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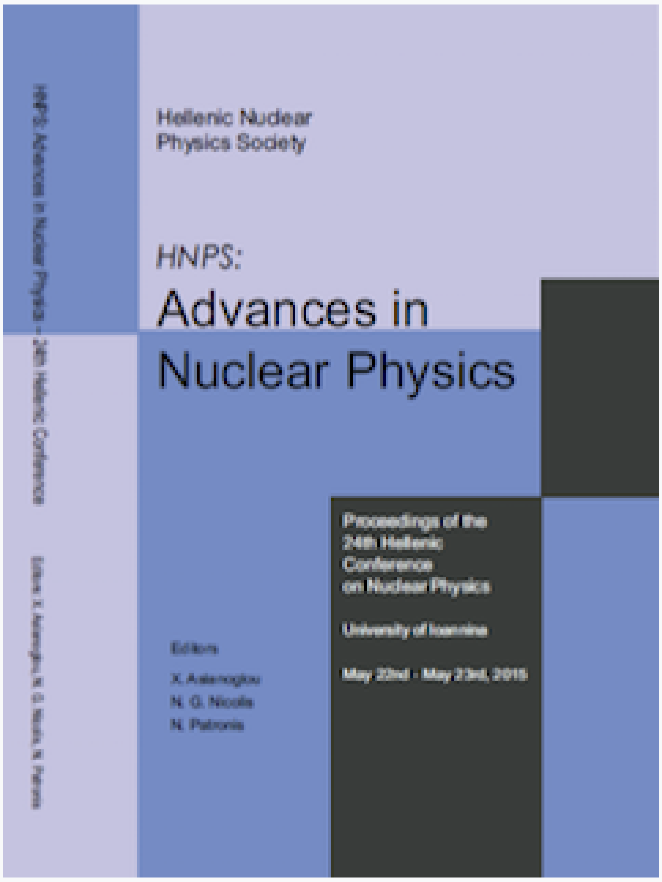

A review of the fission programme at the CERN n_TOF facility

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A review of the fission programme at the CERN n_TOF facility

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Abstract Since 2001, the scientific programme of the CERN n_TOF facility has focused mainly on the study of radiative neutron capture reactions, which are of great interest to nuclear astrophysics and on neutron-induced fission reactions, which are of relevance for nuclear technology, as well as essential for the development of theoretical models of fission. Taking advantage of the high instantaneous neutron flux and high energy resolution of the facility, as well as of high-performance detection and acquisition systems, accurate new measurements on several long-lived actinides, from ^{232}Th to ^{245}Cm, have been performed so far. Data on these isotopes are needed in order to improve the safety and efficiency of conventional reactors, as well as to develop new systems for nuclear energy production and treatment of nuclear waste, such as Generation IV reactors, Accelerator Driven Systems and reactors based on innovative fuel cycles. A review of the most important results on fission cross-sections and fragment properties obtained at n_TOF for a variety of isotopes is presented along with the perspectives arising from the newly added 19 m flight-path, which will expand the measurement capabilities to even more rare or short-lived isotopes, such as ^{230}Th, ^{232}U, ^{238}Pu and ^{244}Cm.

Keywords n_TOF, time-of-flight, neutron-induced fission

INTRODUCTION

Feasibility, design and sensitivity studies on new generation reactors that can successfully address concerns on the use of nuclear power (safety, waste, proliferation) require high-accuracy cross-section data for a variety of neutron-induced reactions from thermal energies to several tens of MeV [1-2], such as capture and fission cross-sections of isotopes involved in the Th/U fuel cycle, long-lived Pu, Np, Am and Cm isotopes, long-lived fission fragments relevant for transmutation projects or isotopes considered as structural material for advanced reactors. Improved knowledge of these cross-sections is also important for the operation of existing reactors, since safety margins can be tightened, leading to a more efficient use of available fuel resources. Furthermore, accurate data on different neutron-induced fission observables are essential for the development of a comprehensive model of fission that accurately describes all its aspects and has satisfactory predictive capabilities.

In this context, as well as for nuclear astrophysics studies and for other fields of basic and applied nuclear physics, the n_TOF (Neutron Time-Of-Flight) facility

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was constructed at CERN over 15 years ago [3] with the aim of measuring neutron cross-sections over a wide energy range, from thermal to GeV, with a very high energy resolution and high instantaneous neutron flux.

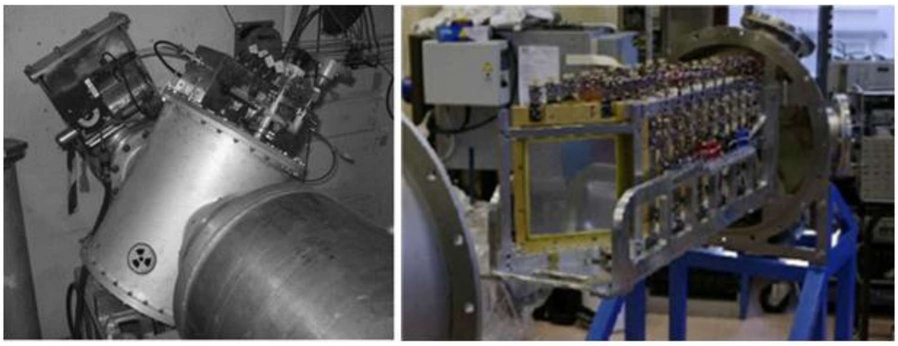
THE N_TOF FACILITY

Neutrons at n_TOF are spallation products created by a bunched 20GeV/c proton beam delivered by CERN's PS (Proton-Synchrotron) accelerator onto a lead target. Since 2009 (Phase-II), the target is a lead cylinder 40cm in length and 60cm in diameter, while previously (Phase-I) it consisted of several lead blocks. A 1cm-thick layer of water surrounds the target and is constantly circulated in order to cool it down. Along the direction of the beam, this layer is immediately followed by a second, 4cm-thick layer which is filled either with demineralised water or borated water, with the addition of boric acid enriched in ^{10}B. The water present around the target, particularly in the beam direction, serves to moderate the neutrons produced in the spallation process and populate energies down to thermal. Two collimators along the beam-line shape the beam and a dipole magnet deflects the charged particles travelling with the neutrons inside the vacuum tube. Since 2009, the experimental area meets the requirements to operate as a Type A Work Sector [4], meaning unsealed radioactive samples can be handled. More detailed presentations of the facility can be found in [5-8]. The detector signals are digitized with flash-ADCs and analysed off-line by means of routines that determine the signal baseline, search for signals and determine the corresponding neutron time-of-flight (and thus the incident neutron energy) and the pulse height, among other quantities [9].

EXPERIMENTAL SETUPS FOR FISSION

A variety of detectors are used for fission measurements at n_TOF. Most of them can be used to measure the cross-section of different isotopes simultaneously, thus optimising the use of beam-time. The **Fission Ionisation Chamber (FIC)** [10] (Figure 1a) consists of a stack of several parallel-plate chambers with 5mm spacing between electrodes, operated with an Ar:CF_4 mixture (90:10) at a pressure of 720 mbar. The samples are deposited on both sides of 100μm thick aluminium foils, used as a cathode, while the anodes are made of a 15μm thick foil. Samples used are typically of 8cm in diameter and with up to 450μg/cm^2 in thickness.

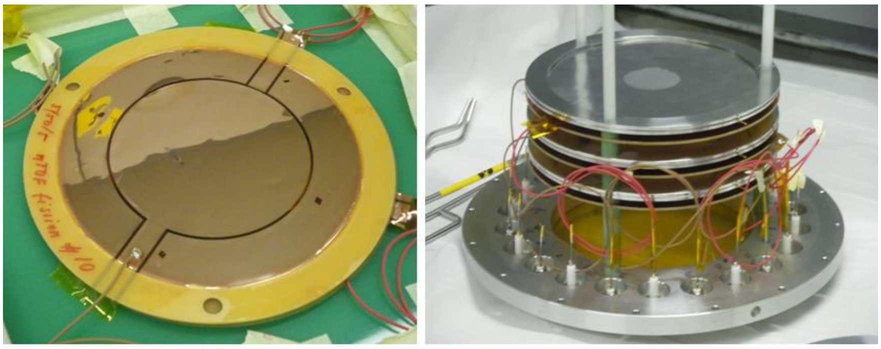
The **PPAC (Parallel Plate Avalanche Counter) assembly** consists of a stack of PPACs placed in a vessel with low-pressure circulating gas (Figure 1b). This setup can detect both fission fragments emitted in a fission event in coincidence, thus efficiently rejecting the α-particle background, as well as competing reactions. The detectors are tilted with respect to the neutron beam to achieve a reasonable efficiency at all fragment emission angles. The samples are deposited on thin (<2μm) backings and placed between two adjacent PPACs. The position sensitivity of this setup allows to measure the angular distribution of fission fragments in addition to the fission cross-section [11].



(a) (b)

Fig. 1. One of the FIC detector variants placed along the n_TOF beam line (a) and an internal view of the PPAC assembly presently used at n_TOF (b).

The most notable design variation of the **Micromegas (Micromesh Gaseous Structure) detector** compared to a more traditional parallel plate avalanche chamber, is the separation of the gas volume into two regions: a drift region whose width can vary from a few hundreds of μm to a few cm and an amplification region, typically of a few tens of μm. The two regions are separated by a micromesh, a thin (~5μm) conductive layer with 35μm diameter holes on its surface at a distance of 50μm from each other. The *"microbulk"* design [12-13] was developed (Figure 2) to minimize the amount of material present in the beam and thus reduce undesirable backgrounds. Among the advantages of Micromegas detectors are their robustness and radiation hardness, as well as a high signal-to-noise ratio, even for small deposited energies.



(a) (b)

Fig. 2. A Micromegas detector of the 'microbulk' variant (a) and (b) a partial setup of Micromegas detectors and Pu samples inside the specially constructed chamber.

Recently, a **"fission tagging"** setup combining the 4π Total Absorption Calorimeter (TAC), consisting of 40 BaF_2 crystals and specially constructed Micromegas detectors was tested at n_TOF for the simultaneous measurement of the fission and capture cross-sections of fissile isotopes, as described in [14].

Fission events are "tagged" with the Micromegas detector and the γ-rays detected in coincidence are assigned to a fission event, rather than capture. A picture of the setup can be seen in Figure 3.

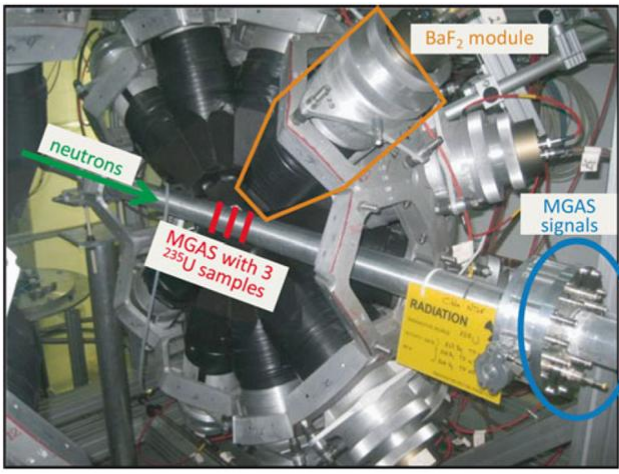


Fig. 3. A view of the "fission tagging" setup at n_TOF with one hemisphere of the BaF_2 array and the chamber with the Micromegas detectors in the centre.

RESULTS FROM N_TOF

The n_TOF Collaboration, which consists of more than 130 scientists from over 30 institutes, has produced a significant collection of high-quality data on a large number of reactions, including fission cross-sections of many isotopes. In most cases, the n_TOF results are characterised by improved accuracy, higher resolution and a wider energy range than previous data. In some cases, the n_TOF data have also helped to solve existing discrepancies between previous experimental and/or evaluated cross-sections.

The many fission measurements performed at n_TOF so far include several isotopes of uranium, that is $^{233\text{-}236,238}$U, ^{232}Th and ^{237}Np (including fission fragment angular distributions), as well as ^{nat}Pb, ^{209}Bi, ^{241,243}Am, ^{242}Pu and ^{245}Cm. An exhaustive list of measurements and related references are given in [15]. Among the many interesting results of the n_TOF fission programme, only a few highlights are presented here.

The ^{233}U fission cross-section was measured from thermal to 2MeV in a single measurement with the FIC detector and with an accuracy of 5% [16-17]. The n_TOF data indicated that significant corrections to evaluations were in order in the region between 10eV and 100keV, as shown in Figure 4a. The ^{245}Cm(n,f) measurement was also performed with the FIC detector and was particularly challenging due the very high activity of the samples (87MBq per sample) [18]. Below 30eV, two very old previous measurements existed with large discrepancies, while, above that energy, a single measurement with neutrons from a nuclear explosion had been performed. As can be seen is Figure 4b, the n_TOF data confirmed the previous data above 30eV and showed that significant corrections were necessary in evaluations at lower energies.

Another interesting case is the fission cross-section of ^{236}U, where n_TOF data showed that JEFF-3.2 and ENDF/B-VII.1 were overestimating the cross-section at thermal energies by a factor of more than 100 [19]. The most recent fission measurement in Phase-II is the cross-section of ^{242}Pu that was measured with a setup based on Micromegas detectors and was the first fission measurement performed with this setup [20-21]. The results above the fission threshold are shown in Figure 4a, while several resonances were also visible above the background from contaminants and from spontaneous fission events.

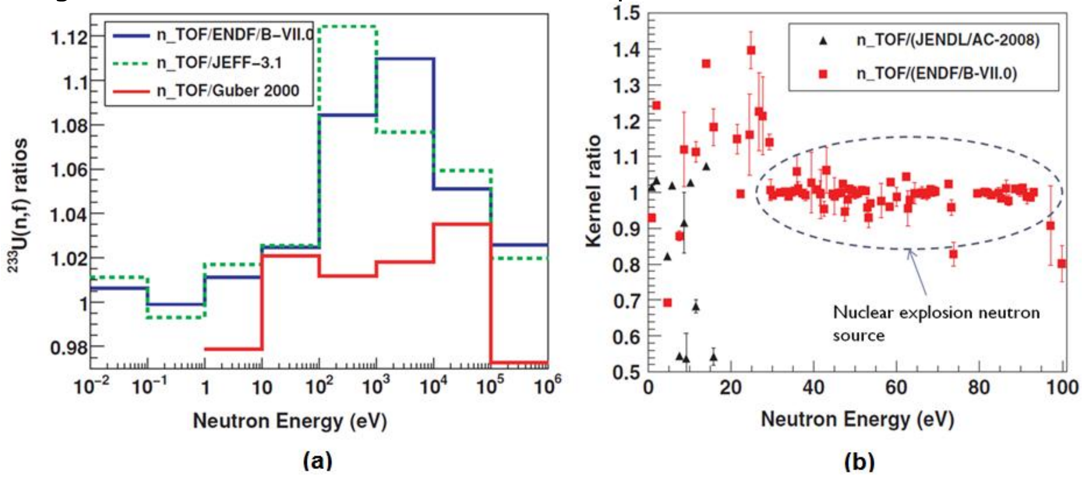


Fig. 4. Ratio of n_TOF data on ^{233}U (a) and $^{245}Cm(n,f)$ (b) with evaluations. Both these results indicated the need for significant corrections to evaluations.

Finally, four different datasets obtained with the FIC and PPAC setups on the $^{238}U/^{235}U$ fission cross-section ratio have been combined by [22] to produce an n_TOF ratio, which is shown in Figure 4b, compared to previous data, evaluations and model calculations. The n_TOF results may help solve a long-standing discrepancy between the two most important experimental datasets available above 20 MeV, while extending the neutron energy range up to 1 GeV for the first time.

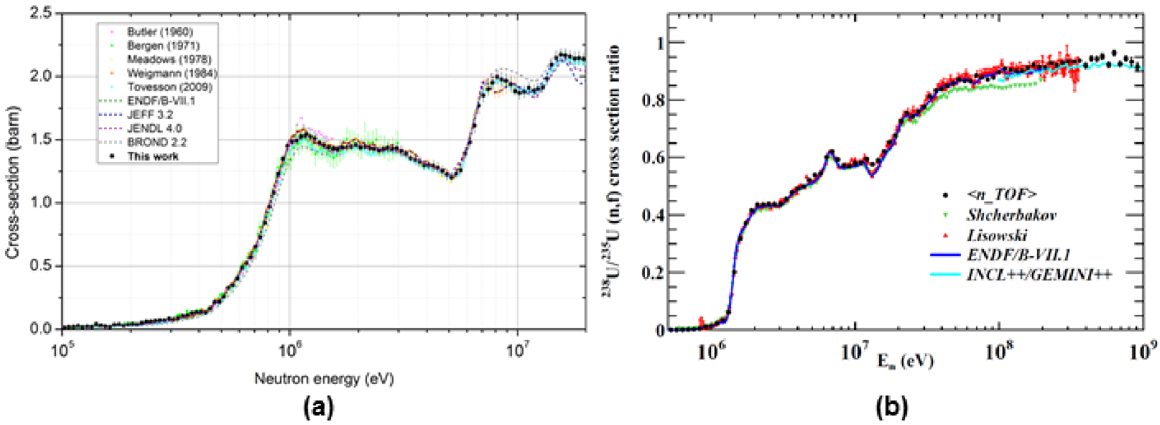


Fig. 5. (a) Data on the $^{242}Pu(n,f)$ cross-section obtained at n_TOF. The results are in good agreement with recent results obtained at LANL [23]. (b) The n_TOF $^{238}U(n,f)/^{235}U(n,f)$ ratio, obtained as the weighted average of four datasets obtained with the FIC and PPAC detectors, compared to previous results and model calculations.

EXPERIMENTAL AREA II AND FUTURE SCIENTIFIC PROGRAMME

A new experimental area (Experimental Area II or EAR-2) [24] was commissioned in the second half of 2014. EAR-2 is located at the end of a 19m neutron beam-line placed vertically above the spallation target. The proximity to the target has yielded a gain in flux of more than 20 times compared to the existing experimental area (EAR-1). The new area will allow n_TOF to expand its measurement capabilities to even more short-lived and rare isotopes, such as ^{230}Th, ^{232}U, ^{238}Pu and ^{244}Cm. The scientific programme of EAR-2 began with the measurement of the fission cross-section of ^{240}Pu [25] with Micromegas detectors.

CONCLUSIONS

Since 2001, n_TOF has carried out an extensive research programme that has produced new results on capture and fission cross-sections of relevance to the fields of nuclear astrophysics and advanced nuclear technologies. A variety of detection systems are employed for these measurements and more are being tested for future use. Recently, a setup for the simultaneous study of capture and fission cross-sections of fissile isotopes has been successfully tested. The commissioning in 2014 of a new 19m flight-path (Experimental Area II), with a neutron flux over 20 times higher compared to the existing 185m beam-line, opens new perspectives for fission measurements at n_TOF with low-mass samples and short-lived isotopes, such as ^{230}Th, ^{232}U, ^{238}Pu and ^{244}Cm, while high resolution measurements can still be performed in Experimental Area.

References

[1] NEA Nuclear Data High Priority Request List, www.nea.fr/html/dbdata/hprl
[2] OECD/NEA WPEC Subgroup 26 Final Report, www.nea.fr/html/science/wpec/volume26/volume26.pdf
[3] C. Rubbia et al., CERN-LHC-98-002-EET
[4] V. Vlachoudis, 2012, CERN EDMS No. 934369,
[5] U. Abbondanno et al., CERN-SL-2002-053 ECT
[6] C. Guerrero et al., Eur. Phys. J. A 49:2, 1-15 (2013
[7] E. Berthoumieux et al., CERN-n_TOF-PUB-2013-001
[8] M. Barbagallo et al., Eur. Phys. J. A 49:12, 1-11 (2013)
[9] P. Zugec et al., Nucl. Instrum. Meth. A 812, 134-144 (2016)
[10] M. Calviani et al., Nucl. Instrum. Meth. A 594, 220-227 (2008)
[11] D. Tarrio, Nucl. Instrum. Meth. A 743, 79-85 (2014)
[12] S. Andriamonje et al., J. Instrum. 5:02 (2010)
[13] S. Andriamonje et al., J. Korean Phys. Soc. 59:23, 1597 (2011)
[14] C. Guerrero et al., Eur. Phys. J. A 48:29 (2012)
[15] A. Tsinganis et al., Physics Procedia 64, 130-139 (2015)
[16] M. Calviani et al., Phys. Rev. C 80, 044604 (2009)
[17] F. Belloni et al., Eur. Phys. J. A 47:2 (2011)
[18] M. Calviani et al., Phys. Rev.C 85, 034616 (2012)
[19] R. Sarmento et al., Phys. Rev. C 84, 044618 (2011)
[20] A. Tsinganis et al., EPJ Web of Conf. 66, 03088 (2014)
[21] A. Tsinganis et al., Nucl. Data Sheets 119, 58-60 (2014)
[22] C. Paradela et al., Phys. Rev. C 91, 024602 (2015)
[23] F. Tovesson et al., Phys. Rev. C 79, 014613 (2009)
[24] C. Weiss et al., Nucl. Instrum. Meth. A 799, 90-98 (2015)
A. Tsinganis et al., CERN-Proceedings-201