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THE NEUTRON_TIME OF FLIGHT FACILITY AT CERN: FIRST COMMISSIONING RESULTS

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Recently the CERN neutron spallation source became operational. Information concerning this new facility will be given as for installation, expected performances and physics program. Some preliminary results of the commissioning campaign of measurements will also be presented..

1 Introduction

The search for alternative sources of energy lead to the concept of Energy Amplifier (EA) proposed by Carlo Rubbia [1]. The practical realization of this concept requires both powerful Monte Carlo simulation programs and the adequate input for these programs: cross sections for relevant materials in the construction of an EA. If the first point is accomplished, for the second one it turns out that the existing data base are not enough precise; moreover, some of the data are yet completely unknown. Therefore, a new project has started, n_TOF, having as aims the construction of a powerful spallation neutron source that will make use of the 20 GeV/c proton beam of the PS booster at CERN [2]. The installation is actually operational and two measuring campaigns have been devoted to its commissioning. A physical program which goes well beyond the initial goal and that includes an important astrophysical part is already approved by the INTC (Program Advisory Committee).

The present paper intends to make a general description of n_TOF features. Then, the results of the commissioning measurements will be presented and compared to the designed parameters. Some conclusions will be given at the end.

2 General View on the n_TOF Project

Fig. 1 shows the general layout of the n_TOF facility in the context of the CERN accelerating complex [3]. The 20 GeV/c proton beam of the CERN PS booster is sent on a massive lead target inducing a wealth of spallation products among which many neutrons. The target is a lead block of $80 \times 80 \times 40$ cm^3 and is immersed in a container filled up with water. A time of flight tube is installed in the TT2a tunnel, making an angle of 10º with the proton beam direction. This angle helps to get read of charged particles produced in the spallation process. A 2 m long sweeping dipole magnet installed at 145 m on the line does a further cleaning of these particles.

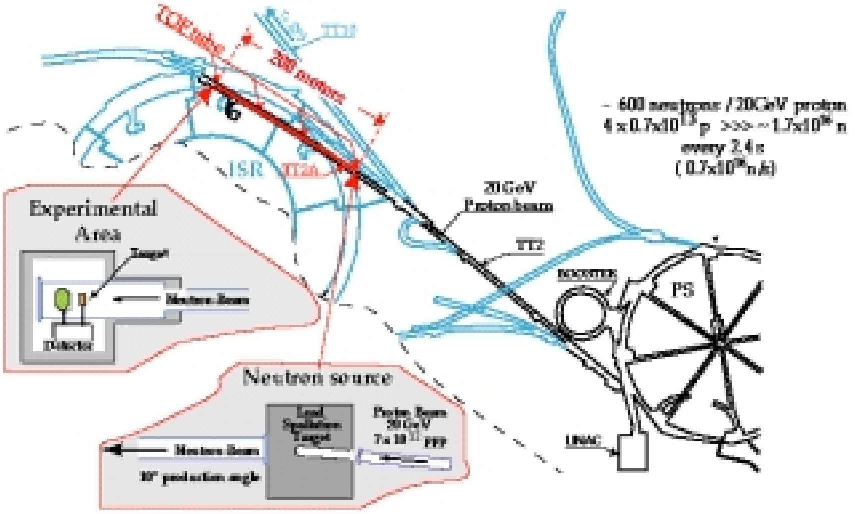

Figure 1. General layout of the n_TOF facility at CERN

The time of flight basis reaches after 182 m the experimental area and ends up into a beam dump 200 m downstream from the target. Fig. 2 shows the display of various elements along the line, like e.g. collimators and shielding. In the actual configuration, two collimators have been installed. The first one (beam shaping collimator), with a diameter of 11.5 cm has a length of 2 m and is located 136.7 m downstream from the target. The second one (source screening collimator) has an inner diameter of 1.8 cm and is made of 50 cm of 5% borated polyethylene, 125 cm of iron and 75 cm of 5% borated polyethylene and is located at 178 m.

The typical proton intensity is 7×10^{12} protons per burst. The burst intensity as a function of time has a gaussian shape with a RMS of about 7ns. These bursts, impinging on the spallation target generate a high neutron flux that amounts to 7×10^{5} n/cm^{2}/burst in the experimental area (without any collimation).

A special care has been devoted to the target design in order to optimize both the neutron flux and the energy resolution [4]. The shape of the target is shown in Fig. 3, together with the relevant dimensions. Towards the TOF line the water layer has a thickness of 5 cm. A thin aluminum window of 1.6 mm thickness separates the TOF line (which is kept under vacuum) of the target container. The water plays the double role of cooling the target and of improving the neutron beam quality. Indeed, the water layer after the target modifies the initial spectral function of the

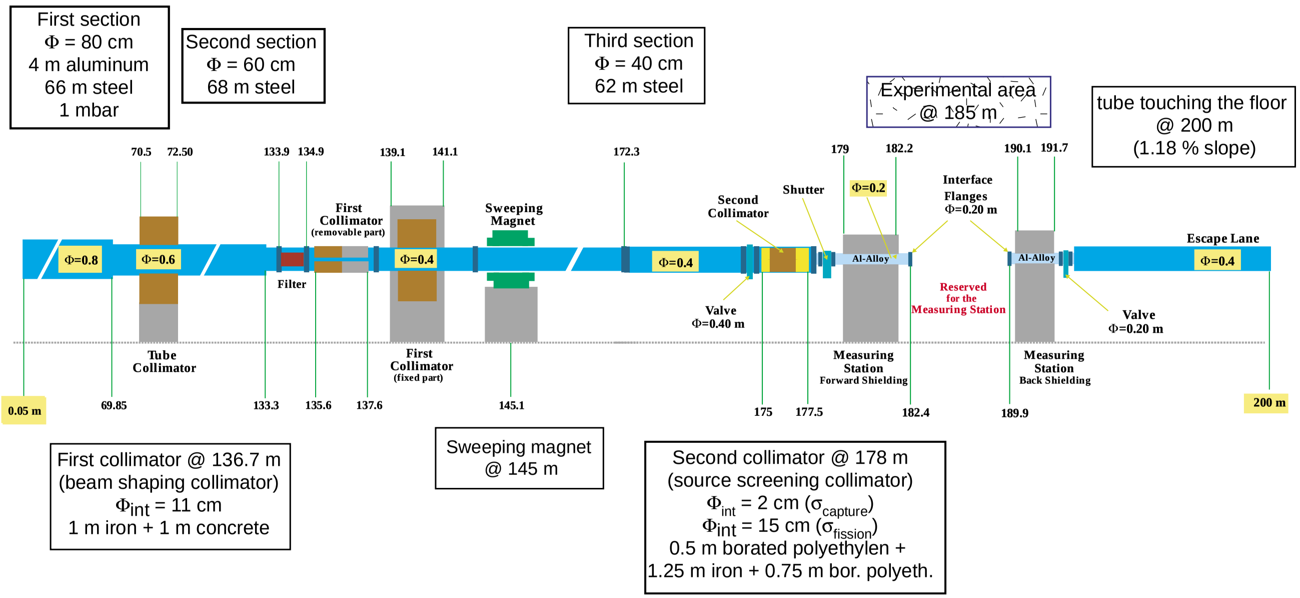

Figure 2. The main elements of n_TOF line

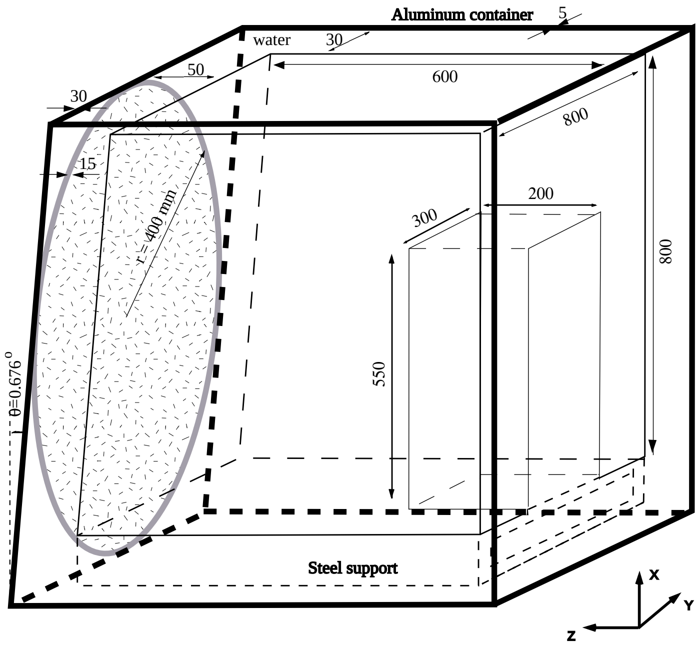

Figure 3. The lead spallation target of n_TOF

produced neutrons such as in an isolethargic representation it becomes rather flat from 1 eV to 10^5 eV (see Fig.5 below). Another important effect is that the neutrons that are moderated by the water emerge with smaller energies. When determining the energy of the neutrons by time of flight, the total time passed by the neutron by inside the target and water is added to the time spent by the neutron to reach the experimental area. As this former time is not known, it gives an uncertainty on the determined energy. Emerging at a lower energy, this quantity becomes relatively less important with respect to the time of flight and therefore the resolution function shrinks. The resolution in energy can be expressed as $\Delta E/E=2\lambda/(\lambda+L)$ where λ is the effective neutron path inside the lead and the 5 cm water layer. One can define this path as follows: $\lambda = v \times t$. where v is the neutron velocity at the exit from the water. For the lowest energies, λ amounts to few centimeters. The variance of λ, as expected from simulations is shown in Fig. 4 and is evaluated either taking the r.m.s. of the λ distribution or the standard deviation for a gaussian fit. A typical figure for the relative resolution ($\Delta E/E$) at 1keV is 2×10^{-4}.

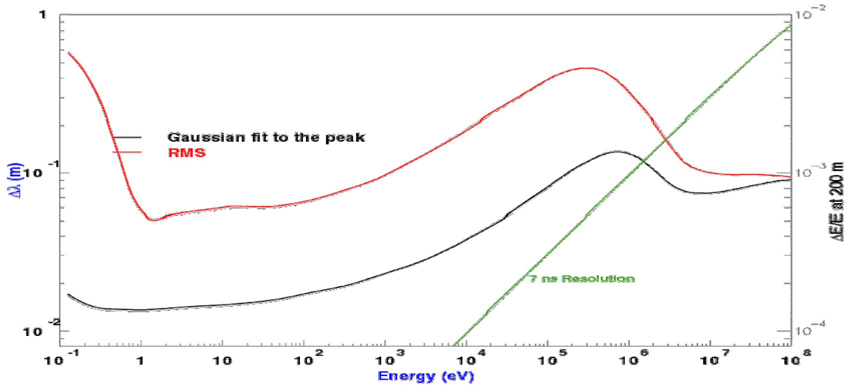

Figure 4. Resolution of the n_TOF facility as expected from Monte Carlo simulations

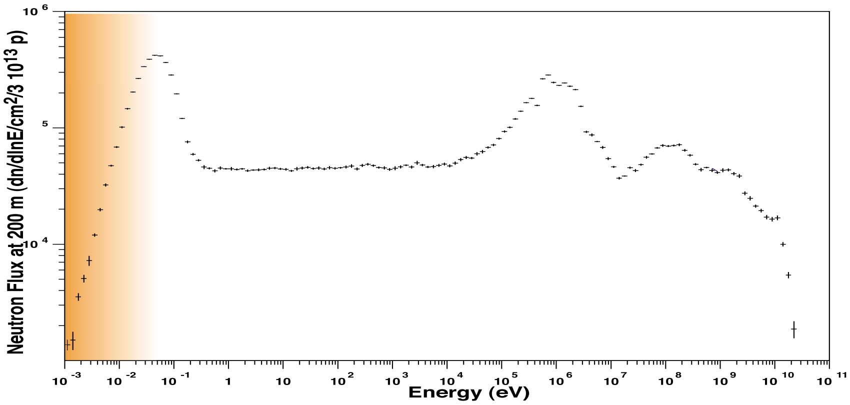

Figure5. The neuton flux of the n_TOF at 200m as expected from Monte Carlo simulations

The estimated spectral function from Monte Carlo simulations is presented in Fig. 5. Both the shape of the spectral function (neutron flux versus energy) and the expected resolution in the energy determination recommend this installation as a unique one for performing neutron cross section measurements. In particular, very thin targets could be used, which is essential for some measurements implying radioactive isotopes.

3 Commissioning of n_TOF

The commissioning has been done in two measuring campaigns: the first one of 15 days in November 2000 and the second one of 12 days in April 2001. The first campaign of measurements has been divided in three periods:

-first one without any collimator and at a distance of 172 m,

-second one with the first collimator in place and at the same distance and
-third one with first and second collimators in place at a distance of 182 m.

In the second campaign, all measurements were done at 182.5 m with both collimators in place.

The cumulated proton intensity for the commissioning periods is given in Fig.6. During commissioning, attention was paid both to the measurements of the physical parameters of the installation and to the safety related aspects.

For the commissioning, a dedicated data acquisition system (DAQ) has been elaborated [5] that took into account the specificity of n_TOF. Both flash ADC and multihit TDC have been used to record the signals from the detectors. The DAQ accommodated also the signals coming from other devices like thermocouples for target temperature measurements, proton intensity of each burst sent on target, positions of detectors, etc.

3.1.1 Target behavior

One key issue in the commissioning was the target behavior when irradiated. The exploitation regime foresees a maximum of four proton pulses per supercycle of 14.4 seconds spaced by at least 1.2 seconds. Considering that about half of the beam energy is deposited in the target, it results that some 3.2 kW are dissipated in the target, leading to a temperature increase and therefore requiring an adequate cooling. A special cooling station has been made for this purpose, having also filtering elements incorporated. Simulation calculations have been performed in order to evaluate the temperature jumps after the bursts. In the commissioning phase, the target temperature has been monitored by a number of 6 thermocouples inserted into the lead block in various positions. Fig. 7 shows the result of the temperature measurements done with the thermocouple placed in the vicinity of the incident beam, in a region of maximum energy dissipation. The incident proton beam has been displaced horizontally with respect to the central position and the regime was with four proton bursts per supercycle at nominal intensity. Also shown are the results of a finite element calculation done before [6]. The agreement is quite good and one can see that the temperature remained always below 90º. Figure 8 shows the temperature variations in time for various proton intensities and numbers of bunches per supercycle. One can see that the maximum steady state temperature attained is of 65°C while the maximum temperature jump after a bunch is 7°C.

Another safety related measurement concerned the activation of the lead target. Two months after the first commissioning period, the target has been extracted from its container for visual examination and radioactivity measurements. The dose measured in contact with the lateral walls of the target varied between 50 and

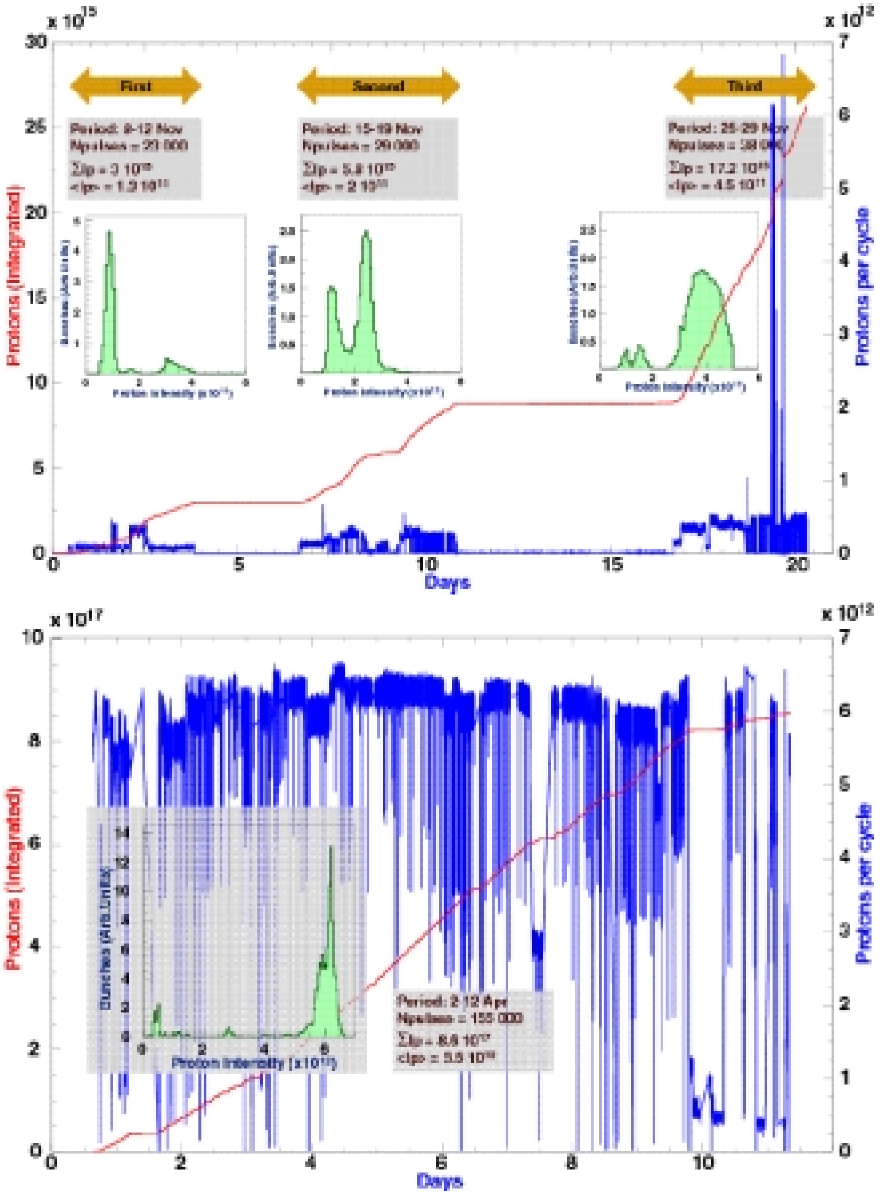

Figure 6. The use of proton beam in the two measuring campaigns.

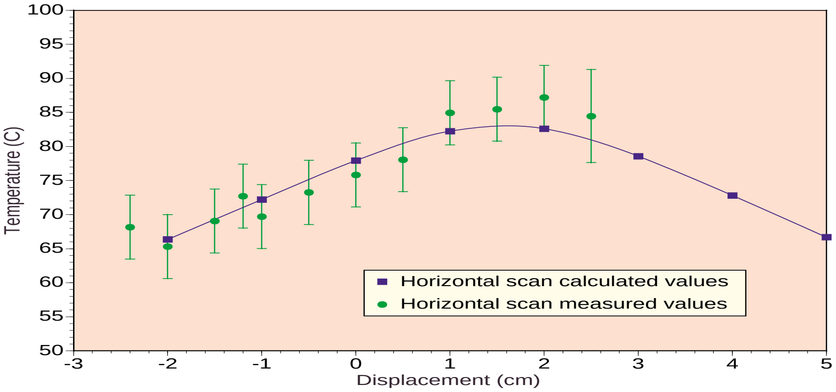

Figure 7. Temperature in the central thermocouple of the n_TOF target during a horizontal beam scan.

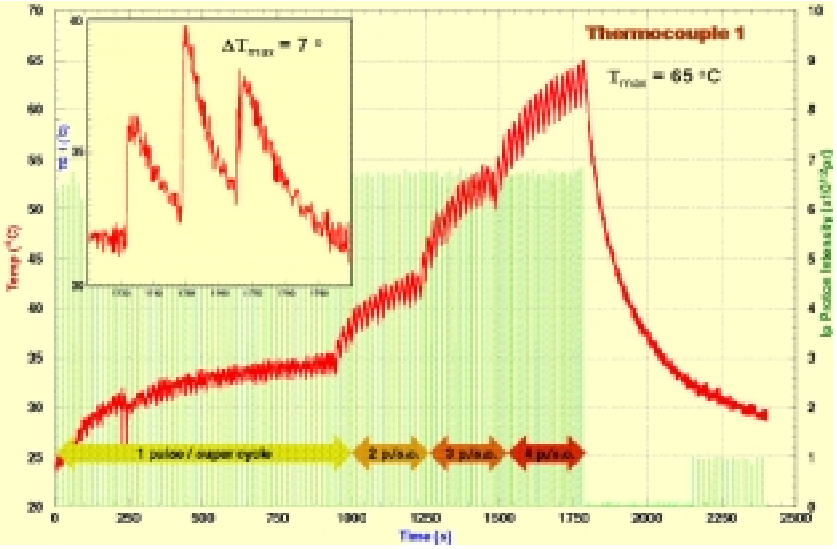

Figure 8. Time variation of the n_TOF target temperature in various regimes.

400 µSv/h. Two "hot spots" have been detected: one where the protons entered the target (2.15 mSv/h) and another one in the center of the exit face (1.1 mSv/h).

3.1.2 Physical parameters

For an installation like n_TOF, the most relevant information concerns the total neutron flux and its spectral and resolution functions, as well as the general measurement conditions like various types of background. The expected spectral function spans many orders of magnitude (see fig. 5); therefore various detectors have been used in order to cover the whole range of energies.

In the first period, a BC702 detector from BICRON has been used for energies up to 10^5 eV, while a plastic scintillator (BC400) was used for energies above 1MeV. In the second period, fission chambers with ^{235}U and ^{238}U deposits have been added to the previous detectors. Besides, gold foils have been irradiated and their subsequent gamma activation determined using the so-called double-foil method. This particular measurement allowed determining the neutron flux at 4.9 eV, the energy where gold has a pronounced capture resonance. While the data obtained from the BC400 plastic scintillator are still under evaluation, the data from the BC702 detector and from the fission chambers will be presented below.

The BC702 detector incorporates a mixture of ^{6}Li salts and ZnS(Ag) embedded in a clear plastic. The (n,t) reaction on ^{6}Li has a Q-value of 4.78 MeV and produces alpha particles and tritons with energies above 2 MeV. These particles, by energy loss induce a scintillation in the ZnS. The produced light is collected by an attached photomultiplier tube (PMT). The pulses have a rise time of about 30 ns and a decay time of about 250 ns. The neutron detection efficiency curve of BC702 follows roughly the cross section of the used reaction. The efficiency of the detector has been determined by using calibrated neutron beams at GELINA facility in IRMM-Geel (Belgium) and at PTB-Braunschweig (Germany). In the experimental conditions of n_TOF, a strong gamma flash produced by the spallation process precedes the arrival of neutrons. This flash induced a huge scintillation that blinded the detector for few microseconds. Moreover, the high neutron flux created in the detector a high density of pulses that sometimes overlapped each other. This fact, together with the known long time afterglow of ZnS gave rise to an dim light that brought the PMT close to saturation and consequently in a nonlinear regime. In order to avoid this effect, the intensity of the proton beam has been decreased (below 10^{11} protons per bunch) as well as the operating voltage of the PMT (from 800 V to 720 V). The efficiency of the detector at this lower voltage decreases and the calibration in efficiency at GELINA and PTB took this fact into account. However, the effect of the high neutron flux on the detector could not be reproduced during the efficiency calibration.

Fig.9 shows the neutron fluence obtained from the measurement with the BC702 detector in the first commissioning period, without any collimator, at a distance of 173 m from the target. During the run, a pair of gold foils preceded the detector. For this reason, the two gold capture resonances at 4.9 eV and 60.3 eV deplete the neutron spectrum. The data are renormalized for a distance of 185 m and for the nominal proton intensity in order to compare them with the data taken after the installation of both collimators, which are shown on the same figure. For this last case, the fluence is calculated for an active surface with a diameter of 2.6cm. Also shown is the result of the fluence determination by means of gold foil activation (the double foil method). On the same figure, with a continuous line is indicated the fluence expected from Monte Carlo simulations. A reduction factor of 7.3 is observed for the fluence measured after the collimation system.

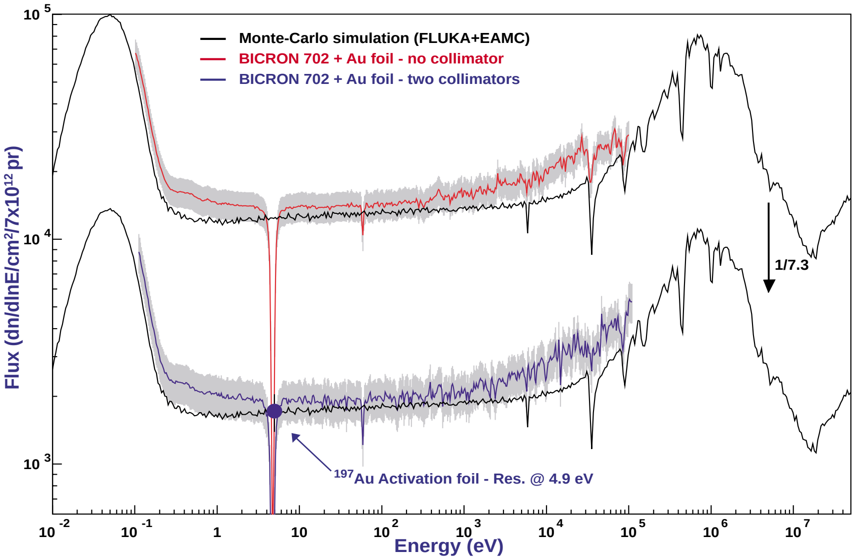

Figure 9. Fluence determined with the BC702 detector in two cases: no collimator and two collimators. The result from the gold activation foils is also indicated.

The BC702 detector served also for scanning the beam profile. A special computer assisted scanning device was used and the results of these measurements are shown in Figure 10. As the detector has an active area of 38 mm, i.e. larger than the beam dimensions, a deconvolution procedure was applied to the measured data. In fact, we started from the beam profile expected from simulations (showed in the figure) and convoluted this profile with the finite detector dimensions (detector profile). The continuous line through the experimental points represents the result of this convolution after minor changes to optimize the fit. One should mention that the measured profile is deduced from an integral measurement that included all energies.

The fission chambers used in the second commissioning period are inter-comparison instruments; their description is given in [7]. Eleven electrodes were contained in a tantalum case with thin walls. Five of them, made of platinum, supported the fissile deposit, which has a diameter of 7.6 cm and a total density of 440 $\mu g/cm^2$. The other six electrodes are made of tantalum. The gas used was a mixture of 90% argon and 10% methane (P10 gas) at atmospheric pressure.

Data of excellent quality were collected for both ^{235}U and ^{238}U deposits. Figure 11 shows a zoom on the data obtained for ^{235}U. For comparison, the reference fission cross section is also figured. The comparison reveals the very good agreement between the measurements and the data base. The filling up of the resonances at low cross sections levels gives an indication about the background of the installation. In the analysis of data done for obtaining the neutron fluence as a function of energy, the contribution of the walls, electrodes and supports was taken into account. Figure 12 shows the obtained results for both ^{235}U and ^{238}U. For comparison, the fluence obtained from the activation of gold foils is also indicated.

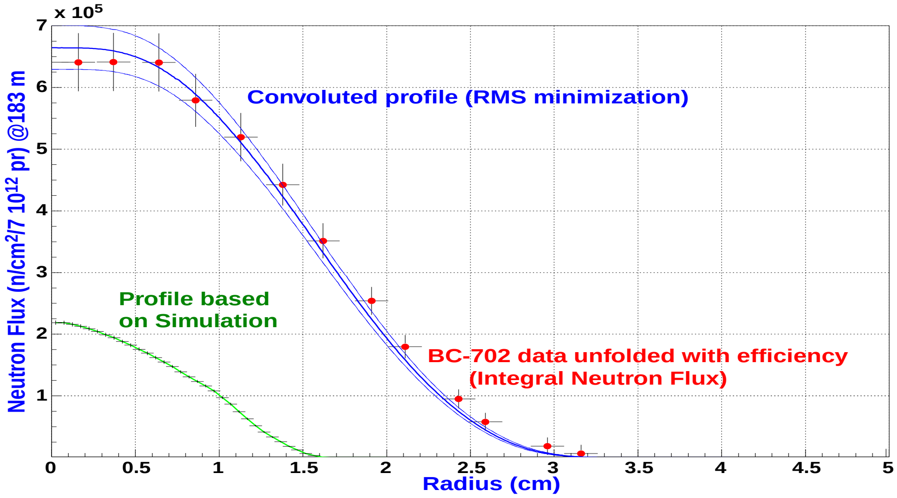

Figure 10. Beam profile scanned with the BC702 detector.

As the data were taken with both collimators in place, the simulated spectral function has been scaled down with a factor 7.3 and also plotted on the figure. For higher energies, a discrepancy can be observed between the ^{235}U and ^{238}U data and also between the ^{235}U data and the simulations, while the ^{238}Udata and the simulations are in fair agreement. Though quantitatively not yet completely understood, the discrepancy can be explained by the presence of a background of quickly thermalised neutrons [7]. They have a high fission cross section for ^{235}U. Moreover, while the active area seen by the beam has a diameter of 2.6 cm, these background neutrons can induce reactions on the whole surface of the fissile deposit with a diameter of 7.6 cm, giving rise in this way to the observed enhancement. In the case of ^{238}U, due to the higher fission barrier, the low energy neutrons from the background have no effect on the measurement. The complementary measurements with the two fission chambers helped to eliminate the background affected one.

In obtaining the above data, corrections have been applied to extract the capture contribution of the walls, supports and electrodes. The resulting value for the integrated neutron flux produced by a single proton bunch with an intensity of 7×10^{12} particles at 182.5 m and with the actual collimating system amounts to 5.6×10^5 neutrons/cm^2.

Some measurements, in particular capture cross section measurements, started in April 2001 at the n_TOF facility. They revealed a too high background in the experimental area that prevented measuring small capture cross sections.

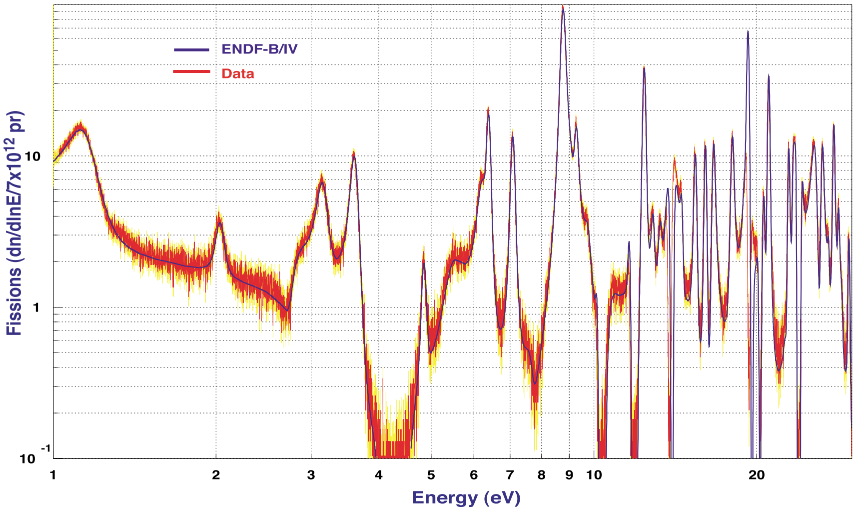

Figure 11. A zoom on data measured with the ^{235}U fission chamber.

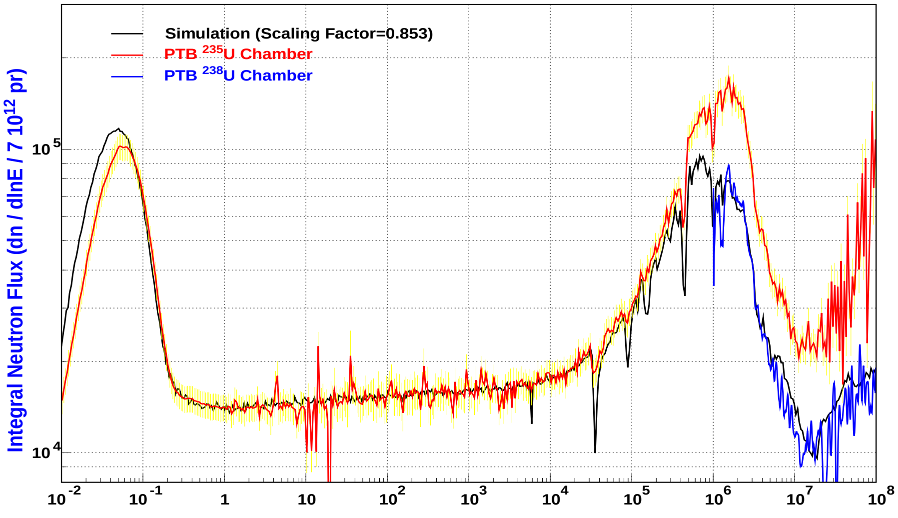

Figure 12. The flux obtained with the ^{235}U and ^{238}U fission chambers as a function of energy.

Special simulation and another cycle of measurements indicated that the observed background originated from the capture of negative muons in the surroundings of the experimental area. As a consequence, an additional iron shielding, 3.2 m thick has been installed in between the sweeping magnet and the second collimator. The measurements performed after this shielding reinforcement [7] indicated a drastic reduction of the muon generated background (more than a factor of 30).

4 Conclusions and outlook

The commissioning of the n_TOF facility at CERN revealed the unique features of this new neutron spallation source. The wide energy domain, from below 1 eV up to 250 MeV, the flat spectral function between 1 eV and 10^5 eV in isolethargic representation, the excellent energy resolution and the very high flux will allow to perform in a rather short time and using targets of very small mass good quality measurements. In particular, the measurements for capture and fission cross section of interest for the ADS design will be a priority along with those concerning astrophysical aspects. Actually, the INTC has already approved four experiments that will be scheduled in 2002. These experiments figure already in the CERN greybook [8].

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