n_TOF: Radiation Protection study for target #3

Production readiness review – May 29th, 2019

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HSE-RP (Radiation Protection group)
Outline

- RP criteria for design of target #3
  - Operational RP aspects
  - Radioactive waste aspects
- N$_2$ cooling station
  - RP aspects
  - Effective dose calculations for activated N$_2$ leak
- Prompt dose rates
  - ISR8
  - EAR2
- Target #3 residual dose rate and comparison with target #2
- Conclusions
RP criteria for the design of target #3

- Feedbacks from target #2 operation
  - Talk\(^1\) given by J. Vollaire in June 2017
  - Tech. note\(^2\): “Preliminary conceptual design of the n_TOF spallation target #3 – RP aspects”

\(^1\)EDMS 1815607
\(^2\)EDMS 1597433
Operational RP aspects 1/2

- Avoid lead/water contact (water contaminated with lead corrosion/erosion/diffusion products)
  - $N_2$ gas as new coolant
  - $N_2$/lead contact: erosion/diffusion?
  - Main risk: internal contamination

- Reduce radiological risks during maintenance of the water circuits
  - Filters for new cooling circuit will be bag-in/bag-out

Typical radionuclides measured in water samples from the water cooling circuit for target #2 (3 months of cooling)

<table>
<thead>
<tr>
<th>Radionuclides</th>
<th>$T_{1/2}$</th>
<th>Specific activity [Bq/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>12.3 y</td>
<td>$6.6e7$ (4%)</td>
</tr>
<tr>
<td>Hf-172/Lu-172</td>
<td>1.87 y</td>
<td>$7.7e2$ (15%)</td>
</tr>
<tr>
<td>Lu-173</td>
<td>1.37 y</td>
<td>$8.6e1$ (24%)</td>
</tr>
<tr>
<td>Au-195</td>
<td>186 d</td>
<td>$3e2$ (13%)</td>
</tr>
<tr>
<td>Os-185</td>
<td>94 d</td>
<td>$3.3e1$ (17%)</td>
</tr>
<tr>
<td>Hf-175</td>
<td>70 d</td>
<td>$1.7e2$ (15%)</td>
</tr>
<tr>
<td>Hg-203</td>
<td>47 d</td>
<td>$1e1$ (37%)</td>
</tr>
<tr>
<td>Bi-207</td>
<td>31.6 y</td>
<td>$1.2e1$ (20%)</td>
</tr>
</tbody>
</table>

$^3$ Spectrometry reference: TOF49500
Liquid scintillation reference: 20190227_1546
Operational RP aspects 2/2

- **Minimize** personnel exposure for target handling (removal) or access in the vicinity of the target
  - RP study for mobile shielding ongoing
  - Detailed documentation for removal of target #2 drafted

- Verification of prompt dose rates in ISR8/EAR2 with new increased neutron production
  - Compliant with RP requirements (see later)

- Consider other development of n_TOF (irradiation facility)
  - RP study for mobile shielding ongoing

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4EDMS 1867100
RW aspects 1/2

- **Constraints for final disposal**
  - **Limit** the amount of **aluminum**
    - Chemical reactions between Al and mortar producing H$_2$
  - New target **vessel** made of low Co **stainless steel** (0.08% wt)
  - **Compatibility** with **PSI container** taken into account in the target design phase

**PSI container during the removal of target #1**
RW aspects 2/2

- **Minimize waste production** related to cooling station
  - **No cartridges** (no elimination pathway identified yet) ☑️
  - HEPA and charcoal filters probably candidates for incinerations ☑️

- **Ensure** that **technical acceptance criteria** for **elimination** of the target are respected
  - Discussion between PSI/NAGRA and CERN
N$_2$ gas cooling: RP aspects

- **Filtering**
  - HEPA for particulate/aerosols
  - Charcoal for volatile (Iodine, Po-210)
  - Filters under dynamic confinement

- **Routine leaks**
  - 5 L/h$^5$ (at blower location, outside the dynamic confinement)
  - Air extracted from the cooling station to ISR8 (not ventilated)
  - What’s the committed effective dose ($E_{50}$) to the personnel?

$^5$Conservative estimate provided by EN-CV
Calculation procedure

- **FLUKA** to score of **particle spectra** in $N_2$ around target
- **ActiWiz 3 Creator** to obtain **radionuclide yield** in $N_2$
  - $N_2$ density = 0.001465 g/cm$^3$
  - Beam intensity = 1.66e12 protons/s
  - 7 months of irradiation (no cooling)
- Python script to assess build up of radionuclides and **calculate $E_{50}$**
  - Breathing rate = 1.2 m$^3$/h
  - Dilution volume$^6$ = 1’400 m$^3$

$^6$Representative of the location of the n_TOF storage and conservative assumption
Results

- **Total exposure** (internal + external) at n_TOF storage
  - 400 hours/year (low-occupancy)
  - Effective dose of 40 μSv/year (0.01xCA)

- **Parametric study** performed as a function of the dilution volume

- **Accident case** study was performed too

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$E_{50}$ due to inhalation of activated N$_2$ as a function of the dilution volume (leak rate – 5 L/h)

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$^7$Below the annual limit of 1 mSv (and 0.05xCA) for non designated area, which is the current classification of ISR8, and below CERN optimization objective of 100 μSv/year
Conclusions on the $N_2$ leak study

- **Limitations**
  - Calculations include *only* radionuclides from direct activation of $N_2$ (C-11, N-13, Be-7, H-3 and C-14)
  - **Other radionuclides** from diffusion/erosion of Pb (e.g. H-3) target **NOT accounted for**
  - Beam intensity baseline: $1.66 \times 10^{12}$ protons per second
  - Leak rate: 5 L/h

- **RP monitoring**
  - 2 CD10 chambers (4 dedicated measurements positions already foreseen in the new cooling circuit)
  - Paper filter to measure aerosols

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*FLUKA geometry of a CD10 differential chamber (courtesy of H. Vincke)*

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*Thanks to F. Dragoni (EN-CV) and M. Widorski (HSE-RP) for their support*
Prompt dose rate: ISR8

- FLUKA simulations\(^9\)
  - 1.66e12 protons/s
  - Importance biasing

- **ISR8 currently non-designated area** (low-occupancy)

- **Prompt** dose rate: < 0.5 µSv/h
- **Annual** dose: < 100 µSv
- N\(_2\) leak exposure not taken into account
- **RP measurements** foreseen during n_TOF commissioning

\(^9\)Thanks to J. Vollaire (HSE-RP) for the input file
Prompt dose rate: EAR2

- During design of EAR2 envelope case considered\(^\text{10}\)
- **Comparison** of target#2 and #3 neutron spectra at the same location\(^\text{11}\)
- Target #3 a **factor of 2** higher dose (and fluence)
- **Operational RP measurements** in 2018 show a max. of **0.4 uSv/h in EAR2** (lasted 1 day)

\(^{10}\)Neutron intensity emerging from collimation system multiplied by 3 (EDMS 1509347)

\(^{11}\)Thanks to V. Vlachoudis and L. A. Damone (EN-STI)

\begin{tabular}{|c|c|c|c|c|}
\hline
Emin [MeV] & Emax [MeV] & Design study [Sv/7e12 protons] & Target #2 [Sv/7e12 protons] & Target #3 [Sv/7e12 protons] \\
\hline
1e-9 & 1e-3 & 4.1e-5 (2\%) & 9.8e-5 (2\%) & 1.0e-4 (1\%) \\
1e-3 & 1 & 8.5e-4 (46\%) & 1.8e-3 (44\%) & 3.5e-3 (43\%) \\
1 & 20 & 7.9e-4 (43\%) & 1.9e-3 (44\%) & 3.8e-3 (47\%) \\
20 & 1e4 & 1.8e-4 (9\%) & 9.9e-4 (9\%) & 6.7e-4 (8\%) \\
Total & & 1.9e-3 & **4.2e-3** & **8.1e-3** \\
\hline
\end{tabular}
Target residual dose rate

- **Stainless steel** with 0.1% wt cobalt
- 10 years of operation
  - Including one LS of 1 year
- **Residual dose** rate for several cooling times
  - 6 months
  - 3 years
  - 10 years
  - 30 years

![Graph showing 2D and 1D residual dose rates after different cooling times (top)](image)
Target residual dose rate

1D residual dose rate after different cooling times (side)

2D residual dose rate after different cooling times (side)

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Target #3 vs Target #2 residual dose rate

1D residual dose rate after 6 months for target #2 and target #3 (top)

1D residual dose rate after 6 months for target #2 and target #3 (side)
Target residual dose rate

- Cooling time: 6 months vs 3 years results in about a factor of 2
- **Final disposal** will require (thick) shielding (2 mSv/h requirement\(^{12}\))
- **Remote handling** for optimization of collective/individual dose for target #3
- **Possibility** to separate the **top plate** of the target frame

\(^{12}\)Requirement for the transport (ADR) and acceptance criterion from PSI
Conclusions 1/2

- Paramount feedback from operation of target #2
  - Extensive documentation and knowledge available\textsuperscript{13}
  - Taken into account in the conceptual design for target #3

- What about N\textsubscript{2} cooling?
  - No radioactive water anymore
  - No more cartridges (maintenance dose and unknown elimination pathway)
  - New system requires dedicated monitoring (leaks, diffusion from Pb to N\textsubscript{2})

\textsuperscript{13}Thanks to J. Vollaire and J. F. Gruber (HSE-RP) and to EN-STI-TCD section
Conclusions 2/2

- **Prompt dose rate**
  - Compliance with CERN radiation area classification (calculations)
  - RP measurements will be performed for final area classification and to benchmark simulations

- **Target residual dose rate**
  - Effort from EN-STI-TCD to optimize target design: Al vs stainless steel and cobalt content
  - Dose rate for removal will remain high: remote handling
  - Dose rate for final disposal requires additional (thick) shielding to comply with limits for transport (separate top plate of the frame)
Prompt dose rate in EAR2

- PAXNT221 located in the preparation room of EAR2
- Average dose rate during operation in 2018: 0.2 μSv/h
- Preparation room is Simple Controlled Radiation Area (10 μSv/h)
RP monitoring at n_TOF

- **Interlock on the beam intensity**
  - Measured by a BCT\(^a\) upstream of the target
  - Interlock threshold of \(1.6\times10^{12}\) protons per second

- **RP monitor\(^b\)** generates an alarm to CCC if a radiation dose corresponding to \(1.76\times10^{12}\) protons per second (10% more than BCT threshold) is measured
HRMT-46 experiment: RP analysis

- Gamma spectrometry on Pb blocks and comparison with FLUKA (ongoing)
- $N_2$: traces of Be-7, Co-58, Zn-65
- Smear test on Pb surface: traces of Be-7, Na-22, Co-57, Co-58, Zn-65 and Nb-95
Spikes in residual dose rate

- Spikes inside the target are due to the activation of the Al anti-creep structure