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Design study for a new spallation target of the n_TOF facility at CERN

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Abstract. The n_TOF facility is a time of flight spectrometer dedicated to measuring neutron capture and fission cross sections. The neutron source consists on a lead target bombarded by a high energetic proton beam. After finishing a successful period of data taking by the end of 2004, it has been decided to upgrade the neutron spallation source with a cladded target. In this study, Monte Carlo simulations are reported for the assessment and comparison of the neutron and gamma fluxes from different target configurations. In addition, the plans for a second vertical measuring station with a flight path of 20 m above the spallation target have been considered in the simulations as well. Results for the energy deposition and the target heating are also presented.

1 Introduction

The n_TOF (neutron time-of-flight) facility consists of a pulsed proton beam (7×10^{12} protons per pulse, 6 ns width, 20 GeV/c) impinging on a $80 \times 80 \times 60\,cm^3$ lead target. The neutrons produced by spallation reactions reach the detector station (experimental area, EAR-1) at 185 m through an evacuated tube. In EAR-1, neutron induced reactions are being studied by using the time-of-flight technique. The facility is unique for its high instantaneous flux (of the order 10^6 neutrons/cm^2/proton pulse at 185 meters), an excellent energy resolution, low background conditions, and very low duty cycle. This combination allows one to measure neutron capture and fission cross-sections in the energy range from 1 eV to 250 MeV with unprecedented precision. The data taking at the facility for the n_TOF experimental programme covered the period from 2001 up to end 2004. By then it has been decided to upgrade the neutron spallation source with a cladded target in order to comply with security regulations and to optimize it for a possible future second experimental area. In order to achieve a solution for this problem, several geometries and structural material for the target block have been simulated. The insertion of a second neutron exiting window for a new experimental area (EAR-2) at 20 m vertical has been considered and simulated. The neutron flux obtained by proton-induced spallation in a lead and in a tungsten target was simulated using the Monte Carlo code MCNPX. All target systems were simulated and compared under the same conditions.

1.1 MCNPX code version

To simulate the n_TOF neutron source consisting of a proton beam of 20 GeV impinging on a lead target, it was necessary to use a non standard version of the MCNPX code featuring the transport of high energy hadrons and fragments and the simulation nuclear reaction mechanisms up to a few tens of GeV. The MCNPX version used is the 25HI7 [1].

1.2 Models and capabilities

The simulations were performed using the LAQGSM model [2]. This model uses the preequilibrium and evaporation physics from the CEM2k model [2] and has a number of improvements and refinements in the cascade and Fermi breakup models.

Both CEM2k and LAQGSM are able to describe fission reactions and production of light fragments heavier than ^4He (using the Generalized Evaporation Model code). This features permit to describe quite well a large variety of spallation, fission and fragmentation reactions at energies from 10 MeV to 800 GeV.

1.3 The lead target system

The description of the lead target geometry and materials implemented in MCNPX, is the same used in previous simulations [3] of the n_TOF neutron and gamma flux using the FLUKA code. The lead target consists of an $80 \times 80 \times 60\,cm^3$ volume submerged in water that works both as a cooling material and as a moderator to shape the neutron flux exiting the target.

1.4 The tungsten target system

The tungsten target consists of a $50 \times 50 \times 35\,cm^3$ volume, a scaled down version of the previously mentioned lead, target. The 5 cm of water in front of the target were kept unchanged. Also, the 2 cm of water surrounding the other faces of the

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tungsten block used for cooling were kept. The thickness of the Antico container is maintained and the gap between the proton beam line and tungsten target is the same as the one used in the lead target. The dimensions of the I-BEAMS (iron support for the target core) and the aluminum window have been adjusted to fit the new Antico container dimensions.

1.5 The tungsten target system with two windows

The tungsten target described above was modified to accommodate a second neutron exiting window on the top. The I-BEAM on the top of the tungsten target was removed and the Antico container dimensions have been adjusted on the top to allow a 5 cm thickness of water for moderation. The air inside the container was removed. The top window follows the geometry of the front window. All other aspects were unchanged.

1.6 Geometric comparison between targets

In the figure 1 it is possible to see the differences between both target systems (lead and tungsten) implemented in the MCNPX simulations. Figure 2 shows the tungsten target modified to accommodate a second neutron exit window on the top. This exit window is to source neutrons to the 20 m measuring station.

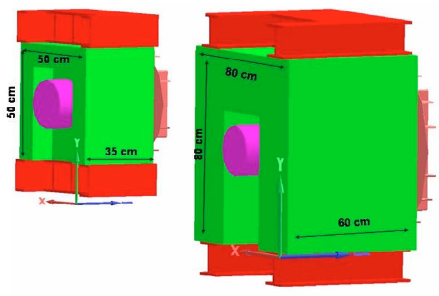

Fig. 1. From left to right, tungsten target and lead target at the same scale.

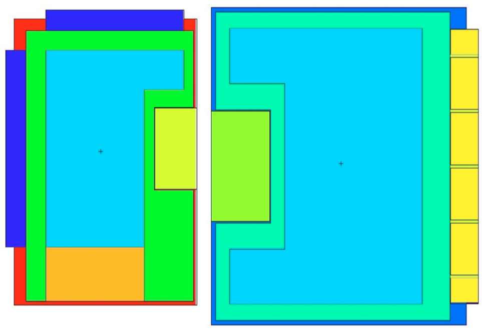

Fig. 2. Modified tungsten target to allow two EARs. From left to right, vertical cut showing the two aluminum windows (blue) and horizontal cut showing the aluminum window structure (yellow).

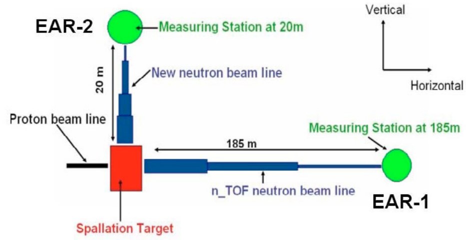

Fig. 3. Layout of the n_TOF facility with two EAR's.

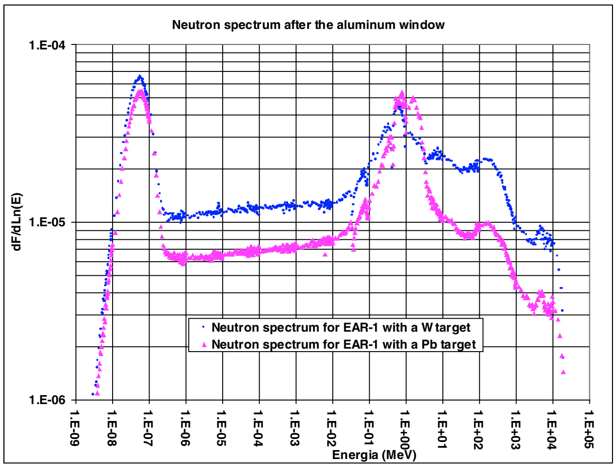

Fig. 4. Neutron spectra for the tungsten and lead targets.

2 Flux comparison

2.1 Tallying methodology

The neutron and gamma flux were tallied outside the aluminum window. Conditions on the exiting angle of the particles were applied. The spectra shown in figure 4 and figure 5 are obtained for particles exiting the aluminum window with a polar angle below 10° relative to the axis of the n_TOF neutron beam line. It must be recalled that only neutrons exiting the target with an angle below 1 mrad relative to the n_TOF beams line will reach the EAR-1 downstream. However, tallying such particles would require an unrealistic simulation time, in order to obtain accurate results. Tallying all exiting neutrons with angles smaller than 10° is an acceptable solution for obtaining a reasonable statistics and having a good approximation to the real flux shape at the very low angles previously mentioned. This method is also applied to score the neutron flux for EAR-2. The proton incident direction makes 10° in respect to the normal of the n_TOF beam line (serving the EAR-1) respecting the real setup conditions.

2.2 Neutron flux

The neutron flux simulated for both target material is plotted in figure 3 in isolethargic units normalized by source proton.

From figure 4 it is possible to see that the neutron fluence is almost a factor 2 higher for the tungsten target in the energy range of relevance for the n_TOF experiments (1 eV to 250 MeV).

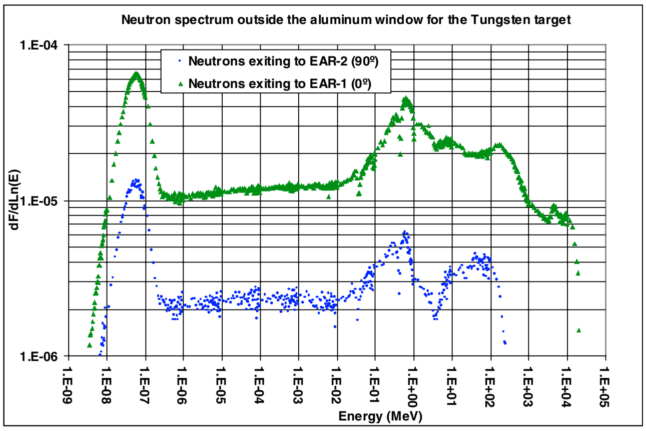

Fig. 5. Neutron spectrum for EAR-1 with the tungsten target modified (insertion of a second neutron exiting window in the vertical direction). Neutron spectrum for EAR-2 with the tungsten target modified.

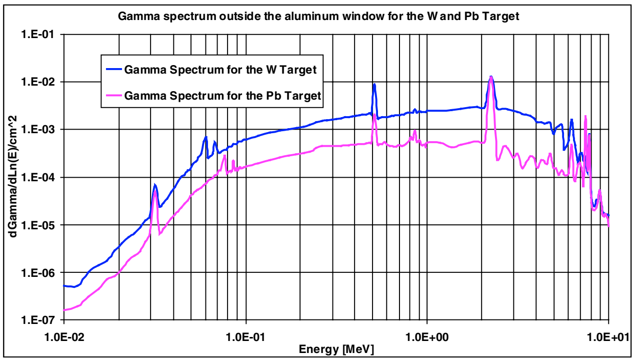

Fig. 6. Gamma spectra for the tungsten and lead targets.

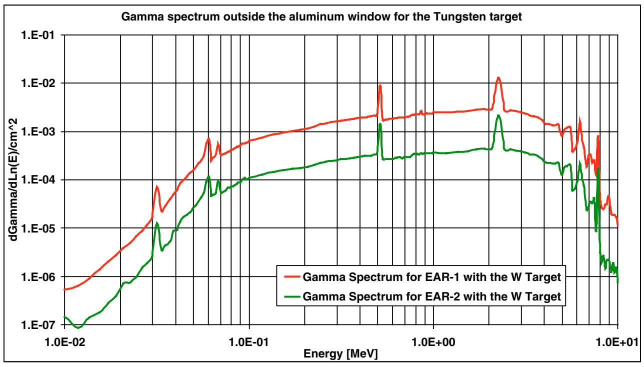

Fig. 7. Comparison of the gamma spectra for the tungsten target with two windows.

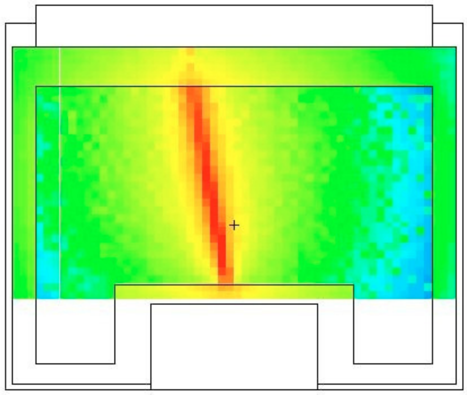

Fig. 8. Energy deposition on the tungsten target. Horizontal cut at proton bean entrance level.

Figure 5 shows that the inclusion of a second neutron exit window in the target system will not alter in a noticeable way the neutron flux in EAR-1.

2.3 Gamma energy spectra

The energy spectra (in isolethargic units per source proton) of the photons exiting the target and crossing the aluminum window are plotted in figure 6 for both lead and tungsten targets in the standard setup (only one neutron exiting window). As can be seen from figure 6, the tungsten target originates a much higher photon flux in the energy range of interest.

Figure 7 shows the gamma spectrum for the tungsten target with two windows. It is possible to see that the gamma background on the windows serving the 20 m measuring station is much smaller.

3 Changes on the target cooling system

One way of solving the transfer of spallation products into the cooling system is by replacing the coolant. The use of a coolant such as air will avoid the reactions between target materials and water. The other solution consists on cladding the target material with a more stable element such tantalum.

3.1 Energy deposition on the target

The replacement of the coolant is heavily constrained by the ability of remove the heat of the target [4]. The energy deposition of the proton beam on the tungsten target with tantalum cladding has been simulated and the corresponding cooling system modelled [5]. The results showed that the uses of materials like tungsten and tantalum allows a less critical cooling system making an air cooled target possible. The maximum target temperature using a cooling system consisting of air at 25° C travelling at a speed of 16.9 m/s through the faces of the target is 93° C. This value is far from the melting point of both tantalum and tungsten.

3.2 Replacement of the cooling water by air

The replacement of the coolant from water to air also allows the use of different moderator material. This possibility is very welcome, as it permits to adapt the facility to a wither variety of experimental situations. The new target setup consists of a tungsten target (50 × 50 × 35 cm^3) with a cladding layer of tantalum (0.1 mm). The moderators are two cylindrical blocks consisting of aluminium canning encapsulating the moderation material (water). The spectrum obtained with this

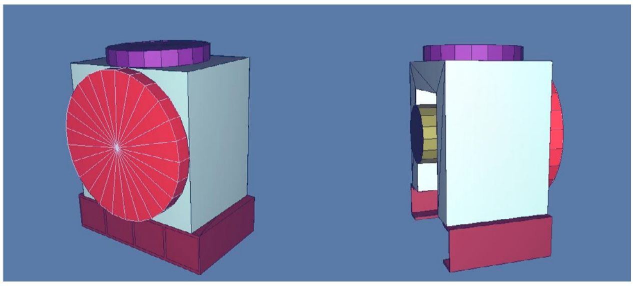

Fig. 9. Tungsten target with tantalum cladding and removable moderators.

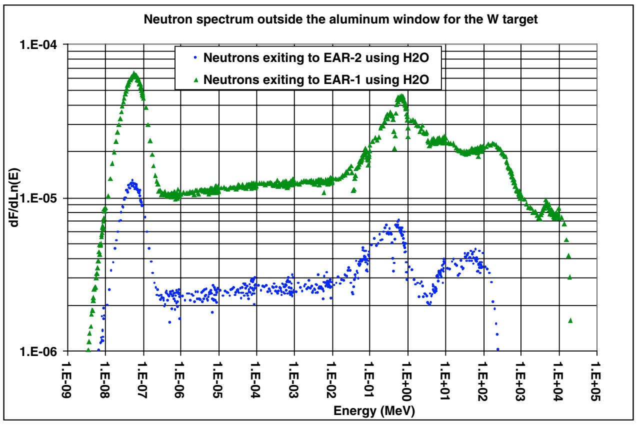

Fig. 10. Neutron spectrum for the tungsten target with tantalum cladding and removable moderators.

setup doesn't differ significantly from the one using the water as moderator and coolant. "Figure 9" shows the moderator setup and figure 10 shows the neutron flux obtained for the two EARs.

3.3 Introduction of a heavy water moderator

The use of a moderator material such as heavy water permits to have a different neutron spectrum. This spectrum is characterise by a very small thermal peak and a higher fluence around 100 keV.

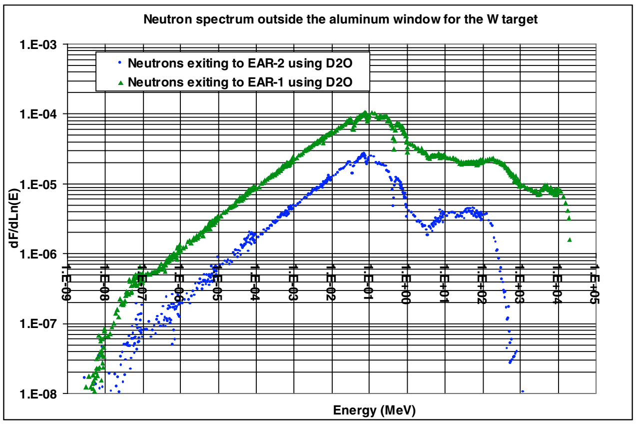

Fig. 11. Neutron spectrum for the tungsten target with tantalum cladding and removable moderators consisting of heavy water.

4 Conclusions

The results show a possible solution to eliminate the potential radiological hazard of having spallation products in the cooling system by using different structural material for the target and a different coolant. The setup consisting of a tungsten target with a tantalum cladding cooled with air and with removable moderator not only is a safer system from the radiological point of view but a more flexible one extending the capabilities of the n_TOF facility and addressing the needs for a second experimental area (EAR-2).

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