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Review of the n_TOF experimental program for Reactor Applications

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Abstract. The n_TOF facility at CERN is devoted mainly to the measurement of neutron-induced reaction cross section of interest for Nuclear Technologies, Astrophysics and Basic Physics. In particular, the list of measurements carried out during the 2nd Phase of experiments n_TOF-Ph2 (2009-2012) includes a significant number of capture and fission experiments on actinides which are considered key for the further development of nuclear reactors. This contribution will contain a description of all these experiments, some of which will be discussed in detail. The future of the n_TOF facility will be also addressed; in particular, the new vertical neutron beam line with a flight path of only 20 m will be presented and the expected performance discussed in detail.

1 Introduction

The research for nuclear reactor applications comprises a wide range of fields, being essential the collaboration between the communities characterizing the reactions that take place in the reactors, simulating experimental and full size reactors, and working on integral experiments and benchmarks in research reactors. In particular, the n_TOF Collaboration makes use of the high intensity neutron beam at CERN to measure with high accuracy the reaction cross sections of relevance for the design and operation of current and future nuclear reactors [1-3].

At the neutron time-of-flight n_TOF facility [4] at CERN, neutrons produced by spallation of 20 GeV/c protons on a lead target travel through an evacuated beam line of 185 meters before reaching the experimental area. The cross section measurements consist then in measuring, as function of the time-of-flight of the neutrons, the reactions occurring in a sample intersecting the beam. The corresponding neutron energy of the reaction is determined from kinematics using the measured time-of-flight. Full details of the facility and the neutron beam characteristics given in Ref. [4].

Since its construction in 2001, the n_TOF facility has provided the nuclear technology and astrophysics community with a large set of new experimental data. Regarding nuclear technology, most measurements have been focused in the capture and fission cross sections of minor and major actinides. In the following sections we describe the detectors used for such measurements and present some of the most recent and/or challenging measurements performed at n_TOF. Last, the new neutron beam facility n_TOF-EAR2 is presented.

2 Detectors for neutron induced-reactions

Several types of detection systems are available at n_TOF, where a significant effort has been devoted to improve both the actual detectors and the associated techniques with respect to previously existing ones.

- The neutron beam monitors used at present are based on an array of silicon detectors (SiMon [5]) looking to a ^{6}Li foil and MicroMegas (MGAS [6]) detectors measuring ^{10}B(n,α) and ^{235}U(n,f) reactions.
- The measurements of capture reactions on isotopes where the neutron scattering dominates over the capture channels are performed with specially built low neutron sensitivity C_6D_6 detectors [7], basing the data analysis in the improved accuracy Pulse Height Weighting Technique [8].
- A higher performance in terms of efficiency, multiplicity and background rejection in neutron capture reactions is provided by the Total Absorption Calorimeter (TAC [9]), a 4π array made of 40 BaF_2 crystals.
- In the case of fission reactions, the MicroMegas (MGAS [6]) is also a high performance detector.
- The use of a set of parallel plate avalanche counters (PPAC [10]) allows to study, in addition to fission cross sections, the angular distribution of the emitted fission fragments.

Using these detection systems, some of which are shown in fig. 1, a large number of experiments have been performed at n_TOF in its second phase (2009-2012).

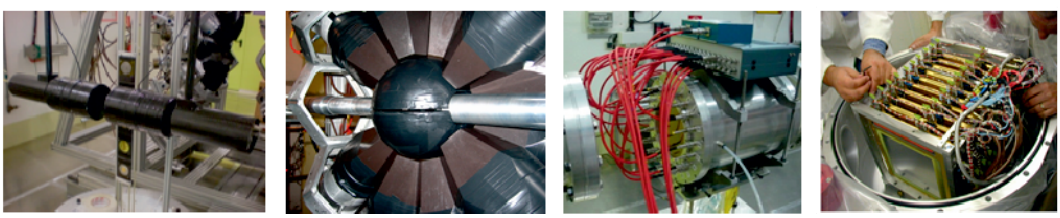

Fig. 1. Photographs of the detectors mentioned in section 2. From left to right: C_6D_6, TAC, MGAS and PPAC detectors.

3 Measurements of relevance for nuclear reactors

Many different reactions, most of them induced by neutrons, play a key role in the design and operation of nuclear reactors. Their cross sections are however not as well known as needed and therefore there are ambitious research programs devoted to improve the accuracy of the nuclear data of interest for reactor applications. The nuclear data needs have been assessed by the WPEC-26 Group of the NEA [11], which also provides an updated High Priority Request List (HPRL [12]) of measurements.

3.1 Fission cross sections of actinides

According to the NEA HPRL, the fission cross section measurements deserve priority are ^{238,239,240,241,242}Pu, ^{241,242}Am and ^{244,245}Cm. Out of these, ^{240,242}Pu [13], ^{241}Am [14] and ^{245}Cm[15] have been already measured at n_TOF.

In particular, the neutron-induced fission cross section of ^{245}Cm was from 30 meV to 1 MeV with 5% accuracy relative to the ^{235}U(*n,f*) cross section normalizing the absolute value at thermal energy to recent measurements performed at ILL and BR1. As seen in fig. 2, the results are in fair agreement with some previous measurements and confirm, on average, the evaluated cross section in the ENDF/B-VII.0 database, although sizable differences are observed for some important resonances below 20 eV. A similar behavior is observed relative to JENDL/AC-2008, a reactor-oriented database for actinides. The new results contribute to the overall improvement of the databases needed for the design of advanced reactor systems and may lead to refinements of fission models for the actinides.

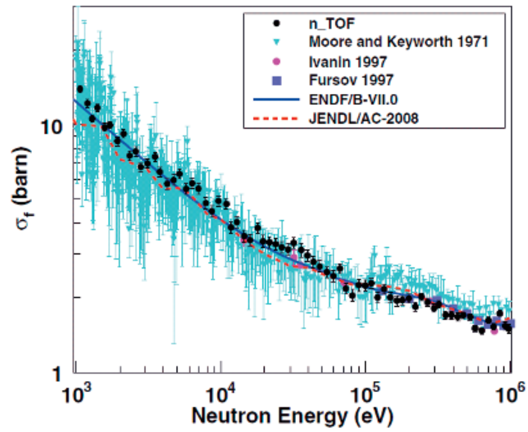

Fig. 2. The ^{245}Cm(n,f) cross section in the unresolved resonance region from 1 keV to 1 MeV neutron energy, compared with the previous data and with the evaluated data sets of ENDF/B-VII.0 and JENDL/AC-2008.

Another interesting measurement is that performed with the PPAC detectors with ^{232}Th samples. This detector provides the means for studying the emission angle of the fission fragments, which varies rapidly as higher fission chance channels open. This is illustrated in fig. 3, which shows the cross section measured at n_TOF (left) together with the associated anisotropy in the emission of fission fragments (right).

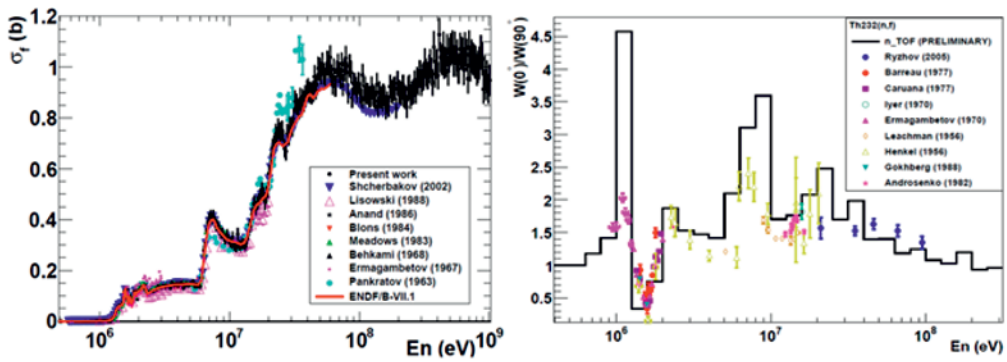

Fig. 3. The ^{245}Cm(n,f) cross section in the unresolved resonance region from 1 keV to 1 MeV neutron energy, compared with the previous data and with the evaluated data sets of ENDF/B-VII.0 and JENDL/AC-2008.

3.2 Capture cross sections of actinides

Most of the experimental program at n_TOF is, however, devoted to neutron capture cross section measurements of interest in nuclear technology, and also nucleosynthesis. In this case the NEA HPRL includes as priority ^{233,235,238}U, ^{239,241,242}Pu, ^{241}Am, out of which ^{233,235,238}U [16-18] and ^{241}Am [18] have been measured recently at n_TOF.
The main challenge of the ^{241}Am capture reactions is related to its very high intrinsic activity, in our case 4 GBq (dominated by the emission of 60 keV γ-rays) for a 40 mg sample with 12 mm in

diameter. The two available capture detection systems, C_6D_6 and TAC, were employed in order to reduce systematic uncertainties. In the case of the C_6D_6 measurement, the full energy range from thermal to 1 MeV was covered, as it is illustrated in fig. 4. The data analysis, which includes the extension of the resolved resonance region beyond 150 eV, is now ongoing a final results will be published along 2013.

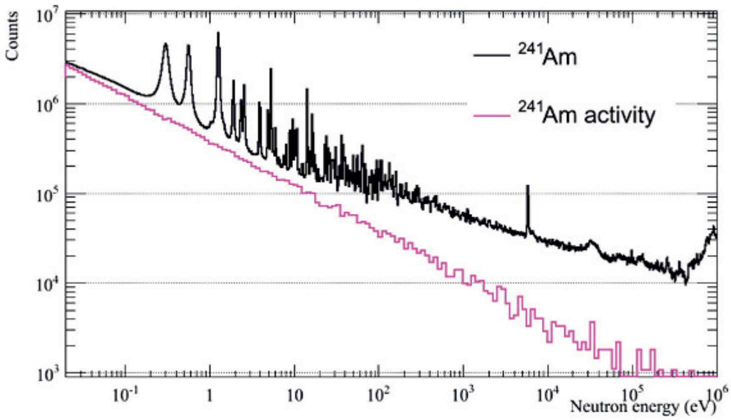

Fig. 4. Neutron energy distribution corresponding to the measurement with C_6D_6 detector of a 40 mg ^{241}Am sample with an activity of 4GBq.

The measurement of capture in fissile isotopes requires distinguishing between the γ-rays emitted in fission and those from capture. In the case of ^{233}U this was done by relying in the different energy and multiplicity of the γ-rays cascades from the two different reactions [16]. In the case of ^{235}U this has been done by combining the TAC with a MGAS fission detector that provided the necessary fission tagging capabilities. The results from a test experiment on ^{235}U made in 2010 [19] are shown in fig. 5. A new experiment covering the full range of interest between thermal and 10 keV has been performed in 2012. The data analysis is now ongoing but some more details can be found in ref. [17].

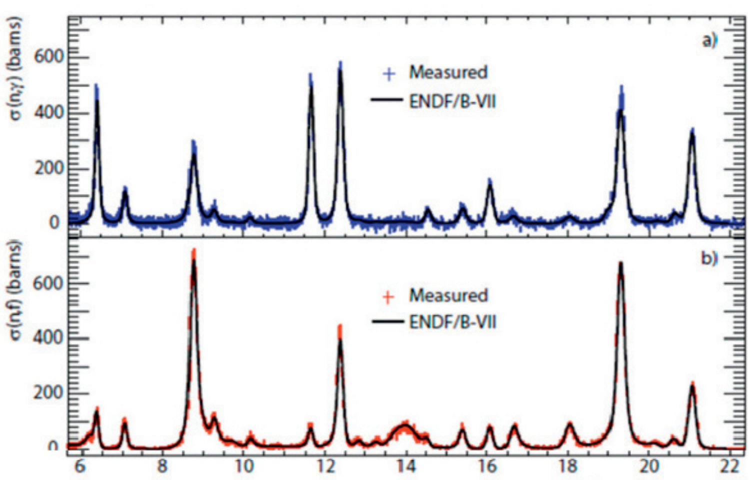

Fig. 5. Capture and fission cross section of ^{235}U measured at n_TOF in a test experiment in 2010. A new measurement covering the full range between thermal and 10 keV has been performed in 2012

4 The new neutron beam line at 20 m flight path

A new neutron beam line, which shall operate in parallel to the existing one, is being designed at CERN. The neutron beam line, sketched in fig. 6, will feature a flight path of 20 meters and will provide a neutron beam covering the energy region between thermal and 300 MeV with a neutron flux that will be 25 times more intense than the one that is now available at n_TOF. See [20] for a more detailed description of the planned n_TOF EAR-2 facility.

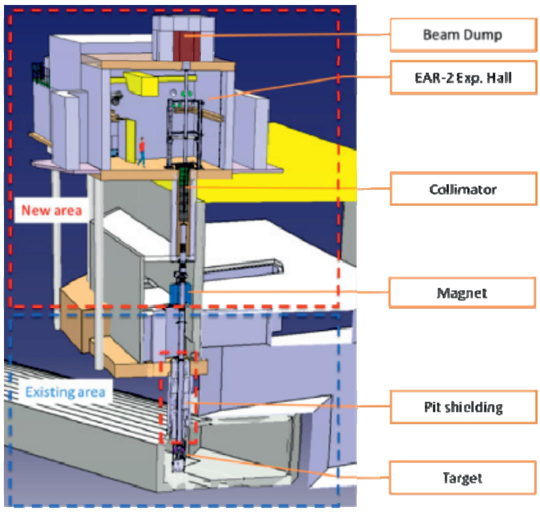

Fig. 6. Sketch of the new neutron beam line facility n_TOF-EAR2.

The new facility will become operative in summer of 2014 and the corresponding experimental program is now under discussion. Surely it will include measurements of radioactive sample in the sub-milligram range and reactions with very low cross section.

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