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TARGET STATION FACILITY SAFETY ASPECTS

ESSNUSB WORKING GROUP SESSION

ESSNUSB WP4 / EURONUNET WG2 - TARGET STATION

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TARGET STATION FACILITY - GLOBAL WORKING PLANS

Target Station Facility Features*

*Inspired from ESS Target Station Report

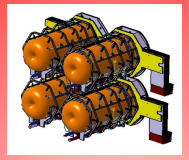
Efficiency

Safety

Reliability

Target Station Facility Sub-Systems

Target Station
- Target + integration
- Horn
- Four Horn Support
- Proton Beam extraction



Power Supply System
- Target Station
- Power Supply Unit
- Cooling System
- Stripline Connection

Fluid System
- Closed cooling Fluid (Helium gas, Water)
- Radioactive Effluents
- Confinement System

Handling and Logistic
- Active Cell
- Casks
- Remote Handling

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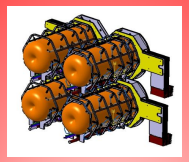

Power Supply System
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- **Safety : Preparation Phase ⇔ Design Study**
  - **Non-radiological risks**
    - **Electrical risk, cooling system, maintenance operation….**
    - **Earthquake**
  - **Radiological risks**
    - **Determine the radiological risks (external or internal contamination) for each part of the facility.**
    - **Investigate biological protections with respect to the prompt dose and residual dose**
    - **Environnemental impact studies (Tritium, 22Na,..)**

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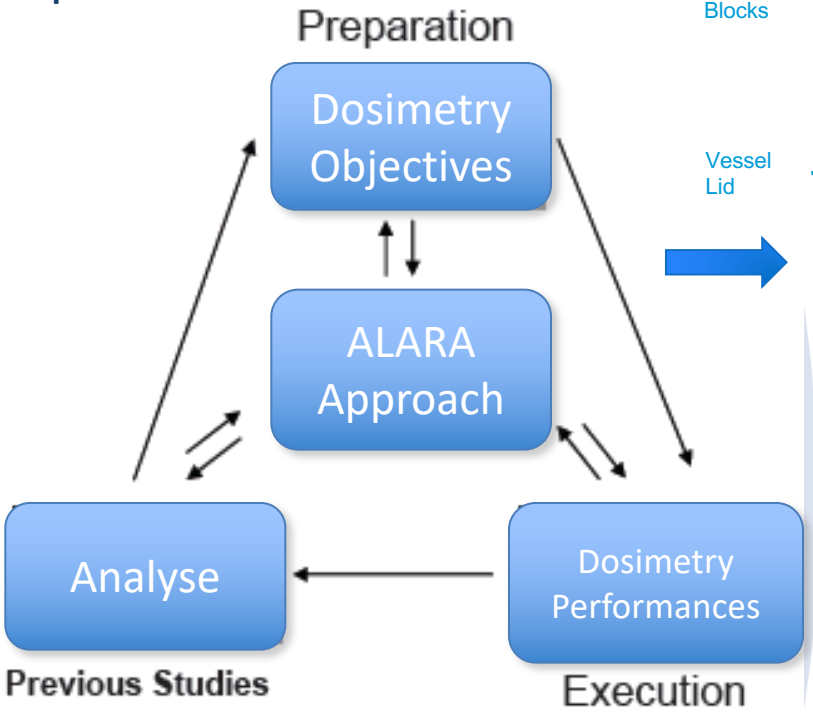
TARGET STATION FACILITY - GLOBAL WORKING PLANS

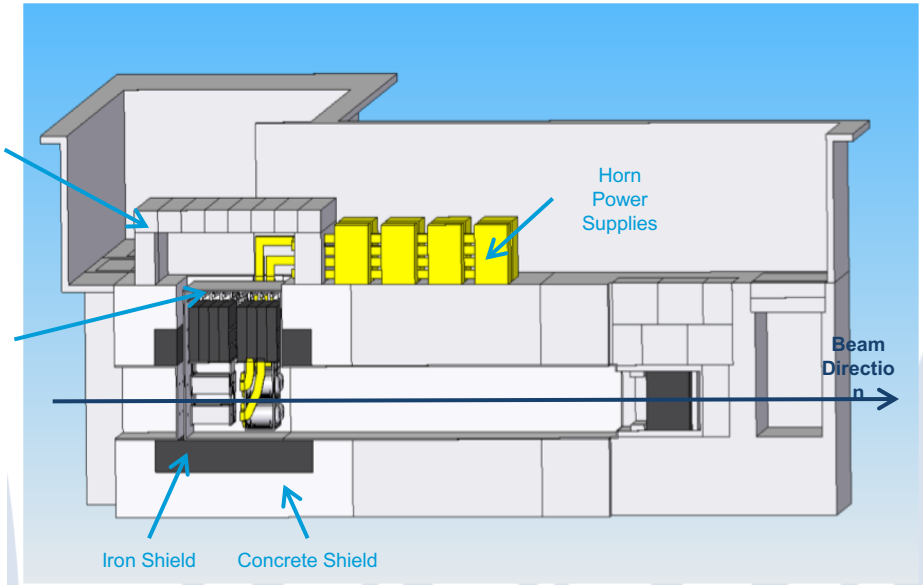
ALARA Approach:

Anticipate and reduce individual and collective exposition to radiations.



As Low As Reasonably Achievable

Feedback from previous experiments is crucial



Building "rooms"

- Open Top geometry for the Target Station Room, Decay Tunnel, Beam Dump
- Hot Cell (Repair Target Station elements)
- Morgue (Store radioactive wastes)
- Horn Power Supply Room , Power supply outside of the main building ?

=> Energy Deposition and Dose Rate Estimation with FLUKA Simulation

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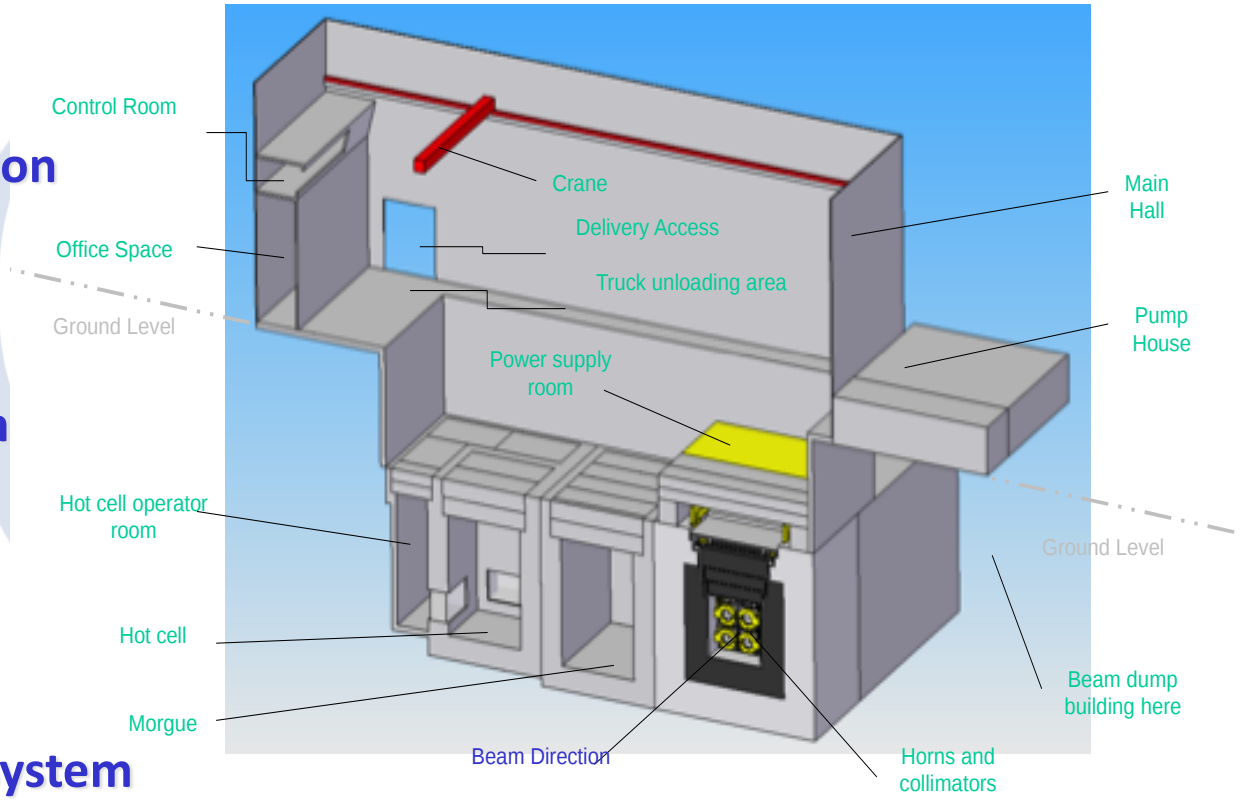
TARGET STATION FACILITY

Building Structure:

- Proton Driver line
- Experimental Hall
  - MW Target Station
  - Decay Tunnel
  - Beam Dump
- Maintenance Room
- Service Gallery
  - Power supply
  - Cooling system
  - Air-Ventilation system
- Waste Area



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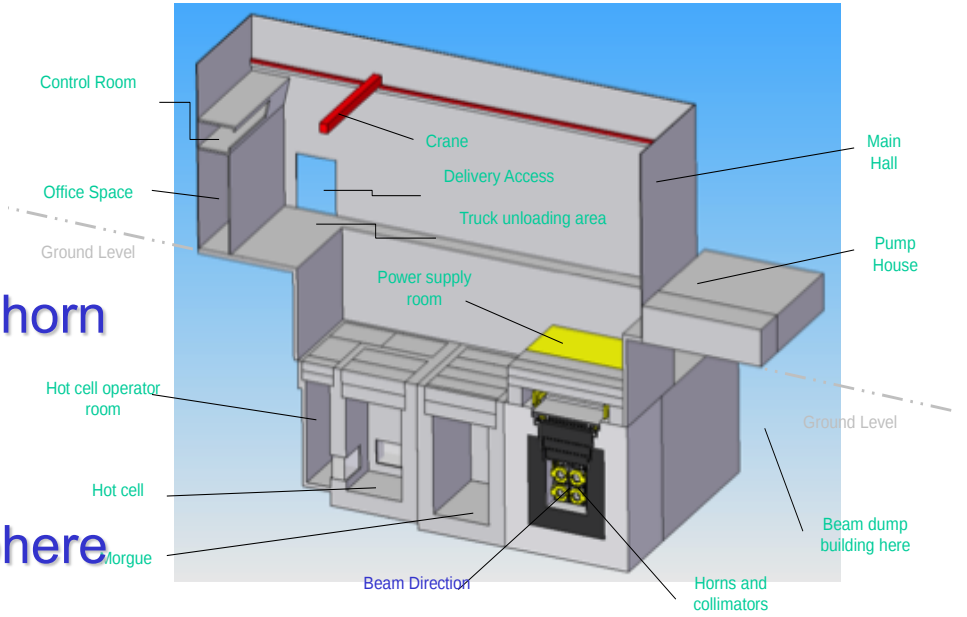
TARGET STATION FACILITY

MW Target Station :

- Focusing System
- Crane System
- Automated robot
- Mechanical structure for the for horn
- Dose Rate Monitoring System
- Residual Dose Rate Plateform
- Operation under helium Atmosphere
  - flushing with air
  - filter to measure radioactive pollution (dust, tritium …)
- Investigation of other radionucleides transport (environmental constraint)
- …



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Non Radiological Risks

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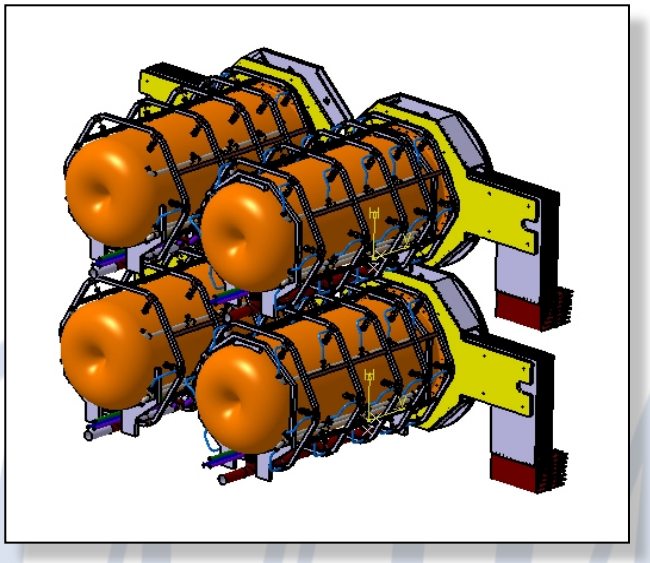
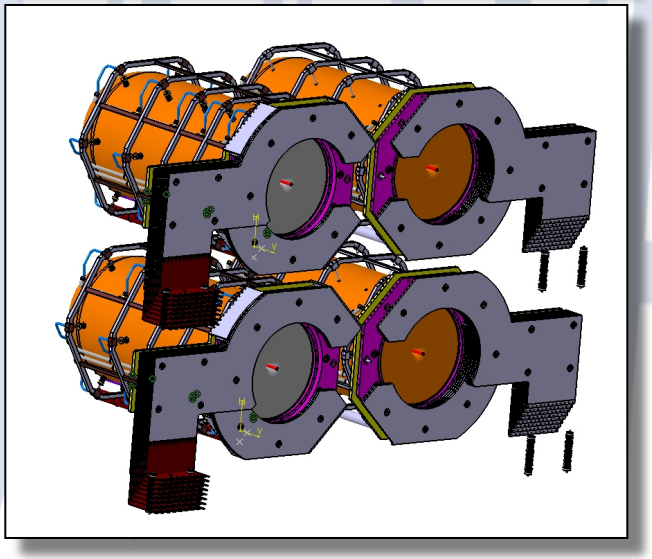
TARGET STATION

Four horns station:

- Solid Static target (Titanium)
- Use multiple 4 targets+ horns
- Beam frequency 56 Hz
- Cooling
- Power distribution due to Joule losses & secondary particles
- Energy balance, to maintain working temperature
- Flow rate
- Jet distribution along the outer conductor
- h correlation for jets' geometry





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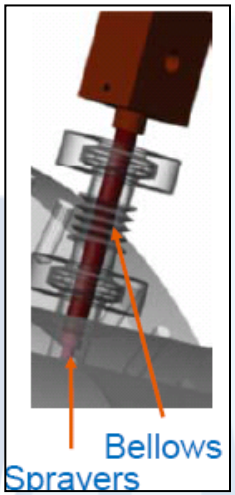
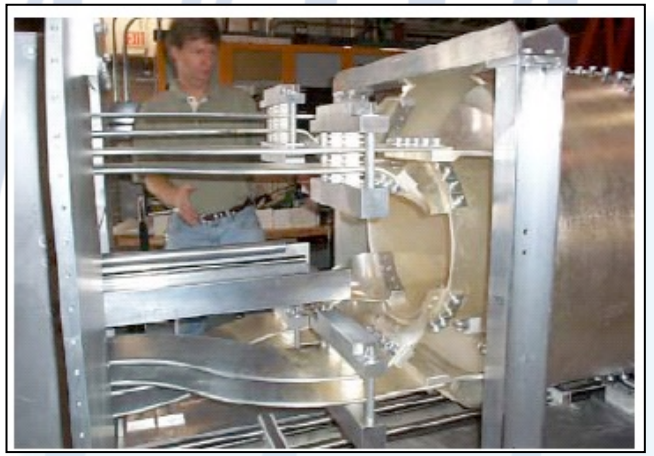
TARGET STATION

- **Recommandations from others facilities:**
  - Cracks in welds
  - Use flexible pipes to reduce stress and fatigue
  - Water leaks due to galvanic corrosion => avoid trapped water and choose material carefully
  - Use semi flexible conductor because of important magnetic force between stripline => can break cable
  - Heat dissipation of the stripline
  - Remote design for repairing/exchange
  - Need Spares
  - …





Striplines plate with soft transition

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HORN INVESTIGATION FAILURES

Failure	Causes	Consequences	Solution	Action/Safety
Cracks, weld junction	Material faults In the weld junction	Water leaks Current discontinuity	Check quality of weld junctions	Electrical shutdown Water flow shutdown
Cracks in the aluminium all, pipes connections	Peak stress too high	Water leaks Large displacement Crack growth Horn destruction	Stress analysis of the pipes connections; Of the details connections	Electrical shutdown Water flow shutdown
Cracks in the aluminium wall	High cyclic stress Fatigue cracks	Water leaks Large displacement Crack growth	R&D studies	Electrical shutdown Water flow shutdown
Striplines/horn connection cracks	Localised high cyclic Stress Corrosion Fatigue cracks	Electrical discontinuity Change in the magnetic field	R&D studies in the stripline horn/connection	Electrical shutdown Water flow shutdown
Striplines/connections Cracks initiation	Stress corrosion	Electric resistance increase	R&D studies	Electrical shutdown

COMPLEMENTARY INFRASCTURURE (FEEDBACK)

SPL Cooling system :

Conceptual design of the SPL II, A high-power superconducting H- linac at CERN – CERN-2006-006 - 12 July 2006

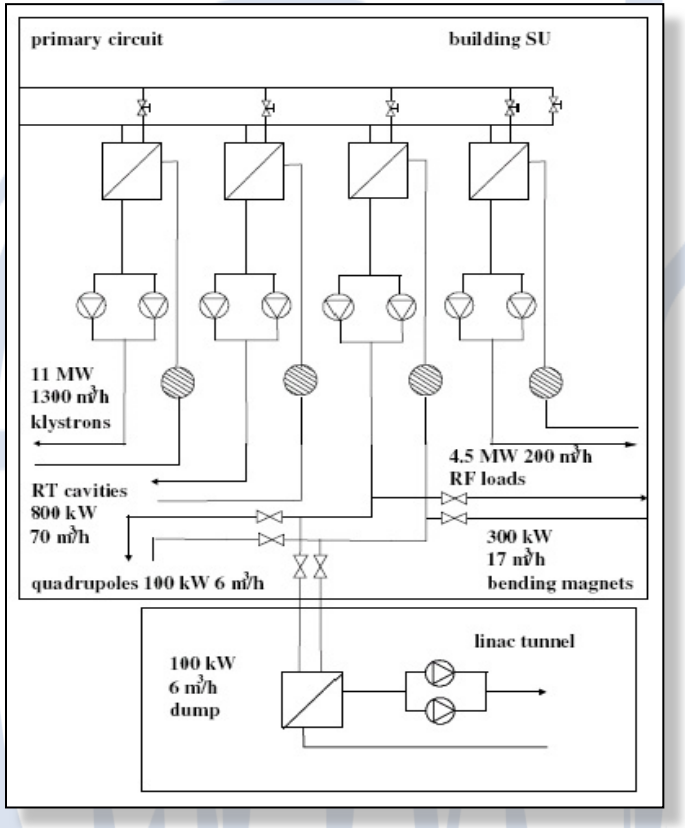

Table 5.5: Primary cooling needs and cooling-circuit parameters

	ΔT [K]	Power [MW]	ΔP [bar]	Flow rate [m³/h]
Primary cooling SPL	9	16.8	5	1600
Cryo-compressors	5.7	4.0	5	600

Table 5.6: Secondary cooling circuits

Item	Fluid	Power [kW]	P_{max} [bar]	ΔT [K]	Flow rate [m³/h]
Klystron	Demineralized water	11000	8.5	7.5	1300
RF loads	Demineralized water	4500	8.5	20	200
RT cavities	Demineralized water	800	8.5	10	70
Magnets (quadrupole)	Demineralized water	100	12	15	6
Magnets (bending)	Demineralized water	300	12	15	17
Dump linac	Demineralized water	100	12	15	6

*Schematic diagram of the main cooling plant

Complementary plants needed for
- **cooling the 4 horns, decay tunnel and beam dump**
- **cooling and recirculating helium inside the vessel**

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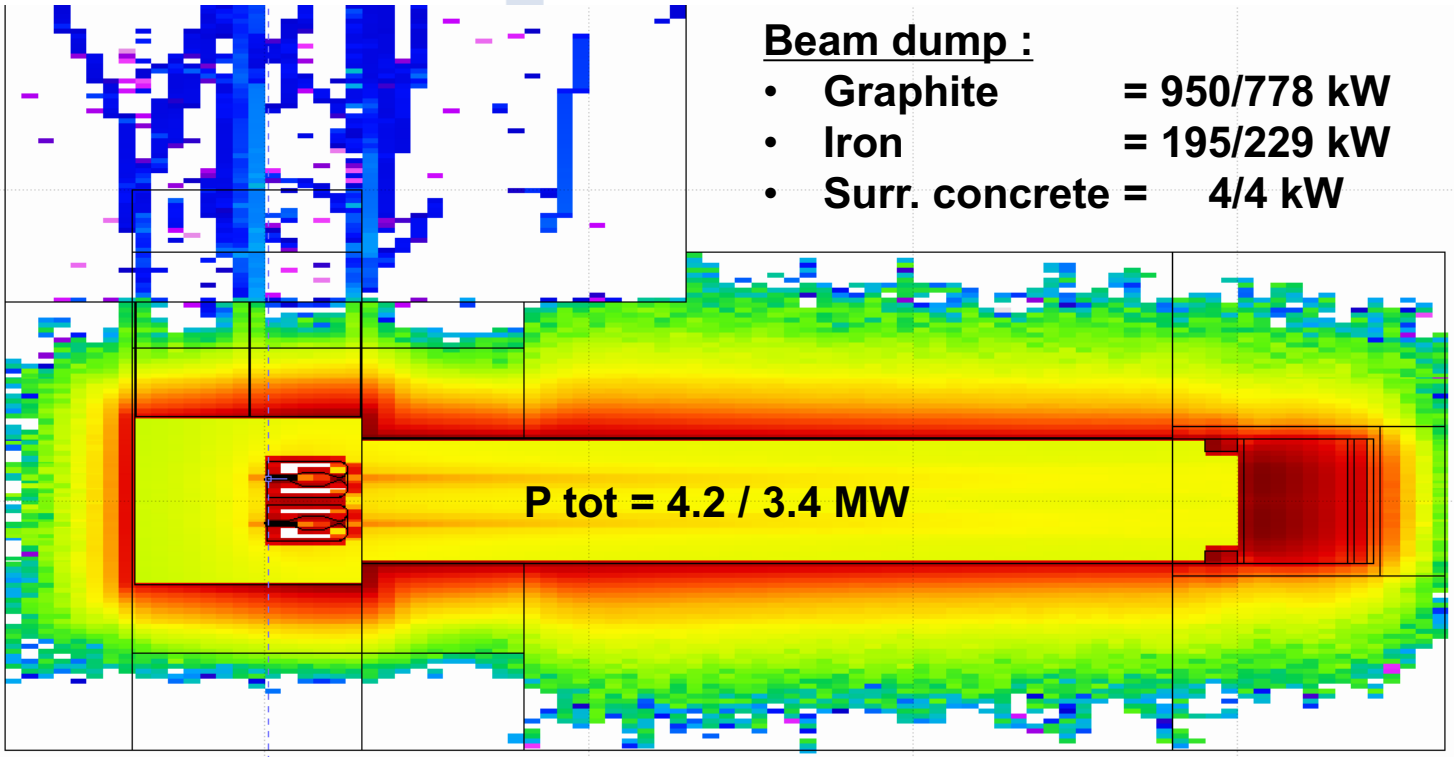

Beam dump :

- Graphite = 950/778 kW
- Iron = 195/229 kW
- Surr. concrete = 4/4 kW

Horns/Target gallery

- Iron = 613/437 kW
- Horn = 50/ 32 kW
- Target = 168/ 85 kW

Decay tunnel

- Iron vessel = 424/390 kW
- Upstream iron = 670/610 kW
- Surr. concrete = 467/485 kW

IPAC'17 Proceedings: E. Bouquerel et al, "*Energy deposition and activation studies of the ESSnuSB Horn Station*", MOPIK029

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COMPLEMENTARY INFRASCTURURE (FEEDBACK)

POWER SUPPLY:

Conceptual design of the SPL II, A high-power superconducting H- linac at CERN – CERN-2006-006 - 12 July 2006

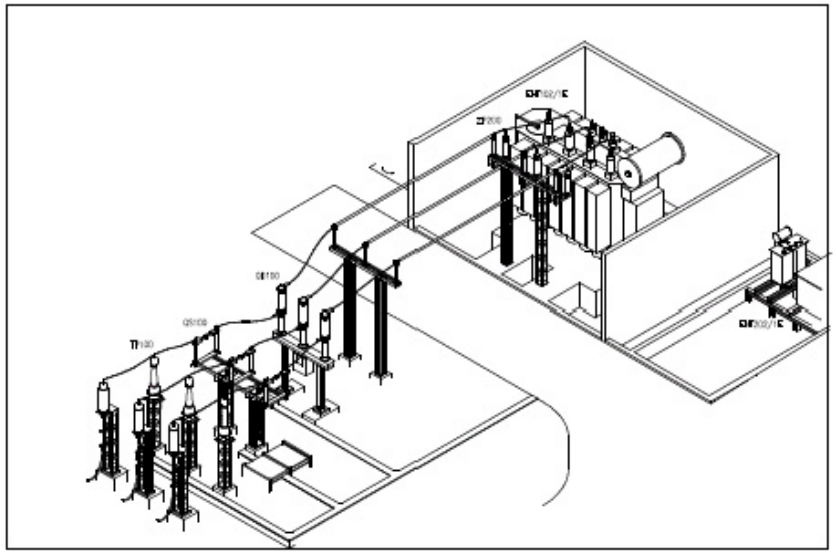

Fig. 5.9: Layout of CERN's standard 66/18 kV substation

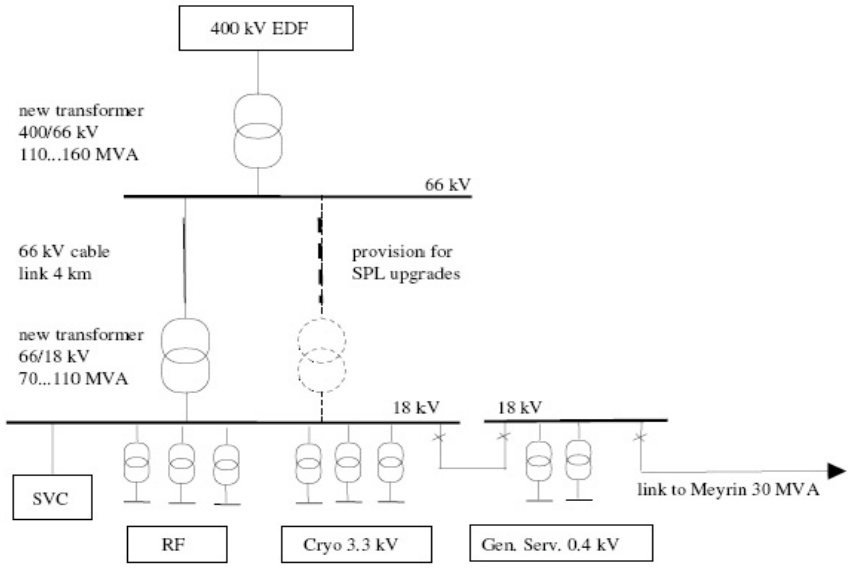

Fig. 5.10: Proposed electrical distribution system for the SPL

Complementary plants needed for the super beam infrastruture

- **alimentation station for the horns**
- **air conditioning installation**

Table 5.9: Electrical power requirements (MW) of the SPL (r.m.s. values)

Load	4 MW neutrino baseline	5 MW EURISOL baseline
RF system†	20.2	24.4
Cryogenics	3.6	4.4
Cooling and ventilation	4	4
Other	1	1
General services (surface + tunnel), racks, computers, controls	3	3
Total	32	37

† Including 30% margin to compensate for Lorentz-force detuning in the SC cavities.

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Radiological Risks

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TARGET STATION FACILITY

Chemical composition of Material*:

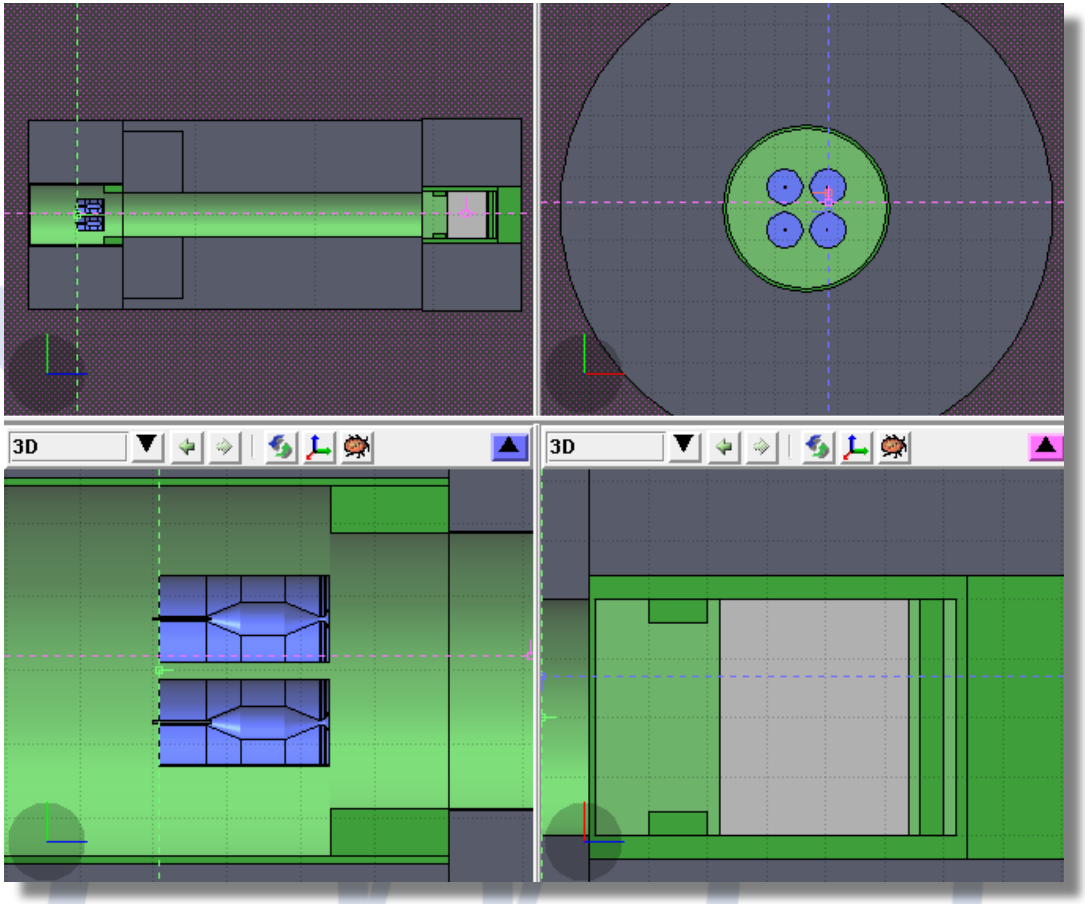
Target => Ti(100%)

Horn => Anticorodal 110 alloy
Al (95.5%), Si(1,3%), Mg(1,2%), Cr(0.2%), Mn(1%), Fe (0.5%), Zn(0.2%), Cu(0.1%)

Decay Pipe => Steel P355NH
Fe(96.8%), Mn(1.65%), Si(0.5%), Cr(0.3%), Ni(0.3%), C(0.2%)

Tunnel => Concrete
O(52.9%), Si(33.7%), Ca(4.4%), Al(3,49%), Na(1,6%), Fe(1.4%), K(1,3%), H(1%), Mn(0.2%), C(0.01%)

Surrounding Environment => Molasse
O(49%), Si(20%), Ca,(9.7%), Al(6.4%), C(5%), Fe(3.9%), Mg(3.2%), K(1%), Na(0.5%), Mn(0.1%)



Four horn station layout

*TO BE UPDATE FOR ESSNUSB

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RADIATION SIMULATION (FROM EURONU)

Beam Features

- Proton Energy : 4.5 GeV/c
- Intensity : 5.55 10^{+15} pps
- Irradiation time : 200 days

Target:

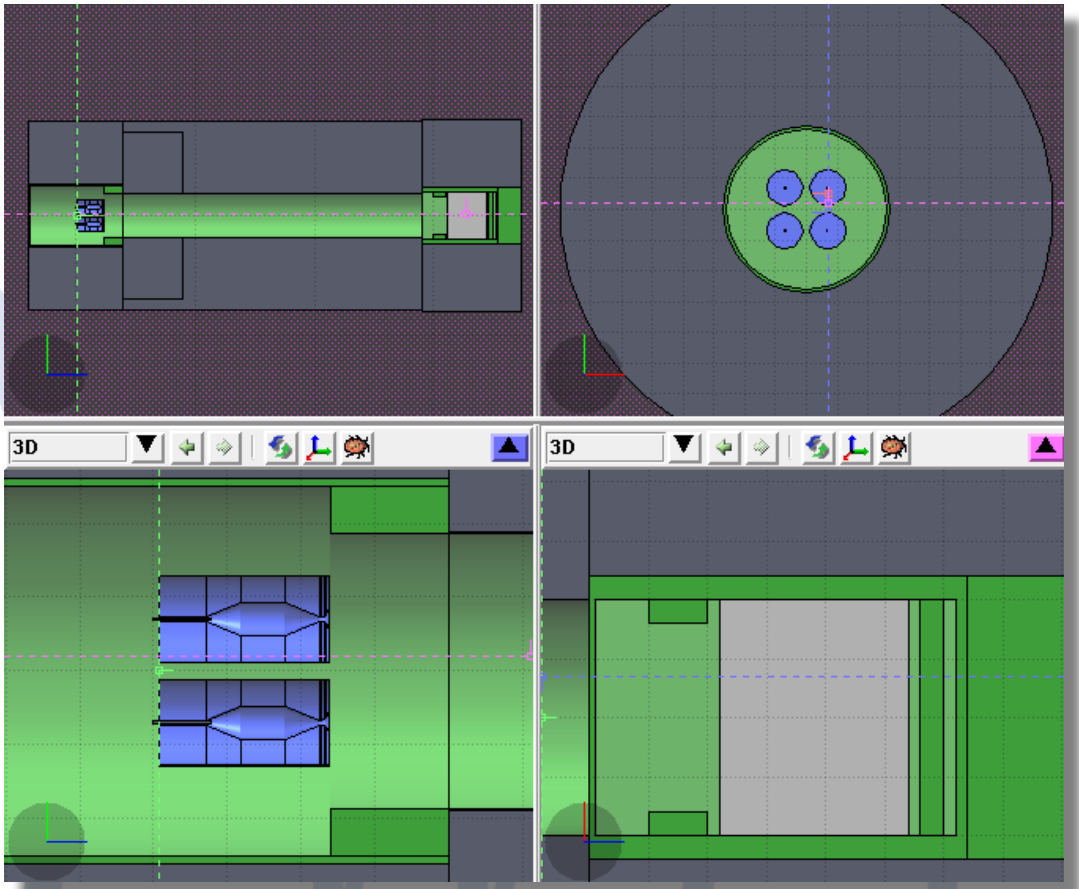
- Material : Titanium
- Density : 3.g/cm3
- Cylinder : 78 cm x 30mm

Horn:

- Material : Anticorodal 110

Activation Target + 4-Horns:

- Targets
- Horns
- Lateral Iron shield
- Lateral Concrete



⇒ Activation Study performed under FLUKA 2011.2.3

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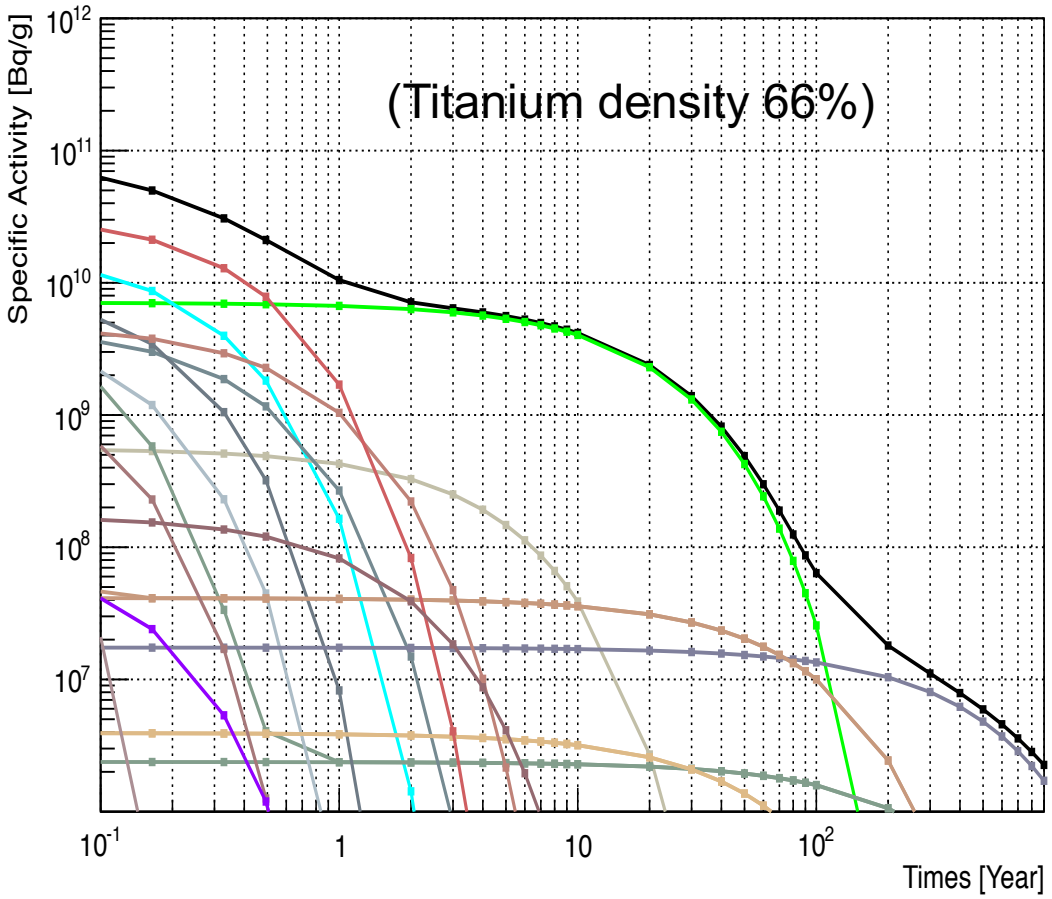
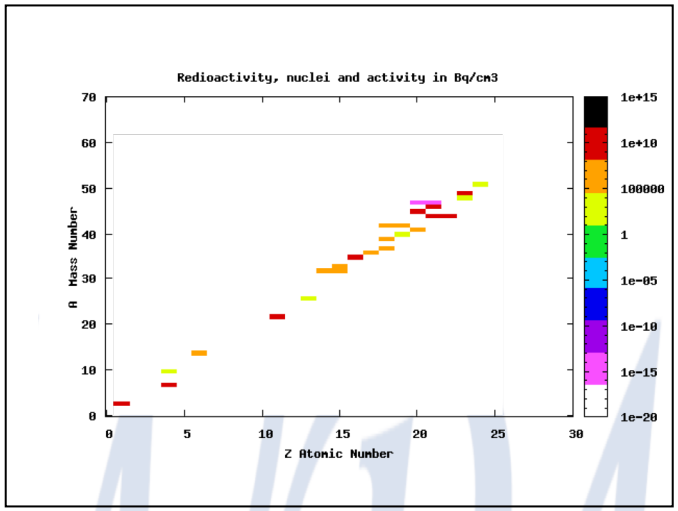
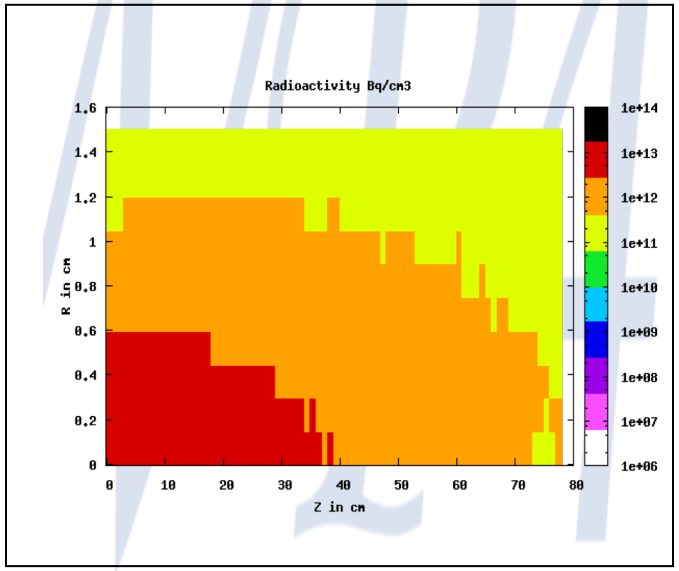
RADIATION SIMULATION (FROM EURONU)

Evolution of the target activity with cooling time:







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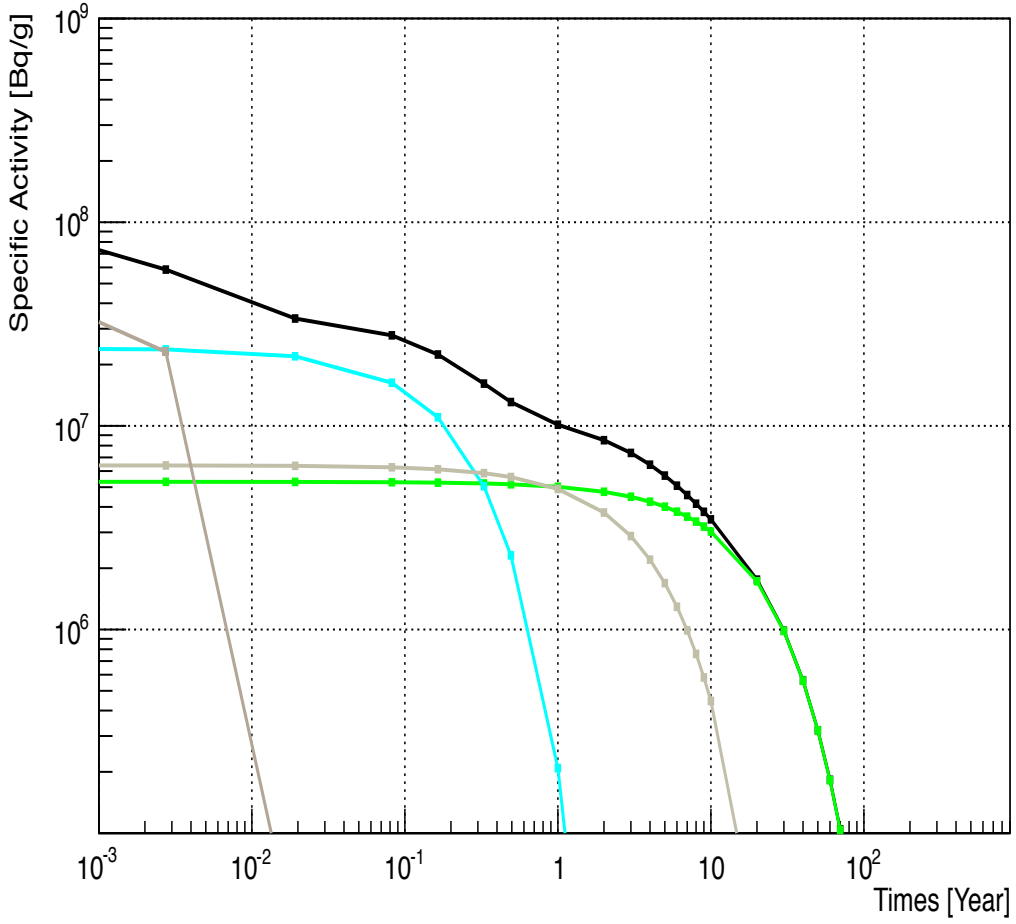
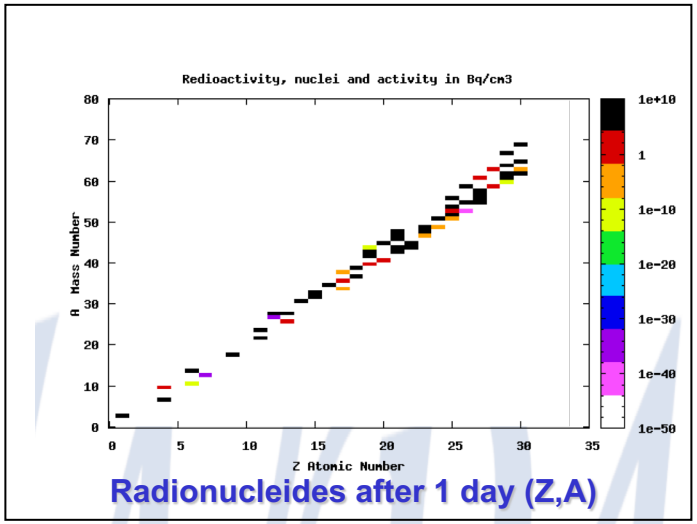
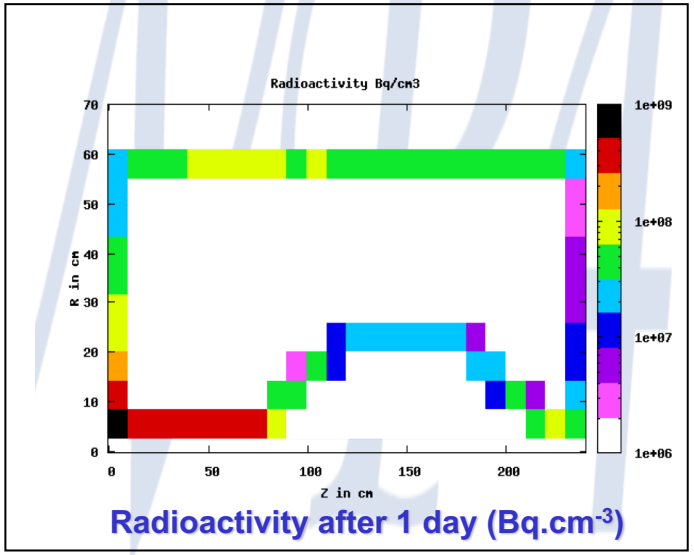
RADIATION SIMULATION (FROM EURONU)

Evolution of the horn activity with cooling time:





Radionucleides after 1 day (Z,A)



Radioactivity after 1 day (Bq.cm^{-3})

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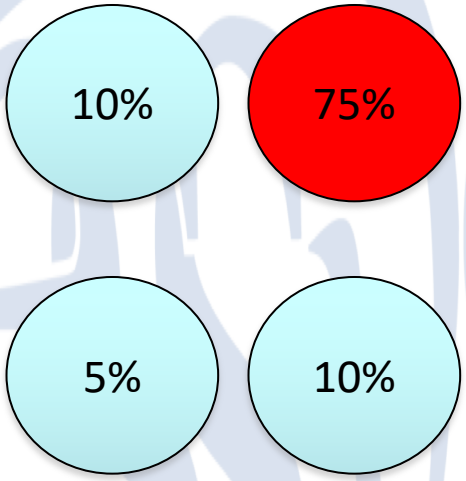
RADIATION SIMULATION (FROM EURONU)

Radionucleides in main horn (Cooling times 1 day) after 200 days of running:



Four Horns System

Top Right Horn Irradiated at 1MW

Radionucleides	$T_{1/2}$	Spec. Avt Bq/g	Vol. Act Bq/cm^3
^{7}Be	53.22 d	2.37E+07	6.5201e+12
^{24}Na	14,96 h	2.31E+07	6.3366e+12
^{22}Na	2,6 y	6.39E+06	1.7549e+12
^{3}H	12.312 y	5.31E+06	1.4582e+12
…	…	…	…

Activation Levels in the main Horn (1MW)

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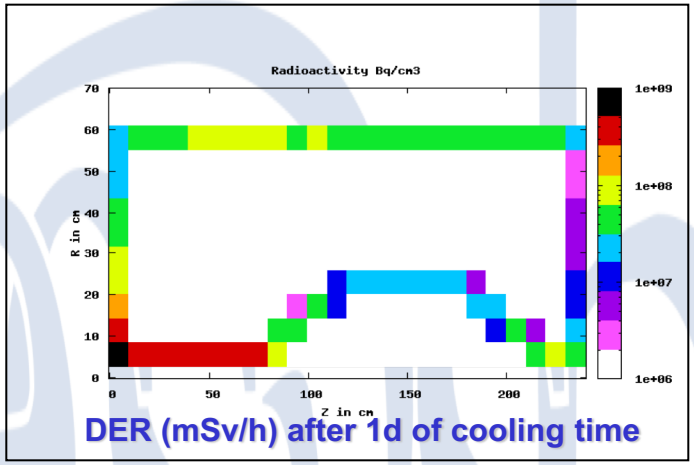
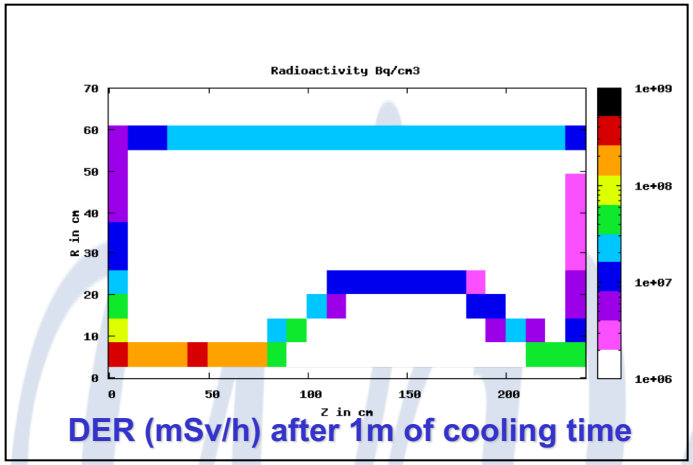
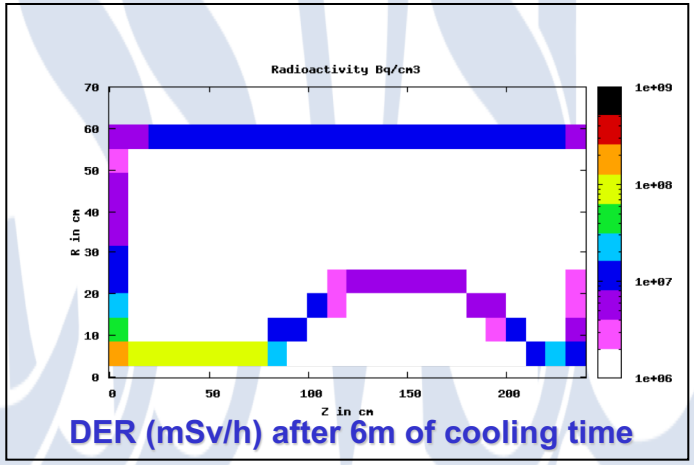
Evolution of the horn activity with cooling time:



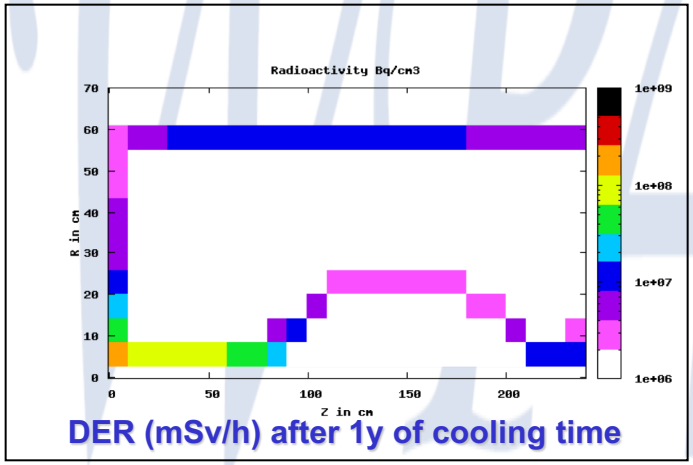
DER (mSv/h) after 1d of cooling time



DER (mSv/h) after 1m of cooling time



DER (mSv/h) after 6m of cooling time



DER (mSv/h) after 1y of cooling time

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RADIATION LAYOUT FROM EURONU

Simulation Parameters :

Beam Power : 4MW
Irradiation Times : 200 days
One Horn : Geometry Updated
Cooling times : 1d,1w,1m, 6m,1y, 10y

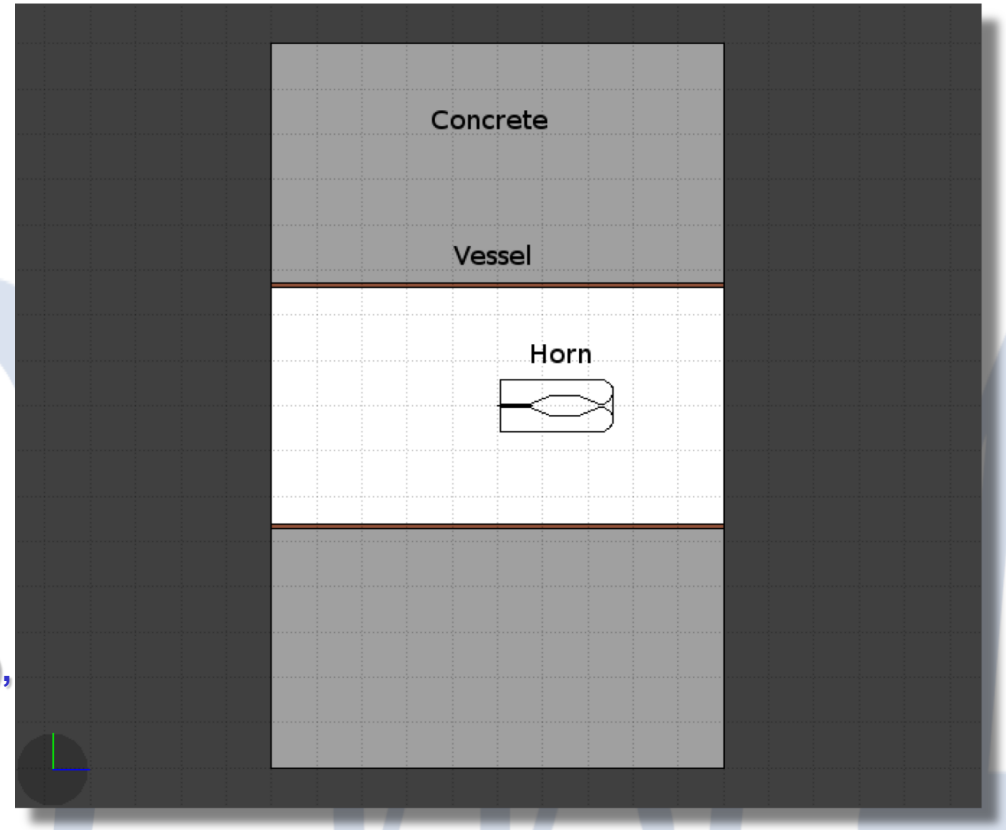
Chemical composition of Material:

Target => Titanium

Horn => Anticorodal 110 alloy
Al (95.5%), Si(1,3%), Mg(1,2%), Cr(0.2%), Mn(1%), Fe (0.5%), Zn(0.2%), Cu(0.1%)

Decay Pipe => Steel P355NH
Fe(96.8%), Mn(1.65%), Si(0.5%), Cr(0.3%), Ni(0.3%), C(0.2%)

Tunnel => Concrete
O(52.9%), Si(33.7%), Ca(4.4%), Al(3,49%), Na(1,6%), Fe(1.4%), K(1,3%), H(1%), Mn(0.2%), C(0.01%)



Radiation layout

Scoring Region : [-200,200]x[-200,200] [-500,500], cell dimension 20cm*20cm*20cm

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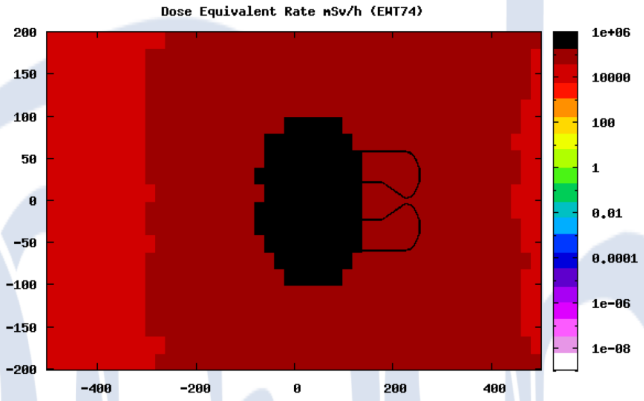
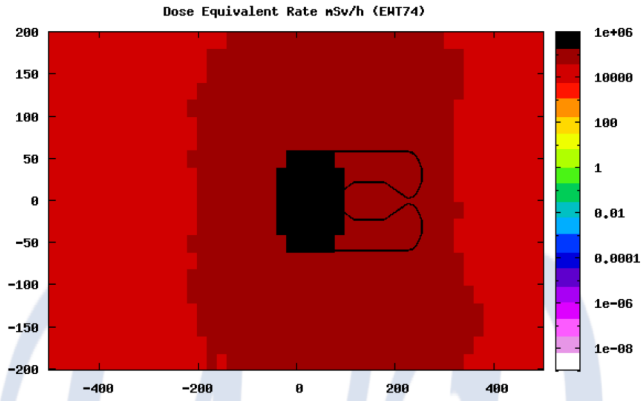
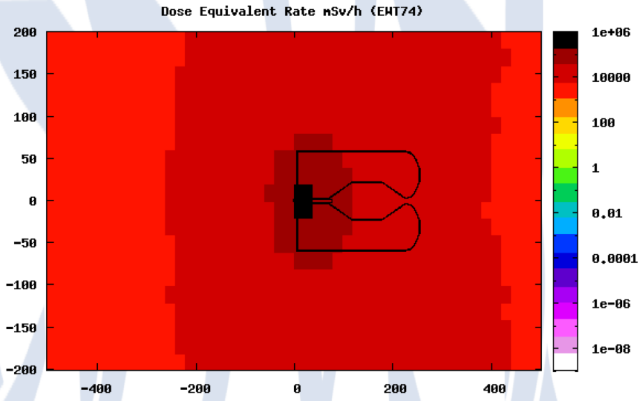
DOSE EQUIVALENT RATE (ALL LAYOUT)



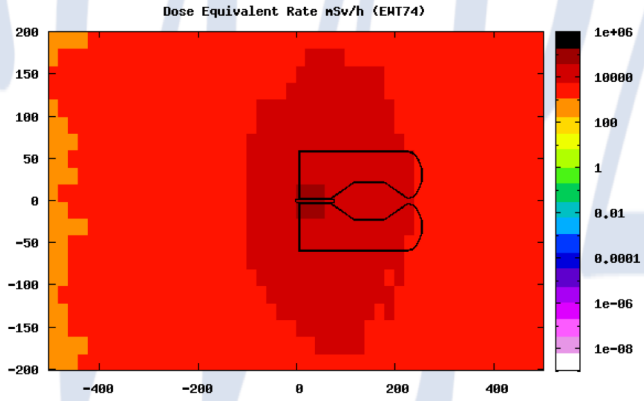
After 1day



After 1 week



After 6m



After 1y

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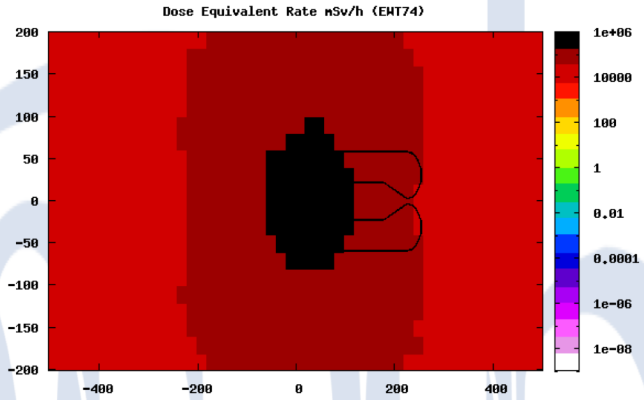
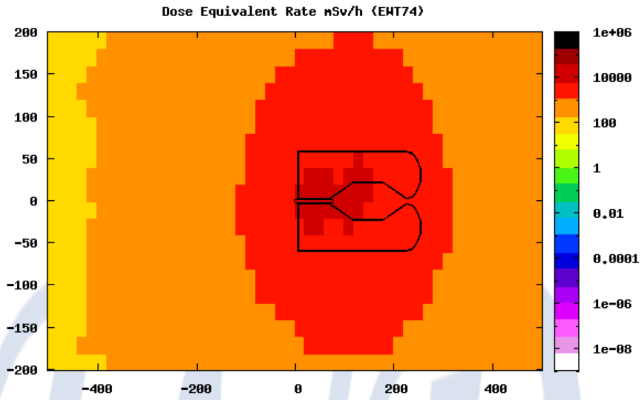
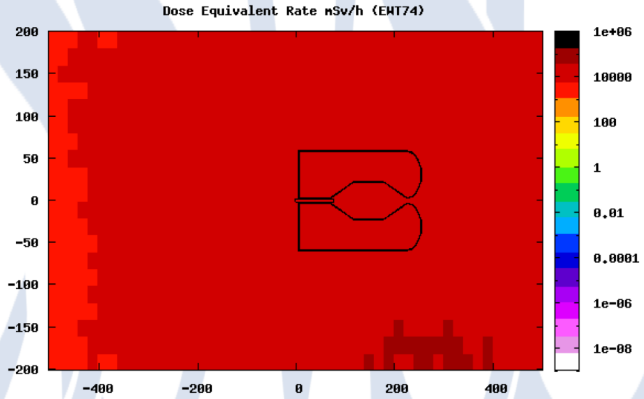
DOSE EQUIVALENT RATE CONTRIBUTION (COOLING TIME 1D)



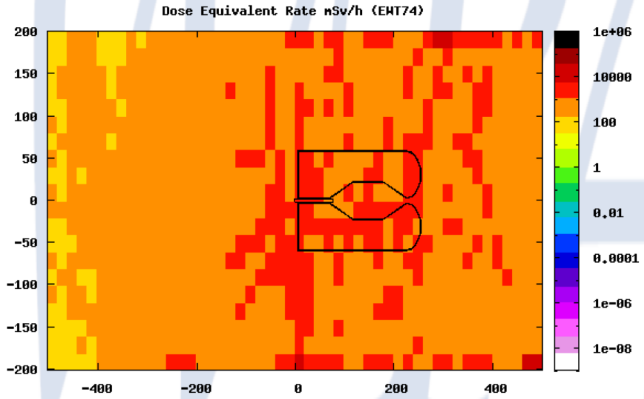
Target Contribution



Horn Contribution



Vessel Contribution



Tunnel Contribution

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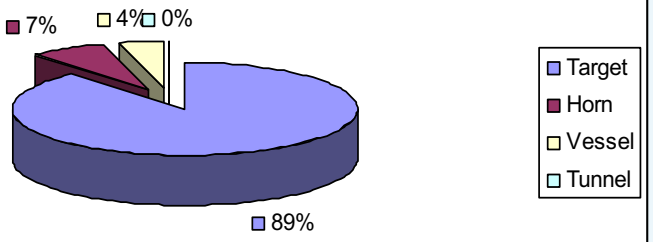
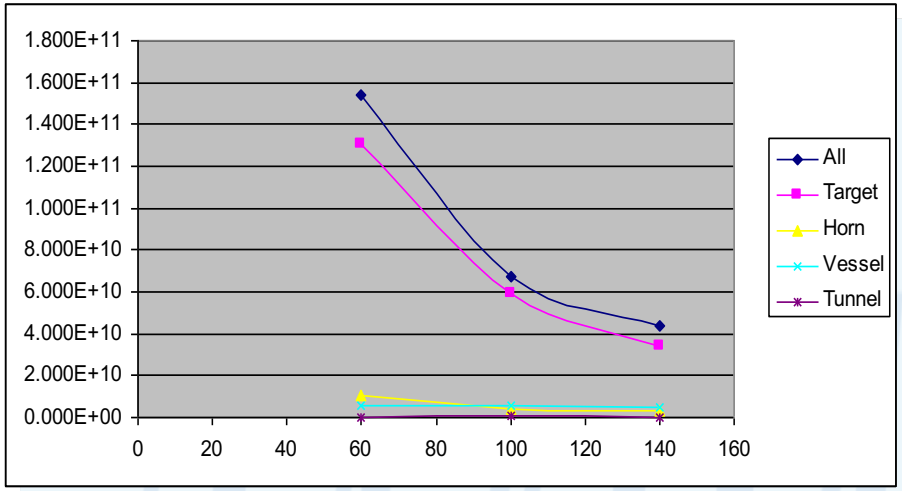
DOSE EQUIVALENT RATE CONTRIBUTION (COOLING TIME 1D)

From EUROnu



DER Contribution to the dose at 60cm



DER Evolution with distance

Fluka parameter Inputs :

Proton Energy : 4.5 Gev
Beam Intensity : 5.56*10^{15} protons
Irradiation times : 200 days

First Step : 10000 Histories
Second Step : 2000000 Histories

=> Increase statistics

Distance (cm)	All	Target	Horn	Vessel	Tunnel*
60	554400	469800	38304	21722.4	82.152
100	240948	213660	15933.6	20746.8	3664.8
140	157716	123372	11300.4	18478.8	418.32

*Vessel act as a shield

DER Estimation mSv/h

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NUCLEAR WASTE MANAGEMENT

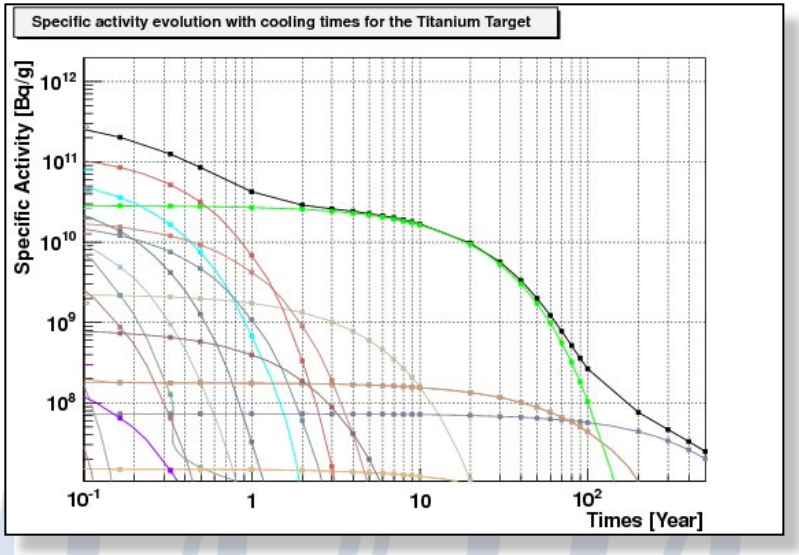
IAEA Waste Classification:

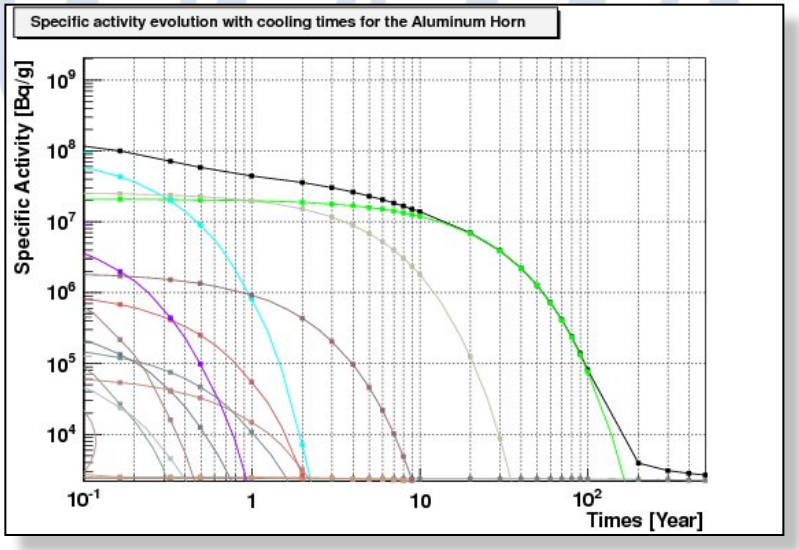
- **HLW** High Level Wastes
  - Highly Radioactive liquid
  - Heat Generating (>2kw/m3)
- **LILW** Low and Intermediate Wastes
  - **LL** Long Lived,
    - 'Half-life > 30 years
    - Long lived alpha emitters >400Bq/g average
    - >4000Bq/g individual package
  - **SL** Short Lived
    - Half-life <30 years
- **EW** Exempted Wastes

Clearance Levels: $$L_i = \min\left(\frac{1000}{E^i_\gamma + 0.1 * E^i_\beta}, \frac{D_w}{e^i_{inh}}, \frac{D_w}{e^i_{ing}}\right)$$

Clearance Index : $$CI = \sum_i^{Radionicleide} \frac{A_i}{L_i}$$

Classification of Radioactive Waste – Safety Series No 111-G-1.1





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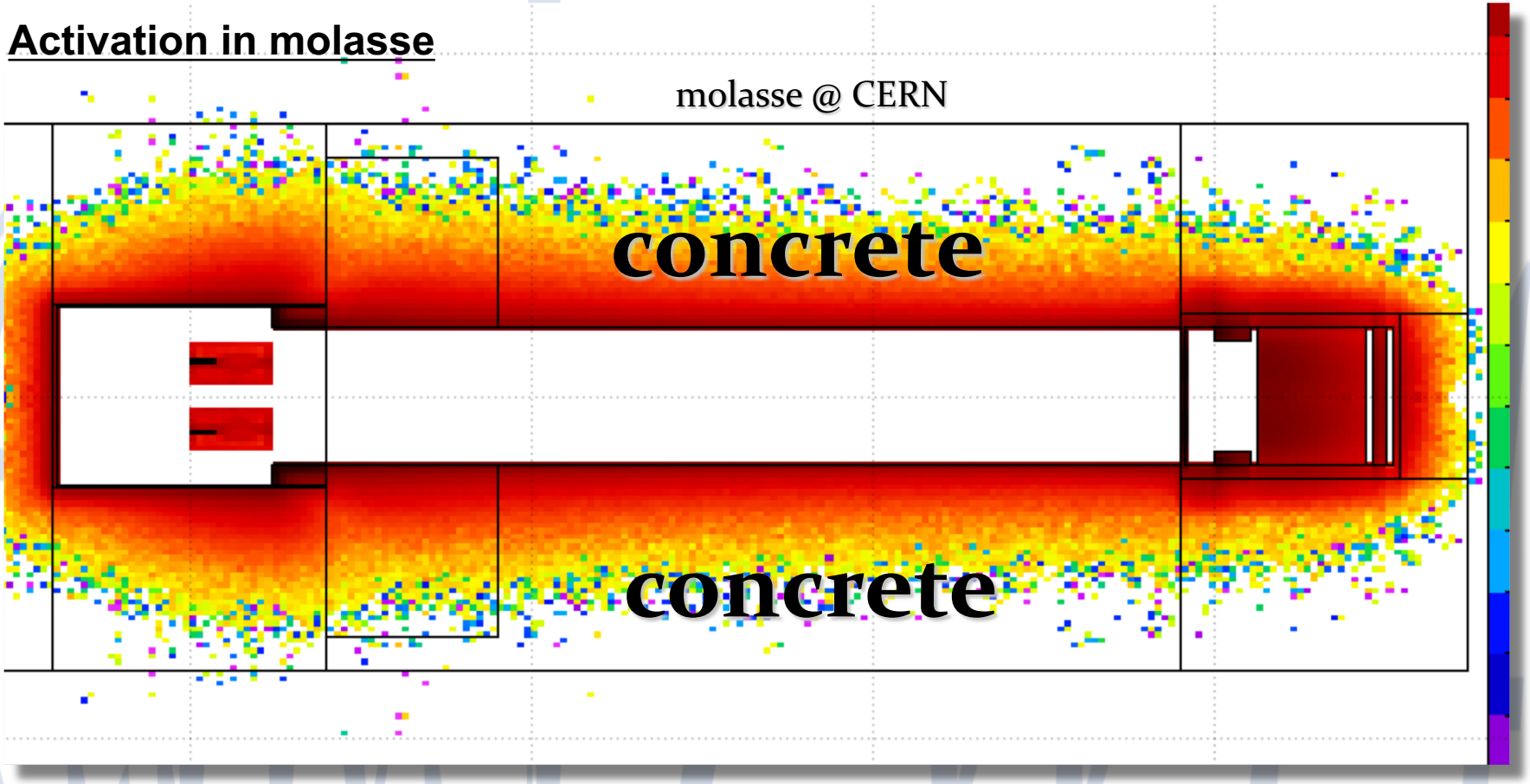
ENVIRONMENTAL IMPACT

Activation in molasse



of all the radionuclide's created ^{22}Na and tritium could represent a hazard by contaminating the ground water. Limits in activity after 1y=200days of beam:

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- **Outline**
  - **Adapt Study with ESSnuSB Parameters**
  - **Feedback from other experiments crucial !!!**
    - **Regular meeting with ESS people in charge of the safety should be organized**
    - **Safety Meeting between Safety people has been organized at CERN during EUROnu and should be renewed**