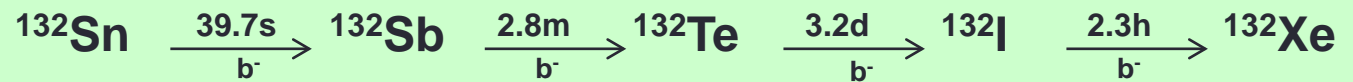^{132}Sn – The only that can create problems because of ^{132}Te, present in the decay chain, with half life of 3,2 days, not sufficient for decaying of all the gaseous products between 2 runs. The result is that the present quantity of ^{132}I will be $> 8 \times 10^8$ Bq. This value can become smalle if the time between 2 runs is going to be greater than 14 days.
^{132}Sn → ^{132}Sb → ^{132}Te → ^{132}I → ^{132}Xe

Charge breeder

Internal exposure by accidental introduction: **inhalation** of <u>volatile</u> radioactivity («All elements are solid at room temperature, except Kr e Xe, <u>if the CB is in atmosferic pressure</u>. In vacuum, someone like iodine is particularly volatile and can sublime slowly arriving up to the pumps» A. Galatà.)

Sn-132 decay chain

$$^{132}Sn \xrightarrow[b^-]{39.7s} {}^{132}Sb \xrightarrow[b^-]{2.8m} {}^{132}Te \xrightarrow[b^-]{3.2d} {}^{132}I \xrightarrow[b^-]{2.3h} {}^{132}Xe$$

$^{132}I \approx 10^9$ Bq

two weeks after the end of beam
(hundreds of mSv/h in 10 m^3 room with adult breath rate 1,2m^3/h using the coefficient 9,4 x10^{-11} Sv/Bq)

Caution and proper equipment in maintenance operations!

Conclusion

1 kCi in UCₓ target

Entrance forbidden when target inside

radiation field up to 2 Sv/h

Thank you for the attention!

More than 1 mSv/h from external exposure and ≈ 100 mSv from inhalation

40 MeV protons

3 mSv/h after 2 years of operation (100 uSv/h from neutron activation)

Wait if possible before maintenance on the object and provide special equipment to work on the plasma chamber

Wait due time before any maintenance on the object and store it in a controlled area

Dose γ: cooling 1 month

Dose γ: cooling 6 months

Dose γ: cooling 1 year