HI ECN3

Radiation protection considerations for the target complex

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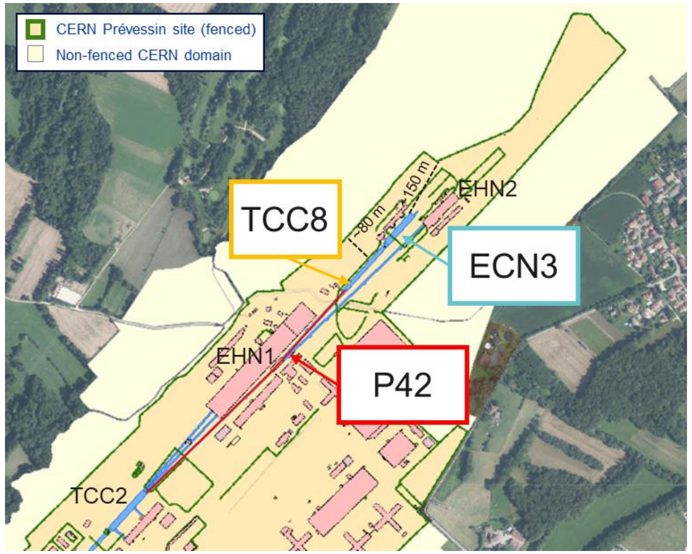
1st BDF Targetry Systems Advisory Committee (TSAC)
4-6th March 2025

Outline

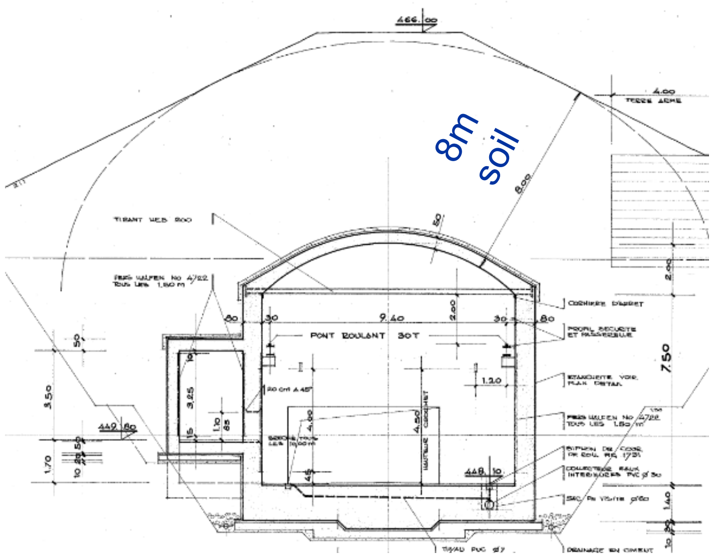
1. Overview of RP Challenges at HI-ECN3
2. Target Complex Design Optimization
3. Target Studies
4. Service building considerations

HI-ECN3 at ECN3

CERN's SPS North Area



TCC8 cross-section



Key beam parameters of BDF/SHiP

	BDF
Intensity (p/spill)	4×10^{13}
Spill duration (s)	≥1
Cycle length (s)	≥7.2
Avg. beam power (kW)	356
Average intensity (p/s)	$\leq5.6\times10^{12}$
Annual POT	4×10^{19}
Duration (years)	15
Total POT	6×10^{20}

- **HI-ECN3:** a state-of-the-art high intensity experimental facility in ECN3 with RP optimization for full lifecycle
- Advantage of underground cavern with shielding created by the soil and beam dump concept

RP challenges

- High beam energy and intensity as well as high POT leading to high prompt radiation and activation levels
- Proximity to surface, experimental and public areas
- Losses during beam transfer (not covered here)

Target Complex Optimization

BDF/SHiP design optimization

- RP studies based on FLUKA MC simulations were performed for a design optimization of BDF/SHiP@HI-ECN3
- **ALARA approach**
  Optimization required to ensure that exposure of personnel to radiation and radiological impact on environment are As Low As Reasonably Achievable

PROMPT RADIATION
Reduce prompt radiation to comply with **radiation area classification** in the surrounding accessible areas as well as the **1 mSv limit** at the **CERN fence**

RESIDUAL RADIATION
Limit activation of target and experimental area to reduce residual dose rates to be compatible with an adequate **area classification**

AIR AND SOIL ACTIVATION
Reduce activation of air and its releases into the environmental. Limit soil activation (^{3}H<1000 Bq/kg, ^{22}Na<50 Bq/kg) and transfer to groundwater

ENVIRONMENTAL IMPACT
Reduce environmental impact from prompt radiation and releases of activated air to fulfill CERN's **dose optimization objective** for the **public** of <**10 uSv/year**

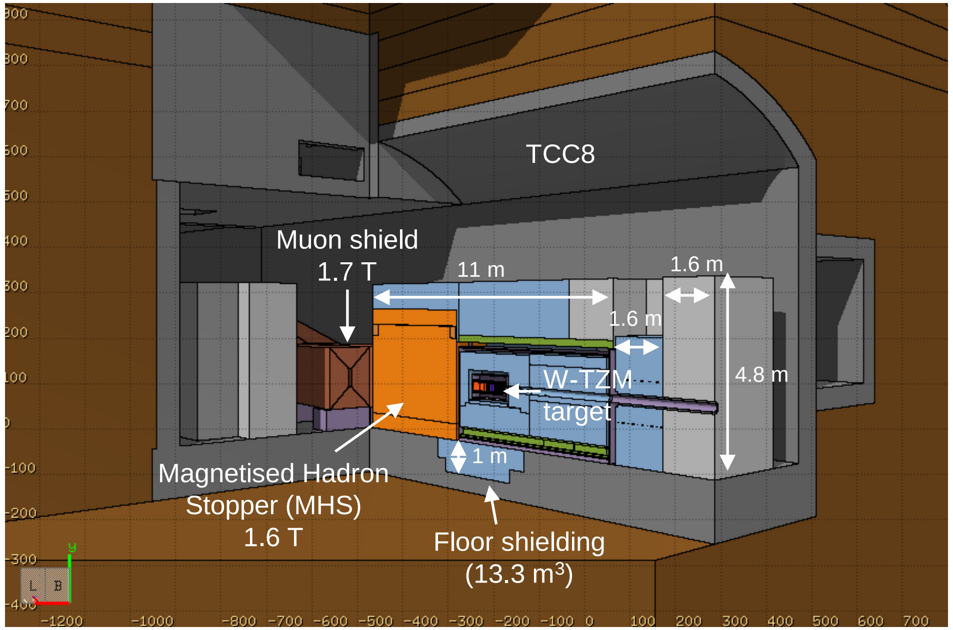
CERN's radiation area classification

	Area	Annual dose limit (year)	Ambient dose equivalent rate		Airborne activity concentration	Surface contamination	
			permanent occupancy	low occupancy			
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	0.05 CA	1 CS	
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	0.1 CA	1 CS	
Radiation Area	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	0.1 CA	1 CS	Controlled Area
Radiation Area	Limited Stay	20 mSv	-	2 mSv/h	100 CA	4000 CS	Controlled Area
Radiation Area	High Radiation	20 mSv	-	100 mSv/h	1000 CA	40000 CS	Controlled Area
Radiation Area	Prohibited	20 mSv	-	> 100 mSv/h	> 1000 CA	> 40000 CS	Controlled Area

BDF/SHiP FLUKA model

FLUKA hosted by CERN [1-3]

Target complex & muon shield, Created using FLAIR [4]



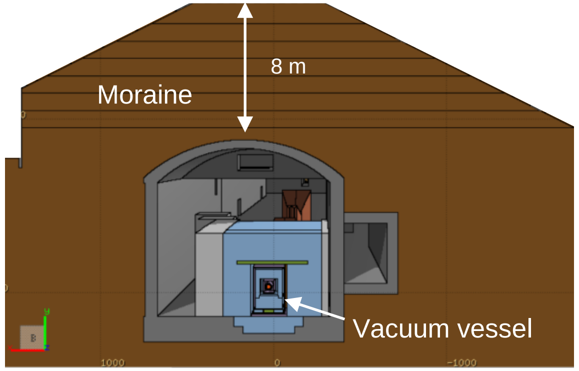
Stainless steel

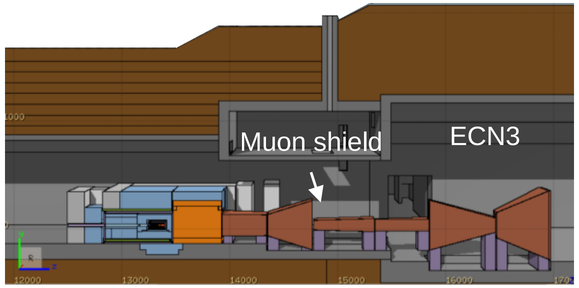
Concrete

Cast iron

US1010

Moraine





~180 m^3 of cast iron + US1010
~360 m^3 of concrete

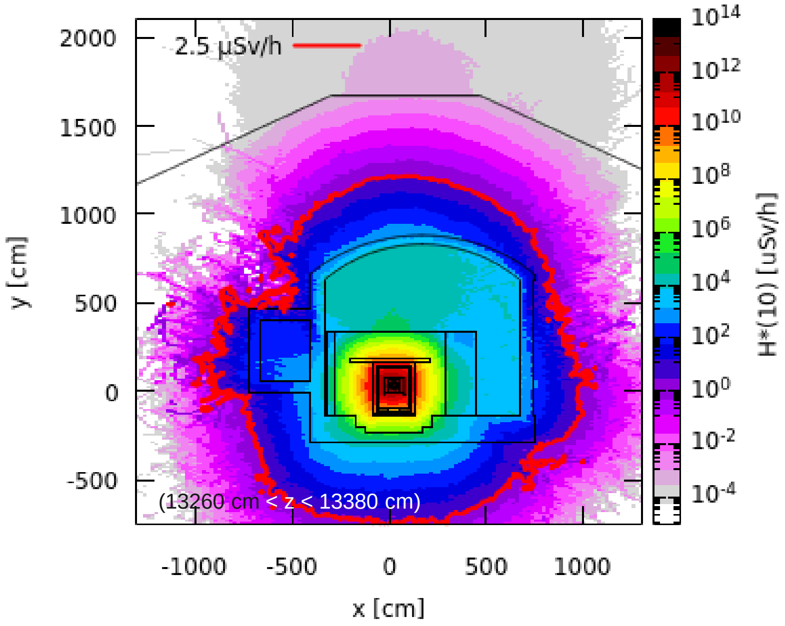
- A detailed BDF/SHiP target complex together with the muon shield was implemented in FLUKA [1-3]
- Optimization of BDF shielding and re-use of existing, already activated TCC8/TT7 shielding blocks, while maintaining SHiP physics performance
- Shielding embedded in vacuum vessel allowing to reduce air activation
- Floor shielding reinforcement to limit soil activation
- FLUKA geometry includes the full underground TCC8/ECN3 cavern and surrounding galleries, tunnels, rooms, etc.
- Ground profile data from CERN's Geographic Information System and technical drawings were used to model the surrounding ground

Prompt radiation in target area

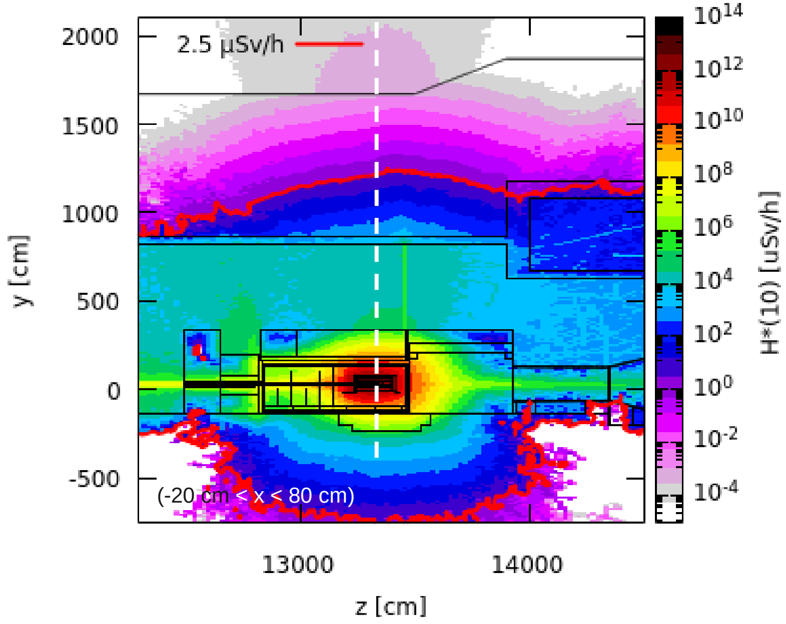
	Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign	
			permanent occupancy	low occupancy		
	Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h		
Radiation Area	Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / Dosimètre obligatoire	
Radiation Area	Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE; Dosimeter obligatory / Dosimètre obligatoire	Controlled Area
Radiation Area	Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ; Dosimeters obligatory / Dosimètres obligatoires	Controlled Area
Radiation Area	High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION; Dosimeters obligatory / Dosimètres obligatoires	Controlled Area
Radiation Area	Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY / DÉFENSE D'ENTRER	Controlled Area

Avg. intensity of 5.6×10^{12} p/s

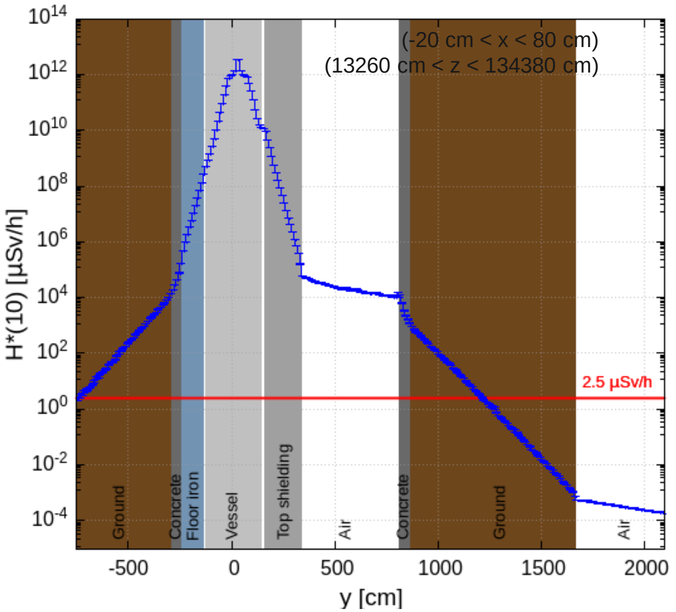
Cross-sectional view



Side view



Along y-axis



- Shielding design is well optimized for the prompt radiation
- Annual limit of Non-designated Area on CERN domain

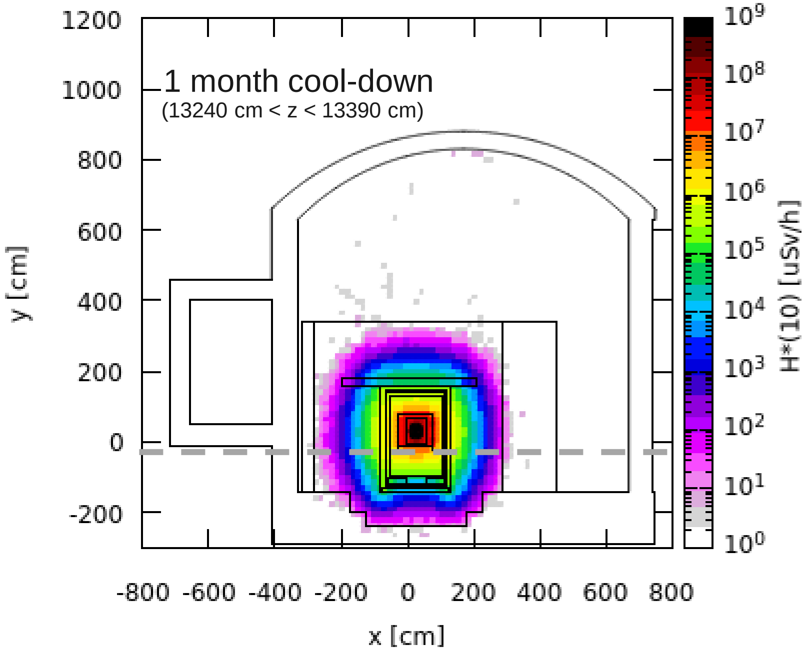
Residual radiation in target area

Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
		permanent occupancy	low occupancy	RADIATION
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / Dosimètre obligatoire
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE; Dosimeter obligatory / Dosimètre obligatoire
Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ; Dosimeters obligatory / Dosimètres obligatoires
High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION; Dosimeters obligatory / Dosimètres obligatoires
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY / DÉFENSE D'ENTRER

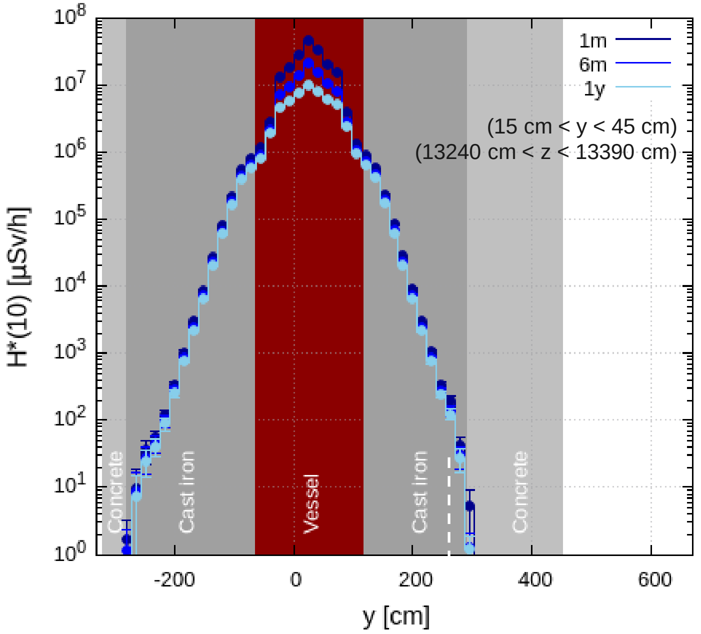
Radiation Area (Supervised to Prohibited); Controlled Area (Simple Controlled to Prohibited)

Total PoT 6×10^{20} (15 years)

Cross-sectional view, target level

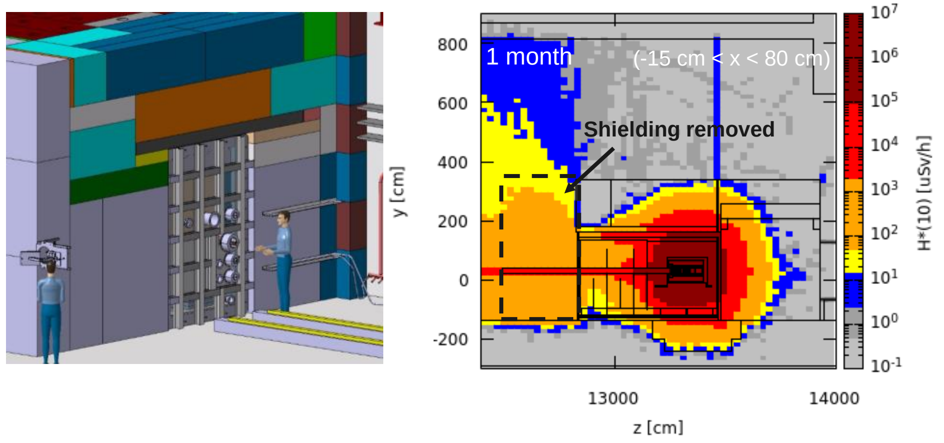


Along x-axis, working height



Upstream of vessel w/o upstream shielding

Preliminary worst case manual intervention scenario



- The shielding design contains well the high residual dose rates reaching in the central target region several 10 Sv/h after 1 month of cool-down requiring remote handling
- The residual dose rates outside the shielding are < 1 µSv/h

100 rem = 1Sv

- After removal of the shielding upstream of the vessel, residual dose rates of several 100 µSv/h are expected
- Supervised Radiation Area on the sides
- Further optimization by movable shielding
- Future detailed handling studies planned

Radioactive waste production

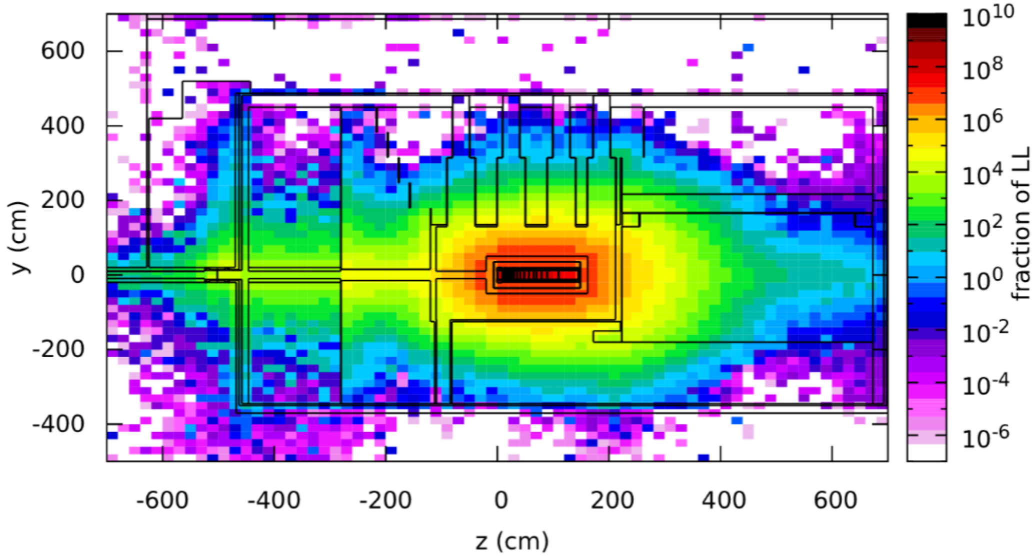
- To distinguish areas of radioactive waste from conventional ones the **Swiss clearance limits (LL)** were used
- The following sum rule was applied for material containing a mixture of radionuclides

$$\sum_{i=1}^{n} \frac{a_i}{LL_i} < 1$$

a_i - specific activity (Bq/g) of the i^{th} radionuclide
LL_i - respective Swiss clearance limit for the radionuclide i
n - number of radionuclides present

- The most activated parts are the target and the iron shielding elements (also for 30 years of cooling)
- The minimisation of radioactive waste is being considered in the shielding design by having a modular shielding such that activated parts can easily be separated from non-radioactive parts

1 year of cooling (CDS design)



SPS Beam Dump Facility - Comprehensive Design Study, CERN-2020-002

Soil and air activation

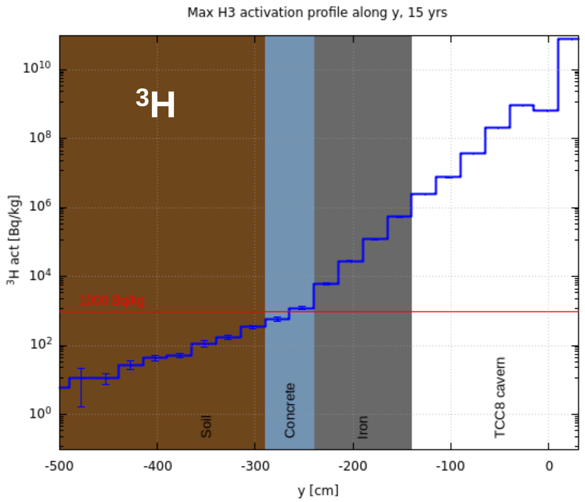
Area	Annual dose limit (year)	Ambient dose equivalent rate		Airborne activity concentration	Surface contamination
		permanent occupancy	low occupancy		
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	0.05 CA	1 CS
Supervised	6 mSv	3 µSv/h	15 µSv/h	0.1 CA	1 CS
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	0.1 CA	1 CS
Limited Stay	20 mSv	-	2 mSv/h	100 CA	4000 CS
High Radiation	20 mSv	-	100 mSv/h	1000 CA	40000 CS
Prohibited	20 mSv	-	> 100 mSv/h	> 1000 CA	> 40000 CS

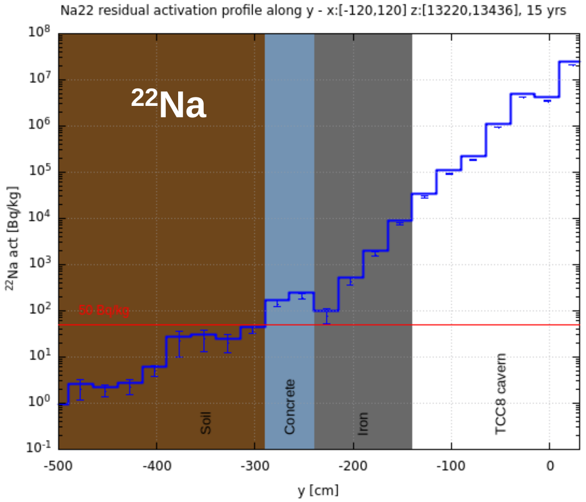
Radiation Area

Controlled Area

Total PoT 6×10^{20}

Specific activity of ^{3}H and ^{22}Na in the soil below TCC8 (most critical area)





- Thanks to floor iron shielding, ^{3}H and ^{22}Na activity concentrations in the soil are below respective design limits
- A hydro-geological study is underway, which will allow to refine the design limits and possibly allow to reduce the required shielding

PoT 4×10^{19} per year

Air activation

- Activation of air in target complex area were studied
- Production of radionuclides evaluated with FLUKA in combination with ActiWiz [5]

Air recycling			Cont. release
A_{tot} (Bq)	A_c (Bq/m^3)	CA [1] multiple	A_{tot} (Bq)
3.7×10^{6}	1.7×10^{3}	3.3×10^{-2}	1.2×10^{11}

Continuous release			
Radionuclide	Half-life	A [Bq]	%
^{15}O	2 min	7.1×10^{10}	60.0
^{13}N	10 min	3.1×10^{10}	26.3
^{11}C	20 min	5.8×10^{9}	4.9
^{41}Ar	110 min	4.5×10^{9}	3.8
^{14}O	1 min	4.2×10^{9}	3.5
^{40}Cl	84 s	9.8×10^{8}	0.8
^{35}P	47 s	2.3×10^{8}	0.2
^{37}S	5 min	2.0×10^{8}	0.2

Air recycling: build-up of radionuclides during operation w/o air extraction and 30 min cooldown time before air release
Continuous release: long-term continuous releases without delay (very conservative for environmental impact)

- Flush of target complex with fresh air before any access will further reduce specific airborne radioactivity
- H-3 out-diffusion/ejection nor potential leakage of He-cooling system not yet considered here

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

Environmental impact

Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Sign
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	
Limited Stay	20 mSv	-	2 mSv/h	
High Radiation	20 mSv	-	100 mSv/h	
Prohibited	20 mSv	-	> 100 mSv/h	

Radiation Area
Controlled Area

PoT 4×10^{19} per year

Dose from air releases

- Used max. dose coefficients from different age groups [6]

Effective dose estimates

	Effective dose (µSv/y)
Air recycling	1×10^{-5}
Continuous release	3×10^{-3}

H-3 release due to air activation of ~80 kBq (w/o out-diffusion)

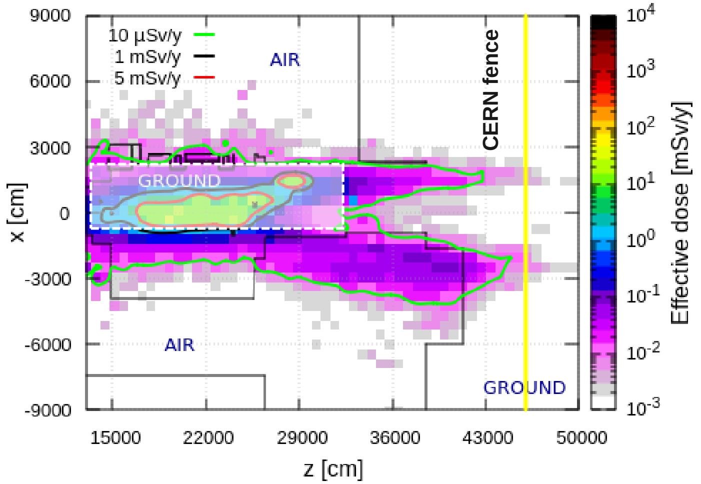
Positions of nearby population groups

- ➢ Continuous air release yields 3 nSv/year (main contributors: N-13, Ar-41, C-11, O-15) and is thus well below the annual dose optimization objective of CERN
- ➢ Additional contribution from H-3 out-diffusion/ejection and potential leakage of He-cooling system to be quantified

100 rem = 1Sv

Dose from stray radiation

Annual effective dose



Prompt radiation aboveground downstream ECN3

- ➢ Annual limit of Non-designated Area on CERN domain and at CERN fence (1 mSv/y) as well as dose optimization objective for members of the public (10 uSv/y) are by far met

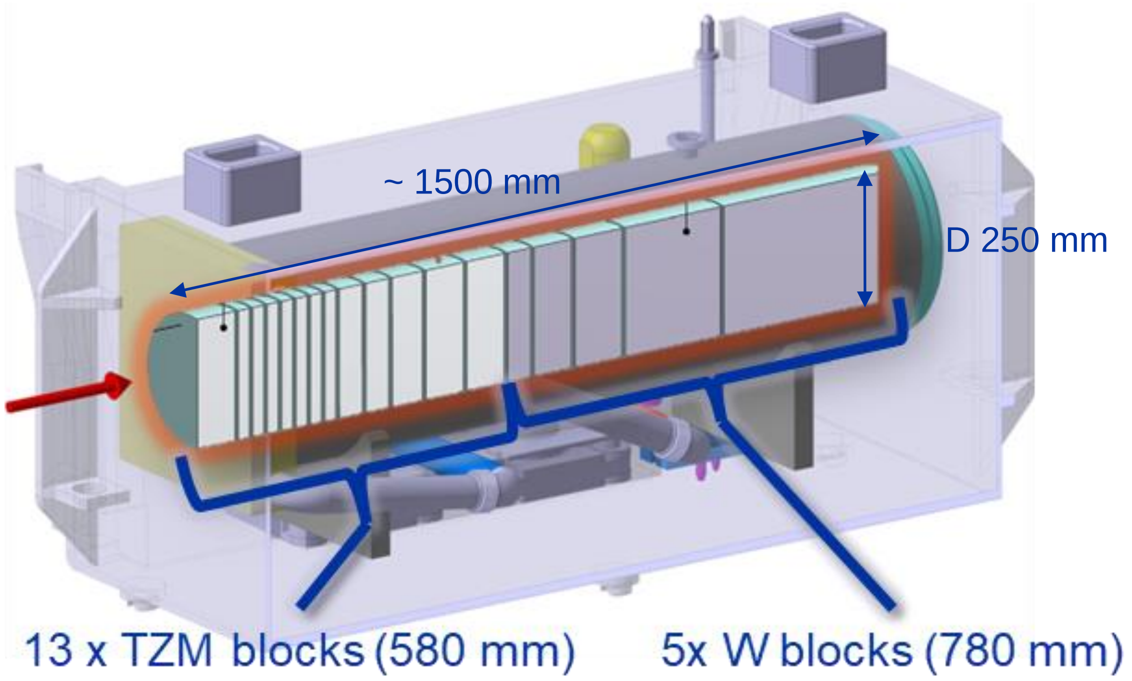
BDF Target Studies

CDS target design

Water-cooled W + TZM target (136 cm) cladded with Ta2.5W

- Pursued during the comprehensive design phase → C. Ahdida et al., *SPS Beam Dump Facility - Comprehensive Design Study*, CERN-2020-002

- Prototype + test with beam + post irradiation examination (see talk R. Ximenes)



CDS target – Residual radiation

Total PoT 4×10^{19} (5 yrs)

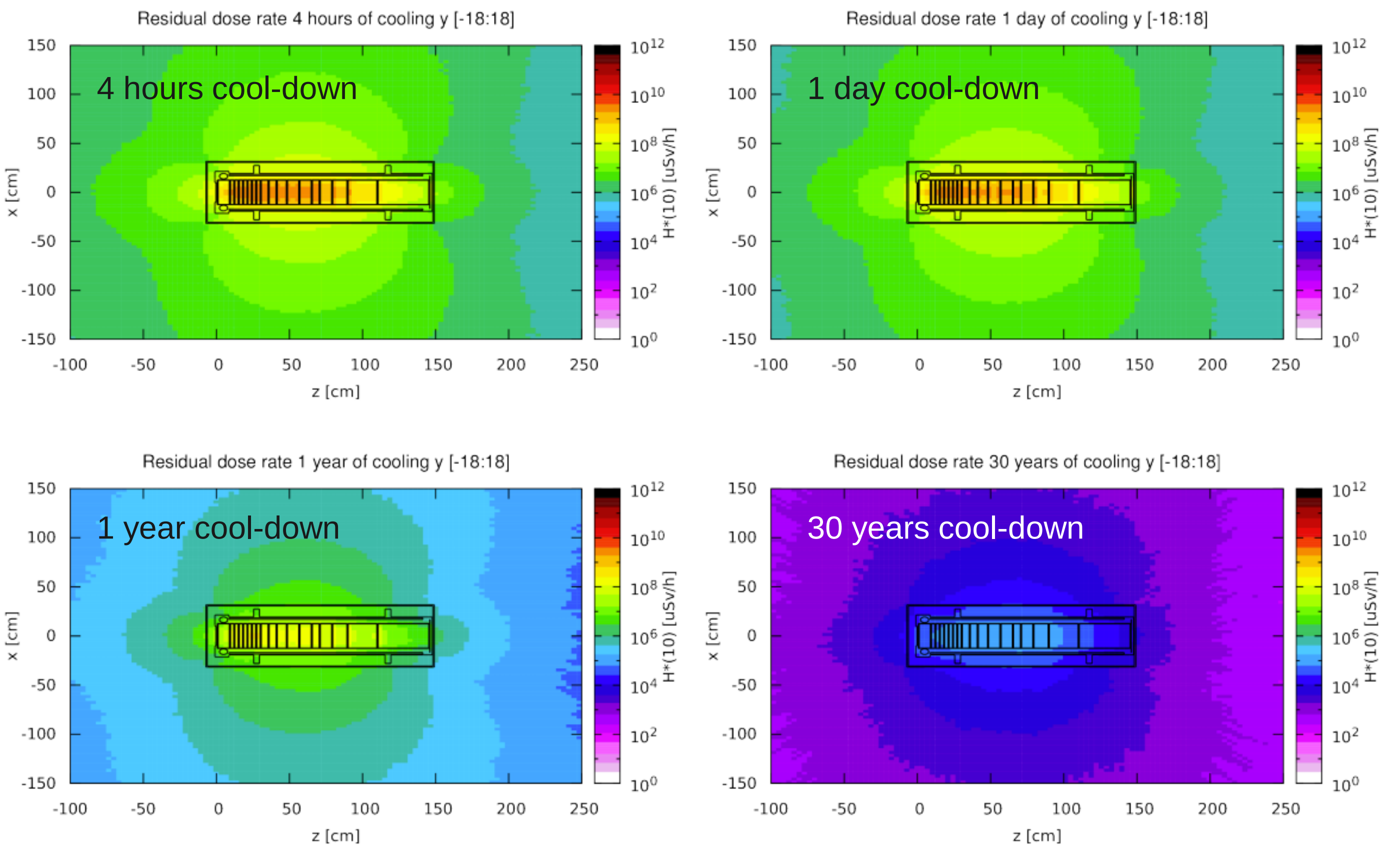
Longitudinal cut along the target

- The residual dose rates of the target were studied for 5 years of operation and different cool-down times
- The highest dose rates are in the order of 100 Sv/h after 4 hours of cooling and a **few Sv/h after 1 year**
- Even after 30 years, dose rates at 40 cm still of the order of a few mSv/h

➢ Shielding cask for handling to be designed allowing to also contain potential contamination

➢ Shielded storage area and service cell to be designed

➢ Shielding further to be foreseen for transport and final disposal (< 2 mSv/h)



CDS target – Radionuclide inventories

Total PoT 2×10[20] (5 yrs)

LA multiples of CDS target materials

Main contributors (>1%), sum for all radionuclides

W

Radionuclide	Half-life	Multiple of LA value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
Gd-148	74.60y	1.5E+08	1.5E+08	1.4E+08	1.1E+08
Yb-169	32.0d	3.2E+06	2.3E+03	2.9E-28	6.8E-97
Hf-172	1.87y	4.9E+07	3.5E+07	1.2E+06	7.5E+02
Hf-175	70.0d	3.1E+06	1.1E+05	8.4E-10	3.4E-41
Ta-182	114.7d	9.5E+06	1.3E+06	5.0E-02	4.7E-02
W-185	75.1d	3.2E+07	1.5E+06	1.0E-07	5.5E-37
Sum of all		2.6E+08	1.9E+08	1.4E+08	1.1E+08

Ta

Radionuclide	Half-life	Multiple of LA value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
Gd-148	74.60y	1.9E+07	1.9E+07	1.7E+07	1.4E+07
Hf-172	1.87y	6.4E+06	4.6E+06	1.6E+05	9.9E+01
m-Hf-178	4s	8.6E+05	8.4E+05	6.9E+05	4.4E+05
Ta-182	114.7d	6.6E+08	8.8E+07	2.1E-01	1.5E-20
Sum of all		6.9E+08	1.1E+08	1.8E+07	1.5E+07

Pure alpha/beta emitters are shown in bold

Dominant radionuclide is shown in red

TZM

Radionuclide	Half-life	Multiple of LA value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	8.2E+04	7.8E+04	4.7E+04	1.5E+04
Si-32	132.00y	7.0E+03	7.0E+03	6.6E+03	6.0E+03
Ti-44	60.00y	2.4E+04	2.4E+04	2.2E+04	1.7E+04
Co-60	5.27y	6.8E+05	6.0E+05	1.8E+05	1.3E+04
Zn-65	244.2d	3.9E+05	1.5E+05	1.4E+01	1.3E-08
Ge-68	271.0d	1.2E+06	5.2E+05	1.2E+02	9.0E-07
Se-75	119.6d	8.5E+05	1.2E+05	6.6E-04	2.8E-22
Sr-82	25.6d	8.8E+06	1.0E+03	2.0E-36	1.9E-122
Rb-83	86.2d	1.6E+06	1.1E+05	3.7E-07	1.2E-32
Sr-85	64.8d	1.4E+06	3.8E+04	2.2E-11	2.8E-45
Zr-88	83.0d	2.2E+07	1.3E+06	1.6E-06	5.4E-33
Y-88	106.6d	9.4E+06	3.1E+06	2.9E-03	7.1E-24
Sr-90	28.79y	4.7E+04	4.6E+04	3.7E+04	2.3E+04
m-Nb-91	60.9d	1.3E+07	2.8E+05	1.6E-11	1.3E-47
Nb-91	680.00y	1.6E+05	1.7E+05	1.7E+05	1.6E+05
m-Nb-93	16.13y	1.6E+05	1.6E+05	1.1E+05	4.9E+04
Mo-93	3999.92y	1.1E+04	1.1E+04	1.1E+04	1.0E+04
Nb-94	19989.57y	7.2E+03	7.2E+03	7.2E+03	7.2E+03
Zr-95	64.0d	1.3E+07	3.5E+05	1.3E-10	6.0E-45
Nb-95	35.0d	7.2E+06	1.9E+05	6.9E-11	3.3E-45
Sum of all		8.4E+07	7.5E+06	5.9E+05	3.1E+05

Total PoT 2×10[20] (5 yrs) + 1 month cool-down

Target	Material	Mass [kg]	Multiple LL	Multiple LA	A [Bq]
CDS	W	695	1.9E+08	2.6E+08	9.2E+14
	TZM	271	1.1E+09	8.4E+07	1.8E+14
	Ta	28	1.7E+11*	6.9E+08	9.8E+14

*Dominated (99.9%) by Ta-182 (115 d half-life)

Authorization Limit (LA) means the value corresponding to the abs. activity level of a material above which **handling** of this material is subject to mandatory licensing. It is based on the risk of inhalation.

Clearance Limit (LL)

CDS target – Alternative Claddings

Cladding materials:

1. Tantalum –16.6 g/cm3
2. Nb (ASTM R04210 – Type 2) – 8.6 g/cm3
3. Nb-1Zr (ASTM R04261 – Type 4) – 8.6 g/cm3
4. Nb-10Hf-1Ti (ASTM R04295) – 8.86 g/cm3

Total PoT 2×10^{20} (5 yrs)

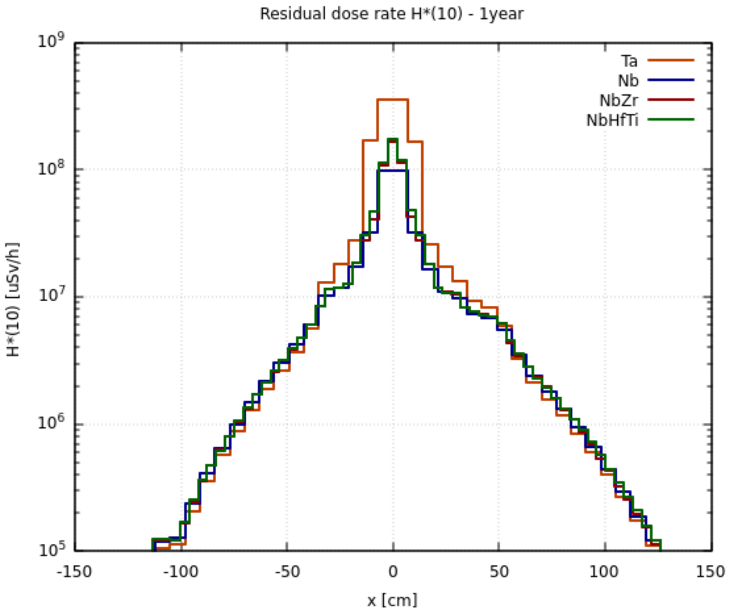
Material	Activity/LL - 5y	Activity/LL - 300y	Max. LMA fraction	RN exceeding LMA	RW Class.
Ta	1.30E+07	7.72E+03	7.58E+01	H-3 (75), Gd-148 (1.65)	FA-MA (CH)
Nb	1.62E+07	7.36E+06	6.19E+03	Nb-94 (6190), H-3 (65)	FA-MA (CH)
Nb-1Zr	1.60E+07	7.28E+06	5.23E+03	Nb-94 (5230), H-3 (66)	FA-MA (CH)
Nb-10Hf-1Ti	1.55E+07	6.22E+06	6.12E+03	Nb-94 (6120), H-3 (65)	FA-MA (CH)

Nb-94 half-life of 20300 yrs

- Waste classification as FA-MA[1] waste to be disposed of in Switzerland (no open pathway so far for such activation of Ta/Nb)

Total PoT 2×10^{20} (5 yrs), 1y cool-down

Residual dose rates (uSv/h)



Includes residual dose rates from surrounding material

- No difference in the residual dose rates for the various Nb claddings

LMA: Acceptance Activity Limits, if activity levels < LMA candidate for elimination in France

[1] Low and intermediate activation waste for elimination in Switzerland

CDS target – Water activation

- Activation of water from cooling circuits was estimated
- Shielding estimate around demineralization cartridges was performed assuming Be-7 to be stopped, but no target debris

  → 50 cm cylindrical concrete shielding was foreseen and for the roof of the area 165 cm concrete
- Remaining water in circuit mostly contains H-3 with a concentration of around 20 MBq/l per year of operation (~4000 litres)
- High production of H-3 in target materials (~15 TBq during 5 years of operation)

➢ Quantification of out-diffusion/ejection with given operational conditions are crucial for evaluating the actual amount of H-3 activity in the cooling water

PoT 4×10^{19} (1 yr), 4 hours cool-down

Total Activity (Bq) for H-3 and Be-7

Radioisotope	Target	Proximity shielding	Magnetic coil
Be-7	1.3×10^{12}	2.6×10^{9}	6.2×10^{6}
H-3	7.4×10^{10}	1.8×10^{8}	4.1×10^{5}

Results above **do not take out-diffusion** from target / shielding into account

CDS target – Prototype tests

- BDF target prototype w/ in total 14 h irradiation in TCC2, leading to 2.4E16 PoT
- **Target activation** was measured and compared to **FLUKA** simulations showing **excellent agreement**
- Cooling water activation was estimated with FLUKA
- Estimated **residual dose rate** after 1h of cooling at 40 cm from the **cartridge** is 18.7 mSv/h, while the PMI monitor measured 16.9 mSv/h
- Both samples showed the presence of high-Z spallation products some of them could have been produced in the target materials
- Water-cooling filter with debris was analysed via EDX
  - No peaks were found for Ta, W, Mo or Ti
  - Metallic particle (Al, Ca, Fe, Cl, Fe, Cr)

Benchmark of residual dose rates (mSv/h)

Position	Ambient dose rate [mSv/h]		Ratio
	Predicted (FLUKA)	Measured	Predicted/Measured
contact	25.15 ± 0.01	26 ± 1	0.97 ± 0.04
40 cm	4.42 ± 0.01	5 ± 1	0.9 ± 0.2

Radionuclides in water samples

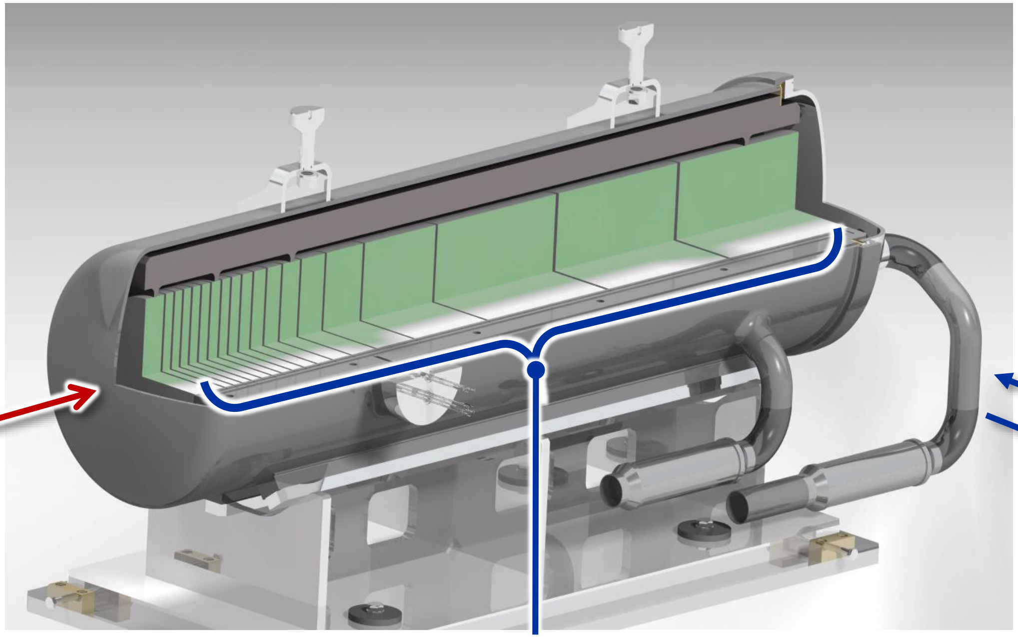
Radionuclide	Activity [Bq/l]	
	Sample 1	Sample 2
H-3	$1.96 \times 10^5 \pm 4.0\%$	$4.8 \times 10^5 \pm 4.0\%$
Be-7	$7.7 \times 10^3 \pm 6.6\%$	$2.37 \times 10^3 \pm 6.8\%$
Sc¡Sc44m	$2.49 \times 10^1 \pm 6.9\%$	$4.85 \times 10^1 \pm 5.7\%$
Sc-46	$1.51 \times 10^1 \pm 7.8\%$	$6.88 \times 10^1 \pm 6.8\%$
Sc-47	-	$1.17 \times 10^2 \pm 9.2\%$
Y-87	$1.45 \times 10^1 \pm 8.4\%$	$4.85 \times 10^1 \pm 6.2\%$
Ru-97	-	$1.27 \times 10^1 \pm 9.3\%$
Ag-106m	$1.41 \times 10^1 \pm 9.6\%$	-
In-111	-	$1.13 \times 10^1 \pm 8.5\%$
Eu¡Gd146	-	$1.19 \times 10^1 \pm 8.3\%$
Gd-149	-	$3.79 \times 10^1 \pm 8.1\%$
Tb-155	-	$4.57 \times 10^1 \pm 7.0\%$
Tm-166	-	$7.05 \pm 7.7\%$
Tm-167	-	$7.14 \times 10^1 \pm 8.9\%$
Yb-169	-	$3.13 \times 10^1 \pm 7.8\%$
Lu-171	-	$8.51 \times 10^1 \pm 6.8\%$

Water samples were analysed by liquid scintillation and gamma spectrometry

W target design

He-cooled, Pure W Core, potentially cladded (tbd)

- Improved physics performance (see talk G. Mazzola)
- Prototype and beam testing in 2025 and 2026 (see talk R. Ximenes)



19x W blocks (L1500 mm) (D250 mm)

W target – Radionuclide inventories

Total PoT 2×10^{20} (5 yrs), 1 month cool-down

LA multiples of W target
Main contributors (>1%), sum for all radionuclides

Radionuclide	Half-life	Multiple of LA	Contribution
Gd-148	**74.60 y**	**4.8E+08**	**59%**
Hf-172	1.87 y	1.5E+08	18%
W-185	**75.1 d**	**8.8E+07**	**11%**
Ta-182	114.7 d	2.7E+07	3%
Yb-169	32.0 d	9.7E+06	1%
Hf-175	70.0 d	9.2E+06	1%
Sum of all		8.0E+08	

Pure alpha/beta emitters are shown in bold
Dominant radionuclide is shown in red

LA for short-cool-down times:

- For 1h (4h), **Hf-178m** (4s half-life) produced via Ta-178m (2.36h half-life) is dominant
- For 1d, **Gd-148** (74y half-life) becomes most important (as for 1 month)

- Investigation of **outgassing of radionuclides** (incl. H-3) and possible formation of **volatile chemicals** ongoing → important for understanding of radiological risks connected to He-cooling circuit
  - Measurements during **prototype target tests** (e.g. analysis of filters/cartridge, quantification of contamination, H-3 measurements, inline gas spectrometer, etc.) are to be defined

Comparison to CDS target

Target	Material	Mass [kg]	Multiple LL	Multiple LA	A [Bq]
W target	W	1420	2.7E+08	8.0E+08	2.6E+15
CDS target	W	695	1.9E+08	2.6E+08	9.2E+14
	TZM	271	1.1E+09	8.4E+07	1.8E+14
	Ta	28	1.7E+11*	6.9E+08	9.8E+14

*Dominated (99.9%) by Ta-182 (115 d half-life)

Authorization Limits (LA)
Swiss Clearance Limits (LL)

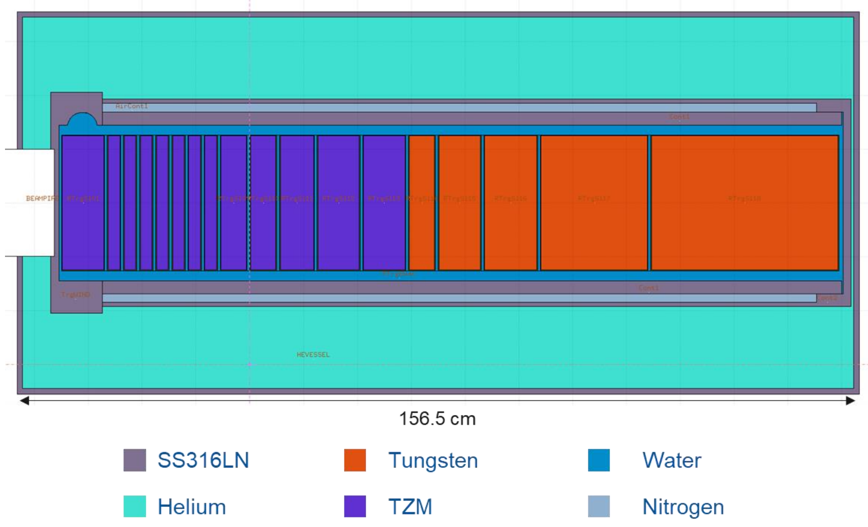
Surface building

RP considerations for service cell

- A HI-ECN3 **service cell** is crucial for **safe packaging** and **disposal** of highly radioactive equipment, as mandated by French and Swiss authorities
- The only available disposal pathway for the BDF target currently involves cutting it to fit within a KC-T12 container designated for disposal in Switzerland
- Alternatives such as transport to external facilities would require significant investments in transport casks and infrastructure, expected to cost several MCHF

➢ The cutting of the BDF target vessel requires a destructive technique (e.g. cable saw) causing contamination

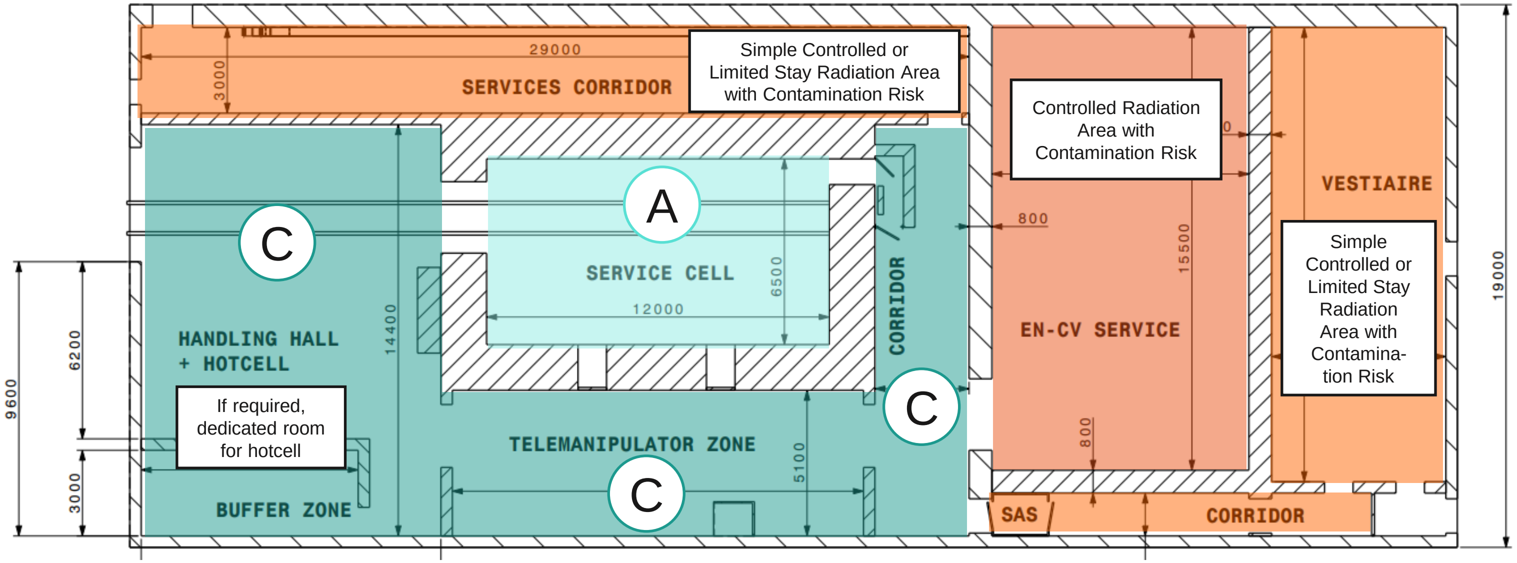
➢ The total resuspended activity was estimated by assuming that 4 cuts on the vessel (stainless steel/Inconel) removing ~7.8 kg



Resuspended activity
Total PoT 2×10^{20} (5 yrs)
+ 1 y cool-down

Material	Multiple LA
Inconel	1.2E+06
Stainless steel	1.3E+05

Service building area classification



Class A and C working areas will in addition have a Controlled Radiation Area classification with contamination risk (Limited Stay or High Radiation Area)

Work sector	Maximum Activity
Normal	LA
Type C	1E+02 LA
Type B	1E+04 LA
Type A	Depending on authorization

Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Airborne activity concentration (CA) and surface contamination (CS)		Sign
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	0.05 CA -		
Supervised	6 mSv	3 µSv/h	15 µSv/h	< 0.1 CA < 1 CS		Dosimeter obligatory / Dosimètre obligatoire
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	< 0.1 CA < 1 CS		SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE
Limited Stay	20 mSv	-	2 mSv/h	< 0.1 CA < 1 CS	< 100 CA < 4000 CS	LIMITED STAY / SÉJOUR LIMITÉ
High Radiation	20 mSv	-	100 mSv/h	< 0.1 CA < 1 CS	< 1000 CA < 40000 CS	HIGH RADIATION / HAUTE RADIATION
Prohibited	20 mSv	-	> 100 mSv/h		> 1000 CA > 40000 CS	NO ENTRY / DÉFENSE D'ENTRER

Radiation Area — Controlled Area

- At CERN, laboratories or working areas in which radioactive substances are manipulated are classified according to the **Swiss Radiological Protection Ordinance** (RPO)
- This area classification is in addition to the standard CERN area classification
- The **work sector classification** is based on the radionuclide dependent **authorization limit LA**

  → **Specific working area requirements**, e.g. ventilation, filters, fire resistance, decontamination possibilities, changing rooms, etc.
- EN-CV service for cooling system:
  1. **He-cooling:** system with filters. In underground target area already HEPA filters + heat exchanger
  2. **Water-cooling:** ion exchanger cartridges w/ shielding underground

➢ Ongoing design definition together with FIRIA

Conclusions and outlook

- Main radiological aspects regarding an implementation of BDF/SHiP in ECN3 were investigated
- First shielding design for an optimization of exposure of personnel to radiation and radiological impact on environment

➢ Further detailed studies and optimization in the Technical Design Phase including amongst others:
  - BDF handling studies and target cask requirements
  - Service building and service cell studies including shielding requirements (walls, storage, waste container, etc.)
  - Evaluation of risks related to H-3 out-diffusion/ejection, and volatile radionuclides in the He-cooling system

home.cern

Bibliography

[1] Website: https://fluka.cern

[2] C. Ahdida, D. Bozzato, D. Calzolari, F. Cerutti, N. Charitonidis, A. Cimmino, A. Coronetti, G. L. D'Alessandro, A. Donadon Servelle, L. S. Esposito, R. Froeschl, R. García Alía, A. Gerbershagen, S. Gilardoni, D. Horváth, G. Hugo, A. Infantino, V. Kouskoura, A. Lechner, B. Lefebvre, G. Lerner, M. Magistris, A. Manousos, G. Moryc, F. Ogallar Ruiz, F. Pozzi, D. Prelipcean, S. Roesler, R. Rossi, M. Sabaté Gilarte, F. Salvat Pujol, P. Schoofs, V. Stránský, C. Theis, A. Tsinganis, R. Versaci, V. Vlachoudis, A. Waets, M. Widorski, *New Capabilities of the FLUKA Multi-Purpose Code,* Frontiers in Physics 9, 788253 (2022)

[3] G. Battistoni, T. Boehlen, F. Cerutti, P.W. Chin, L.S. Esposito, A. Fassò, A. Ferrari, A. Lechner, A. Empl, A. Mairani, A. Mereghetti, P. Garcia Ortega, J. Ranft, S. Roesler, P.R. Sala, V. Vlachoudis, G. Smirnov, *Overview of the FLUKA code*, Annals of Nuclear Energy 82, 10-18 (2015)

[4] V. Vlachoudis, *FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA*, in Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York (2009)

[5] H. Vincke, C. Theis, *ActiWiz – optimizing your nuclide inventory at proton accelerators with a computer code,* Progress in Nuclear Science and Technology (2014)

[6] P. Vojtyla, *Models for assessing the dosimetric impact of releases of radioactive substances from CERN facilities to the environment – Air*, CERN Internal report (2021)

Activities multiples – CDS target

Total PoT 2×10^{20} (5 yrs)

Activities of BDF target materials

W

Radionuclide	Half-life	Activity [Bq]			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	6.2E+12	5.9E+12	3.6E+12	1.2E+12
Pm-145	17.70y	6.6E+10	8.1E+10	7.0E+10	3.2E+10
Gd-148	74.60y	3.0E+10	3.0E+10	2.7E+10	2.3E+10
Tb-157	99.00y	2.8E+10	2.8E+10	2.6E+10	2.3E+10
Lu-172m	3.7min	4.9E+12	3.5E+12	1.2E+11	7.5E+07
Lu-172	6.7d	5.0E+12	3.5E+12	1.2E+11	7.6E+07
Hf-172	1.87y	4.9E+12	3.5E+12	1.2E+11	7.5E+07
Lu-173	1.34y	6.9E+12	4.3E+12	4.0E+10	1.3E+06
Hf-175	70.0d	1.9E+13	6.7E+11	5.0E-03	2.0E-34
Ta-178	9.3min	2.9E+13	6.3E+08	1.0E-37	1.9E-139
W-178	21.6d	2.9E+13	6.3E+08	1.0E-37	1.9E-139
Ta-179	1.61y	2.8E+13	1.9E+13	3.9E+11	7.2E+07
W-181	121.0d	1.0E+14	1.5E+13	1.0E+05	6.8E-14
Ta-182	114.7d	6.7E+12	8.8E+11	3.5E+04	3.3E+04
W-185	75.1d	6.5E+14	2.9E+13	2.0E+00	1.1E-29
Sum of all		9.2E+14	8.8E+13	4.6E+12	1.3E+12

Pure alpha/beta emitters are shown in bold

Dominant radionuclide is shown in red

Main contributors (>1%), sum for all radionuclides

Ta

Radionuclide	Half-life	Activity [Bq]			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	7.8E+11	7.4E+11	4.4E+11	1.4E+11
Pm-145	17.70y	8.6E+09	1.0E+10	9.0E+09	4.1E+09
Gd-148	74.60y	3.8E+09	3.8E+09	3.5E+09	2.9E+09
Tb-157	99.00y	3.7E+09	3.7E+09	3.5E+09	3.0E+09
Lu-172	6.7d	6.7E+11	4.6E+11	1.6E+10	1.0E+07
m-Lu-172	3.7min	6.4E+11	4.6E+11	1.6E+10	9.9E+06
Hf-172	1.87y	6.4E+11	4.6E+11	1.6E+10	9.9E+06
Lu-174	3.56y	4.1E+10	3.8E+10	6.9E+09	1.4E+08
m-Hf-178	4s	1.7E+10	1.7E+10	1.4E+10	8.8E+09
n-Hf-178	31.00y	1.7E+10	1.7E+10	1.4E+10	8.8E+09
Ta-179	1.61y	3.5E+12	2.4E+12	4.9E+10	9.0E+06
Ta-182	114.7d	4.6E+14	6.1E+13	1.5E+05	1.0E-14
Sum of all		4.8E+14	6.7E+13	6.1E+11	1.7E+11

TZM

Radionuclide	Half-life	Activity [Bq]			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	8.2E+12	7.8E+12	4.7E+12	1.5E+12
Fe-55	2.73y	2.7E+11	2.1E+11	2.2E+10	1.4E+08
Zn-65	244.2d	7.8E+11	3.0E+11	2.7E+07	2.7E-02
Ga-68	1.1h	7.3E+11	3.1E+11	6.9E+07	5.4E-01
Ge-68	271.0d	7.3E+11	3.1E+11	6.9E+07	5.4E-01
m-Ge-73	0.5s	2.0E+12	1.1E+11	5.5E-02	2.4E-29
As-73	80.3d	2.0E+12	1.1E+11	5.5E-02	2.4E-29
Se-75	119.6d	2.5E+12	3.7E+11	2.0E+03	8.5E-16
Rb-82	1.3min	5.3E+12	6.0E+08	1.2E-30	1.2E-116
Sr-82	25.6d	5.3E+12	6.0E+08	1.2E-30	1.2E-116
Rb-83	86.2d	8.1E+12	5.5E+11	1.8E+00	5.9E-26
m-Kr-83	1.8h	6.1E+12	4.1E+11	1.4E+00	4.4E-26
Mo-93	3999.92y	4.2E+10	4.2E+10	4.2E+10	4.2E+10
Sr-85	64.8d	1.1E+13	3.1E+11	1.7E-04	2.2E-38
Zr-88	83.0d	2.2E+13	1.3E+12	1.6E+00	5.4E-27
Y-88	106.6d	1.9E+13	6.1E+12	5.7E+03	1.4E-17
m-Nb-91	60.9d	2.5E+13	5.5E+11	3.2E-05	2.6E-41
Nb-91	680.00y	1.6E+11	1.7E+11	1.7E+11	1.6E+11
m-Nb-92	10.2d	4.2E+12	4.9E+02	1.8E-95	-
m-Nb-93	16.13y	9.7E+11	9.3E+11	6.4E+11	2.9E+11
Nb-95	35.0d	2.9E+13	7.7E+11	2.8E-04	1.3E-38
Zr-95	64.0d	1.3E+13	3.5E+11	1.3E-04	6.0E-39
Sum of all		1.8E+14	2.2E+13	5.6E+12	2.1E+12

Radionuclide inventory of W target

D = 25 cm, L = 150 cm

Total PoT 2×10^{20} (5 yrs) + 1 month cool-down

Tungsten – Total Activity (Bq)

H-3		2.23E+13
W-185	67%,	1.75E+15
W-181	13%,	3.49E+14
Ta-178	3%,	8.80E+13
W-178	3%,	8.79E+13
Ta-179	3%,	8.34E+13
Hf-175	2%,	5.54E+13
Sum of all		2.60E+15

Tungsten – Multiple of LL

H-3		1.57E+05
Ta-182	49%	1.32E+08
Hf-175	15%	3.90E+07
W-181	9%	2.45E+07
Lu-173	5%	1.46E+07
Lu-172	4%	1.06E+07
Ta-178	2%	6.19E+06
W-178	2%	6.19E+06
Ta-179	2%	5.87E+06
Re-184m	2%	4.53E+06
Eu-146	1%	3.06E+06
Gd-146	1%	2.77E+06
Sum of all		2.69E+08

Tungsten – Multiple of LA

H-3		2.23E+05
Gd-148	59%	4.78E+08
Hf-172	18%	1.48E+08
W-185	11%	8.77E+07
Ta-182	3%	2.68E+07
Yb-169	1%	9.67E+06
Hf-175	1%	9.23E+06
Sum of all		8.03E+08

Multiples of Swiss Clearance Limits (LL)

CDS Target

Total PoT 2×10^{20} (5 yrs)

LL multiples of BDF target materials

W

Radionuclide	Half-life	Multiple of LL value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	9.0E+04	8.5E+04	5.1E+04	1.7E+04
Co-60	5.27y	1.3E+05	1.2E+05	3.6E+04	2.6E+03
Ba-133	10.54y	8.8E+05	8.3E+05	4.6E+05	1.2E+05
Pm-145	17.70y	9.6E+03	1.2E+04	1.0E+04	4.6E+03
Eu-146	4.6d	1.9E+06	1.6E+04	5.1E-17	1.5E-62
Gd-146	48.3d	1.7E+06	1.4E+04	4.6E-17	1.4E-62
Gd-148	74.60y	4.3E+04	4.3E+04	4.0E+04	3.3E+04
Eu-150	36.36y	3.4E+03	3.4E+03	2.8E+03	1.9E+03
Lu-172	6.7d	7.1E+06	5.0E+06	1.8E+05	1.1E+02
Hf-172	1.87y	7.0E+05	5.0E+05	1.8E+04	1.1E+01
Lu-173	1.34y	9.9E+06	6.2E+06	5.8E+04	1.8E+00
Lu-174	3.56y	1.4E+05	1.3E+05	2.4E+04	4.9E+02
Hf-175	70.0d	2.7E+07	9.7E+05	7.2E-09	2.9E-40
Ta-178	9.3min	4.2E+06	9.1E+01	1.5E-44	2.7E-146
W-178	21.6d	4.2E+06	9.1E+01	1.5E-44	2.7E-146
Ta-179	1.61y	4.0E+06	2.7E+06	5.7E+04	1.0E+01
W-181	121.0d	1.5E+07	2.1E+06	1.4E-02	9.8E-21
Ta-182	114.7d	9.6E+07	1.3E+07	5.0E-01	4.7E-01
Re-184m	168.0d	3.2E+06	8.0E+05	1.0E+00	8.6E-14
Sum of all		1.9E+08	3.4E+07	9.6E+05	1.9E+05

Ta

Radionuclide	Half-life	Multiple of LL value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	2.8E+05	2.7E+05	1.6E+05	5.2E+04
Co-60	5.27y	4.8E+05	4.3E+05	1.3E+05	9.4E+03
Ba-133	10.54y	3.0E+06	2.8E+06	1.5E+06	4.1E+05
Pm-145	17.70y	3.1E+04	3.8E+04	3.3E+04	1.5E+04
Gd-148	74.60y	1.4E+05	1.4E+05	1.3E+05	1.0E+05
Eu-150	36.36y	1.2E+04	1.2E+04	1.0E+04	6.9E+03
Lu-172	6.7d	2.4E+07	1.7E+07	5.9E+05	3.6E+02
Hf-172	1.87y	2.3E+06	1.7E+06	5.9E+04	3.6E+01
Lu-173	1.34y	3.7E+07	2.3E+07	2.2E+05	6.8E+00
Lu-174	3.56y	1.5E+06	1.4E+06	2.5E+05	5.1E+03
m-Hf-178	4s	6.2E+04	6.1E+04	5.0E+04	3.2E+04
Ta-179	1.61y	1.3E+07	8.6E+06	1.8E+05	3.3E+01
Ta-182	114.7d	1.7E+11	2.2E+10	5.3E+01	3.7E-18
Sum of all		1.7E+11	2.2E+10	3.4E+06	6.5E+05

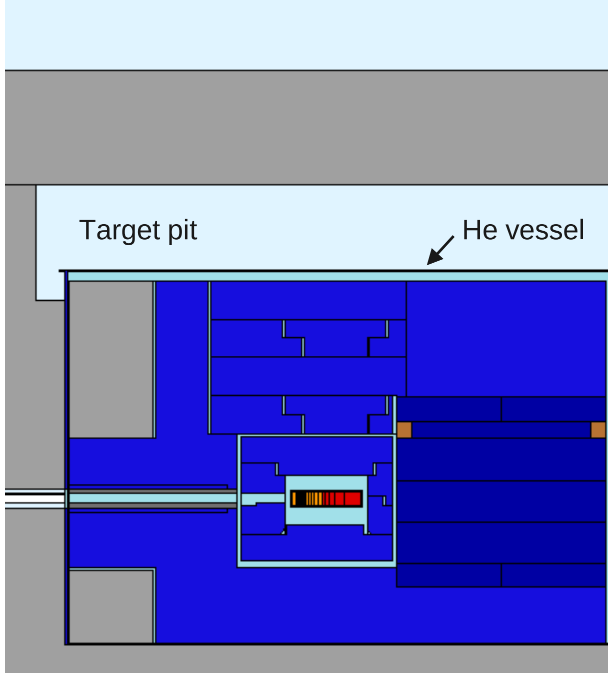
Pure alpha/beta emitters are shown in bold
Dominant radionuclide is shown in red
Main contributors (>1%), sum for all radionuclides

TZM

Radionuclide	Half-life	Multiple of LL value			
		T_c = 1m	T_c = 1y	T_c = 10y	T_c = 30y
H-3	12.33y	3.0E+05	2.9E+05	1.7E+05	5.7E+04
Na-22	2.60y	7.5E+05	5.9E+05	5.3E+04	2.6E+02
Ti-44	60.00y	6.3E+04	6.2E+04	5.6E+04	4.4E+04
Sc-46	83.8d	2.2E+07	1.4E+06	2.1E-06	1.3E-32
Mn-54	312.1d	1.4E+07	6.5E+06	4.4E+03	4.0E-04
Co-60	5.27y	2.2E+06	2.0E+06	6.1E+05	4.4E+04
Zn-65	244.2d	2.9E+07	1.1E+07	1.0E+03	1.0E-06
Rb-83	86.2d	3.0E+07	2.0E+06	6.8E-06	2.2E-31
Sr-85	64.8d	4.1E+07	1.1E+06	6.4E-10	8.3E-44
Y-88	106.6d	6.9E+08	2.3E+08	2.1E-01	5.2E-22
Zr-88	83.0d	8.0E+07	4.9E+06	6.0E-06	2.0E-32
Sr-90	28.79y	1.0E+04	1.0E+04	8.1E+03	5.0E+03
Nb-91	680.00y	6.0E+03	6.2E+03	6.1E+03	6.0E+03
Nb-93m	16.13y	3.6E+05	3.4E+05	2.4E+05	1.1E+05
Mo-93	3999.92y	1.6E+04	1.6E+04	1.6E+04	1.5E+04
Nb-94	19989.57y	5.3E+04	5.3E+04	5.3E+04	5.3E+04
Nb-95	35.0d	1.1E+08	2.8E+06	1.0E-09	4.9E-44
Zr-95	64.0d	4.8E+07	1.3E+06	4.6E-10	2.2E-44
Tc-99	213995.36y	6.2E+03	6.2E+03	6.2E+03	6.2E+03
Sum of all		1.1E+09	2.6E+08	1.2E+06	3.4E+05

CDS air and He activation

Air and He regions in the target complex



A helium purification system provides a purity of at least **99.9% He** (<0.1% air contamination)

Annual releases from the target pit and the He vessel

Radioisotope	Target pit [Bq/y]	He vessel [Bq/y]
H-3	5.5×10^{4}	1.44×10^{9}
Be-7	9.0×10^{5}	1.46×10^{6}
Be-10	1.5×10^{-1}	3.57×10^{-1}
C-11	3.9×10^{9}	2.77×10^{6}
C-14	9.4×10^{3}	2.66×10^{4}
N-13	1.8×10^{10}	7.81×10^{6}
O-14	7.5×10^{8}	1.29×10^{5}
O-15	2.0×10^{10}	3.60×10^{6}
O-19	2.0×10^{6}	1.02×10^{3}
F-18	2.0×10^{5}	1.39×10^{3}
Ne-23	3.2×10^{6}	1.06×10^{3}
Ne-24	7.9×10^{5}	4.60×10^{2}
Na-22	2.4×10^{1}	9.44×10^{1}
Na-24	3.3×10^{4}	1.51×10^{3}
Na-25	5.9×10^{6}	1.73×10^{3}
Mg-27	5.0×10^{6}	2.70×10^{3}
Mg-28	1.2×10^{4}	8.41×10^{2}
Al-26	6.6×10^{-5}	2.10×10^{-4}
Al-28	4.0×10^{7}	7.89×10^{3}
Al-29	1.4×10^{7}	5.01×10^{3}
Si-31	1.7×10^{6}	8.91×10^{3}
Si-32	5.3×10^{-1}	1.57×10^{0}
P-30	1.6×10^{7}	2.86×10^{3}
P-32	3.7×10^{4}	2.17×10^{4}
P-33	2.2×10^{4}	2.13×10^{4}
P-35	2.6×10^{7}	4.15×10^{3}
S-35	1.3×10^{4}	2.22×10^{4}
S-37	5.7×10^{7}	1.35×10^{4}
S-38	6.2×10^{5}	4.01×10^{3}
Cl-34	1.2×10^{6}	1.19×10^{3}
Cl-36	1.7×10^{-2}	3.83×10^{-2}
Cl-38	3.6×10^{7}	3.94×10^{4}
Cl-39	6.8×10^{7}	1.12×10^{5}
Cl-40	1.4×10^{8}	1.82×10^{4}
Ar-37	6.2×10^{4}	6.67×10^{4}
Ar-39	1.4×10^{2}	3.08×10^{2}
Ar-41	5.4×10^{8}	1.70×10^{6}
K-38	3.1×10^{4}	8.54×10^{0}
K-40	4.3×10^{-9}	1.19×10^{-8}
Sum	4.5×10^{10}	1.5×10^{9}
Short-lived	4.4×10^{10}	1.6×10^{7}

1.4 GBq H-3 released to the air would lead to 5 nSv

Effective dose to reference groups

	Effective dose [Sv/y]	
Radioisotope	NW	A
H-3	4.73379×10^{-9}	2.42462×10^{-9}
Be-7	1.64454×10^{-9}	6.71669×10^{-12}
Be-10	2.9091×10^{-15}	2.30395×10^{-16}
C-11	6.10442×10^{-10}	0
C-14	1.27261×10^{-11}	3.15714×10^{-11}
N-13	1.79319×10^{-9}	0
O-14	2.73733×10^{-11}	0
O-15	4.48658×10^{-10}	0
O-19	7.182×10^{-15}	0
F-18	4.96779×10^{-13}	1.40334×10^{-18}
Ne-23	2.76003×10^{-15}	0
Ne-24	1.65388×10^{-14}	0
Na-22	4.39769×10^{-11}	6.0038×10^{-11}
Na-24	3.25718×10^{-12}	1.42659×10^{-12}
Na-25	2.53092×10^{-14}	0
Mg-27	1.03207×10^{-11}	0
Mg-28	1.4961×10^{-12}	3.69057×10^{-12}
Al-26	1.16683×10^{-15}	7.18052×10^{-19}
Al-28	3.22696×10^{-11}	0
Al-29	2.02626×10^{-12}	0
Si-31	1.74293×10^{-12}	4.41491×10^{-17}
Si-32	2.70759×10^{-14}	4.70469×10^{-16}
P-30	9.3639×10^{-13}	0
P-32	6.49838×10^{-11}	2.33565×10^{-9}
P-33	9.95586×10^{-12}	2.83428×10^{-10}
P-35	8.69143×10^{-12}	0
S-35	9.02045×10^{-12}	1.6713×10^{-10}
S-37	1.02981×10^{-11}	0
S-38	5.07684×10^{-12}	1.0884×10^{-14}
Cl-34	1.78834×10^{-12}	1.2214×10^{-26}
Cl-36	1.44043×10^{-14}	3.91422×10^{-13}
Cl-38	4.53519×10^{-11}	3.86606×10^{-23}
Cl-39	1.12714×10^{-10}	5.53001×10^{-19}
Cl-40	7.20983×10^{-12}	0
Ar-37	4.84585×10^{-19}	0
Ar-39	8.3041×10^{-18}	0
Ar-41	1.37001×10^{-10}	0
K-38	2.39231×10^{-14}	0
K-40	1.00467×10^{-20}	4.9991×10^{-20}
Total	9.78×10^{-9}	5.31×10^{-9}

Alternative cladding materials

Material:		Niobium (ASTM R04210 Type 2)	Nb-1Zr (ASTM R04261 Type 4)	Nb-10Hf-1Ti "C103" (ASTM R04295)
Density (g/cm3):		8.6	8.6	8.86
Composition:	C	0.01	0.01	0.015
Max Weight %	N	0.01	0.01	0.01
	O	0.025	0.025	0.025
	H	0.0015	0.0015	0.0015
	Zr	0.02	0.8-12	0.7
	Ta	0.3	0.5	0.5
	Fe	0.01	0.01	-
	Si	0.005	0.005	-
	W	0.05	0.05	0.5
	Ni	0.005	0.005	by difference
	Mo	0.02	0.05	-
	Hf	0.02	0.02	9-11"
	Ti	0.03	0.03	0.7-1.3"
Reference:		[1]	[2]	[3]

[1] - https://www.navstarsteel.com/niobium-sheet.html
[2] https://www.tantalum-niobium.com/niobium/nb-1zr-wire-rod.html
[3] Ximenes Franqueira R., Internal communication, (2021)

Target vessel materials

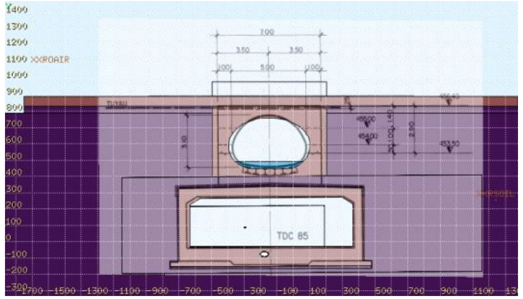
Inconel - AW3.7 - 8.4 g/cm3	
ALUMINUM	1.15E-02
BORON	6.00E-05
CARBON	8.00E-04
CHROMIUM	2.10E-01
COBALT	1.00E-02
COPPER	8.00E-03
IRON	1.11E-01
MANGANESE	3.50E-03
MOLYBDENUM	3.30E-02
NICKEL	5.50E-01
NIOBIUM	5.50E-02
PHOSPHORUS	1.50E-04
SILICON	3.50E-03
SULFUR	1.50E-04
TITANIUM	3.00E-03

SS316LN - AW3.7 - 8 g/cm3	
CARBON	3.00E-04
COBALT	1.00E-03
CHROMIUM	1.73E-01
IRON	6.39E-01
MANGANES	2.00E-02
MOLYBDEN	2.50E-02
NITROGEN	1.70E-03
NICKEL	1.30E-01
PHOSPHO	2.25E-04
SULFUR	7.50E-05
SILICON	1.00E-02

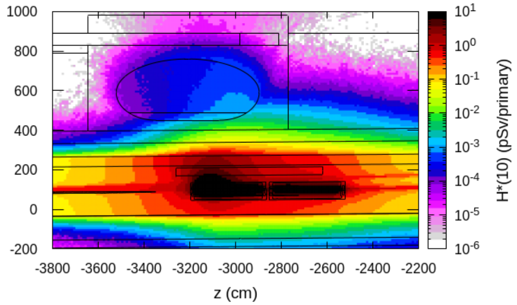
Some additional studies

Beam transfer

- Several RP studies for the high intensity SPS-ECN3 beam transfer were performed
- This includes studies for a bridge above the TDC85 transfer tunnel near ECN3



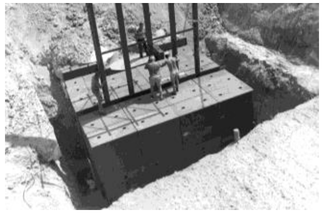
Prompt H*(10)



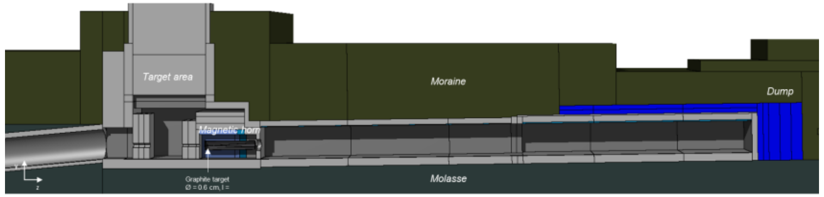
Various beamline and shielding configurations were investigated

TT7 shielding recovery

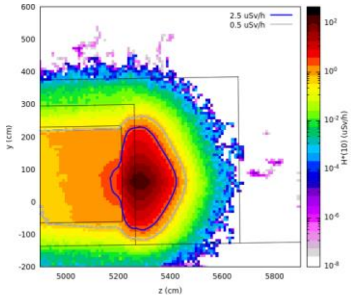
- Shielding recovery from discontinued CERN PS Neutrino Facility (PSNF)



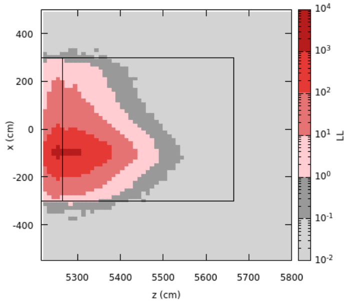
– ~100 m^3 std. cast iron blocks
– ~50 m^3 non-std cast iron blocks
➢ ~3 MCHF, investment <1/3



Residual H*(10)

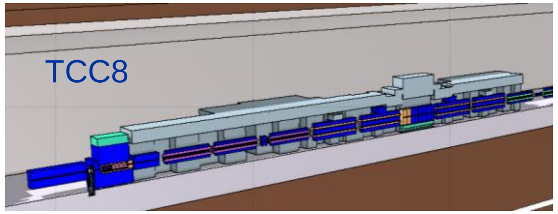


Radioactive waste zoning

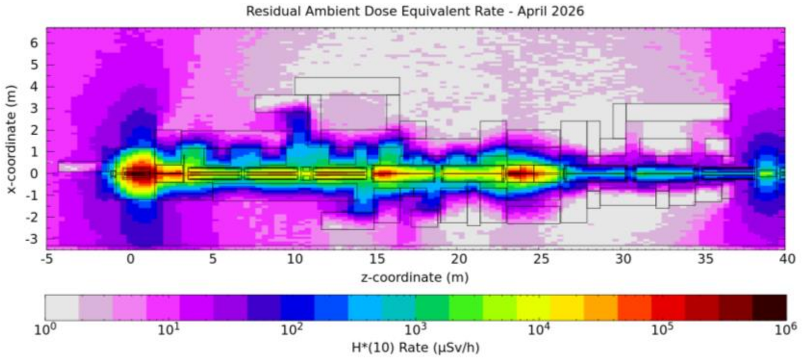


TCC8 dismantling

- Dismantling of the highly radioactive TCC8 target area in 2026
- Evaluation of residual dose rates and radio-nuclide inventories for operational RP as well as radioactive transport and waste studies



Residual H*(10)



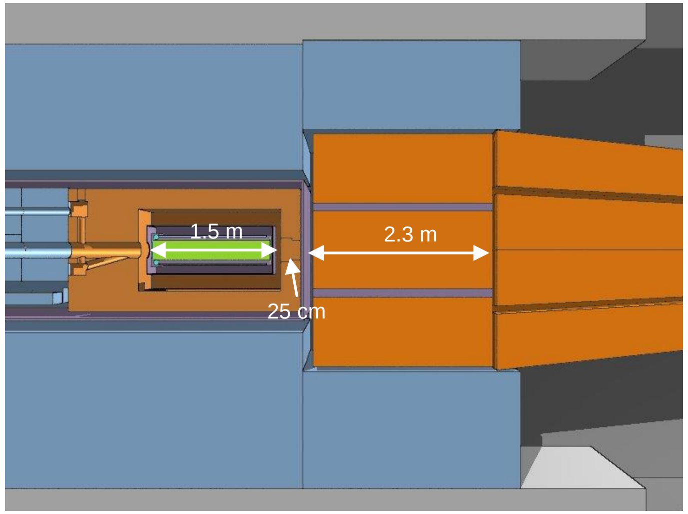
Optimization of MHS length

Area	Annual dose limit (year)	Ambient dose equivalent rate		Sign
		permanent occupancy	low occupancy	
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	Dosimeter obligatory / Dosimètre obligatoire
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	SIMPLE CONTROLLED / CONTRÔLÉE SIMPLE; Dosimeter obligatory / Dosimètre obligatoire
Limited Stay	20 mSv	-	2 mSv/h	LIMITED STAY / SÉJOUR LIMITÉ; Dosimeters obligatory / Dosimètres obligatoires
High Radiation	20 mSv	-	100 mSv/h	HIGH RADIATION / HAUTE RADIATION; Dosimeters obligatory / Dosimètres obligatoires
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY DÉFENSE D'ENTRER

Radiation Area — Controlled Area

Ongoing optimization of MHS length to enhance SHiP's physics performance, while maintaining optimization goals for radiation (RP, radiation to material) in the downstream area

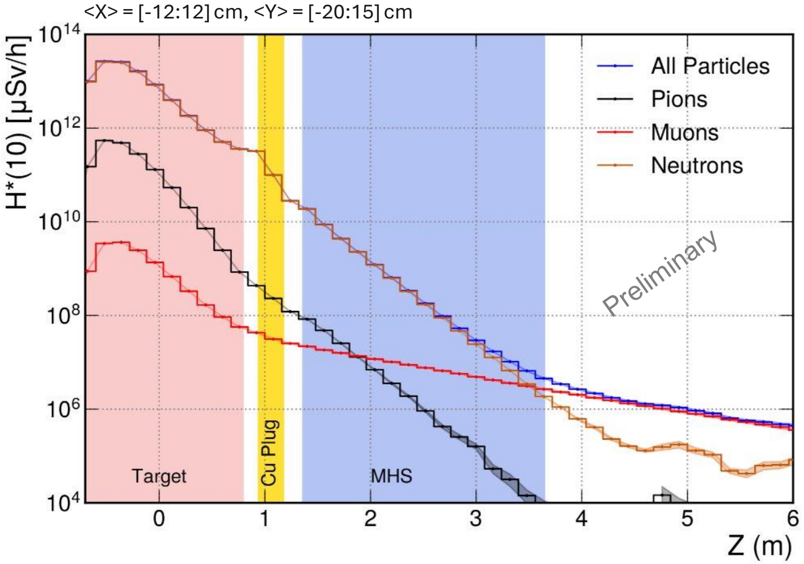
FLUKA model
w/ reduced MHS length



MHS length and dump reduced from 4.5 m to 2.3 m with full W target and Cu plug

Prompt radiation

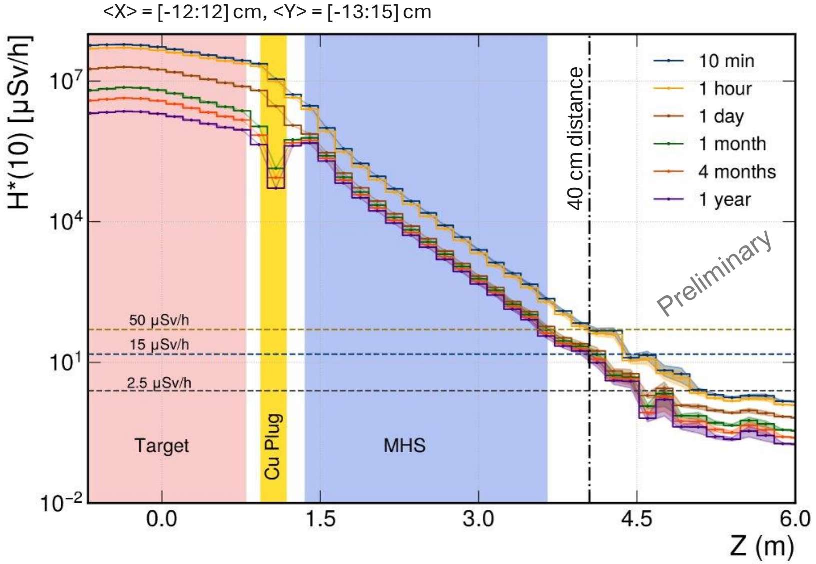
Along z-axis



Prompt dose rate for the reduced length is ~7 times higher than for the longer version

Residual radiation

Along z-axis



Along beamline dose rates are compatible with Supervised Radiation area after 1 day. On sides expected to be lower

Radioactive Material

When is a material radioactive?

Specific and total activity exceed clearance limits (LL values)
as given in the Annex of EDMS 942170 (adopted from Swiss legislation)

Examples: 0.1 Bq/g for ^{22}Na, ^{54}Mn, ^{60}Co
1000 Bq/g for ^{55}Fe

OR

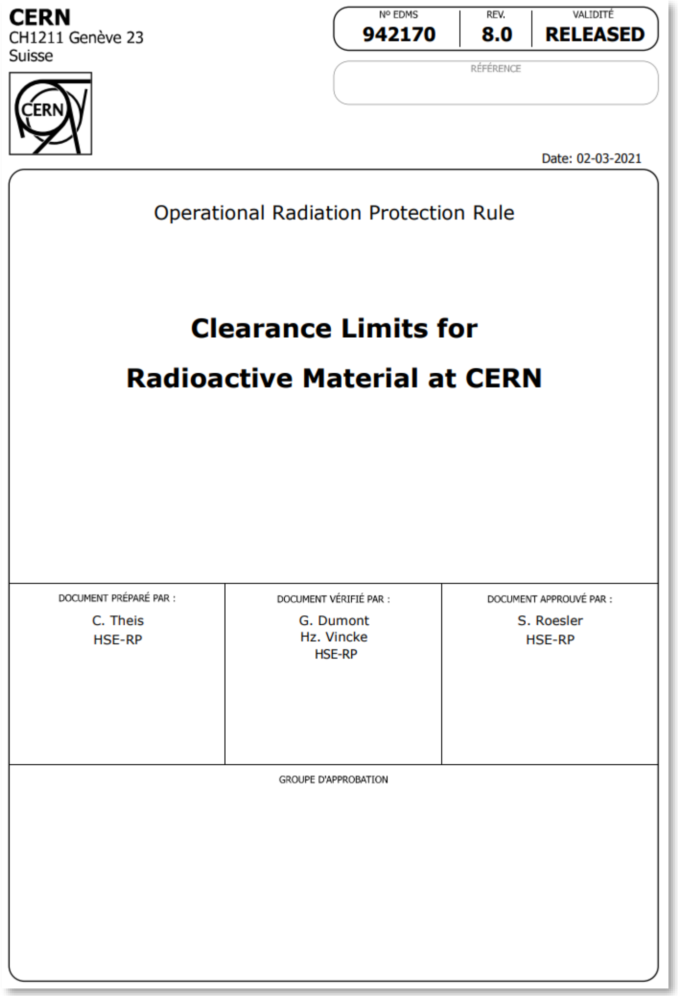
Sum rule for mixture of radionuclides: $$\sum_{i=1}^{n} \frac{a_i}{LL_i} < 1$$

Net ambient dose equivalent rate > 0.1 µSv/h in 10 cm distance

OR

Surface contamination exceeds limits
as given in the Annex of EDMS 942170 (> 1 CS)

Sum rule for mixture of radionuclides: $$\sum_{i=1}^{n} \frac{c_i}{CS_i} < 1$$


CERN
CH1211 Genève 23
Suisse

Nº EDMS	REV.	VALIDITÉ
942170	8.0	RELEASED

RÉFÉRENCE

Date: 02-03-2021

Operational Radiation Protection Rule

Clearance Limits for
Radioactive Material at CERN

DOCUMENT PRÉPARÉ PAR :	DOCUMENT VÉRIFIÉ PAR :	DOCUMENT APPROUVÉ PAR :
C. Theis HSE-RP	G. Dumont Hz. Vincke HSE-RP	S. Roesler HSE-RP

GROUPE D'APPROBATION