Radiation and Enviromental studies for BDF

M. Casolino – H. Vincke – S. Roesler
HSE-RP

NBI2017
20th September 2017

Outline

- General considerations
- RP evaluation
- Prompt and residual dose
- Classification of the ventilation system
  - Tritium production
  - Tritium out-diffusion
  - Air activation
  - Enviromental impact
- Activation and radioactive waste
- Summary

Recap on the BDF target complex

- High intensity proton beam: **355 kW average beam power, 2×10^{20} pot/5 years**
  - Constraints on the design coming from radiation protection
- Dense target → **High cumulated radiation dose**, radiation damage on material
- High radiation environment close to CERN boundary
  - Detailed study needed to **minimize enviromental impact**
- New permanent facility → keep **flexibility for future installations**
  - Ventilation system
  - Dismantling and waste treatment

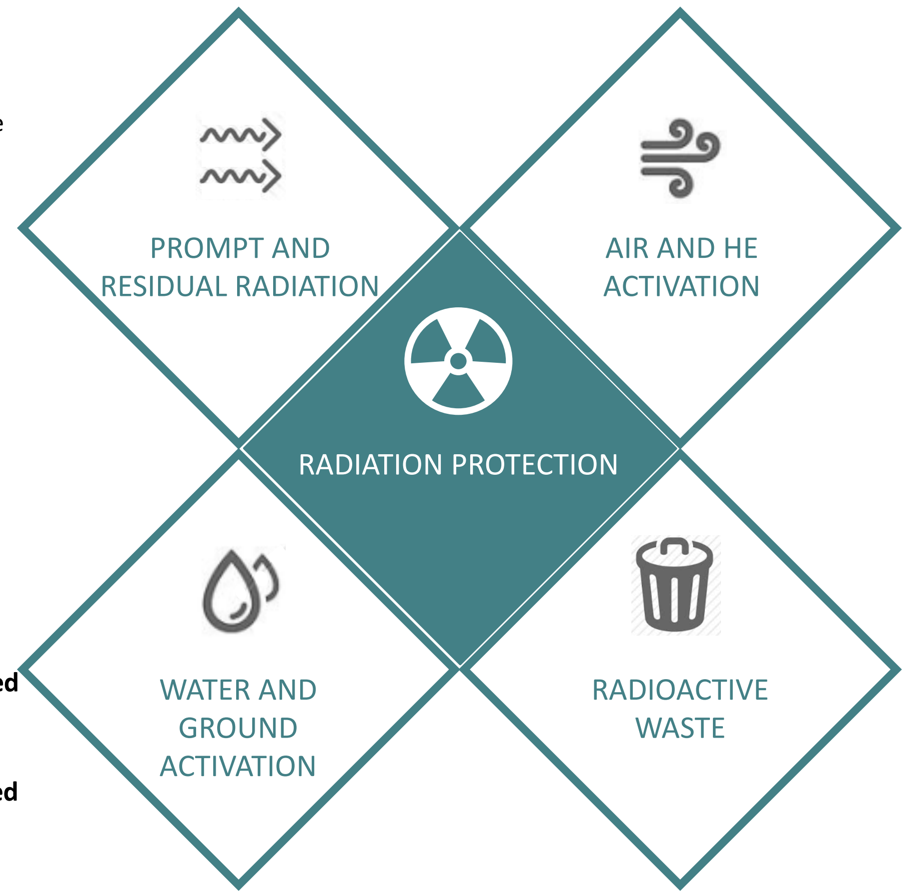
Calviani 18/09/17

Key beam parameters foreeseen for BDF	
Momentum [GeV/c]	400
SPS beam Intensity per cycle [10^{13}]	4.0
Cycle length [s]	7.2
Spill duration [s]	1
Expected r.m.s. spot size (H/V) [mm]	6/6
Avg. beam power on target [kW]	355
Avg. beam power on target during spill [kW]	2900
Protons on target (POT)/year	4×10^{19}
Total POT in 5 year's data taking	4×10^{20}

General considerations for the BDF target complex

- **High prompt dose** in BDF target area calls for adequate shielding around the target
- **Only** absolute **necessary equipment** should be installed in **"hot" areas**
- Depending on residual dose rate and tasks, **manual interventions** should partially/completely be **replaced** by **remote maintenance/repair**

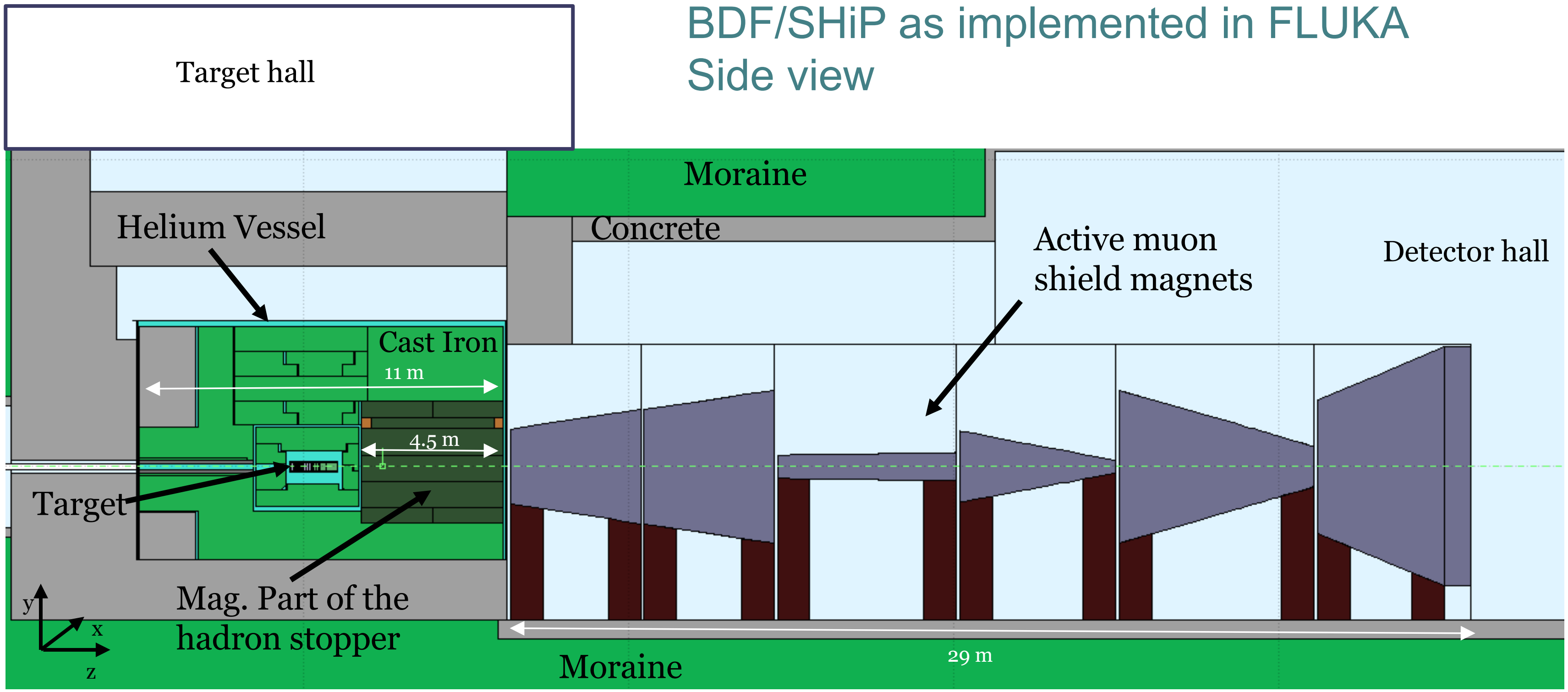
- **Air volumes** to be **minimized i**n 'hot' areas or to be **replaced by He/vacuum** environment
- **Static confinement** of air by physical barriers to separate air in contaminated areas from outside
- **Dynamic confinement** by a ventilation system guaranteeing a pressure cascade from low to high contaminated areas



- **Water cooling circuits** for highly radioactive elements should be **closed and separated** from others
- **Activation** and **contamination** of ground water and earth to be **avoided**

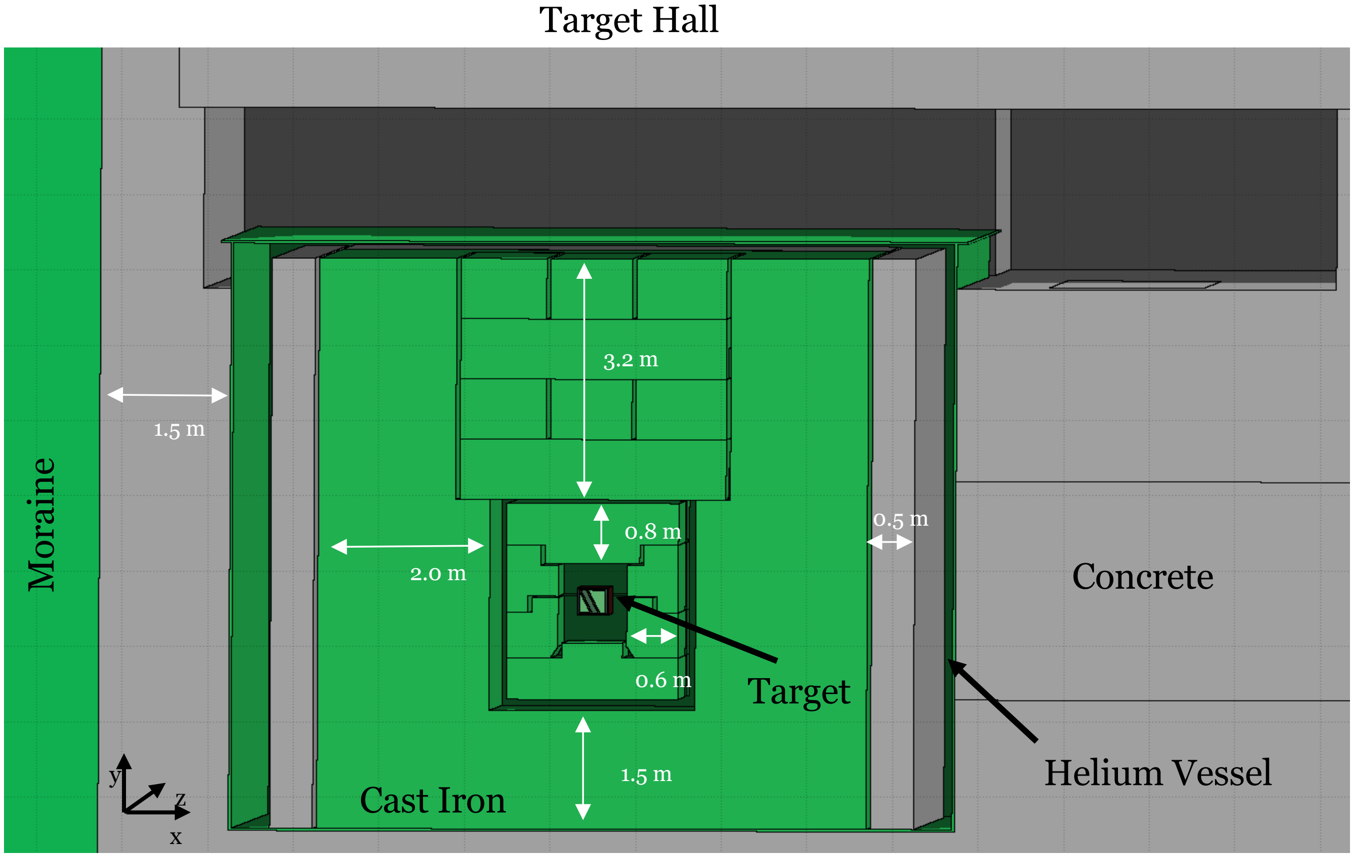
- The design must consider minimization, decommissioning and dismantling of radioactive waste

RP evaluation based on FLUKA simulations



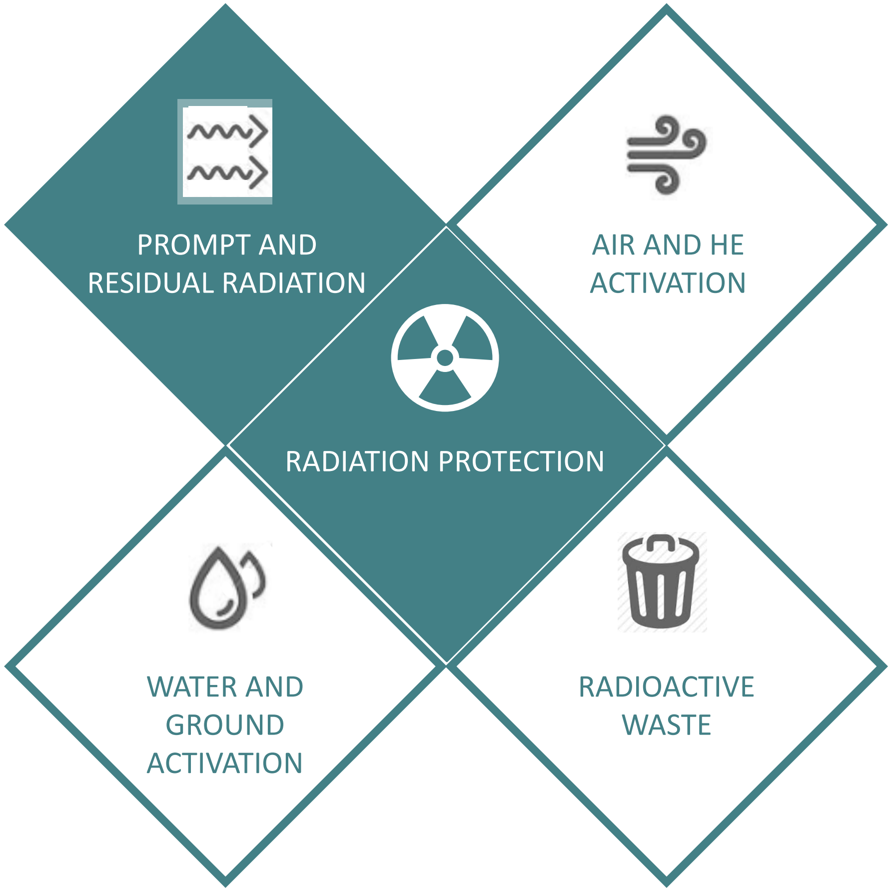
- **No access during operation** into the detector hall is the main condition for current design
- **Massive shielding** to keep prompt/residual dose rate and airborne **radioactivity as low as possible**
- Active muon shield with magnets (1.8 T) from the SHiP experiment was included

RP evaluation based on FLUKA simulations



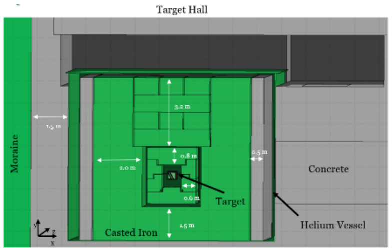
BDF/SHiP as implemented in FLUKA
View across the target

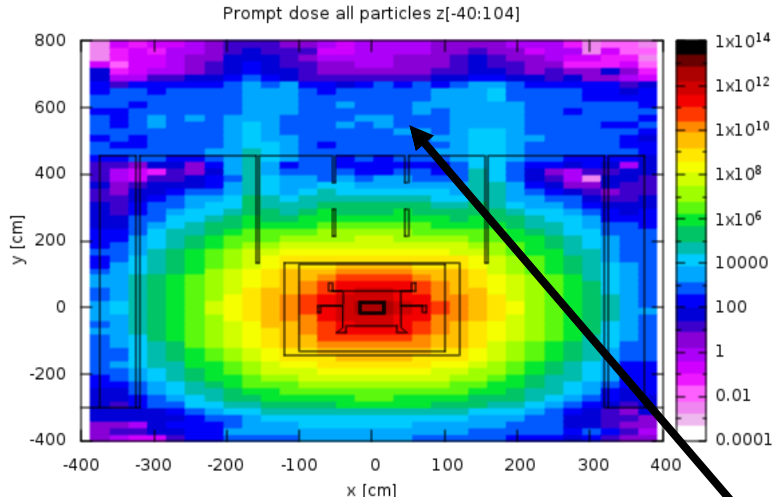
- Air volumes were minimized to lower production of airborne radioactivity
- Most critical area was embedded in He-environment
- Accurate material compositions were used (AISI316LN w 0.1% Cobalt, ASTM A48 w 0.04% Cobalt, US1010, CENF moraine, …)

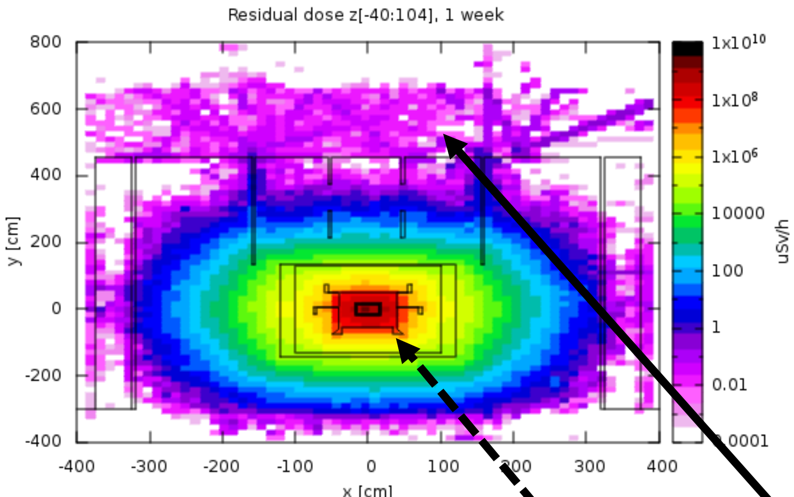

PROMPT AND
RESIDUAL RADIATION
AIR AND HE
ACTIVATION
RADIATION PROTECTION
WATER AND
GROUND
ACTIVATION
RADIOACTIVE
WASTE

Prompt and residual dose rates

- Prompt rate @ 4×10^{13}p / 7.2s
- Residual dose rate @ 2×10^{20} pot







Prompt dose rates reach **~100 mSv/h** above the He-vessel and drop down to **below 1 μSv/h** above the top concrete shielding (conservative assumption due to non-optimized gaps)

→ Expected classification: **Supervised Radiation Area** (up to 2000h/year) **(<3uSv/h)** in the target hall

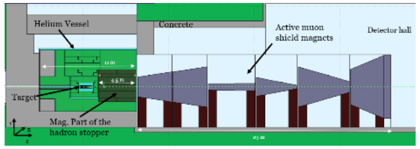
Residual dose rates are at the level of **a few μSv/h** above and next to the He-vessel

Very high residual dose rates next to the target and to the cast iron shielding **O(100) Sv/h (1 week cooling)**

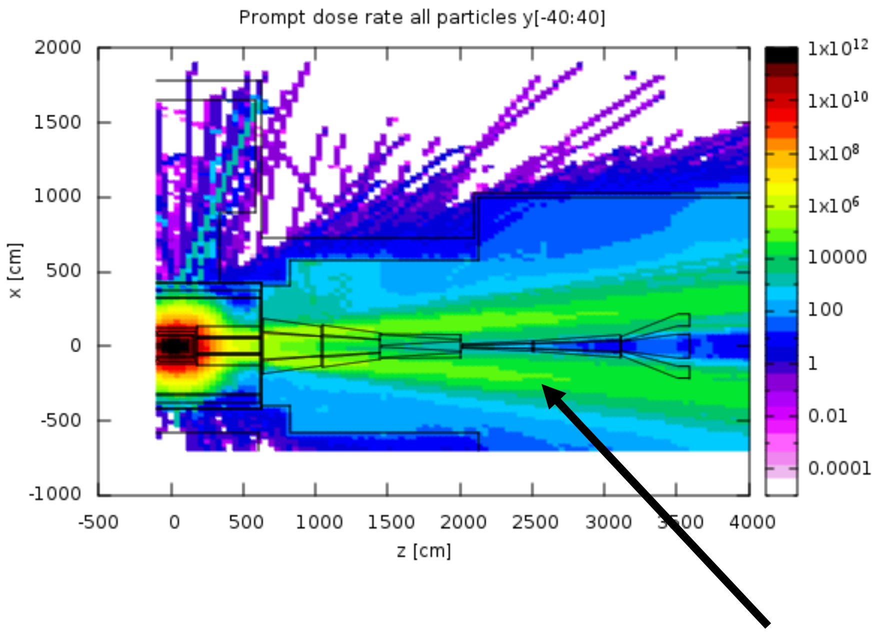
Remote handling and designated storage areas are therefore foreseen for these elements.

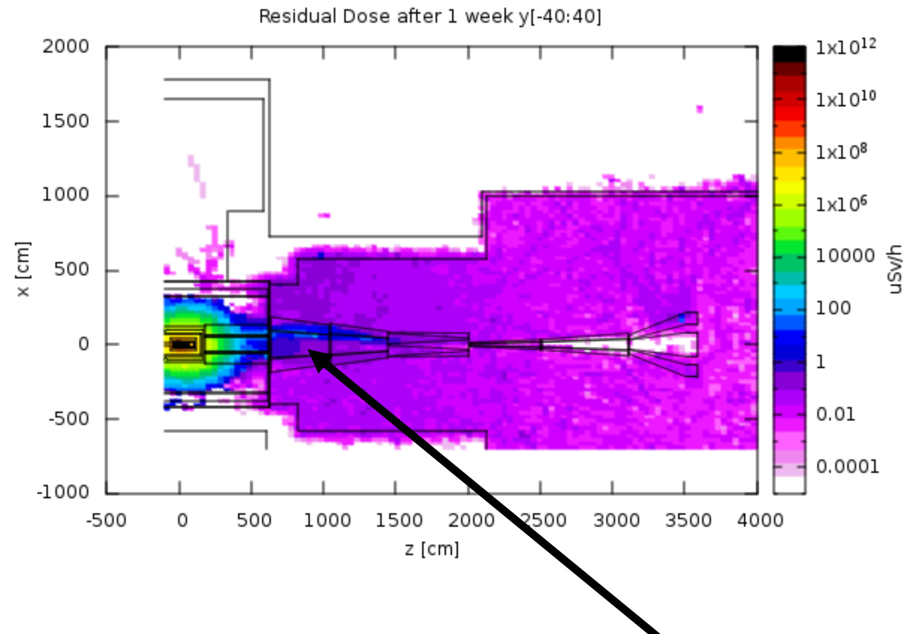
100 rem = 1Sv

Prompt and residual dose rates



- Prompt rate @ 4×10^{13}p / 7.2s
- Residual dose rate @ 2×10^{20} pot





Prompt dose rates reach **~100 mSv/h** around the magnet mostly from muons.

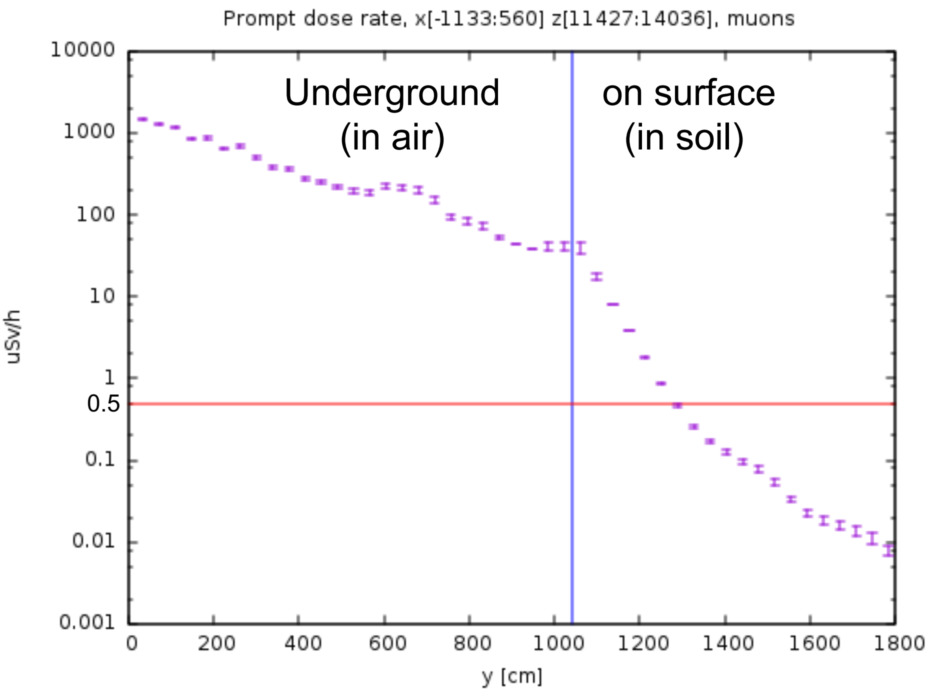
Residual dose rates close to the first part of the muon shield can reach **~10 µSv/h**.

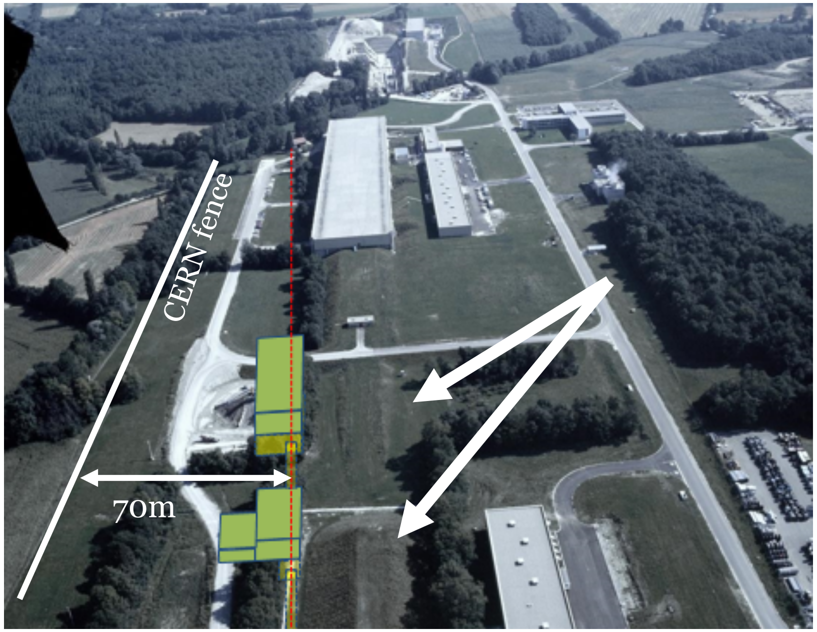
→ Expected classification: **Supervised Radiation Area (<15 µSv/h) or Simple Controlled Radiation Area (<50 µSv/h) with limited stay (400 h/year)** in the experimental hall

100 rem = 1Sv

Prompt dose rate on the surface

- Prompt rate @ 4×10^{13}p / 7.2s



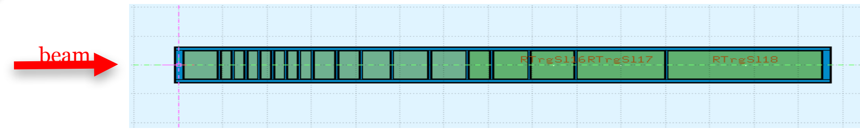


Muon prompt dose on surface **~50 μSv/h**, need to cover the tunnel with at least **~3m of soil on top** to lower it down to non-designated area level (<0.5 μSv/h).

100 rem = 1Sv

BONUS: T6 test beam

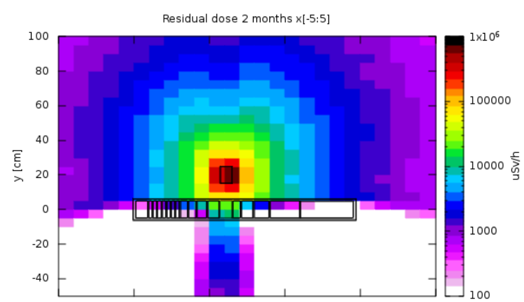
Residual dose rate

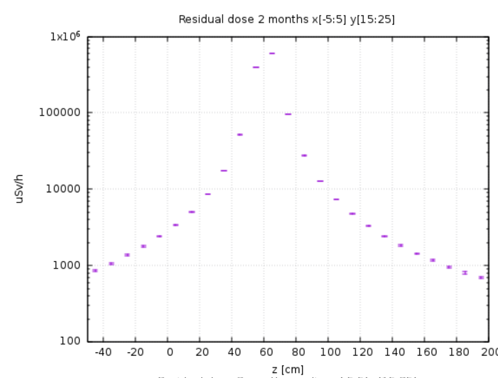


- Prototype target: reduced dimensions
- 18 blocks: 13 TZM -5 Tungsten
- Calculations performed on last block of TZM and first of Tungsten
- $3x10^{16}$ pot assumed
- Need to use remote handling

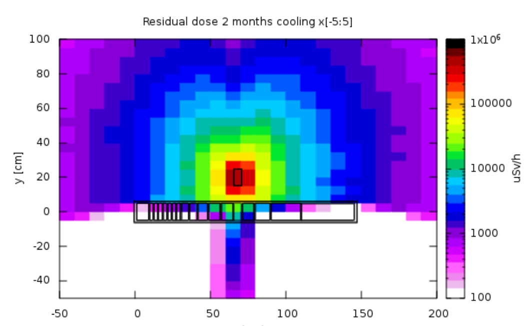
Lopez 20/09/17

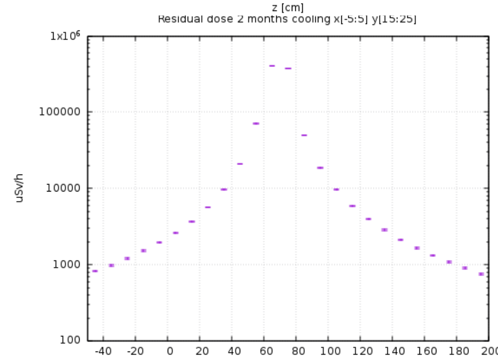
TZM block





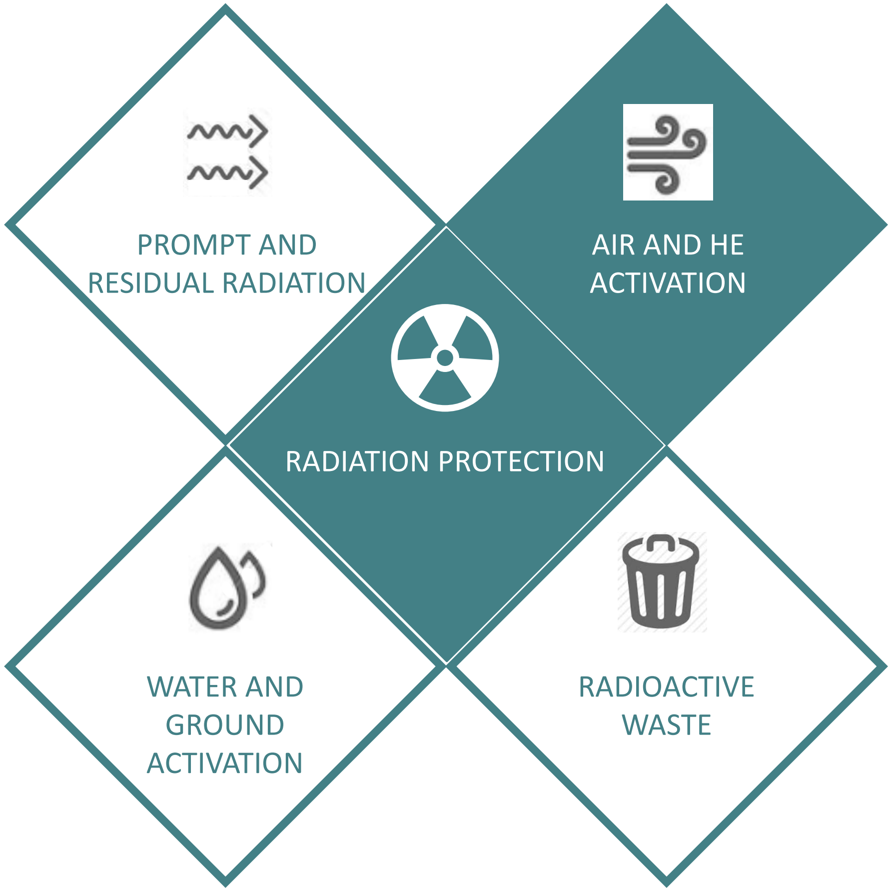
W block





Dose rate mSv/h	At contact	At 10 cm	At 40 cm
TZM Block	600	200	10
W Block	400	100	10

Need a cask of 90 cm of concrete or 30cm of iron


PROMPT AND RESIDUAL RADIATION
AIR AND HE ACTIVATION
RADIATION PROTECTION
WATER AND GROUND ACTIVATION
RADIOACTIVE WASTE

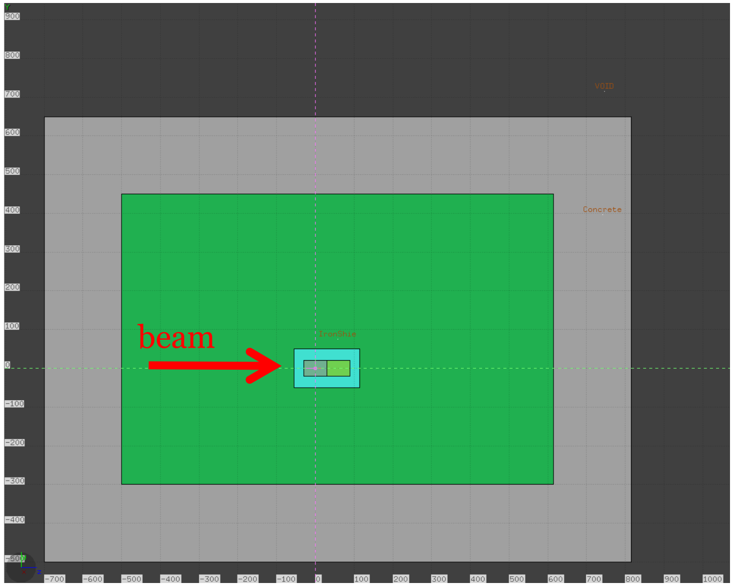
Tritium production

H-3 has a very low radio-toxicity but it can be a radiation hazard when:

- inhaled
- ingested via food or water
- absorbed through the skin

A simplified geometry was used:

- Target: one section of Mo, one section of W. No water cooling, no Ta cladding
- Region between target and proximity shielding filled by He
- Proximity shielding and passive shielding in Cast Iron
- 2 m concrete thick walls around passive shielding



Tritium production

Calculations performed assuming 5 years of operation → $2*10^{20}$ pot

	H-3 activity
Mo	10 TBq
W	8 TBq
He	0.9 GBq
Cast Iron	1 TBq
Concrete	2 MBq

- 95% of H-3 is produced in the target, need to understand **out-diffusion** from the target**.**
  - It can be absorbed by the water (HTO form) and circulated in the water cooling system.
- For the iron and concrete shielding tritium outgassing contributes to contamination of air as well as during no beam periods.

Tritium out-diffusion

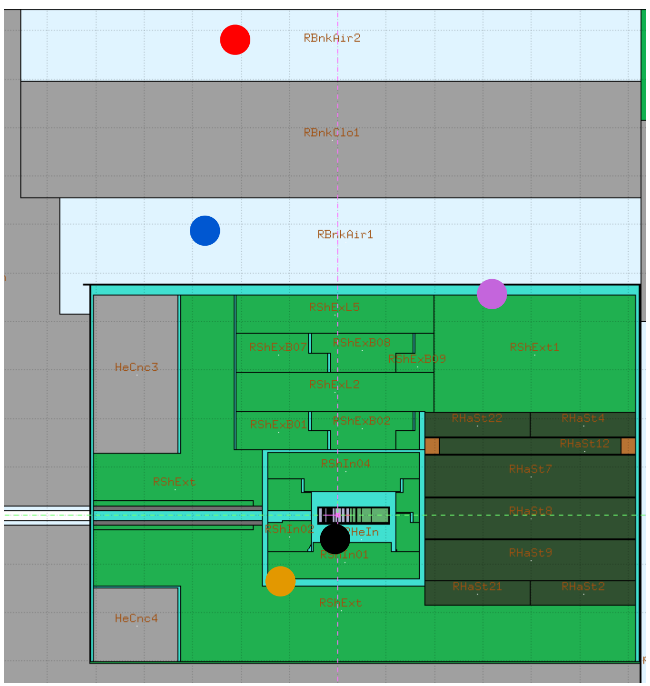
- Assumption of an immediate **release efficiency of 100%** can be **over-conservative**
  - Tritium releases were measured years after the shutdown of CERN facilities (e.g. CNGS)
- Diffusion equation has to be solved for arbitrary geometries
  - A newly coded **plug-in for FLUKA [1]** solves diffusion equation using a Monte Carlo approach
  - It transports nuclides using a stochastic approach in the continuous limit
- In literature **diffusion coefficients** for tritium are **available only for few materials** and not in the full temperature range
  - Arrhenius equation used to extrapolate to operational temperatures
- Study of feasibility to **measure out-diffusion of tritium** from Tungsten, Tantalum, TZM, Cast Iron and Concrete
  - Possibility to measure diffusion constants
- **Simulated out-diffusion** @298K (@423K) from **Iron** shielding after 2 months is about **33%** (38%), while from **Tungsten** is **0.18%** (2.43%)

[1] Development of a computational model for the out-diffusion of radioisotopes from metals, C.Theis and H.Vincke, CERN-RP-2016-173-REPORTS-TN

Air activation

- Calculations performed assuming 5 years operation → 2 * 10^{20} pot
- **99.9% He purity** from He purification system → assumed 0.1% air contamination
- For the CA[1] calculation:
  - Assumed a standard breathing rate (1.2 m^3/h)
  - For the moment no leakage term

[1] Person working 40h/w, 50w/y with standard breathing rate in air contaminated environment with CA = 1 receives 20 mSv.



	Activity (Bq) after 60 s cooling	Multiple of CA
Air in inner He volume	$5.6*10^7$	$7.5*10^5$
Air in middle He volume	$7.8*10^5$	$1.3*10^3$
Air in external He volume	$1.5*10^2$	$2*10^{-2}$
First air volume	$1.7*10^7$	0.7
Second air volume	$8.3*10^4$	$6.7*10^{-3}$
Inner He volume	$2.8*10^9$	0.42
Middle He volume	$4.1*10^7$	$8.7*10^{-4}$
External He volume	$9*10^3$	$1.5*10^{-8}$

Classification of the ventilation system

- The ventilation system requirements (e.g. pressure cascades) are defined in the ISO 17873:2004
- **Four classifications** are possible

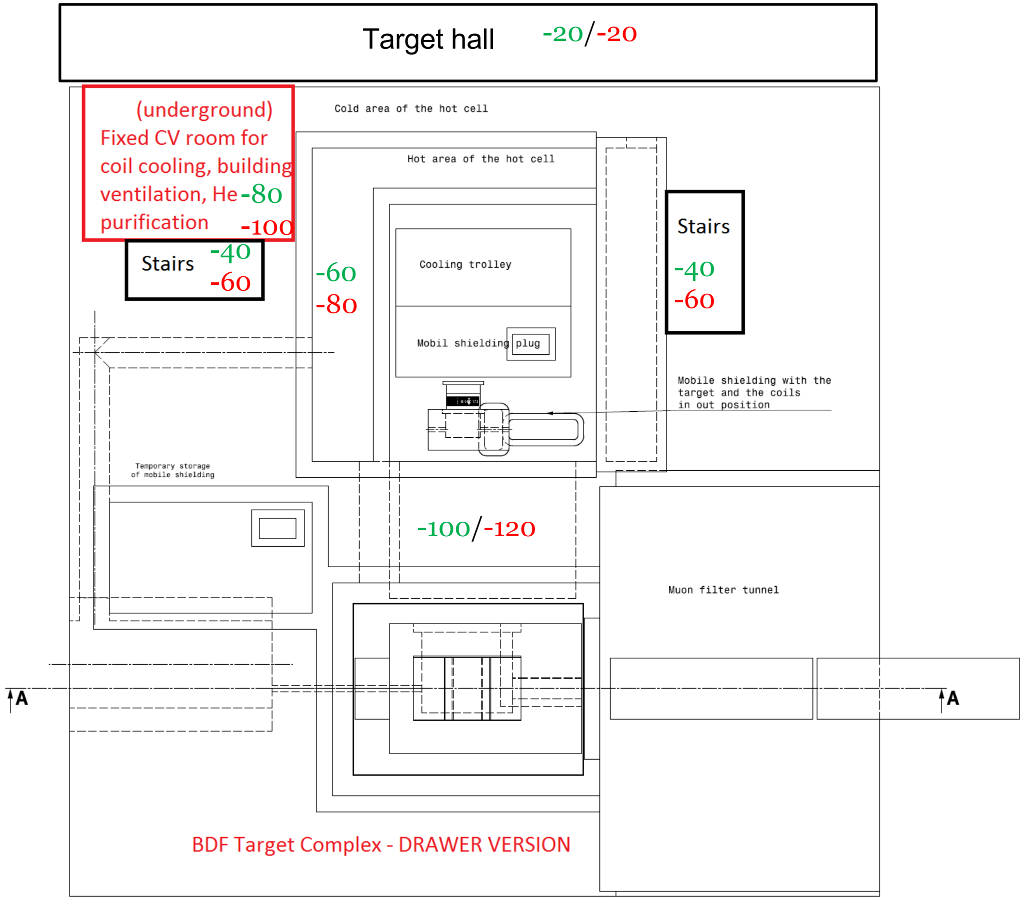
Classification	Depression values	DAC[1] values permanent (accident)
C1	<60 Pa	0 (<1)
C2	80 to 100 Pa	<1 (<80)
C3	120 to 140 Pa	<1 (<4000)
C4	220 to 300 Pa	>1 (any)

[1] Slightly different definition compared to CA

- Accident case analysed → **breakdown of He vessel**
  - CA values calculated mixing the helium and the air of the closed loop
  - CA for accident ~ 2.7 (2000 for 100% Air)
  - Inhaled dose 8 μSv (3 mSv for 100% Air) in ~1 hour in case of accident
- Classification for the ventilation system: C2
- For flexibility for future installations could be classified as C3

Dynamic confinement

- Classification for the ventilation system: C2/C3



Values in Pa

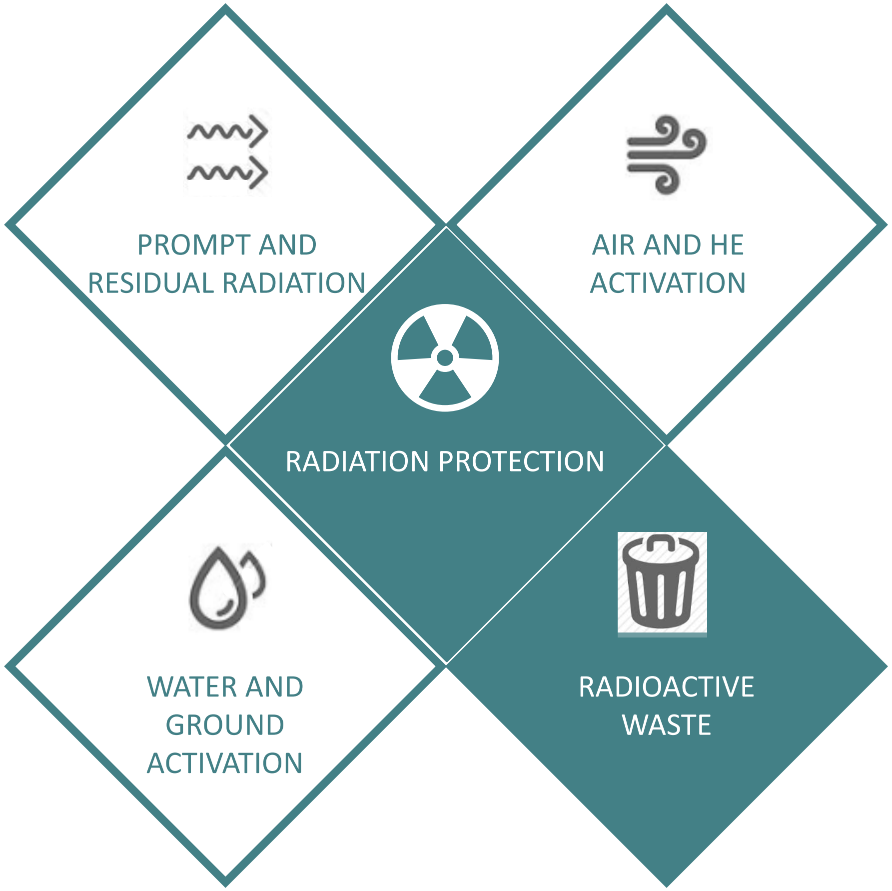
Radiological impact of air releases

- Identified 6 reference groups around the new BDF target facility
  - Estimates age-independent way

- Parameters of the ventilation stack not yet defined
  - Conservative approach: ground release

	Workers Dechetterie	North-East	North-West	West	South-East	Agriculture
Received dose [nSv/year]	0.07	0.3	0.5	0.5	0.08	0.1

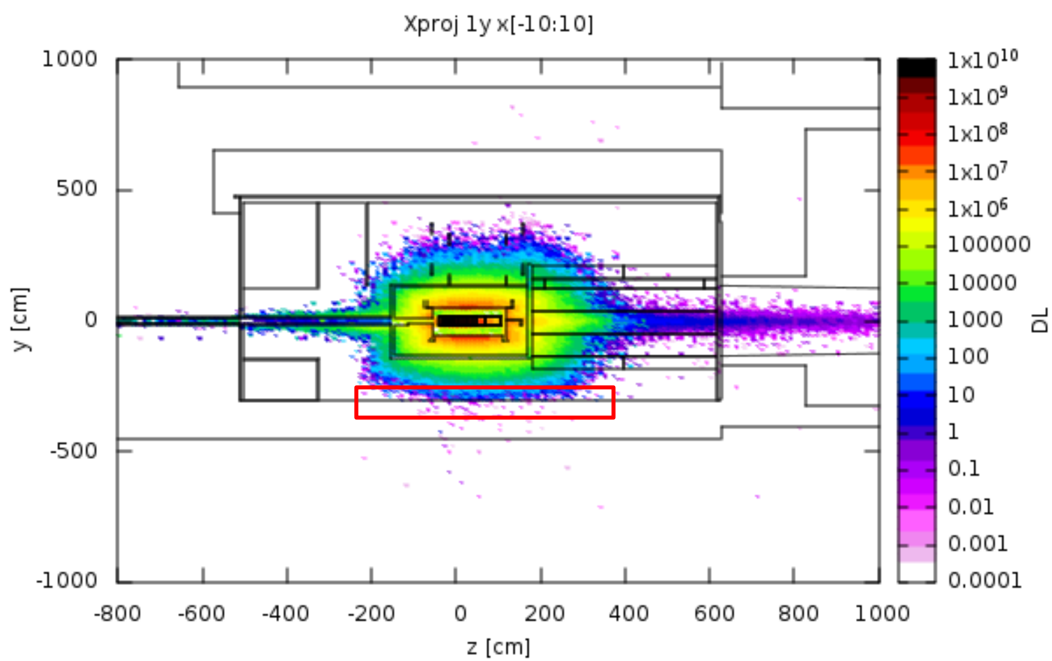
Doses sufficiently below 10 µSv/year from all facilities at CERN, which is the dose objective for public


PROMPT AND RESIDUAL RADIATION
AIR AND HE ACTIVATION
RADIATION PROTECTION
WATER AND GROUND ACTIVATION
RADIOACTIVE WASTE

Radioactive waste production

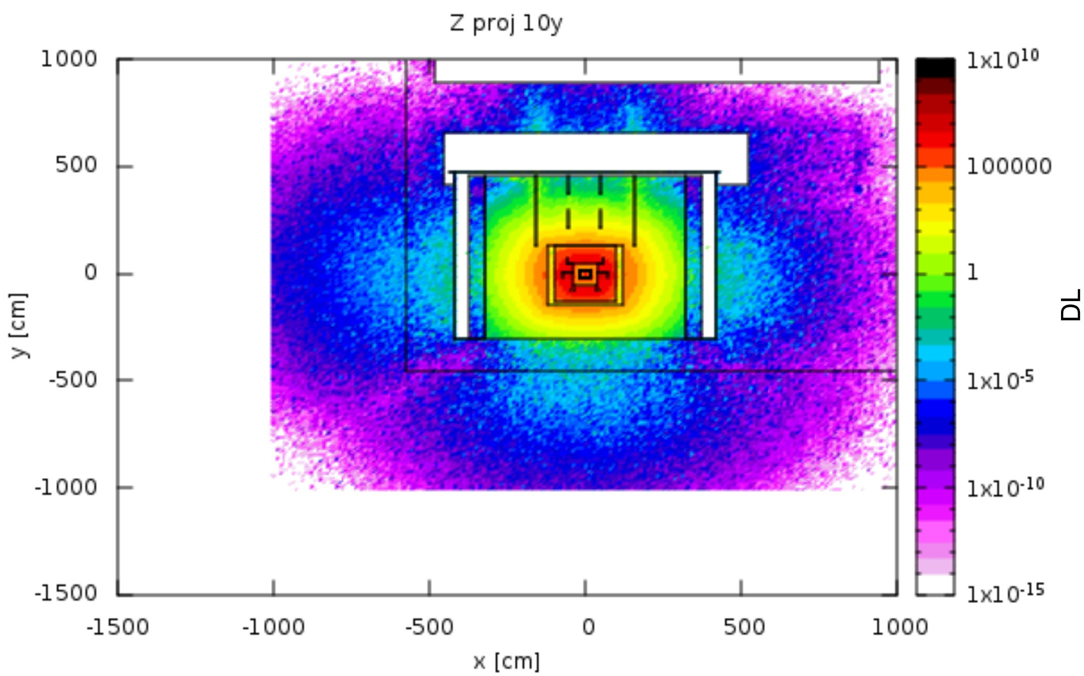
- Calculations performed assuming 5 years operation → 2 * 10^{20} pot
- Results presented in terms of Design Limits (DL)
  - If DL > 1 the material/waste is radioactive
- Floor below the target slightly radioactive, increase iron thickness in the helium vessel to leave the facility ‘clean’ for future installations

1 year of cooling



Radioactive waste production

- Calculations performed assuming 5 years operation → 2 * 10^{20} pot
- Results presented in terms of Design Limits (DL)
  - If DL > 1 the material/waste is radioactive
- After 10 years of cooling DL > 1 for proximity and passive shielding in the He-vessel



10 years of cooling

Summary

- The proposed BDF will be a **new permanent facility in the North Area** with unprecedented average beam power
- High prompt & residual dose rates → **shielding and remote interventions**
- He and Air activation:
  - ~95% of H-3 is produced in the target
  - Need to understand out-diffusion from the target
  - Air activation drives the **classification** of the ventilation system to **C2** (C3 for flexibility) according to ISO17873:2004
  - **No radiological impact** on public from air releases
- Waste production:
  - Proximity and passive shielding will have **DL >> 1 even after 10y of cooling**
  - Floor below the target radioactive → increased thickness of the iron shielding in the helium vessel
- First radiological studies were presented

Thank you for your attention