Radiation Protection Aspects of the SPES facility at LNL

L. Sarchiapone, D. Zafiropoulos

INFN, Laboratori Nazionali di Legnaro, Italy

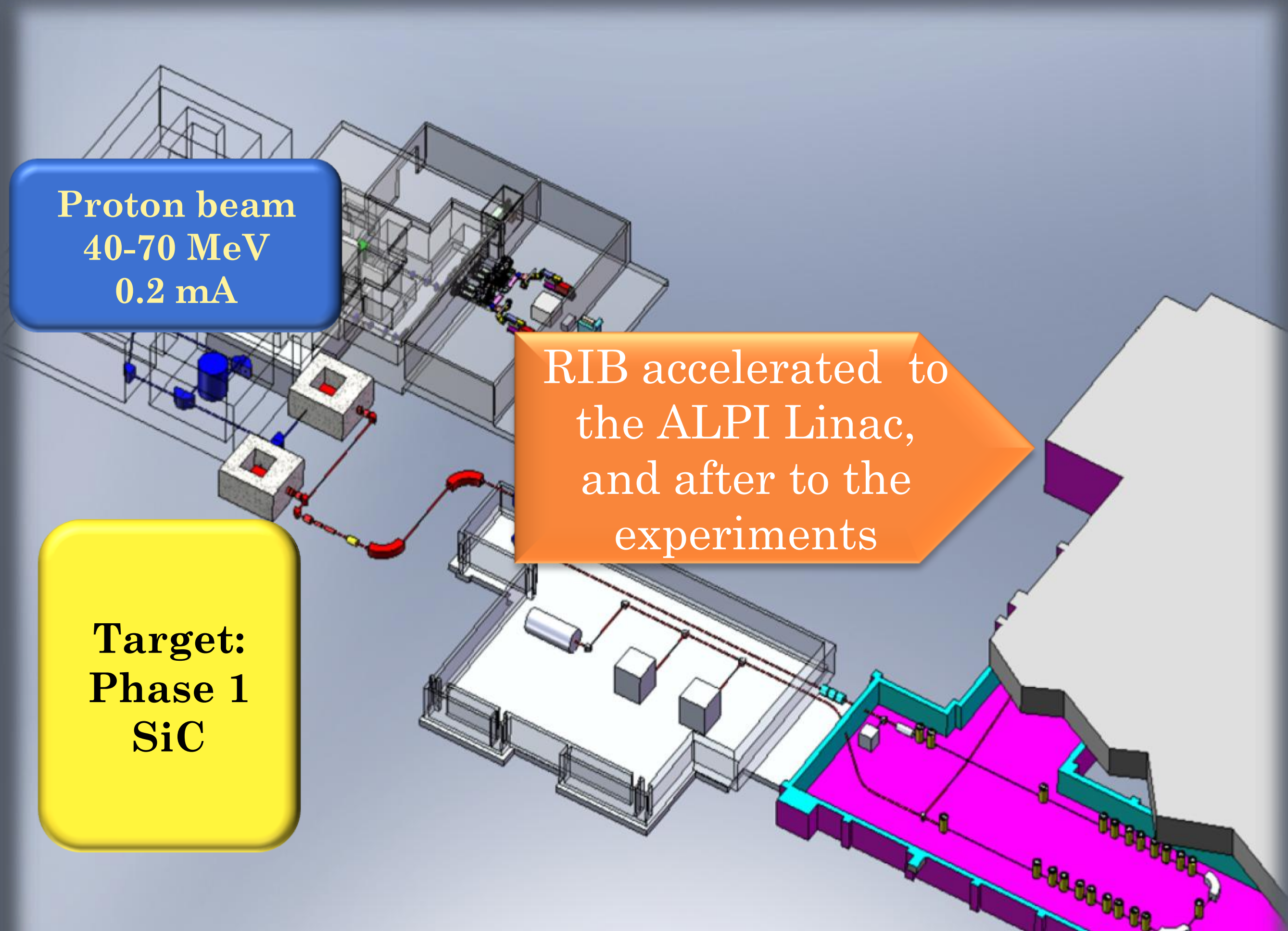
Shielding Aspects of Accelerators, Targets and Irradiation Facilities, 2-4 June 2010

SUMMARY

- The SPES Project
- Shielding Aspects
- Activation problems:
  - Shielding
  - Target and Front-End
  - Cyclotron
  - Air
- Conclusions

The SPES Project

Selective Production of Exotic Species



All the radiation protection aspect object of this work have been evaluated using the FLUKA Monte Carlo code.

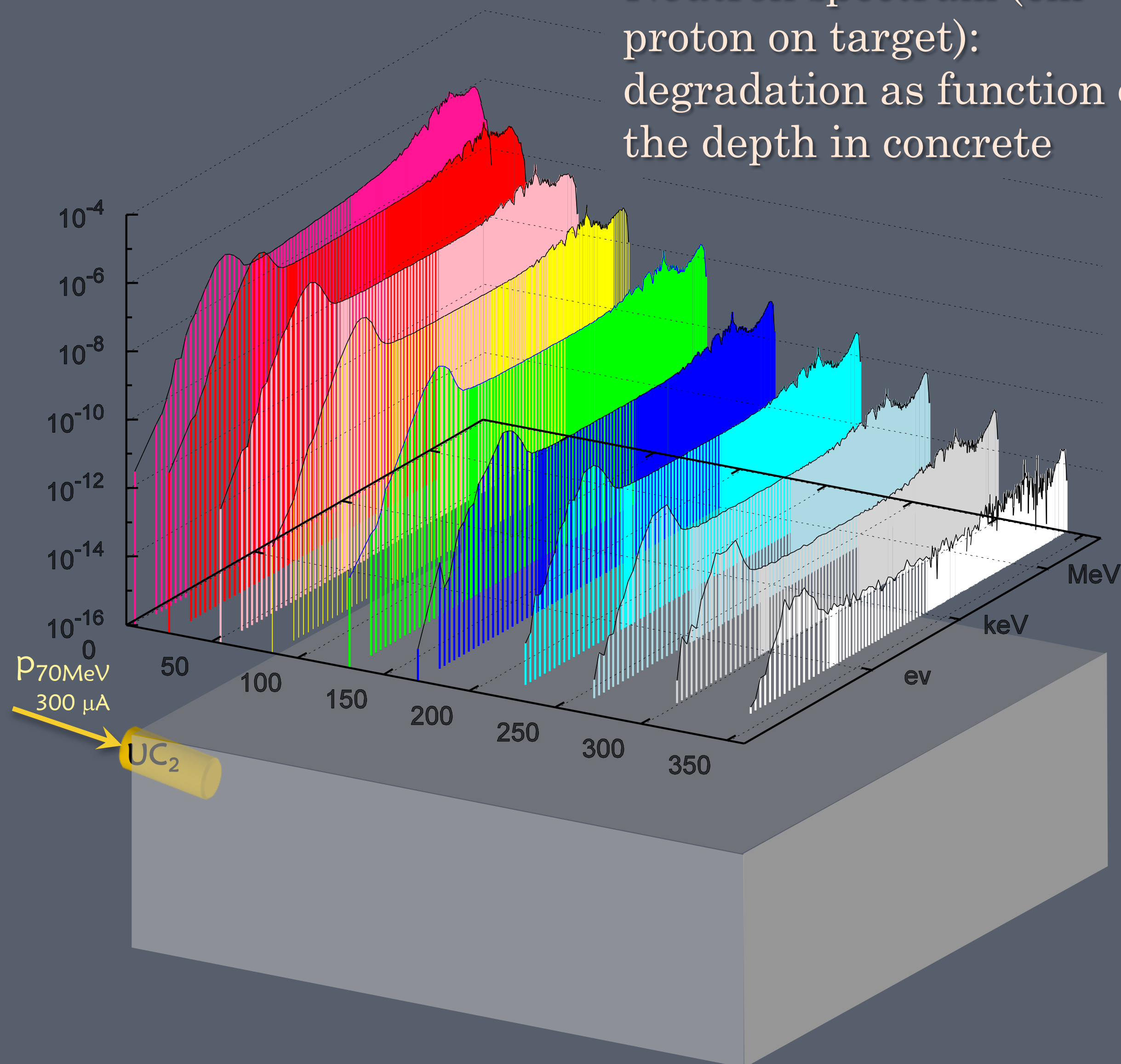
Shielding Aspects

- Project dose constraints:
  - 5 μSv/h for controlled classified areas
  - 0.3 μSv/h for non classified areas
  - 2000 hours/y working load rate of operation

- Goal: verify that the proposed hall shielding based on ARRONAX project (360 cm of concrete in the forward beam direction) was suitable also for our facility

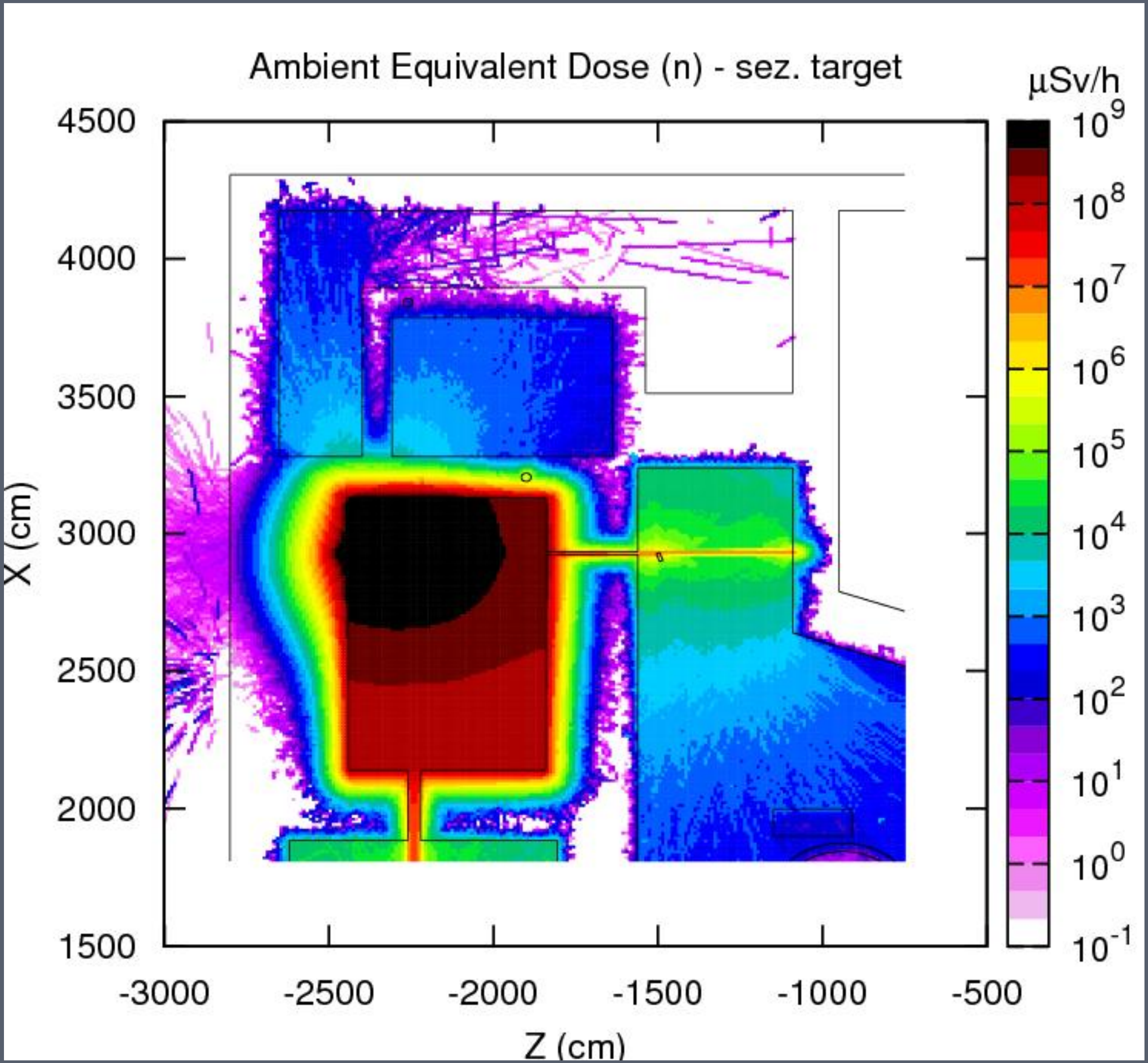
- The "safe-side" approach is guaranteed by the worst condition scenario, i.e. proton beam of 70 MeV, 300 μA. on UC_2 target.

Shielding Aspects

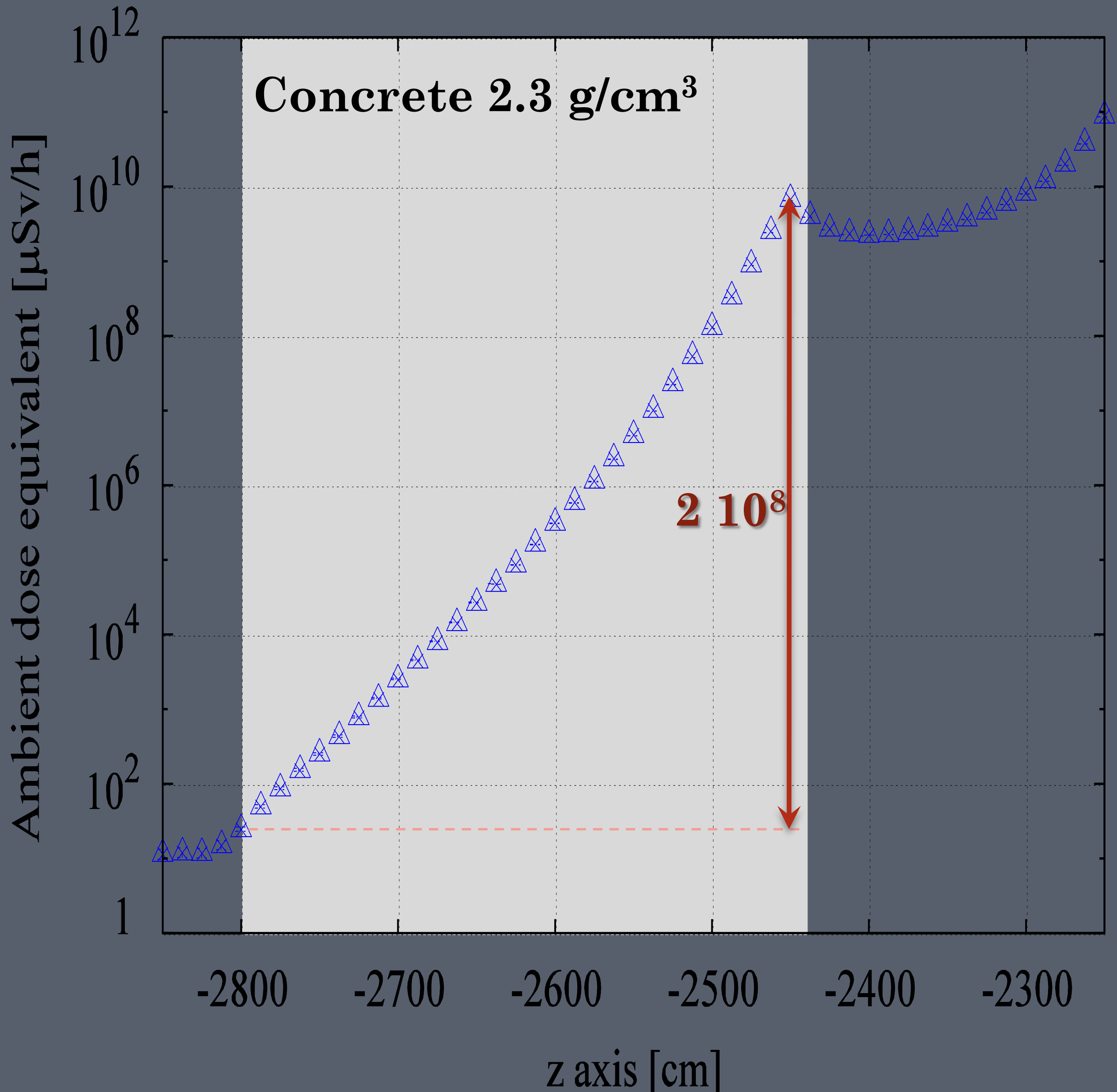


Neutron spectrum (cm^{-2} per proton on target): degradation as function of the depth in concrete

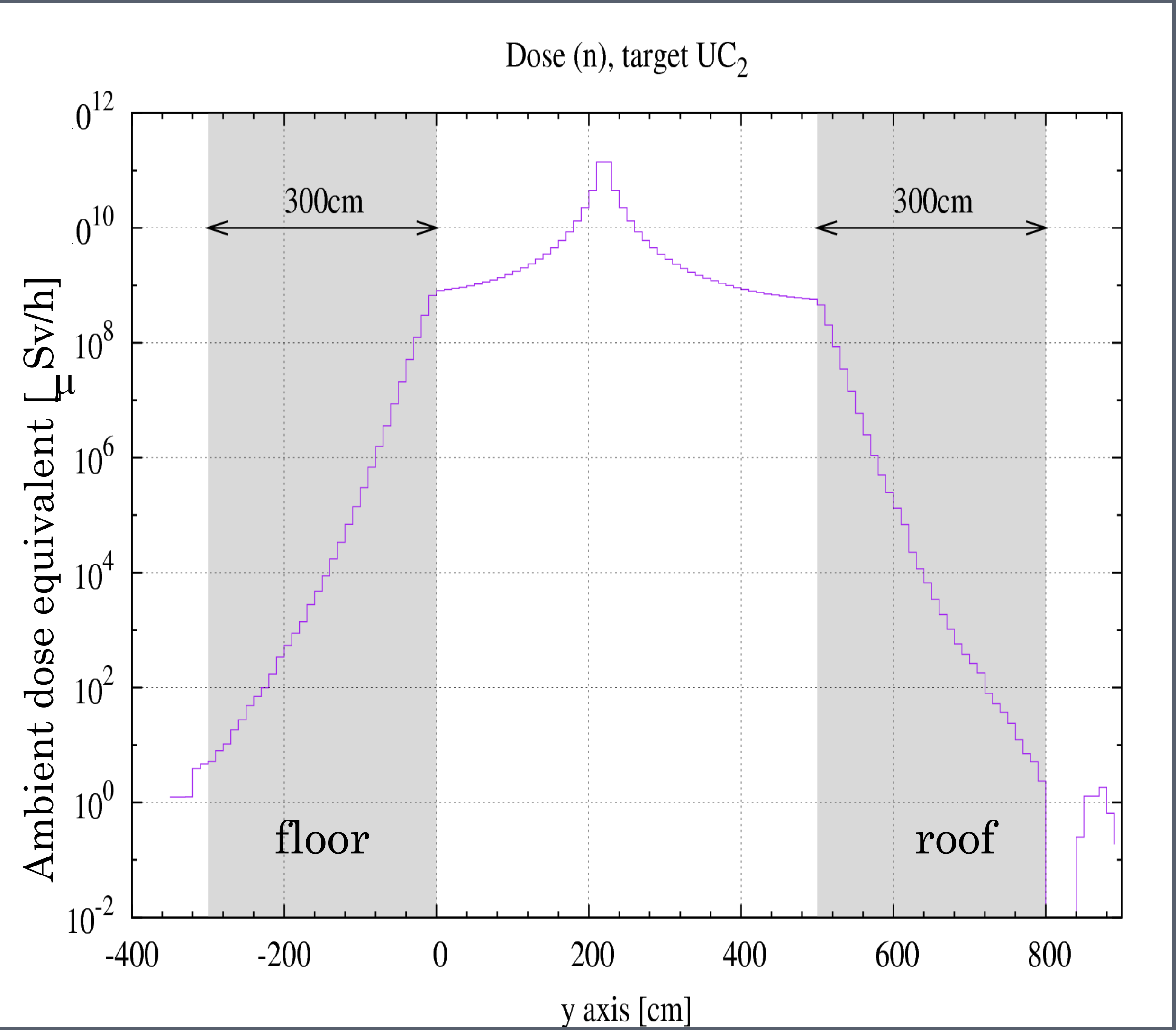
SHIELDING ASPECTS: TARGET UC_2



SHIELDING ASPECTS: TARGET UC_2

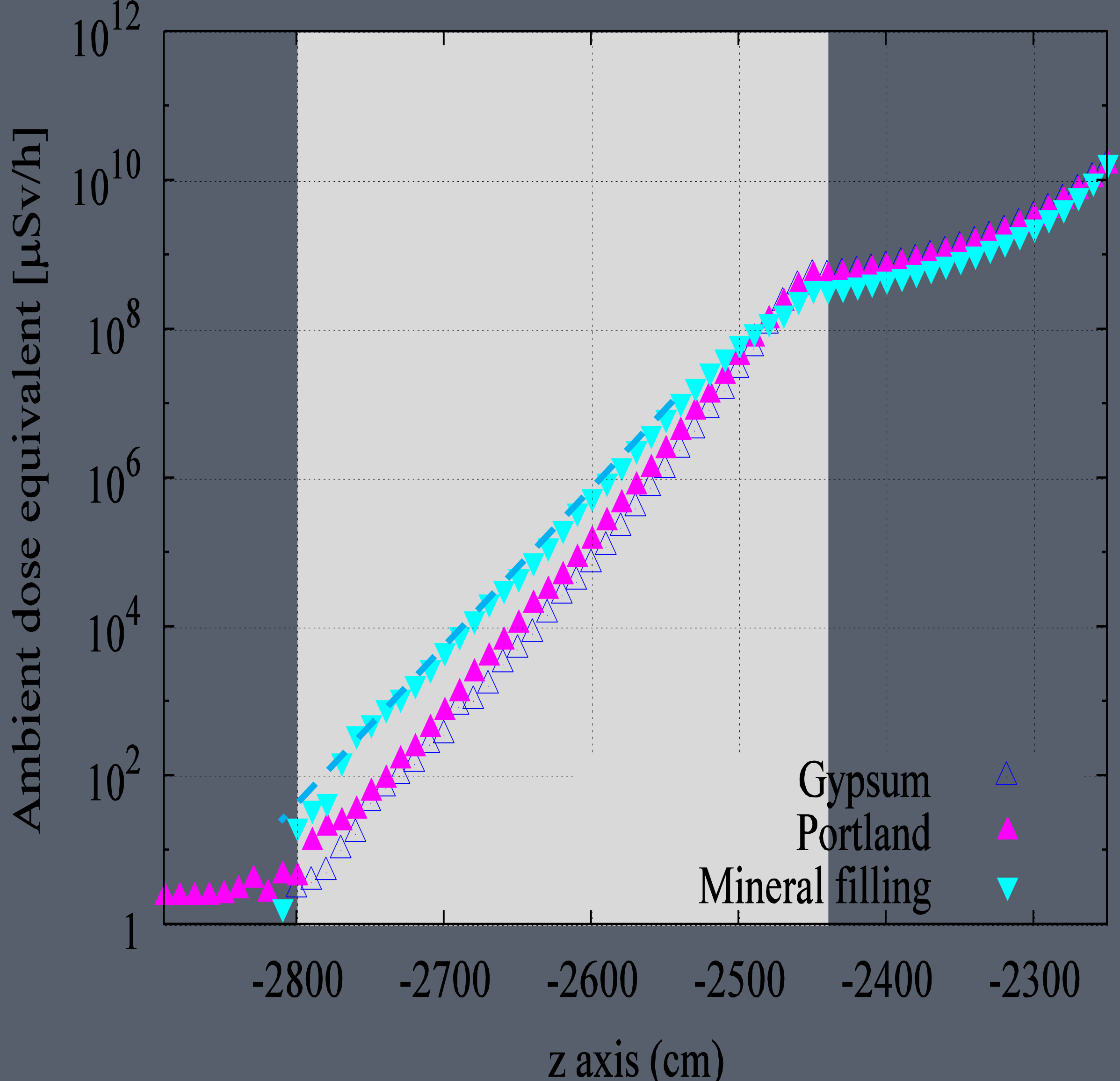


Shielding Aspects: target UC_2

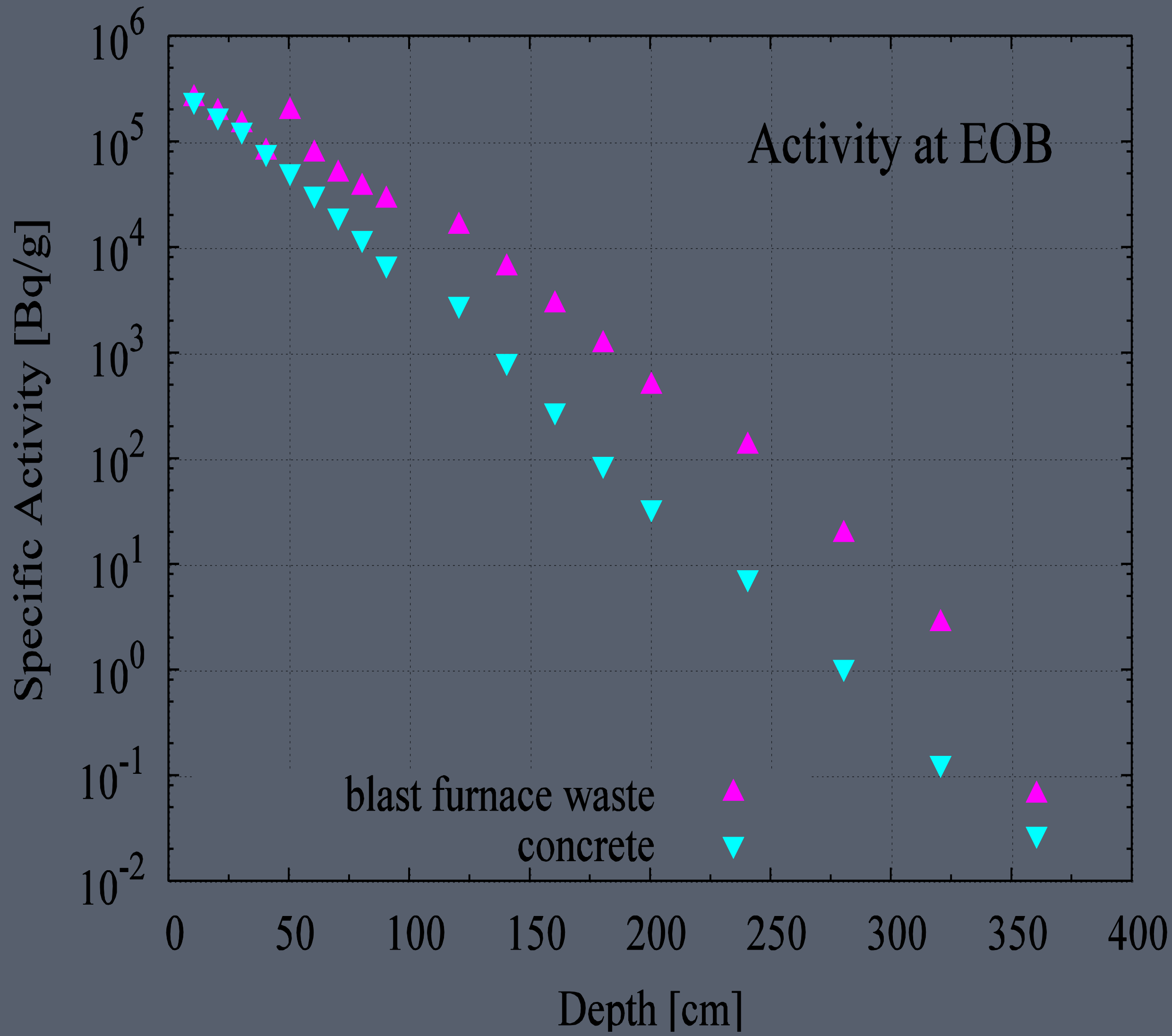


SHIELDING ASPECTS: TARGET SiC

- The same calculation with different materials leads to some preliminary conclusions…



ACTIVATION PROBLEMS: SHIELDING



Target: SiC

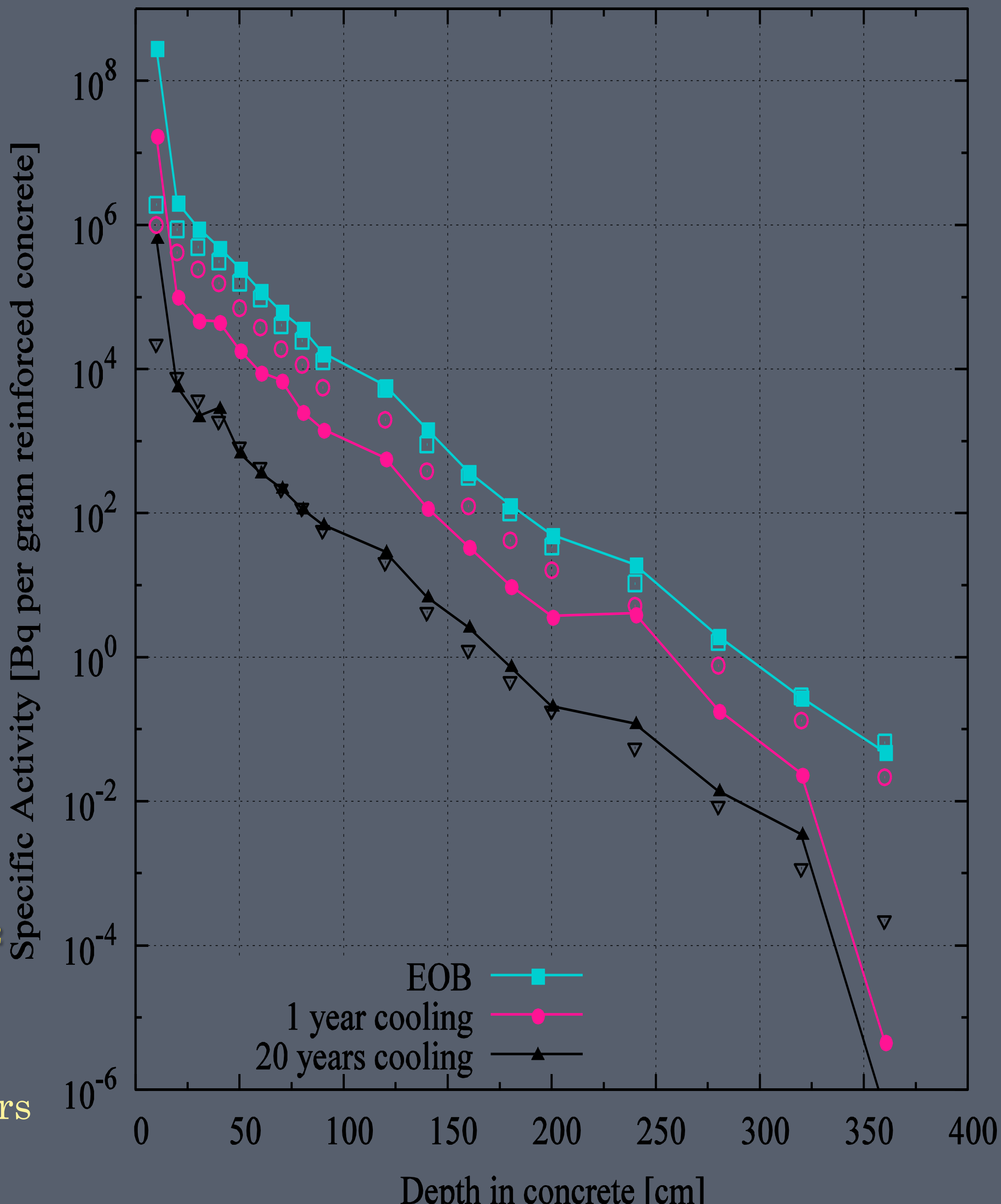
E: 70 MeV

I: 0.3 mA

T_{irr}: 20 years

W: 5000 h/y

Activation Problems: shielding



Target: UC_2

E: 70 MeV

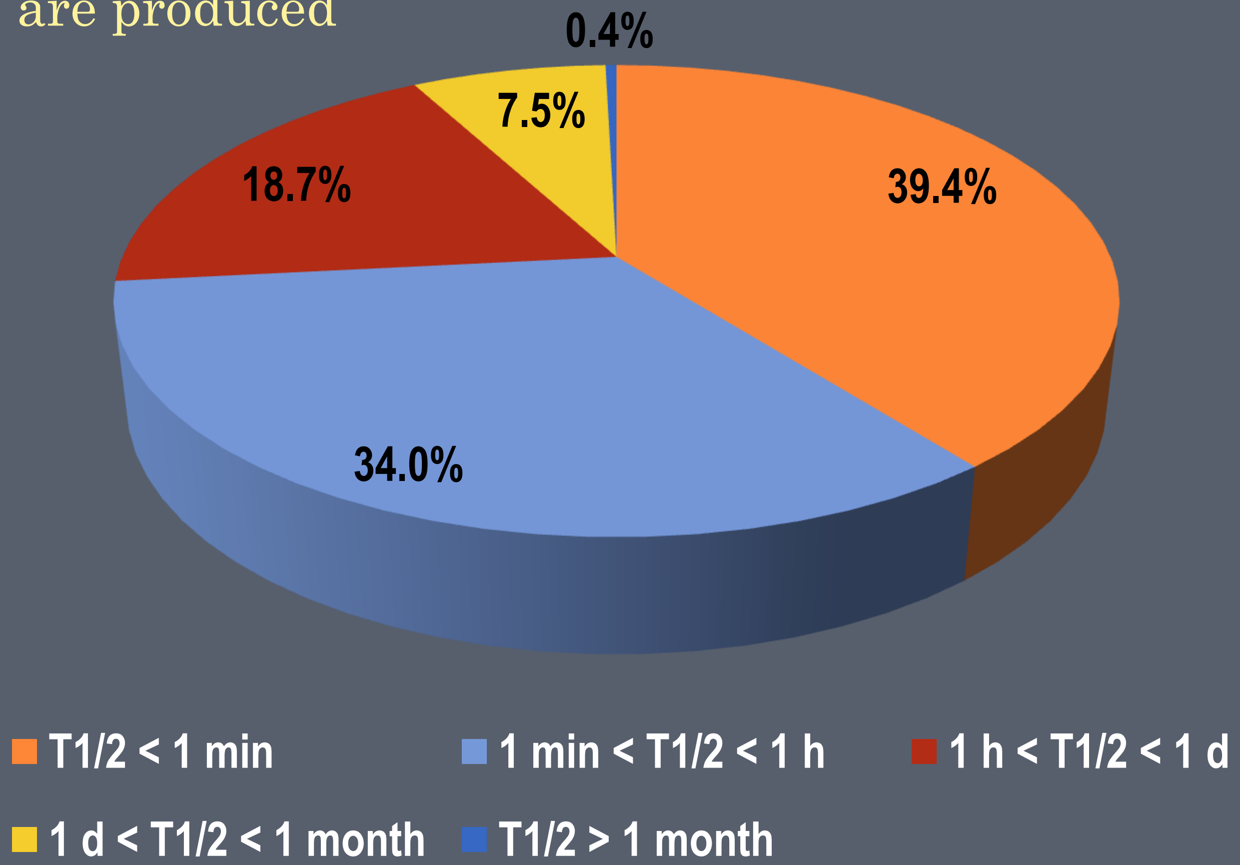
I: 0.3 mA

Tirr: 20 years

W: 5000 h/y

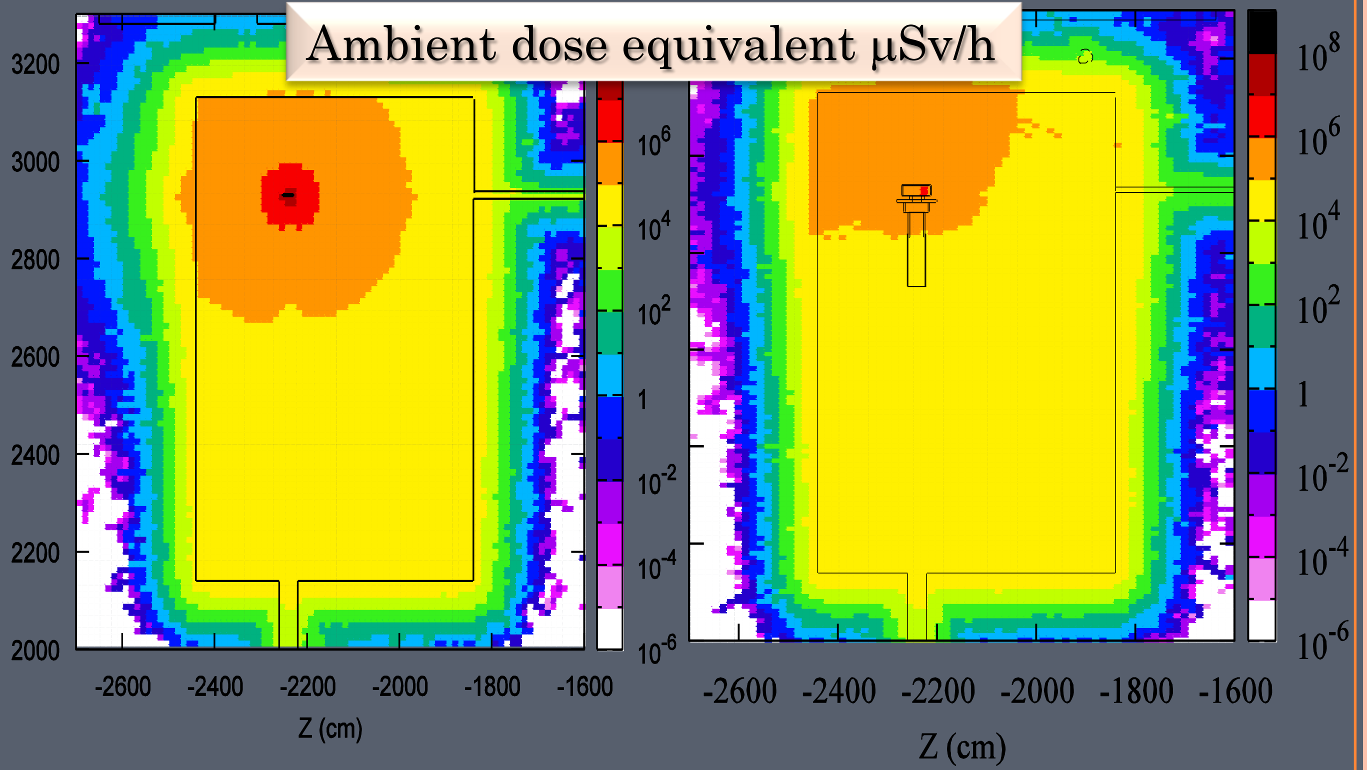
Activation Problems: target

- The emission of γ radiation following the activation of materials in the target hall and in the cyclotron vault, arises the problem of timed and controlled access.
- In the target, after 14 days of irradiation **10^{14} Bq** are produced



ACTIVATION PROBLEMS: TARGET AND F-E

Ambient dose equivalent μSv/h



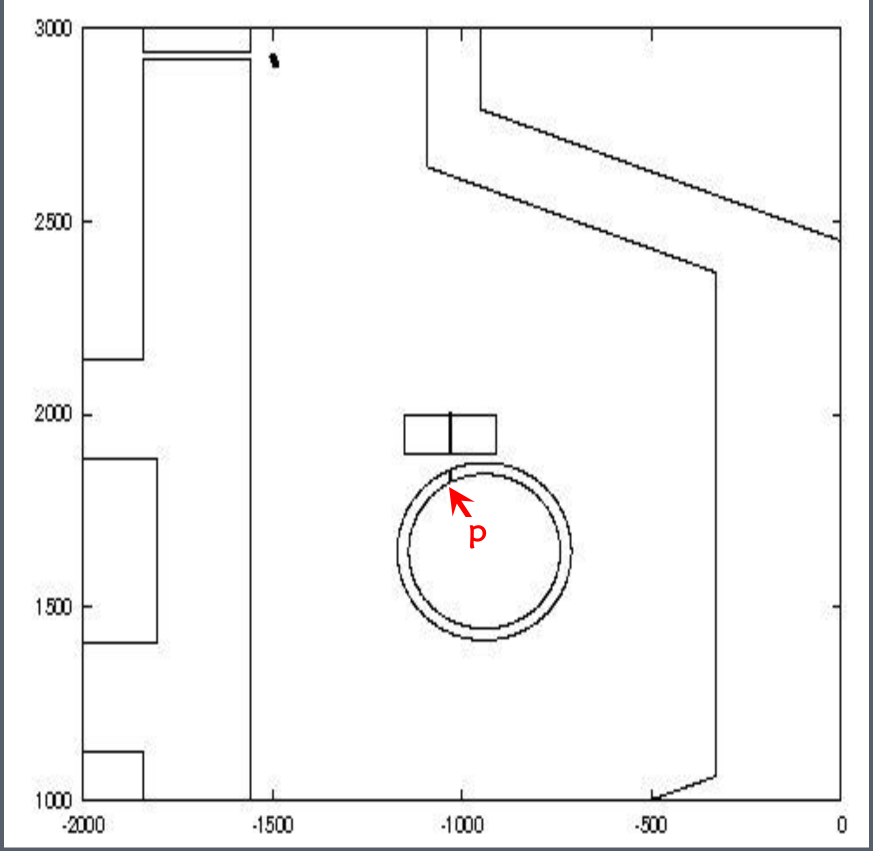
Cooling time	Residual γ dose rate: **target**	Residual g dose rate: **front end**
	Sv m²/h	
1 second	9.8	0.7
1 day	0.5	0.1
10 days	0.1	$2.7\ 10^{-3}$
1 year	$2.0\ 10^{-3}$	-

ACTIVATION PROBLEMS: CYCLOTRON

- Foreseen losses during acceleration and extraction
- Working time:

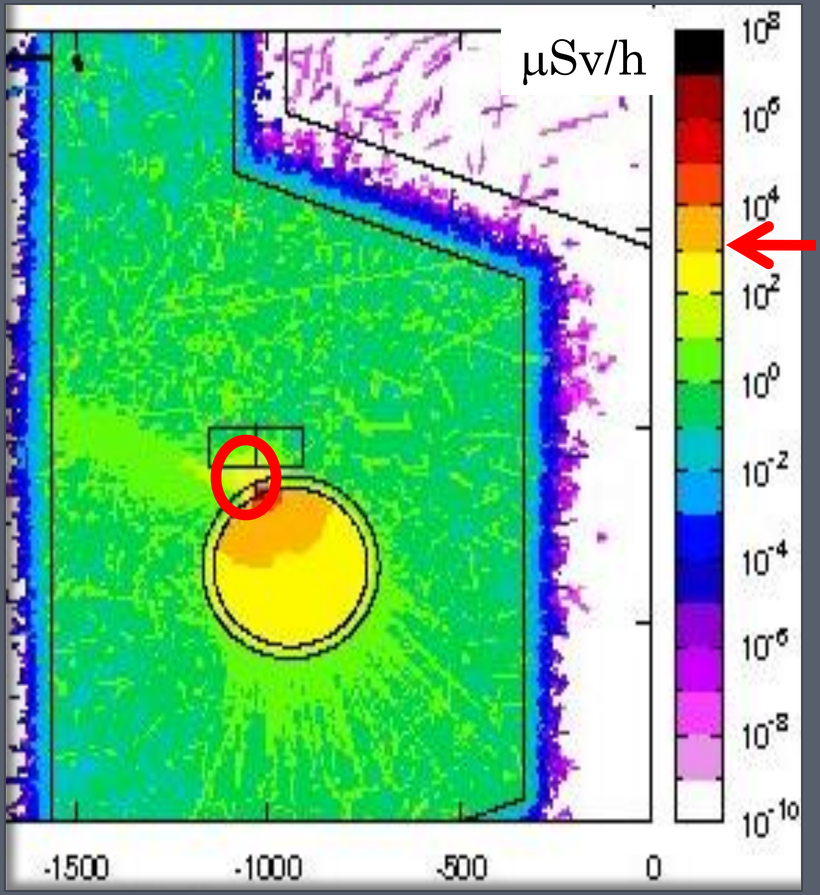
  2 weeks

MeV	%	…of 750 μA
30	3%	22.5
40	3%	22.5
50	1.5%	11.25
60	1.5%	11.25
70	6%	45
TOT	**15%**	**112.5**



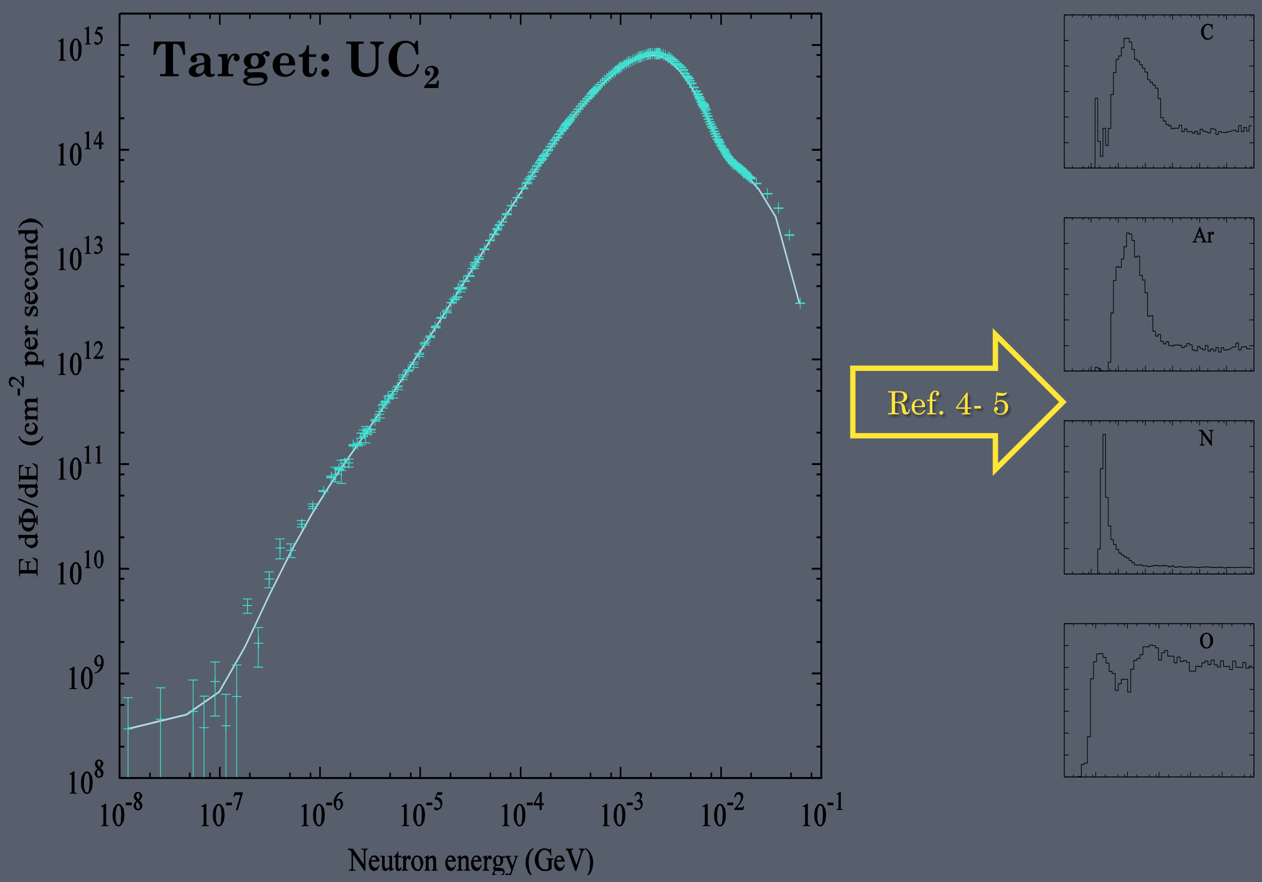
ACTIVATION PROBLEMS: CYCLOTRON

- After 2 weeks of irradiation and 10 days of cooling time the dose rate inside the cyclotron vault is < 10 μSv/h
- Close to the extraction point the dose rate is around 1 mSv/h
- CONTROLLED ACCESS for maintenance intervention
- Time keeping is essential for emergency interventions



ACTIVATION PROBLEMS: AIR

- Airborne activity has been evaluated in a 2 step approach: particles fluences scored with FLUKA simulation have been folded with isotope production cross sections.



ACTIVATION PROBLEMS: AIR

- Activation in presence of a ventilation system

$$dN = Pdt - \lambda Ndt - RNdt$$

N: radioactive atoms per cm^3

P: production rate (atoms/cm^3/s)

λ: decay constant (s^{-1})

R: air changes rate (s^{-1})

$$N(t) = P/(\lambda+R) * (1-e^{-(\lambda+R)\,t})$$

$$A(t) = \lambda\, N(t) = P\lambda/(\lambda+R) * (1-e^{-(\lambda+R)\,t})$$

$$RA(t) = PR\lambda/(\lambda+R) * (1-e^{-(\lambda+R)\,t})$$

Activation Problems: air

- For each radioisotope in air it has been calculated:
  - the production rate in the enclosed volume;
  - the activity at the extraction, considering a ventilation rate of $50 m^3/h$: this value is supposed to compensate for the leaks in the depression system ($V=300\ m^3$);
  - the dose rate due to inhalation and submersion in the exhausted plume, using the recent ICRP coefficients for dose-activity conversion (by means of the Hotspot code).
- The calculation has been made considering the UC_2 target and the SiC target.

ACTIVATION PROBLEMS: AIR TARGET: UC_2

- The annual activity released is $7\ 10^{14}$ Bq
- More than 99% of the total activity is due to nuclides with half life lower than 75 days (^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{41}Ar)
- Less than 2 hours "storage" time is sufficient to lower the concentration to 1 Bq/g: in this condition release to the environment is permitted without further authorization
- For nuclides with half life longer than 75 days it is shown that the total effective dose equivalent (TEDE) is less than 10 μSv/y, thus – according to the italian legislation - is not relevant from a radiological point of view.

Nuclide	$T_{1/2}$	Activity release rate Bq/y	TEDE Sv/y
^{3}H	12.33 y	$1.8\ 10^{9}$	$3\ 10^{-6}$
^{14}C	5730 y	$2.7\ 10^{8}$	
^{35}S	87.51 d	$7.7\ 10^{8}$	

ACTIVATION PROBLEMS: AIR
TARGET: SiC

- The annual activity released is 5 10^{12} Bq
- More than 99% of the total activity is due to nuclides with half life lower than 75 days (^{7}Be, ^{11}C, ^{13}N, ^{15}O, ^{41}Ar)
- The concentration is already1 Bq/g at the exhaust and there would be no need of storage time (in practice the system must be designed for the worst case facility – see UC_2 case)
- For nuclides with half life longer than 75 days it is shown that the total effective dose equivalent (TEDE) is less than 1 μSv/y, thus is definitely not relevant from a radiological point of view.

Nuclide	$T_{1/2}$	Activity release rate Bq/y	TEDE Sv/y
^{3}H	12.33 y	1.1 10^{8}	3 10^{-7}
^{14}C	5730 y	4.3 10^{7}	
^{35}S	87.51 d	6.8 10^{6}	

CONCLUSIONS

- All calculations have been done using FLUKA. No need to couple the code with others for activation evaluations
- A thickness of 300 cm of concrete at ceiling and floor is enough to guarantee a neutron ambient dose eq. of 5 μSv/h out of the shield
- A value of at least 50 μSv/h is present out of the 360 cm shield, if composed by concrete and mineral filling
- After 20 years of cooling time a reference value of 1 Bq/g is reached in the concrete, after 175 cm of thickness in the beam direction. Pure concrete, even reinforced with iron rods, is activated much less than sandwich shielding made by concrete and blast furnace waste
- In the SPES target at the EOB 10^{14} Bq are produced but only 0.4% with $T_{1/2} > 1$ month. After 10 days of cooling time and the target removed, hands on maintenance on the front end can be foreseen.

CONCLUSIONS

- Close to the extraction point of the cyclotron, maintenance can be made after 10 days of cooling time and according to a careful programme of operations
- In the case of UC_2 and with a ventilation rate of 50 m^3/h, the short lived nuclides in the activated air of the target area can be released in the environment after 2 h of storage (concentration < 1 Bq/g). In the case of conventional target no storage is needed.
- Long lived nuclide effective dose contribution is less than 10 μSv/y; such a dose is considered of no radiological relevance.

References

[1] *"The FLUKA code: Description and benchmarking"*
G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft,

[2] *"FLUKA: a multi-particle transport code"*
A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala

[3] *"SPES Technical Design Report"*
G. Prete, A. Covello

[4] *"Determination of Cross Sections for Assessments of Air Activation at LHC"*
M. Huhtinen

[5] *"Effective Dose to the Public from Air Releases at LHC Point 7"*
M. Brugger, D. Forkel-Wirth, S. Roesler, P. Vojtyla

[6] *"Hotspot v. 2.06"*
Lawrence Livermore National Laboratory

Blast furnace waste

Compound	Partial density
CaO	26%
Fe	26%
Na_2O	45%
SiO_2	13%
Al_2O_3	6%
MgO	5%
Cr_2O_3	2%
MnO_2	0.6%
As, Cd, Co, Cu, Hg, Mb, Ni, Pb, V, Zn	<0.1%