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Past, Present and Future of the n_TOF Facility at CERN

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The n_TOF spallation neutron facility is operating at CERN since 2001. Neutrons are produced with a very wide energy range, from thermal up to 1 GeV and with a very high instantaneous flux (10^5n/cm^2/pulse at 200 m from target) thanks to the high intensity (7×10^{12} protons/pulse) and low repetition rate of the Proton Synchrotron (PS) which is delivering protons to a lead spallation target. The experimental area is located at 200 m from the target, resulting in a very good energy resolution and beam quality thanks to the adoption of an optimal collimation system. At the end of 2008 the n_TOF facility has resumed operation after a halt of 3 years due to technical issues. This contribution will outline the main physics results obtained by the facility since its inception in 1999, and show the importance of the measured nuclear data in the field of Nuclear Astrophysics and Nuclear Technology. Then it will present the future perspectives of the facility, aiming mainly in the direction of measuring highly radioactive samples, for which the facility has unique capabilities, with a lower background.

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I. INTRODUCTION

High precision neutron cross-section data are of major importance for a wide variety of research fields in basic and applied nuclear physics. In particular, neutron data on neutron-nucleus reactions are essential in Nuclear Astrophysics for understanding the production rate of heavy elements in the Universe, which occurs mainly through slow and rapid neutron capture processes during the various phases of stellar evolution [1,2]. In the field of nuclear technology, a renewed interest in nuclear energy production has triggered new studies aimed at developing future generation systems that would address major safety, proliferation and waste concerns. For these applications the available nuclear data for many nuclides is of insufficient accuracy and sometimes even lacking. In order to improve the accuracy of the evaluated neutron cross-section libraries such as ENDF/B-VII, JEFF and JENDL [3], the availability of accurate measurements attainable at advanced neutron sources is critical. Based on these motivations the neutron time-of-flight facility n_TOF has been constructed at CERN, Geneva.

II. THE N_TOF FACILITY

The idea of a new neutron time-of-flight facility at CERN was proposed by C. Rubbia in 1998 [4], as a follow up of the TARC experiment, also conducted at CERN.

The concept of the n_TOF neutron beam [5] makes use of both the specifically high flux of neutrons attainable using the spallation process of 20 GeV/c protons on a massive lead target (containing practically the whole spallation shower) and the remarkable beam density of the CERN Proton Synchrotron (PS) [6]. After the initial proposal, in a short amount of time the facility was accepted for construction by CERN. The CERN n_TOF facility has been set in operation and commissioned during 2001 with performances matching the expectations. The PS machine of CERN can generate high intensities up to 7×10^{12} ppp (protons per pulse) - high enough to produce the vast number of 2×10^{15} neutrons per pulse - in the form of short (6 ns width) pulses with a repetition time varying from 1.2 s to 16.7 s and a prompt "flash" considerably smaller compared to electron machines. The high neutron flux, the low repetition rates and the excellent energy resolution of 3×10^{-4} open new possibilities to high precision cross section measurements in the energy range from thermal to GeV, for stable and,

Fig. 1. (Color online) Time Line of n_TOF facility.

in particular, for radioactive targets. During the first years of operation 2001 – 2004 the n_TOF collaboration has attained a rich experimental program measuring in total 40 isotopes and producing numerous scientific papers and proceedings. In 2005 the experimental program was brought to halt due to radiation protection issue regarding the spallation target. Several solutions have been envisaged and finally in 2008 the facility restarted its operation with a new spallation target with equal performances as the previous one, but with a strongly enhanced water-cooling system.

III. PERFORMANCE OF THE N_TOF FACILITY

A series of measurements has been performed to characterize the neutron beam in the experimental area. These measurements have been performed during the commissioning phase in 2001 [7] with the PTB Ionization chambers [8], the Silicon Monitors SiMON [9], the C_6D_6 gamma-ray detectors [10], the Fast Ionization Chamber FIC and with the PPACs detectors [11]. All these measurements allow characterizing with a very high accuracy the characteristics of the neutron beam, both in terms of neutron fluence, and in terms of energy resolution . The latter have been analyzed with the help of well known and isolated resonances of ^{56}Fe at 11.2, 34.2, 80.8 and 175.9 keV. To better understand the properties of the facility an extensive simulation campaign has been performed in parallel with the measurements [12].

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Table 1. List of measurements of capture and fission cross sections already performed at n_TOF (2002 – 2004).

CAPTURE	MEASUREMENT CAMPAIGNS 2002-2004
^{151}Sm ^{204,206,207,207}Pb, ^{209}Bi ^{24,25,26}Mg ^{90,91,92,94,96}Zr, ^{93}Zr ^{186,187,188}Os, ^{139}La ^{232}Th, ^{233,234}U ^{237}Np, ^{240}Pu, ^{243}Am FISSION ^{233,234,235,236,238}U ^{232}Th, ^{209}Bi ^{237}Np, ^{241,243}Am, ^{245}Cm	Systematic measurements of capture and fission cross sections of actinides: - Nuclear properties (barriers, lecvel spacing, etc.) - Development of new fuel cycles (Th/U) - Relevant for transmutation projects (ADS) - Needed for development of Gen-IV reactors Most results already available (publications, EXFOR, etc.)

IV. THE EXPERIMENTAL CAMPAIGNS 2001 – 2004

The measurements so far performed at n_TOF have covered capture and fission cross section measurements on a large number of samples. The full list is given in the Table 1. Most of the measurements have been performed for the n_TOF-ND-ADS Project, within the EC FP5 initiative. The motivations and physics cases of the various measurements have been given in great details in the proposal for measurements submitted to the CERN INTC Committee [13].

V. THE N_TOF FACILITY FROM 2008

After a three year long stop due to reported cooling water activation by spallation products diluted in the water, a new lead target was constructed, and new systems developed in order to meet safety requirements for the restart of the facility. In particular, a ventilation system was installed in the primary target area, while a new optimized cooling system was developed, which allows to control and balance the chemical parameters of the water (in particular the oxygen content and conductivity) and to properly filter activation products eventually present in the water circuit. An extensive study of target corrosion mechanism had been performed, in order to improve the long term stability of the system. A new cylindrical shape lead block of 40 cm radius and 60 cm length, developed in order to optimize cooling and neutron production was designed and built. An improvement for the new target consists in a separated cooling and moderator circuit, which enables the use of different moderator materials, thus allowing a greater flexibility on the characteristics of the neutron beam [14].

VI. COMMISSIONING RUN 2009

The n_TOF program has used 7.5×10^{18} protons over the course of the 2009 run. Following the complete characterization of the neutron beam, the Collaboration has initiated the foreseen physics program, with the mea-

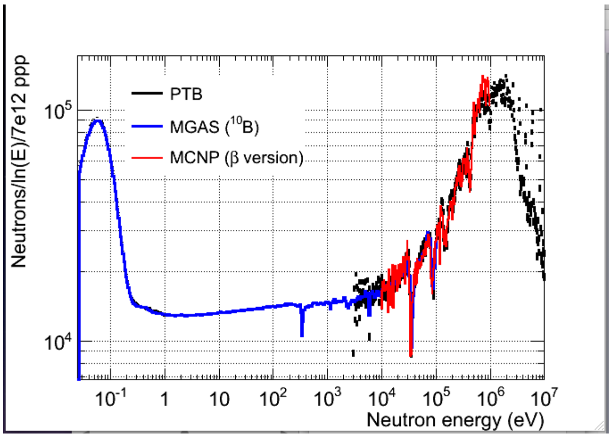

Fig. 2. (Color online) Preliminary neutron fluence corresponding to the new spallation target using water as moderator.

surement of ^{56}Fe and ^{62}Ni capture cross-section, performed with the C_6D_6 detectors.

Several detectors have been used for the commissioning: for the evaluation of the neutron fluence (see Fig. 2) a calibrated ^{235}U-based fission chamber from PTB has been employed, complemented with a MicroMegas detector loaded with ^{10}B and ^{235}U samples, with the standard n_TOF silicon monitor and by the activation technique with two gold foils. For the neutron beam profile, two independent apparatus have been used, a Medipix detectorwith a LiF and polyethylene converters and the X-Y MicroMegas detector, an innovative system [15] based on the Bulk technology and capable of producing a 2D image of the neutron beam at any incoming energy. Preliminay result are reported in [16].

VII. FUTURE

Future upgrades of the facility have already been planned by the n_TOF Collaboration in order to improve the characteristics of the facilities.

The first of these steps is the implementation of a different moderator material other than light water. In particular, the present program envisages to use water enriched in ^{10}B, which will greatly enhance the measuring capabilities by reducing significantly the presence of the in-beam photon component, produced both by neutron capture in hydrogen (which give rise to a 2.2 MeV γ-rays) and by neutron capture in structural materials such as lead and iron, which produce γ-rays between 7 and 7.5 MeV. Since this photon contribution is delayed, *i.e.*, emitted after about 1 microsecond from the proton interaction, it results in a background component in the 1 – 100 keV neutron energy range, which is problematic for capture reaction measurements performed with C_6D_6 detectors. The conceived system will reduce the 2.2 MeV photon background component by a factor of about 10, leaving the neutron fluence unchanged above 1 eV. The upgrade is already in the engineering stage

Table 2. Measurements proposed for n_TOF Phase II.

CAPTURE MEASUREMENTS	
Mo, Ru, Pd (stable)	r-process residuals calculation
Fe, Ni, Za and Se (stable) ^{79}Se	s-process in massive stars Accurate ND for structural materials
A = 150 (isotopes varii)	s-process branching points Long-lived fission products
^{234,236}U, ^{231,233}Pa	Th/U nuclear fuel cycle
^{235,238}U	Standards, conventional U/Pu fuel cycle
^{239,240,242}Pu, ^{241,243}Am, ^{245}Cm	Incineration of MA (WSTA)
FISSION MEASUREMENTS	
MA, ^{240,242}Pu, ^{245}Cm, ^{241,243}Am	ADS, high burn-up, GEN-IV (WSTA)
^{235}U(n,f) with p(n,p')	New ^{235}U(n,f) cross section standard
^{234}U	Study of vibrational resonances at fission barrier
OTHER MEASUREMENTS	
^{147}Sm(n,α), ^{67}Zn(n,α), ^{99}Ru(n,α), ^{58}Ni(n,p), other (n,lcp)	p-process studies Gas production in structural material
Al, V, Cr, Zr, Th, ^{238}U(n,lcp)	Structural and fuel material for ADS/GEN-IV
He, Ne, Ar, Xe	Low energy nuclear recoils (development of gas detectors)
N + D_2	Neutron-Neutron scattering length

and it will be ready for the 2010 n_TOF run.

Another upgrade foreseen for the 2010 run is the transformation of the n_TOF experimental area into a Work Sector of Type A, which will allow to perform measurement of capture and fission cross-section of "unsealed" samples of highly radioactive isotopes, such as actinides like ^{241}Am, ^{243}Am and ^{241}Pu, taking full advantage of the facility's high instantaneous neutron flux. This will require a complete revision of the experimental area and of the related technical services. The refurbishment will be ready for the 2010 run restart.

A longer term project involves the possibility to construct a second experimental area located above the spallation target pit. The two main advantages over the experimental area at 200 m are the reduced prompt-flash and the increased flux, by around a factor 20. The latter factor will allow reducing the mass of the samples, especially in the case of short lived-highly radioactive isotopes, for which the main problem is the cost and the availability in significant amounts. The project is under study and a technical report will be released by end 2010.

VIII. FINAL MARKS

CERN n_TOF has proven to be a unique facility in the world for its performances and also of the rich scientific program that has been performed, produced numerous publications and valuable data in the field of nuclear physics. A similar strength experimental program is foreseen for the near future.

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