Third-generation CERN n_TOF spallation target: final design and examinations of irradiated prototype

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The CERN neutron Time-Of-Flight (n_TOF*) facility [1, 2]

- Neutron spallation target coupled to two neutron flight paths
- Driven by a pulsed proton beam from the CERN Proton Synchrotron (PS)
- Two Experimental AREas:
  - EAR1: 185 m downstream of the target
  - EAR2: 20 m above the target

<table>
<thead>
<tr>
<th>Beam parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse intensity</td>
<td>$8 \times 10^{12}$ protons per pulse</td>
</tr>
<tr>
<td>Momentum</td>
<td>20 GeV/c</td>
</tr>
<tr>
<td>Energy per pulse</td>
<td>32 kJ</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1.2 s</td>
</tr>
<tr>
<td>Average power</td>
<td>6.4 kW</td>
</tr>
<tr>
<td>Pulse length</td>
<td>7 ns (RMS)</td>
</tr>
<tr>
<td>Peak power</td>
<td>1.5 TW</td>
</tr>
<tr>
<td>Beam size</td>
<td>15 mm (1σ)</td>
</tr>
</tbody>
</table>

* https://ntof-exp.web.cern.ch
The third-generation n_TOF target [3, 4]

- Six pure lead slices (>99.99 wt%)
- Cooled by nitrogen gas
- Al-6082-T6 anticreep support structure
- Low-cobalt stainless-steel vessel
- Two Al-5083-H112 water moderators filled with:
  - Demineralised water
  - Borated water
- EAR1 moderator bonded to stainless-steel vessel by explosive bonding

Max. temperature (FEM simulations) during three 36 s supercycles at periodic regime. Beam sizes of 15 mm and 25 mm (1σ along x and y). The worst-case scenario is obtained with six consecutive pulses in a single supercycle.

Beam irradiation experiment (CERN HiRadMat facility [5])

- Reduced-scale prototype \((10\times10\times50 \text{ cm}^3)\)

- Short and high-intensity beam pulses coupled with pure lead low resistance to plastic flow induce plastic stress wave propagation in the material.

- The beam parameters have been chosen to induce a fatigue damage in the prototype comparable to the one in the target at the end of its lifetime.

- Post-irradiation examinations:
  - Neutron tomography at Paul Scherrer Institut (PSI), Switzerland → No internal voids
  - Metrological measurements → Permanent deformations on the surface (up to 115 \(\mu\text{m}\))
  - Brinell hardness → Unhardened material

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**Beam parameters (SPS beam)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse intensity</td>
<td>(4.5\times10^{10}) protons per pulse</td>
</tr>
<tr>
<td>Momentum</td>
<td>440 GeV/c</td>
</tr>
<tr>
<td>Beam size</td>
<td>4 mm (1(\sigma))</td>
</tr>
<tr>
<td>Number of pulses</td>
<td>1500</td>
</tr>
<tr>
<td>Temperature range</td>
<td>100 - 140 (^\circ\text{C})</td>
</tr>
</tbody>
</table>

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Stress relaxation tests

Uniaxial tests:
- cyclic strain controlled (up to ±1.5% strain)
- strain rate 0.1 s⁻¹
- followed by strain-holding for 20 minutes

Possibly due to stress relaxation and hardening recovery (creep, static recovery, recrystallization), especially relevant at 100-140 °C

Hardness tests
Irradiated lead blocks seem unhardened
Conclusions

- The final design of the third-generation neutron spallation target for the CERN n_TOF facility has been presented.
- A prototype of the target has been subjected to a beam irradiation test in the HiRadMat facility at CERN.
- Post-irradiation examinations, including neutron tomography, did not reveal any internal void.
- Mechanical tests have shown sensible stress relaxation effects even at room temperature, confirmed by hardness measurements on the irradiated blocks.
- Despite being a soft material with low resistance to plastic flow, pure lead remains the best candidate for the n_TOF target. Besides providing the best physics performance, it responds well to the high-intensity beam impacts from the PS:
  - Sensitive to plastic deformations and creep (needs to be contained)
  - It does not develop internal voids
  - Residual stresses due to thermal shocks are quickly relaxed thanks to recovery and recrystallization phenomena at the operating temperature (100-140 °C).
- The target has been installed in the facility in the first half of 2021
- Commissioning with beam will start in July 2021.
Thank you for your attention