The n_TOF facility at CERN

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A new neutron facility has recently been constructed and became available at CERN. The high instantaneous neutron flux, high resolution and low background make this facility well suited for high quality neutron cross section measurements. The scientific program, together with the description of the facility and the main features of the experimental apparatus will be mentioned. The results of the first measurements campaign, which have confirmed the innovative aspects of the facility are presented.

1 Introduction

The interaction of neutrons with nuclei in the neutron energy region from the thermal to a few tens of MeV has for long been of primary interest for nuclear technology, astrophysics and fundamental symmetries.
The concern in high resolution neutron capture cross section data has gained much interest in recent years due to the development of new activities related to nuclear energy, like the transmutation of nuclear waste, the thorium-based nuclear fuel cycle and accelerator driven system (ADS) [1][2][3][4]. All these activities requires high precision experimental determination of cross sections for neutron capture, neutron-induced fission and neutron inelastic scattering on several isotopes, many of them radioactive.
Capture and fission data are needed for fertile and fissile isotopes involved in the Th-cycle as ^{232}Th, ^{233}U, ^{234}U and ^{236}U. Similarly, the design of ADS for nuclear waste transmutation requires reliable experimentally determined capture, fission and (n,xn) cross-sections for transuranic isotopes, in particular ^{237}Np, ^{238,240,240}Pu, ^{241,243}Am and ^{244,245}Cm, while the transmutation scheme of Long Lived Fission Products (LLFP) requires accurate data on capture reaction for ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, ^{151}Sm, etc... The cross-section for structural materials considered as neutron-production target or as coolant, are still far from being accurately known, especially at high neutron energy. Finally, advances in laboratory measurements of neutron cross-sections are required for improving the understanding of neutron capture nucleosynthesis in evolved stars and supernova explosions, especially for radioactive species or isotopes with very low cross-section.
Many of the aforementioned needs can be addressed at a neutron time-of-flight facility recently set in operation at CERN: n_TOF. Based on an idea of Rubbia et al [5], an intense pulsed neutron beam, with a wide energy range 1 eV - 250 MeV, is produced by spallation of a 20 GeV proton beam from the PS accelerator on a lead target. The high instantaneous neutron flux, low duty cycle, high resolution, low background and an innovative data acquisition system make this facility unique for cross-section measurements relevant to many fields of applied and fundamental physics. Due to the high instantaneous neutron flux, n_TOF results particularly suited for capture cross-section measurements on radioactive isotopes which are hampered not only by their intrinsic activity, but also because suited samples are only available at limited quantities. The wide energy range will allow to extend the present knowledge of the fission and inelastic cross-section to regions still largely unexplored.
An ambitious experimental program on neutron capture, fission and possibly (n,xn) reaction cross-section has started in 2002 in the frame of an international collaboration, involving more than hundred physicists.The facility, experiment apparatus and the first results at n_TOF are presented.

2 The n_TOF facility

Neutrons are generated by spallation of a 20 GeV/c proton beam from the PS accelerator on a lead target, of 80x80x60 cm^3. A 5 cm water layer surrounds the target, acting as coolant and also as a moderator, to produce an isolethargic neutron flux distribution over a wide energy range (1 eV - 250 MeV). Neutrons emerging from the target propagate in a pipe inside a time-of-flight tunnel 200 m long. Along the flight path, two collimators placed at 135 and 180 m from the spallation target, with aperture of 13.5 and 2 cm diameter, respectively, are used to shape the neutron beam. A sweeping magnet placed at 40 m upstream the experimental area is used to deflect outside the beam charged particles traveling along the vacuum pipe. For an efficient background suppression, several concrete and iron walls are placed along the time-of-flight tunnel.
The measuring station is located inside the tunnel, centered at 187.5 m from the spallation target, and delimited by two concrete walls 7.5 m apart. An escape line, 12 m long and ending in a polyethylene block, ensures a negligible background from the backscattered neutrons and capture γ-rays. The main features of the n_TOF facility are summarized in Table I. Fig 1 shows a schematic view of n_TOF facility.

TABLE I. Main features of the n_TOF facility

Neutron energy range	1 eV-250 MeV
Proton beam energy and intensity	20 GeV/c; 7x10^{12} p/pulse
Pulse repetition frequency	0.25 s^{-1}(average in dedicated mode)
Neutron flux at 187.5 m (uncollimated)	4x10^5 n/cm^2/pulse
Neutron flux with Φ=1.9 cm collimator	1.4x10^5 n/cm^2/pulse
Fraction of flux in 1 eV - 1 Mev range	2/3
Resolution ΔE/E	3x10^{-4} at 1 eV; 1.5x10^{-3} at 30 KeV
Background (fluence out/in beam)	10^{-5}

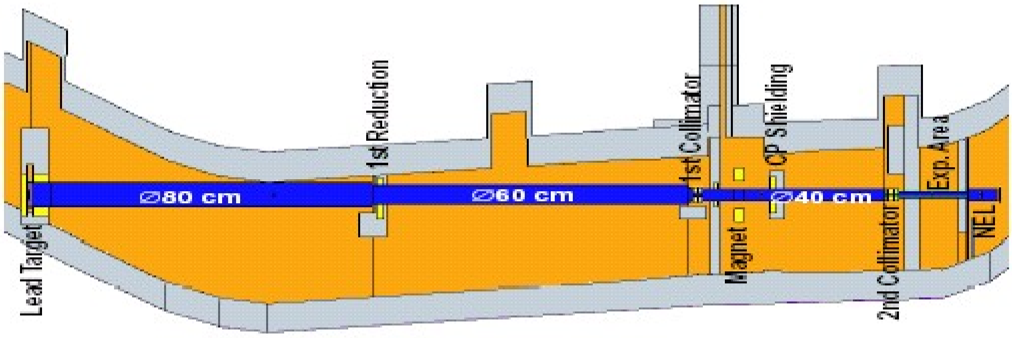

Figure 1. Lay out of the TOF tube.

The neutron flux produced by spallation is more than two orders of magnitude higher than the ones available at other facilities. This facility is particularly useful for cross-section measurements of small and radioactive samples, as it improves considerably the signal-to background ratio.

Furthermore, other important features of n_TOF neutron beam are the high resolution and the low level ambient background, which should give a significant improvement of the quality and accuracy of the existing data over a wide energy range.

Finally, the availability of high-energy neutrons allows to study the processes of fission and inelastic scattering involved in the operation of a spallation neutron source in the ADS.

3 The experimental set-up

Different experimental set-ups are used for capture and neutron-induced fission measurements. The neutron-beam is monitored up to 1 MeV by a low-mass system, based on a thin Mylar foil with ^{6}Li deposit placed in the beam, surrounded by an array of silicon detectors placed outside the beam. The detection by the silicon detectors of the tritons and α's produced in the ^{6}Li(n,α) reactions gives a direct measure of the neutron flux. The small amount of material in the beam ensures a negligible level of scattered neutrons. The scattering chamber is made of carbon fibre to minimize the neutron-induced γ background.

Measurements of neutron capture cross-sections in the first stage of the project are performed with specifically made C_6D_6 detectors with a carbon fibre container, characterized by an extremely low neutron sensitivity that makes them suited even for samples with a large scattering to capture ratio [6]. The measurements are based on the detection on γ-rays emitted in the de-excitation cascade following neutron capture, and rely on the use of a pulse height weighting function technique, which consists of modifying by software the detector's response so that the overall efficiency does not depend on the details of the cascade but only on the total capture energy [7]. Weighting functions for each sample are obtained by means of detailed Monte Carlo simulations of the detector response [8], validated by the well-known capture cross-sections of ^{197}Au, ^{109}Ag and ^{nat}Fe.
For the second stage of the neutron capture measurements, in 2004, a total absorption calorimeter made of 40 15 cm thick BaF_2 crystals thick will be used. Such a detector covers a 4π solid angle and has 100 % efficency for the γ rays of interest up to roughly 10 MeV. It will allow the measurement of low-mass and fissile samples.

The measurements of neutron-induced fission processes are performed with two different detection systems: one based on Parallel Plate Avalanche Counters (PPAC) and the other one based on Fission Ionization Chambers (FIC), both of them hosting up to 11 samples. These detectors are based on completely different principles, in particular with respect to the α pile-up and the self-absorption effects. Therefore they are subject to different and independent systematic uncertainties. This will allow to derive a more consistent set of cross-section data. In both systems the monitor of the neutron flux is performed by a ^{235}U sample, covering the whole range, and by ^{238}U and ^{209}Bi for the high-energy region.

The first system is based on a stack of several position

sensitive PPAC's, with thin entrance windows, the measured isotopes are deposited on thin Mylar or Al backings, placed between two PPAC's so that both fission fragments from the reaction can be detected. The coincidence requirements, together with position information, allows to reject spurious reactions, in particular the α-particles from the natural radioactivity of the samples and the charged products of neutron elastic and inelastic reactions with the window and sample backing. Another advantage of PPAC concerns in the fast charge collection time, particularly useful to minimize the probability of pile-up events.
In the second system, FIC, the optimization of the gas pressure and the electrode distance leads to a good discrimination of fission fragments from other competing reactions. The fission fragment events are recognized by simple amplitude discrimination, the efficiency of this detector is only limited by the fission fragment absorption in the target itself. With the deposit in use during the measurements, 150 μg/cm^2, the efficiency is 95%.
Due to the high instantaneous neutron flux, several events are generally produced inside the detectors for a single neutron bunch, producing is some case pile-up between signals. In these conditions standard acquisition systems are inadequate. The data acquisition system (DAQ) of n_TOF is entirely based on flash ADCs with a sampling rate of up 1 GHz for recording the detector signals during nearly 20 ms. This generates a high data rate but ensures zero dead-time and a full reply of the events in the entire neutron energy range.
To reduce the amount of data, software zero suppression is applied, so that only a small amount of points, including a few pre- and post- samples for baseline determination, are kept for signals above a given threshold. A suitable procedure for signal reconstruction allows to extract all pertinent information, such as the time-of-flight, amplitude, charge and, for liquid scintillator detectors, the n/γ discrimination [9].

4 First results at n_TOF

The first measurement campaign, performed in 2001, was dedicated to the determination and experimental validation of the n_TOF neutron beam. In particular, the activity was focused on the measurement of the neutron flux, beam profile, energy resolution and background.

The results of these measurements clearly demonstrate the innovative features of the n_TOF neutron beam [10][11][12].

In the year 2002 neutron capture measurements with C_6D_6 detectors were performed for the isotopes ^{56}Fe, ^{197}Au, ^{151}Sm, ^{204,206,207,208}Pb, ^{209}Bi and ^{232}Th [13][15]. The fission measurements, where both detectors, PPAC and FIC were used, for the isotopes ^{234}U and ^{232}Th relative to ^{235}U and ^{238}U fission cross section [16][17].
The measuring campaign has been continued in 2003, the measurement of neutron capture cross-section for isotopes ^{24,25,26}Mg, ^{186,187,188}Os,^{90,91,92,94,96}Zr and ^{139}La has just finished by the time of this symposium [13][14]. The 2003 campaign will be completed with fission measurement on ^{233,236}U, ^{237}Np, ^{241,243}Am and ^{245}Cm [18].

Fig. 2 and Fig. 3 show the first preliminary results of some of the 2002 measurements.
Fig. 2 shows the results of the SAMMY [19] fit for some of the ^{151}Sm resonances. The (n,γ) cross section of the ^{151}Sm was not yet measured because of the radioactivity of the sample. With the unique features of the n_TOF facility it has been possible to measure this quantity. The neutron capture of ^{151}Sm has important implications for Nuclear Astrophysics and for ADS. In particular the unstable isotope ^{151}Sm is instrumental for analyzing the branching in the neutron capture flow at A=151 in terms of temperature at the stellar site of the slow neutron capture process (s-process). The ^{151}Sm is also a LLFP, produced during nuclear reactor operation and because of its large thermal cross section represents an important neutron poison.

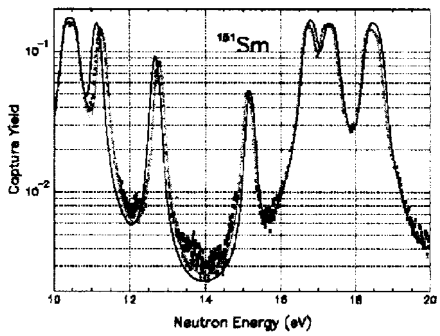

Figure 2. A comprehensive view of the first resonances of ^{151}Sm with the SAMMY fit. The darker curve represents the yield extracted from the resonance parameters currently available in the ENDF/B-VI database.

In Fig. 3 the comparison between fission yield of ^{235}U data, measured at n_TOF and the evaluated yield form the ENDF-B/VI database is shown. These are only preliminary results and they are used here only to show the good quality of the measurements at n_TOF facility, in particular in Fig. 3 can be seen the improvement in the nuclear data for ^{235}U.

5 Conclusion

Neutron capture and fission cross-section are still needed for applications like ADS, nuclear transmutation and astrophysics. A vast program of measurements has started at the innovative neutron time-of-flight facility n_TOF at CERN. The innovational features of the facility and of the high-performance detectors and DAQ system will allow to improve the neutron cross-section databases particularly for many radioactive isotopes for which data are still missing. The first experimental results have confirmed the high accuracy that can be achieved at n_TOF facility, for the first time the neutron capture cross section of isotope ^{151}Sm was measured.

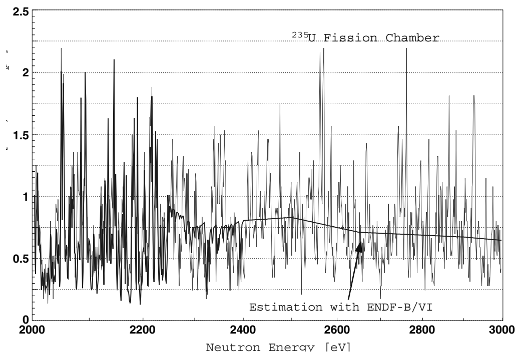

Figure 3. Comparison between ^{235}U data, measured at n_TOF and the evaluated cross-section from ENDF-B/VI database.

The measured data will be evaluated and made available to the scientific community.

Acknowledgments

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