*PHYSOR 2010 – Advances in Reactor Physics to Power the Nuclear Renaissance*
Pittsburgh, Pennsylvania, USA, May 9-14, 2010, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2010)

# COMMISSIONNING OF THE n_TOF-Ph2 FACILITY

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n_TOF-CONF-2010-010
09/05/2010

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## ABSTRACT

The white spectrum neutron time-of-flight facility n_TOF is operating at CERN since 2001. The neutron beam has a very high instantaneous flux and high resolution in energy and it is delivered in the experimental area located 187 m downstream from the spallation target. The intense neutron fluence per proton burst results in a much enhanced signal to background ratio for neutron capture and fission reactions on radioactive isotopes, thus making the facility well suited for accurate measurement of neutron-induced reaction cross-sections. This is especially true to highly radioactive targets which are of major importance in new nuclear energy system such as Gen-IV reactors, especially those with fast spectrum. Combined with state-of-the-art detectors and with advanced data acquisition systems, the innovative characteristics of the n_TOF neutron beam allow collecting data on a variety of stable and radioactive isotopes of interest for nuclear astrophysics and for applications to advanced reactor technologies.

*Key Words*: neutron, time-of-flight, measurement

## 1. INTRODUCTION

High accuracy neutron cross-section data are of major importance for a wide variety of research fields ranging from basic to applied nuclear physics. In particular in the context of nuclear technology, a renewed interest in nuclear energy production has triggered studies aimed at developing future generation systems that would address several safety, proliferation and waste concerns.

For these applications the available nuclear data of many nuclides are not sufficiently accurate and sometimes even lacking [1,2]. Fast spectrum Gen-IV reactor requirements are pointing to the threshold region of several highly radioactive isotopes for which big discrepancies exists between present experimental data. In order to improve the evaluated neutron cross-section libraries such as ENDF/B, JEFF and JENDL, accurate measurements attainable at advanced neutron sources are of crucial importance. Based on these motivations the neutron time-of-flight facility n_TOF has been constructed at CERN, Geneva, Switzerland.

At n_TOF neutrons are produced by spallation reactions induced by a pulsed, 10 ns wide, 20 GeV/c proton beam with up to $7x10^{12}$ protons per pulse, impinging on a massive lead target which is surrounded by a water layer of 5 cm acting both as coolant and moderator of the spectrum. Thanks to this the n_TOF neutron energy spectrum spans over nine orders of magnitude, from thermal energy up to approximately 1 GeV [3,4]. Together with the wide energy range, other important characteristics of the n_TOF facility are the very high instantaneous flux in the experimental area (around $10^6$ neutrons/pulse), which makes the facility particularly suited for cross-section measurements on radioactive isotopes, while the very low duty cycle (0.5 Hz) eliminates the problem of bunch wrap around. An evacuated neutron beam line leads to the experimental area located at 187 m from the lead target, which allows one to reach a high resolution in neutron energy. Two collimators exactly define the beam profile in the experimental area and a resulting low ambient background is obtained by massive iron and concrete shielding.

In 2008 a new spallation target has been installed. It consists of a cylindrical Pb block of 60 cm diameter and 40 cm length, cooled by a forced flow of water. The water is chemically controlled in order to minimize its dissolution and corrosion capacity. The lead and the water are enclosed in an aluminum vessel which fits into the old target container, which acts as a secondary retention vessel. Inside the target pit, the cooling and moderator circuit are decoupled, offering the possibility to use various moderators. During the commissioning phase that started last May, we investigated the shape and intensity of the neutron fluence, the neutron beam profile, and the energy resolution of the facility by using a wide range of materials and detectors system.

After a brief description of the new n_TOF spallation target, this contribution will present the measurements and the results concerning the intensity and energy distribution of the neutron, together with its spatial profile. Moreover the results of the 2009 physics campaign will also be shown, together with perspectives of future measurements.

## 2. THE NEW n_TOF SPALLATION TARGET

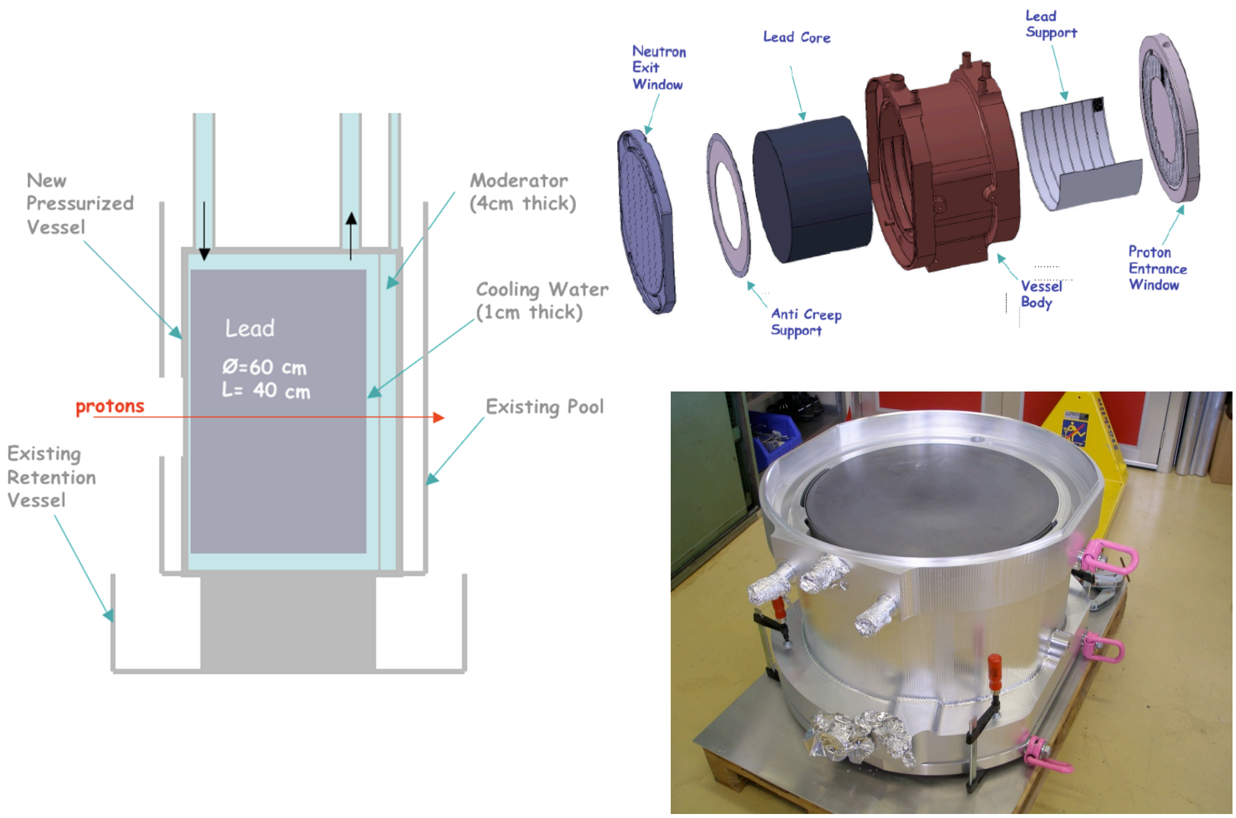


**Figure 1. Schematics of the new spallation target (left and top right), and the assembly during construction (bottom right)**

After a three year long stop due to activation of the cooling water by spallation products, a new lead target was designed and constructed as well as new systems to fulfill the safety requirements before the restart of the facility. In particular a ventilation system has been installed to maintain the primary area depressurized with respect to the adjacent galleries. An optimized cooling system was developed allowing to control the chemical parameters of the water, in particular its oxygen content, and to reliably filter the activation products from the water. An extensive study of the corrosion mechanism has been performed to improve the long-term stability of the target.

In order to optimize the cooling efficiency, without loosing in neutron production, the new target was shaped as a cylinder of 60 cm in diameter and 40 cm in length. The vessel surrounding the target has been designed to optimize the water circulation around the target, particularly at the proton beam impact spot. This later has also been significantly increased compared to the previous situation to avoid thermal stress on the target.

Another improvement was achieved by the separation of the target cooling and of the moderator circuit. This enables the use of different moderator composition, providing greater flexibility in choosing the characteristics of the neutron beam.

Since the size of the target, and the moderator thickness are similar to the previous one, the neutron flux and spectral shape are expected to be very close to the ones available in the past as predicted by simulations [5] performed with the FLUKA code [6]. Nevertheless, since the new target had to be installed inside the pool of the previous target, bigger absorption dips are expected in the 1-100 keV energy range, due to the increased aluminum thickness neutrons have to cross to reach the experimental area.

## 3. NEUTRON FLUENCE SHAPE MEASUREMENTS

In order to investigate the energy distribution of the neutron beam several measurements have been performed:

- A five plates fission chamber calibrated at PTB [7] containing 201.4(5) mg of $^{235}$U. The neutron fluence is determined from the counting rate, taking care of the well-known detector efficiency and the expected fission yield computed from a detailed MCNP simulation [8].
- A Silicon Monitor, **SiMon**, [9] consisting of 4 silicon detectors measuring tritium emitted by the (n,$\alpha$) reaction from a thin (300 $\mu$g/cm$^2$) $^6$Li foil.
- A monitoring MicroMegas, **MGAS**, [10] consisting in two detectors containing a $^{10}$B deposit for measuring low energies neutrons and a $^{235}$U deposit for measuring high energies neutrons.

Results, expressed in isolethargic units, are shown in figure 2. The black curve is the result from the PTB fission chamber. The red curve shows the results from the SiMon detector, while the green curve corresponds to the MGAS detector with the $^{10}$B deposit. The SiMon and MGAS results are scaled to the PTB fission chamber results in the neutron energy range below 1 eV. The results from the PTB fission chamber are shown only below and above the resonance region, since the analysis in this region still need some improvements. Data for the MGAS above 200 keV are not shown, since others reactions than the $^{10}$B(n,$\alpha$) are contributing to the detector's counting rate above this energy. Data from the SiMon detector are also cut at 200 keV due to the large uncertainties in the angular distribution of the reaction products.

As can be seen from figure 2, the flux shape of the n_TOF facility presents a peak in the thermal region. From 1 eV to few tens of keV the flux is almost isolethargic. In the MeV region one can see the peak associated with evaporation neutrons. Because of the presence of thick aluminum windows at the spallation target station, the flux presents big dips at 5.9, 35 and 86 keV. A dip at about 300 eV is also present due to the presence of manganese inside the aluminum alloy.

As can be seen from figure 2 there is a very good agreement between the 3 measurements. Thanks to these measurements an overall uncertainty of 3% will be achievable in the flux shape determination.

## 4. INTENSITY OF THE NEUTRON BEAM

Although the absolute intensity of the neutron beam is not so critical for cross section measurements, this number is of importance to have a good knowledge of the facility performance. Since the PTB fission chamber is a very well known apparatus, one can obtain, in addition to the fluence shape, a precise determination of its intensity. The SiMon and MGAS detectors can also be used to reach this goal, but with a lower accuracy.

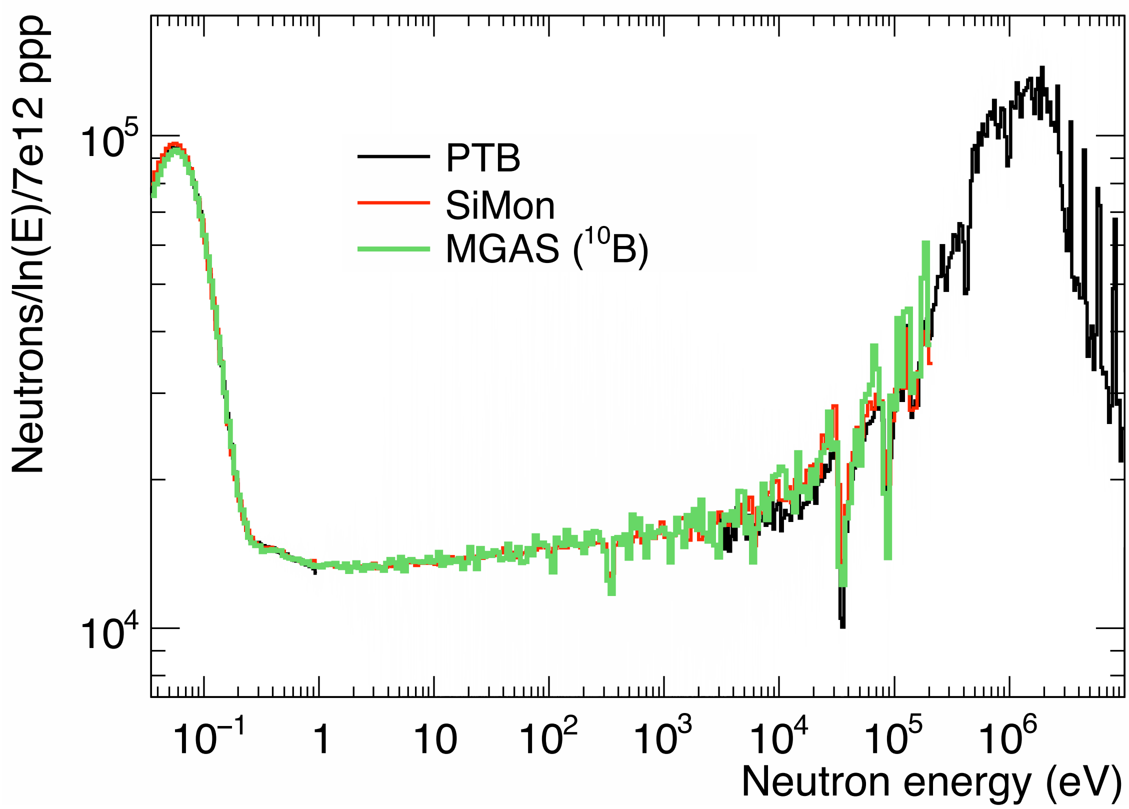


**Figure 2. Neutron fluence shape in isolethargic units, resulting from the analysis of the PTB fission chamber (black), SiMon (red) and MGAS with the $^{10}B$ deposit (green).**

In addition to these previous measurements the flux intensity has also been determined at 4.9 eV by using the activation technique and the **S**aturated **R**esonance **M**ethod, **SRM**, performed with the n_TOF **T**otal **A**bsorption **C**alorimeter, **TAC** [11]. For the activation two gold foils with 25 µm thickness each and 45 mm in diameter (i.e. bigger than the beam spot) were placed back to back in the neutron beam. From the difference of counts, associated with the decay of $^{198}Au$, between the two foils on can estimate with an accuracy of about 10% the neutron fluence around the 4.9 eV resonance of gold [8]. Finally, the combination of the saturated resonance method with the high detection efficiency of the n_TOF TAC also allowed us to determine the neutron fluence in the first resonance of gold energy region [8]. Figure 2 shows the absolute neutron fluence determined thanks to the PTB fission chamber. The ratio to this measurement, and their associated errors, from the others measurement in summarized in the following table.

**Table I. Comparison of the neutron fluence with respect to PTB fission chamber measurement.**

| | PTB | SiMon | MGAS | Activation | SRM/TAC |
|---|---|---|---|---|---|
| **Average ratio over PTB** | 1 | 0.96 | 1.03 | 1.04 | 0.88 |
| **Absolute accuracy** | 3% | 6% | 7% | 10% | 15% |

All the measurements are well in agreement within their associated uncertainties. Nevertheless one should note that the measured fluence is 16% lower than the one foreseen by the simulations [5].

## 5. NEUTRON BEAM PROFILE

The neutron beam at n_TOF is shaped by means of two collimators located at, respectively, 135 and 175 m from the lead spallation target, the latter being responsible for the shape of the beam in the experimental area. The knowledge of the beam profile, as well as its dependence with neutron energy is of primary importance for capture measurements, where the samples are smaller than the beam spot. The beam profile has been investigated by means of two position sensitive detectors, a MEDIPIX [12] and a bidimensional MicroMegas (XY-MGAS) [13].

For the MEDIPIX detectors two neutrons converters have been used, $^{6}$Li for low energy neutrons (up to 1 keV) and polyethylene for fast neutrons. Measurements have been performed in four neutron energies interval: 0.01-1 eV, 1-103 eV, 0.08-1 MeV , 0.08-200 MeV.

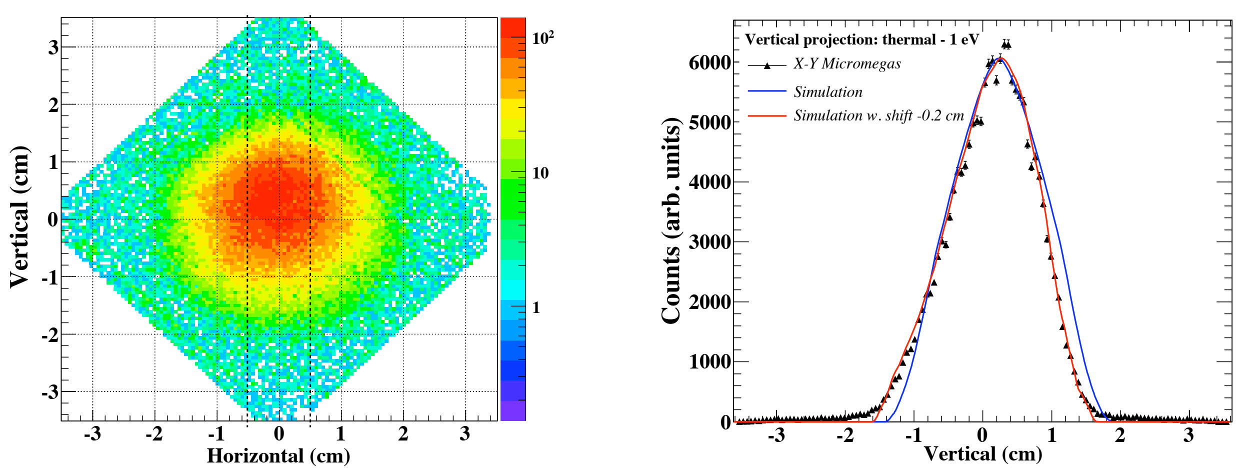


**Figure 3. Results from XY-MGAS detector. Left: spatial distribution of neutrons below 1 eV. Right: vertical profile compared with simulation (see text).**

The XY-MGAS detector, based on the bulk technology, consisted in a 6x6 cm$^2$ active area, spited in 106x106 strips read by two 96 channels Gassiplex cards allowing to obtain the beam profile at any neutron energy. A $^{10}B$ converter has been used with two different thicknesses: 20 nm to investigate low neutron energy, and 2 μm to study the profile for neutron energy up to 1 MeV.

Figure 3 left shows the spatial distribution of neutron below 1 eV measured with XY-MGAS. Symbols on the right part of figure 3 correspond to a slice along the vertical axis for horizontal values between -0.28 and +0.28 cm. The blue curve is the resulted from the simulated profile with similar conditions. If one assumes a 2 mm tilt in the second collimator one can reproduce very well the experimental data as shown by the red curve in figure 3. This small misalignment in the collimator system may also explain, at least partially, the discrepancy between the absolute neutron intensity and the measured one, as shown in the previous section.

## 6. RESOLUTION FUNCTION

Due to the finite size of the spallation target and the water moderator, the neutrons of a given energy do not arrive always at the same time to the experimental area. The time-to-energy distribution describing this process, known as the **R**esolution **F**unction, **RF**, causes a broadening of the resonances that dominates over the Doppler broadening at energies above a few keV. Hence, the RF must be determined and taken into account for the analysis of resolved resonances.

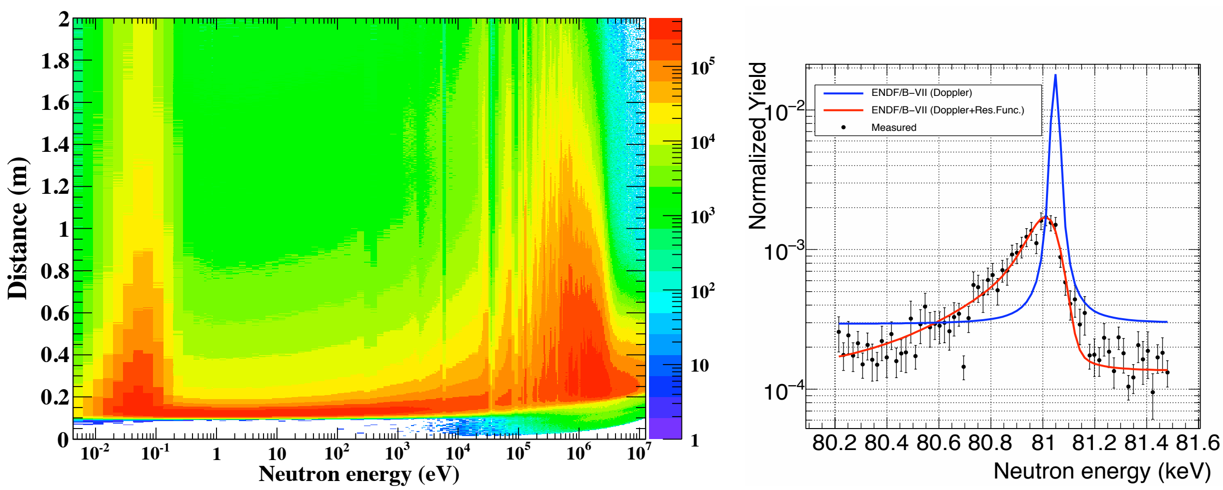


**Figure 4. . Left: n_TOF Resolution Function determined from MC simulations with FLUKA. Right: measured and calculated (with and without RF) capture yield for the 80.8 keV resonance of $^{56}Fe$.**

We have determined the RF associated to the n_TOF target and moderation system by means of FLUKA simulations [5] of the complete process: neutron production in the target by 20 GeV protons, neutron transport inside the target and neutron transport through the 5 cm thick water moderator. The resulting RF is shown in the left panel of figure 4, where it is observed that both the width and the tail of the RF increase with neutron energy.

The broadening effect is illustrated in the right panel of figure 4, which shows the measured and expected capture yield for the 80.8 keV resonance of $^{56}Fe$. It is observed that taking into account the RF determined from MC simulation it is possible to reproduce with the good accuracy the measured yield with high accuracy.

## 7. CONCLUSIONS AND PERSPECTIVES

The n_TOF facility, which is aimed at measuring neutron cross sections relevant for the design and operation of advance nuclear energy systems, has resumed operation after a three years halt. The design and construction of a new spallation target ensures the long term use of the facility thanks to an improved cooling and ventilation systems. The new target also envisages the use of different moderators that fulfill the requirements of the different measurements.

The first measurements of the 2009 campaign have aimed to fully characterize the neutron beam in terms of intensity and neutron energy distribution, spatial profile and resolution in energy. The preliminary analysis show that a 3% accuracy in the neutron energy distribution is achievable, thanks to the combination of various measurements using several standard reactions. The neutron flux shape is very similar to the past, but present stronger structures due to several thick aluminum windows close to the target. The neutron spatial distribution has been investigated thanks to the use of a MEDIPIX and a 2D-MicroMegas detectors. First comparison close to the thermal energy region with a simulation of the optical transport of neutrons up to experimental area seem to indicate a small misalignment of our collimation system. If confirmed, the system will be re-aligned during the winter shutdown at CERN. The resolution in energy, that is the Resolution Function (RF) of the facility, have been determined by means of MC simulations with FLUKA. The resulting RF has been validated by comparison of the calculated shape of narrow $^{56}Fe$ resonances with the experimental data.

In order to measure with radioactive samples without requiring the ISO2919 sealed certification, it is foreseen to transform the experimental area in work sector of type A. This action will reduce the background associated to the sample canning in the case of radioactive samples, allowing to perform more accurate measurement up to higher neutron energies.

## ACKNOWLEDGMENTS

The n_TOF collaboration is grateful to the CERN technical staffs that contribute with their daily work to improve the safety and the reliability of our facility. In particular, thanks are due to members of EN/CV for cooling and ventilation issues, DG/SCR for support on radioprotection controls, EN/MEF and EN/STI for mechanical and technical helps and BE/OP for optimal beam conditions.

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