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

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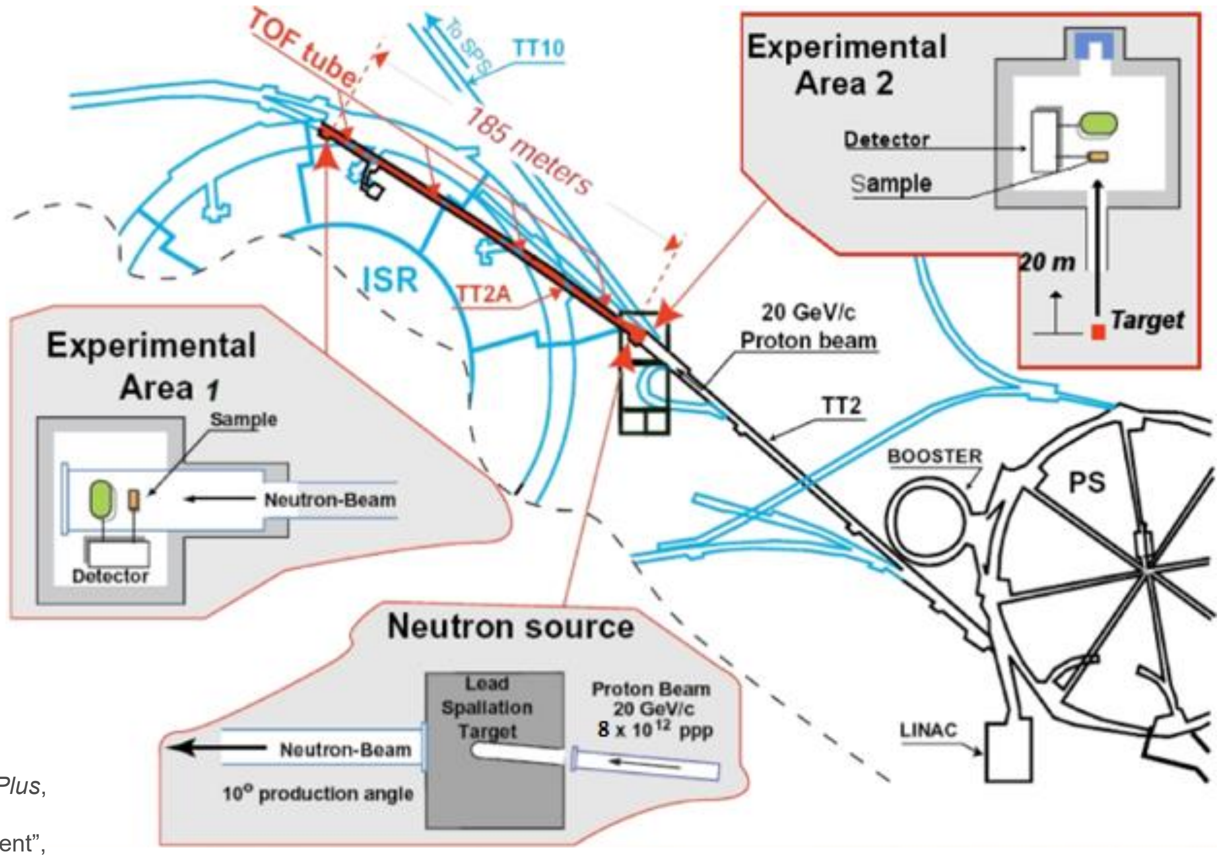
The CERN neutron Time-Of-Flight (n_TOF*) facility [1, 2]

- 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

Beam parameters	
Pulse intensity	8×10^{12} protons per pulse
Momentum	20 GeV/*c*
Energy per pulse	32 kJ
Repetition rate	1.2 s
Average power	6.4 kW
Pulse length	7 ns (RMS)
Peak power	1.5 TW
Beam size	15 mm (1σ)



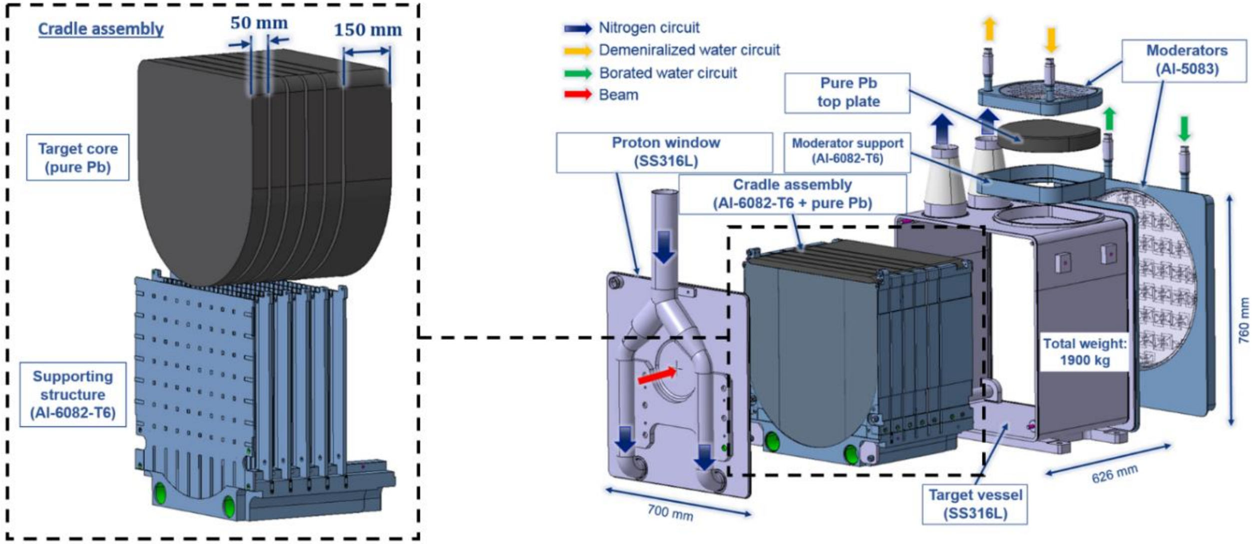
* https://ntof-exp.web.cern.ch

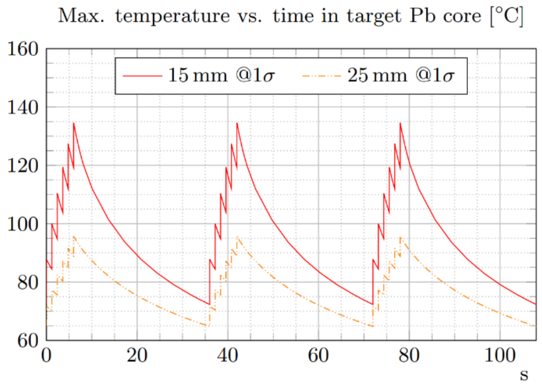
[1] F. Gunsing *et al.*, "Nuclear data activities at the n_TOF facility at CERN", *Eur. Phys. J. Plus*, vol. 131, no. 10, Art no. 371, Oc. 2016. doi: 10.1140/epjp/i2016-16371-4

[2] F. Mingrone *et al.*, "The CERN n_TOF facility: a unique tool for nuclear data measurement", *EPJ Web Conf.*, vol. 122, Art no. 05001, Jun. 2016. doi: 10.1051/epjconf/201612205001

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





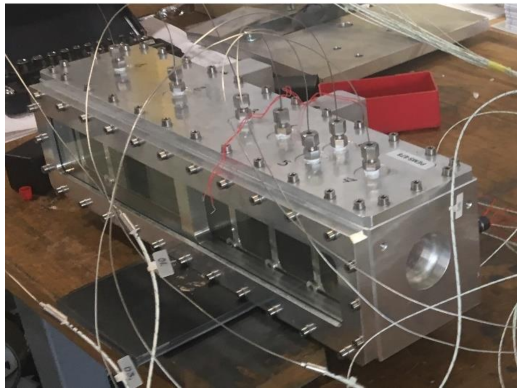
Max. temperature (FEM simulations) during three 36 s supercycles at periodic regime. Beam sizes of 15 mm and 25 mm (1σ along x and y). The worst-case scenario is obtained with six consecutive pulses in a single supercycle.

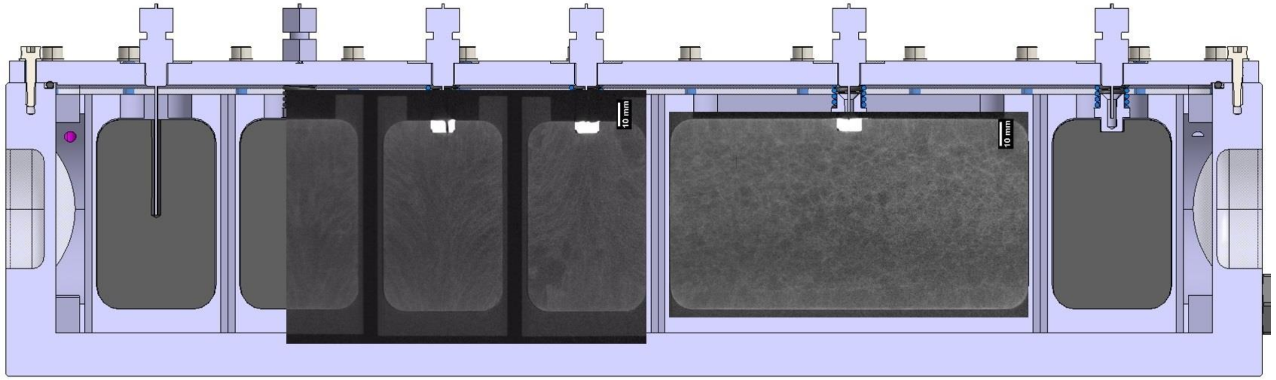
Third-generation n_TOF target before installation in the beamline.

[3] R. Esposito and M. Calviani, "Design of the third-generation neutron spallation target for the CERN's n_TOF facility", *J. Neutron Res.*, vol. 692, no. 2-3, pp. 221-231, 2020. doi: 10.3233/JNR-190137
[4] M. Calviani *et al.*, "n_TOF neutron spallation Target #3 N2 cooled bare Pb core – Engineering Design Report", CERN, Geneva, Eng. spec. TOF-TAR-ES-0002, 2017.

Beam irradiation experiment (CERN HiRadMat facility [5])

- Reduced-scale prototype (10×10×50 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 μm)
  - Brinell hardness → Unhardened material

Beam parameters (SPS beam)	
Pulse intensity	4.5×10^{10} protons per pulse
Momentum	440 GeV/*c*
Beam size	4 mm (1σ)
Number of pulses	1500
Temperature range	100 - 140 °C

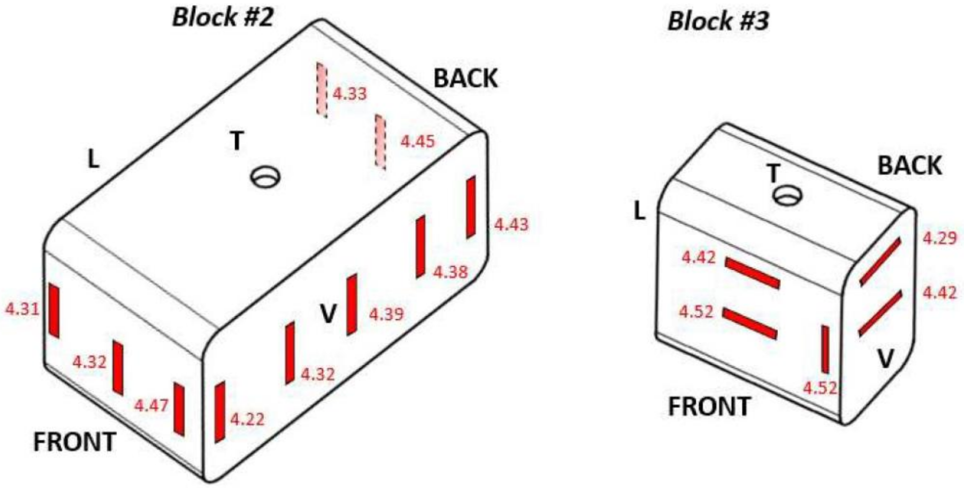
[5] I. Efthymiopoulos *et al.*, "HiRadMat: a new irradiation facil-ity for material testing at CERN", in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastián, Spain, Sep. 2011, pp. 1665-1667.

Stress relaxation tests

Hardness tests

↓

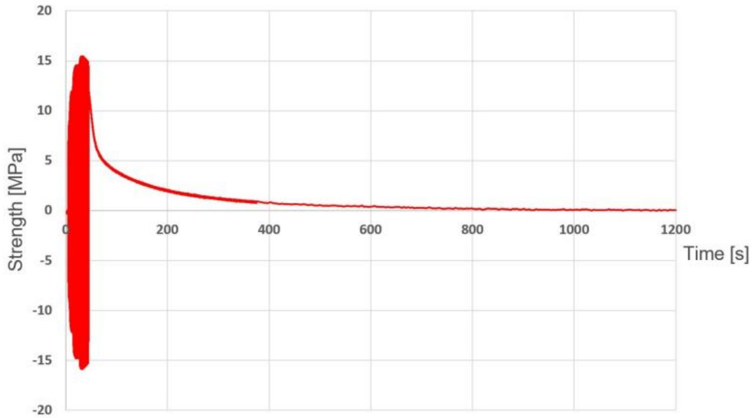
Irradiated lead blocks seem unhardened



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

Uniaxial tests:

- cyclic strain controlled (up to ±1.5% strain)
- strain rate 0.1 s^{-1}
- followed by strain-holding for 20 minutes



- Plateau at 15 MPa after 120 cycles
- Measured stress already recovered after 7 minutes at room temperature

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