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# THE n_TOF FACILITY AT CERN: PRESENT STATUS AND FUTURE UPGRADES

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## ABSTRACT

The n_TOF facility is a spallation neutron source operating at CERN from 2001. It produces, thanks to the characteristics of the proton driver and of the massive Pb target, a wide energy, very high instantaneous neutron flux, which is employed for neutron-induced cross-section measurement. In this contribution some technical details of the spallation target design and operation will be explained, together with future perspective for the performances of the facility.

## 1. Introduction

The neutron Time-Of-Flight facility n_TOF at CERN [1] is an intense source of white neutrons, obtained by the spallation process of 20 GeV/c high intensity protons from the Proton Synchrotron (PS) impinging onto a solid lead target. The facility is fully operational since 2001 and by the end of 2004 the first phase of data taking was successfully terminated. After 4 years of stop due to radioprotection issues connected with the operation of the target, the n_TOF facility resumed operation in November 2008. It features a new lead spallation target with a more robust design a more efficient cooling, separate moderator circuit and a target area ventilation system. The facility has resumed operation in May 2009 and has undergone a new neutron beam characterization phase as well as performed two physics measurement. It is scheduled to restart in May 2010 after a major upgrade to the experimental area, which will enhance the measurement capabilities of the facility.

## 2. The renewed n_TOF Facility at CERN

### *2.1 The lead spallation target*

A complete investigation has been performed during 2007-2008 on the first spallation target, when it was removed from the pit and brought on the surface for visual inspection and for sample taking. As a consequence of the energy deposition and therefore of the high temperature at the beam interaction point, the mechanical stability was affected. A deformation of the central part of the target was observed, an effect enhanced by the non-monolithic structure and by the presence of creep in lead. A system based on a laser scanning procedure revealed displacements greater than 1 cm around the proton beam spot. During the investigation, a hole was found on the target in the position corresponding to the beam impact point: this has been generated by pitting corrosion, induced by the local boiling of the water close to the impact point, due to insufficient cooling. The latter also inhibited the passivation of the target surface and the stabilization of the Pb oxide layer. Moreover, the lack of control on the water chemistry in the case of the previous target generated the release of spallation products in the water, due to the increased solubility of lead oxides resulting from the corrosion of the lead target.

Several options have been investigated for the design of a new spallation target for the n_TOF facility: the chosen option has been a cylindrical high purity 99.99% lead block of 60 cm diameter and 40 cm lenght cooled by demineralized water (without cladding). The lead core is enclosed in a new pressurized vessel, which is placed in the same aluminium alloy vessel used for the containment of the cooling water of the first spallation target. The support and the anticreep structure are made of an AW5083 H111 aluminum alloy, as a best compromise between the best corrosion resistance, mechanical properties, availability and weldability. In order to increase the flexibility in the optimization of the target, the pressurized vessel is separated in two volumes: the first one, filled with demineralized water, is in direct contact with the lead and is used for the target cooling (with a flux optimized to provide the required heat convection coefficient), while the second one, not in contact with the cooling loop, could be filled with a different type of liquid and separates the cooling water on the lead surface from the external pool. The effective thickness of the cooling circuit liquid on the lead part facing the vacuum tube towards the experimental area is 1 cm, while this is 4 cm for the moderator liquid. The two volumes are connected to the cooling system by four pipes, allowing the separate circulation of the cooling liquids. During the 2009 commissioning run, the moderator circuit has been connected with the target cooling one, since only one circulating station had been installed. Figure 1 shows the new target assembly being lowered in the n_TOF pit in October 2008.

**Figure 1:** n_TOF new spallation target assembly being lowered in the pit.

The thermal calculations have been performed assuming 4 dedicated bunches from the PS accelerator of 7x$10^{12}$ protons per pulse spaced by 1.2 s and distributed in a supercycle of 16.8 seconds, corresponding to an average proton intensity of 1.66x$10^{12}$ protons/s. In these conditions the energy deposited in the target every supercycle is roughly 46 kJ during a time interval of 4.8 s, corresponding to an average power, which corresponds to the maximum achieavable peak power, of 9.5 kW. The average power over a supercycle of 16.8 s long then becomes about 2.7 kW. Assuming to operate the facility at nominal cooling capabilities (for a maximum of 1.66x$10^{12}$ protons/s), the maximum attainable integrated intensity for a 200 days run is 2.9x$10^{19}$ protons, compatible within an efficiency of roughly 60% needed to reach the 1.6x$10^{19}$ requested by the n_TOF experiment to perform the physics measurements. A sketch of the new spallation target is reported in Figure 2.

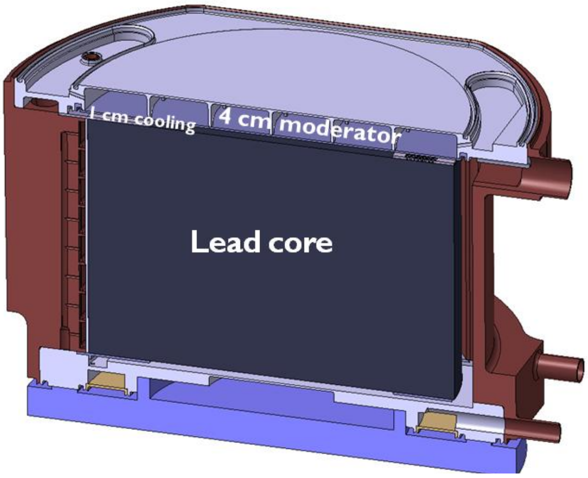

**Figure 2**: Scheme of the new spallation target, with the 4 cm thickness for the moderator and the 1 cm thickness for the cooling liquid. The 60 cm diameter, 40 cm lenght cylindrical lead core is placed at the center enclosed within a pressurized vessel.

### *2.2 The proton beam characteristics*

The 20 GeV/c n_TOF proton beam can be delivered to n_TOF in two different operational modes, dedicated or parasitic, according to the scheduling of the n_TOF bunch in the Proton Synchrotron. For dedicated pulses the intensity is roughly 7x$10^{12}$ protons per pulse while for the parasitic ones this value is about 3x$10^{12}$ protons per pulse. The beam spot has a round shape with a 6 cm diameter. Starting from 2009, in order to reduce the energy density and therefore prevent pitting corrosion effects, the beam spot area has been increased by a factor of 9 relative to what has been delivered in previous years, a change which does not affect the yield of the spallation neutrons. The beam is diverging from a small size at about 80 meters from the spallation target, and impact on the lead with an angle of 0.5 mrad with respect to the nominal central trajectory. The bunch time distribution has a Gaussian shape with a witdh of 20 ns at 4$\sigma$ [2].

### *2.3 Neutron beam characteristics*

The n_TOF neutron beam, thanks to the characteristics of the PS proton beam, present a very high instantaneous neutron flux in the experimental area 185 meters from the spallation target, in the order to $10^5$ neutrons/cm$^2$/bunch of $7x10^{12}$ protons. Thanks to the presence of a water moderator the provided spectrum is characterized by a wide energy range, from thermal to about 1 GeV with nearly 1/E isolethargic flux dependence up to 1 MeV. Figure 3 shows the experimental neutron fluence as measured during the 2009 run with the new spallation target and compared with the simulations. All the fluence smeasurements are referred to the measurement performed with the H19 fission chamber from the Physikalisch-Technische Bundesantalt (PTB) in Braunschweig.

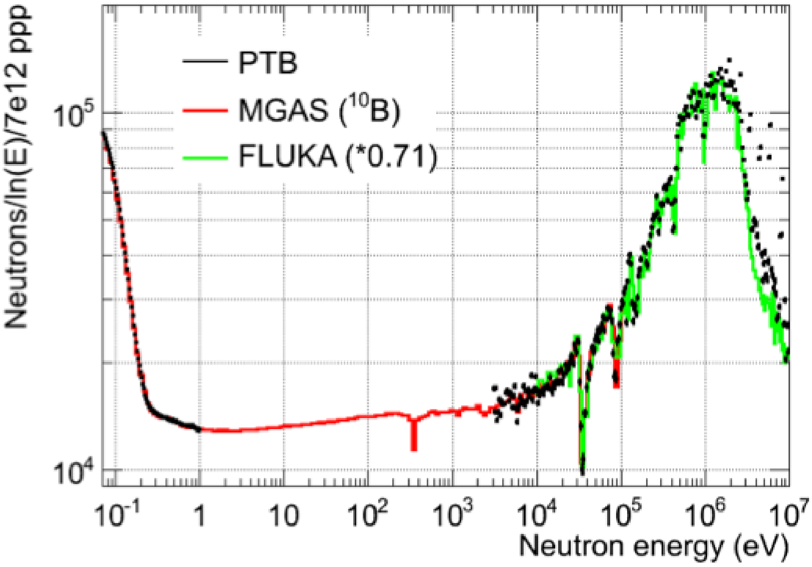

**Figure 3**: Experimental neutron fluence, as number of neutrons per cm2 at 185 m for a standard pulse of $7x10^{12}$ protons. The MicroMegas $^{10}$B(n,$\alpha$) data as well as the FLUKA simulations have been rescaled to the PTB measurement between 0.1 and 1 eV. The rescaling of the simulations is needed due to misalignment of the neutron beam collimators.

### *2.4 Experimental setup*

During the period 2001-2004, the n_TOF Collaboration has setup all the necessary infrastructure for neutron capture and fission cross-section measurements in the present n_TOF Experimental Area.

For the detection of $\gamma$-rays following a capture events two methods are implemented at n_TOF; the first one involves an in-house developed deuterated benzene $C_6D_6$ gamma-ray detectors contained in a cylindrical low mass carbon fiber housing [3]. The low neutron capture cross-section of both carbon and deuterium insure a low contribution from sample scattered neutrons to the background. Measurements on the isotopes $^{90,91,92,93,94,96}$Zr, $^{186,187,188}$Os, $^{56}$Fe, $^{197}$Au, $^{151}$Sm, $^{209}$Bi, $^{204,206,207,208}$Pb, $^{232}$Th, $^{139}$La have been performed. The second system is a 4p ~100% efficiency total absorption capture detector [4], constituted by 42 $BaF_2$ crystals in $^{10}$B-loaded carbon fiber capsules. Samples are placed in the center of the calorimeter and are surrounded by a neutron absorber.

Optimized radioactive isotopes, measurements of $^{197}$Au, $^{233,234}$U, $^{237}$Np, $^{240}$Pu and $^{243}$Am have been performed.

Also fission experiments have been performed with two dedicated detector systems. A Fast Ionization Chamber (FIC) [5] has been specially developed for n_TOF and makes use of fissile isotopes deposited on 100 μm think aluminum foils. The other system is based on parallel plate avalanche counters (PPACs), with target deposited on 1.5 μm thin mylar or 2 μm aluminum foils, allowing to detect the two fission fragments in coincidence. Measurement have been performed on the following isotopes: $^{209}$Bi, $^{nat}$Pb, $^{232}$Th, $^{233,234,235,236,238}$U, $^{237}$Np, $^{241,243}$Am and $^{245}$Cm.

## 3. Present status

Several upgrades have been performed before the 2009 campaign, to align the facility to the safety and operational requirements of CERN and of the respective French and Swiss Safety Authorities.

### *3.1 The target area ventilation*

The ISO17873 regulation, which concerns the design and operation of ventilation systems for nuclear installation other than nuclear reactors, recommends the confiment of the Target Areas. The n_TOF Collaboration has therefore implemented a primary target area ventilation system, which is required to ensure the confinement of the target area, capture the aerosols containing radioactive isotopes in absolute filter and allow the monitoring of the released dose to the public. Due to the low energy deposited in the target (< 5 kW) compared to its size and to the ~1200 m$^3$ volume of the tunnel sector defined as the target area, a cooling system has not been considered necessary. The Target Area volume is continuously flushed out in order to set a negative pressure of roughly 40 Pa between the target area and the adjacent rooms, accomplished with an air flow rate of 500 m$^3$/h; no fresh air enters the area except through the leak tightness of the static confinement and an adjustment damper. The air is then relesead in the atmosphere, after having passed from two H10 and H13 HEPA (EN1822 standard) absolute filters and from an activation monitoring systems connected to the CERN integrated radiation monitoring system. The dose rate for the general public outside of the CERN perimeter is estimated to be in the order or less than 1 μSv/year, in agreement with CERN’s radioprotection rules.

### *3.2 The cooling station characteristics*

The spallation target cooling system is constituted by a pressurized circuit ensuring a water flow in the target vessel in order to keep the temperature of the lead surface at a value sufficiently below the water boiling point, particularly on the proton entrance face of the spallation target, where the pitting corrosion damage was observed in the old target. The water flow in the secondary circuit is produced by means of seal-less pumps and a differential pressure automatic valve will ensure that the supply return pressure drop will not exceed design values in order to protect the thin separation layer between the target and the moderator circuit.

The system also features a gas separator to reduce the $O_2$ content in the water circuit, in order to reduce target corrosion. The degassing system uses a microporous membrane acting as a separation between the liquid and gas phases. The transfer of dissolved gas from the liquid phase to the gas one is performed by applying a flow of $N_2$ gas that flushes the accumulated oxygen. The operation of the device during 2009 showed that a flush of 2 minutes duration every 30-40 minutes with a flow rate of ~4 $m^3/h$ is needed during normal beam condition to reduce the $O_2$ level to the nominal value of 80 ppb. A fraction of the gas stream containing the excess $O_2$ condenses and is collected in a liquid trap, while the rest leave the degassing system to be collected by a gas extraction system and then rejected into the atmosphere. In August 2009 the extraction system has been modified to create a buffer time of about 10 minutes, much longer than the ~20 seconds in place before, for the gas extracted from the degassing device: this is enough to allow the decay of short lived activation products, such as $^{14}O$, $^{15}O$ and $^{13}N$ (with half-lives ranging from 70 seconds to 10 minutes) which are being produced in the cooling and moderator circuits.

### *3.3 The Work Sector Type A*

One of the serious limitations of the experimental activity during the n_TOF Phase 1 was the impossibility to make use of unsealed sources, neither for capture nor for fission measurement. This lead to the need to employ cannings and container certified according to the ISO2919 regulation: this is a problem for most of the measurements, both for background (in the case of capture) and for feasibility and costs point of view (in the case of fission). According to the Swiss-adopted CERN Radioprotection regulations, for every radioactive isotope it defined an authorization limit (defined also as "LA – legal activity". The value is defined as such that the inhalation of 1 LA would give a dose due to internal irradiation of 5 mSv [6].

In order to use samples with more than 1 LA of activity, avoiding the use of sealed sources, it has been necessary to reclassify the experimental area as a special Work Sector, which designates a room in which precautions have been taken to protect the personnel from incorporation and to protect the environment from dispersion of radioactive material. CERN's Safety Code F, in line with the Swiss Ordinance for Radiological Protection [7] and the Ordinance for Handling of Unsealed Radioactive Sources [8] define 3 types of Work Sectors, from Type C to Type A with increasing technical and organisational requirements, allowing handling higher and higher quantities of unsealed radioisotopes.

Due to the peculiarity of the position of the n_TOF experimental area located underground in the CERN tunnels, it has been particularly complex to satisfy the technical requirements for a Work Sector Type A. Some of the necessary and implemented solutions include complying with fire resistance rules, provide artificial ventilation, realized rooms with higher hazard potential under pressurd with respect to room with lower hazard, changing room for personnel protection and control and decontamination tools. The complete description of the performed activities are reported in the n_TOF Facility Safety File [9] while the requirements are reported in Ref. [6].

The work at n_TOF is being performed during the 2009/2010 n_TOF winter shutdown, and it will be ready for the n_TOF beam restart around the middle of May 2010.

### *3.4 Borated Water moderator circuit*

In order to reduce the background in the experimental area due to the 2.2 MeV in-beam γ-rays generated by the neutron capture on $^1$H, which is a significant problem for the neutron-capture measurements performed with the $C_6D_6$ detector, it has been decided to fill the moderator loop of the spallation target with borated water. The system will work in saturated conditions, which corresponds to boric acid dissolved in water with an atomic percentage concentration of 1.28%, with enrichment in $^{10}$B around 95%. FLUKA simulations have shown that the reduction of the 2.2 MeV γ-rays will be in the order of a factor of 10; the neutron fluence will remain unchanged above ~10 eV, while the thermal peak, due to the presence of $^{10}$B, will decrease by around 1 order or magnitude, but it will be still high enough to provide a normalization point at 0.0253 eV, if needed by the measurement. Figure 4 shows the comparison between the simulated neutron fluence with 5 cm of demineralized water (black line), a situation similar to that of the 2009 run, and the one in which the borated water is introduced in the moderator circuit (red line).
The system is in the engineering phase and it will be ready for the 2010 physics run.

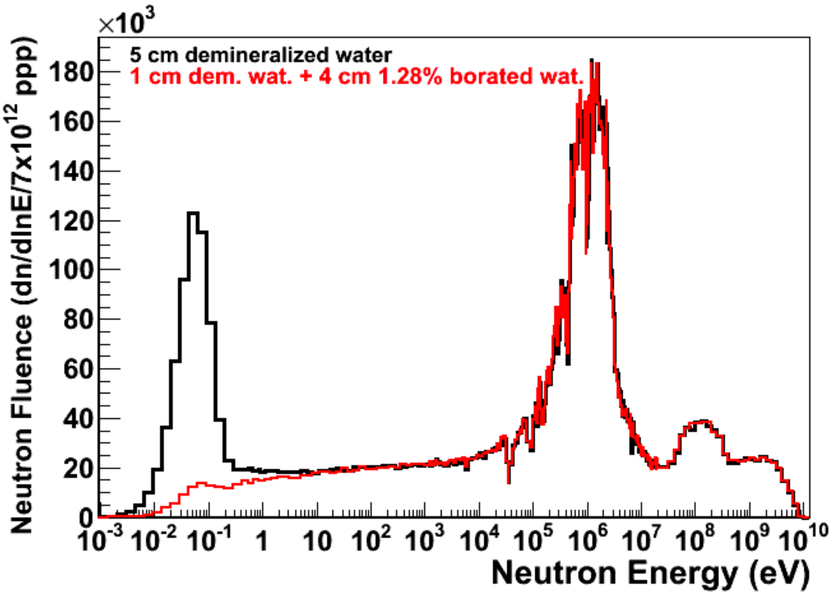

**Figure 4**: FLUKA simulation of the neutron fluence in the experimental area under the present conditions (5 cm layer of demineralized water) (black line) and the neutron fluence expected with the borated water in the moderator loop (red line).

## 4. Future perspectives

In the context of the facility consolidation and improvement of measurement possibilities, a new project has been started, which will involve the construction of a 2$^{nd}$ experimental area in addition to the present one.

### *4.1 Experimental Area 2*

The present 185 meters long flight path of the n_TOF facility is of great advantage for measurements with high resolution in neutron energy. The overall efficiency of the experimental program and the range of the possible measurements could be enourmously improved, however, with the construction of a shorter flight path of approximately 20 meters. This will lead to a tenfold increase of neutron flux, with a corresponding reduction of the background caused by the prompt-flash induced in the detectors by the spallation reactions. The idea is to use the existing vertical shaft through which the spallation target was brought into its present position. Several questions will have to be addressed, including issues related to civil engineering and radioprotection. A technical design report will be released by the end of 2010, for a possible realization during the 2012/2013 technical shutodown.

## 5. Acknowledgements

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