CERN-INTC-2024-037 / INTC-I-277
09/04/2024

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

Fission Fragment Identification Arm Detector Test to Measure ^{235}U Fission Fragments at n_TOF EAR2

April 9, 2024

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Abstract: n_TOF fission experiments frequently employ actinide targets for cross section measurements [1], which could be re-used for complementary fission yield measurements, such as mass yields as a function of neutron energy. Frequently, such targets have thick backings, which precludes using methods reliant on information on both fragments. 1-Energy 1-velocity ($1E1v$) spectrometers measure fragment mass based on single fragment information and thus offer a solution to using thick-backing targets for mass yield measurements. The authors propose a detector test of such a spectrometer at n_TOF EAR2 with ^{235}U target available from a recent cross section measurement [1]. Around 1000 fragment signals are expected in the 0.5-10 MeV region, which is particularly interesting for future reactor and waste transmutation data needs, and will provide information on upper neutron energies measurable with with the spectrometer. Furthermore, a preliminary mass yield can be calculated in the thermal region to develop yield-measurement techniques at n_TOF using $1E1v$ devices.

Requested protons: 7×10^{17} Protons-on-Target
Experimental Area: EAR2

1 Introduction

A recent measurement of ^{243}Am fission cross section at n_TOF [1] has been motivated by a General Request (GR) by the Nuclear Energy Agency (NEA) aimed at providing data needed for waste transmutation needs [2]. A range of actinide targets have been made available by this measurement, and ^{243}Am presents an interesting case for secondary fission fragment (FF) mass yield measurement due to scarcity of fission fragment information particularly for the light fragment masses at neutron energies relevant for waste transmutation [3].
Targets used during the ^{243}Am campaign have 25 μm aluminium backing, which precludes measurements of both fission fragments required by the 2-energy ($2E$) technique employed by the Double-Gridded Bragg Detector (DGBD), which has recently been tested at n_TOF EAR2 for FF mass yield measurements [4]. An alternative method, 1-energy 1-velocity ($1E1v$) can be used, whereby fission fragment mass is extracted from information on fission fragment velocity and total kinetic energy. A test of $1E1v$ spectrometer, called Fission Fragment Identification (FiFI) arm, with the aim of using thick-backing targets is proposed here. The target characteristics, spectrometer design, and expected statistics are discussed below.

2 Target Characteristics

The test will be conducted using a ^{235}U target of 6 cm diameter. As mentioned above, the target is deposited on 25 μm backing and has a total ^{235}U mass of 2145 μg with areal density of 76 μg/cm^2. The target has an alpha activity of 350 Bq, which is expected to make a minute contribution to experimental statistics due to geometric efficiency discussed below.

3 Fission Fragment Identification Arm

As stated above, Fission Fragment Identification (FiFI) arm is a $1E1v$ device dedicated to measuring FF masses by measuring time-of-flight (TOF) and total remaining energy. TOF is measured using two secondary-electron emission detection (SEED) foils as timing START and STOP detectors with microchannel plates (MCPs), while total remaining energy of the fragments is obtained from ionization chamber (isobutane-filled Bragg detector) signals. SEED foils are made of ≈100 nm of Mylar with ≈250 Å aluminium coating, have a diameter of 8 cm, and are supported by a thin wire grid. FWHM timing resolution of 700 ps has been measured using a ^{241}Am alpha source for the START-STOP assemblies separated by TOF section, whose length can be varied, and 56% intrinsic efficiency has been measured for fission fragments. TOF section is operated at 10^{-7} mbar vacuum.
≈850-keV FWHM energy resolution has been observed for FiFI at Lohengrin separator at Institut Laue-Langevin in Grenoble [5], corresponding to 1-1.5% depending on fragment mass. A schematic diagram and a photograph of FiFI are shown in Fig. 1, and a schematic diagram of a timing detector is shown in Fig. 2.

Actinide target will be positioned inside a dedicated volume, shown in Fig 1 with letter A. Mylar beam-in and beam-out windows will be placed around it.

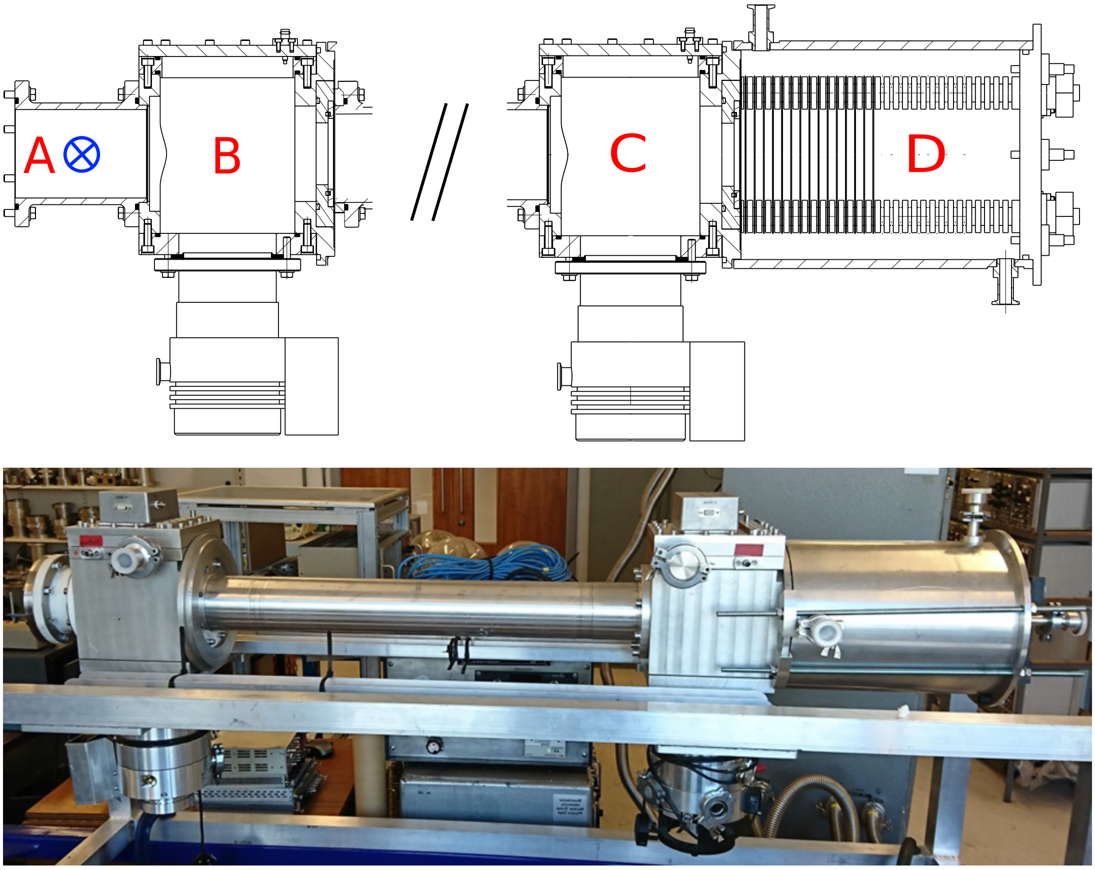

Figure 1: A schematic diagram (top panel) and a photograph (bottom panel) of Fission Fragment Identification arm. Section marked A represents target/source mounting volume, B is the START timing detector, C is the STOP timing detector, and D is the ionization chamber. Time-of-flight section between START and STOP has been truncated for visibility in the top panel, bottom panel shows 1-meter flightpath configuration. Blue crossed circle indicates beam direction.

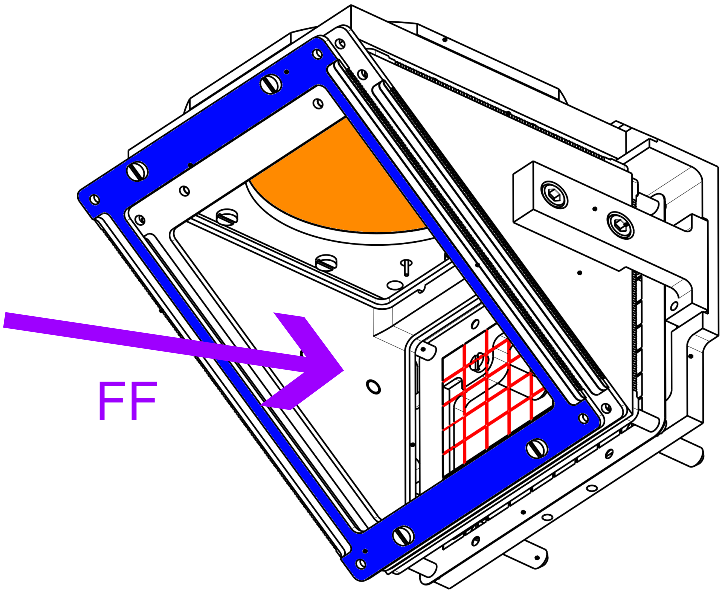

Figure 2: A schematic diagram of a timing detector. Red color marks the wire grid supporting timing foils, blue shows electrostatic mirror used to deflect secondary electrons into MCP, which is shown in orange. Purple arrow indicates the direction of fission fragment travel.

4 Expected Statistics

A major limitation of $1E1v$ experimental technique lies in the requirement of long TOF-section separations to obtain good mass resolution, which results in low geometric efficiencies of the spectrometers using this technique. In the case of FiFI, depending on the choice of flightpath L, geometric efficiencies are typically around 0.1%. In fast-neutron measurements at EAR2, actinide cross-sections are frequently on the order of one barn, and neutron flux reduces by around one order of magnitude between 1 MeV to 10 MeV, and therefore geometric efficiency must be maximized for such measurements as a trade-off to mass resolution. A plot of effects of change in flightpath L on mass resolution is shown in Fig. 3, where evaluated JEFF 3.3 [6] ^{235}U FF mass yield for 400-keV neutrons is convolved with expected resolution effect from change in L itself, resolution due to target diameter (which causes variation in flightpath length), and inherent resolutions of the experimental setup detailed previously (including energy loss in foils and gas window). The shortest flightpath shown, 24 cm, corresponds to START and STOP sections placed against one another without any intermediary pipeline.

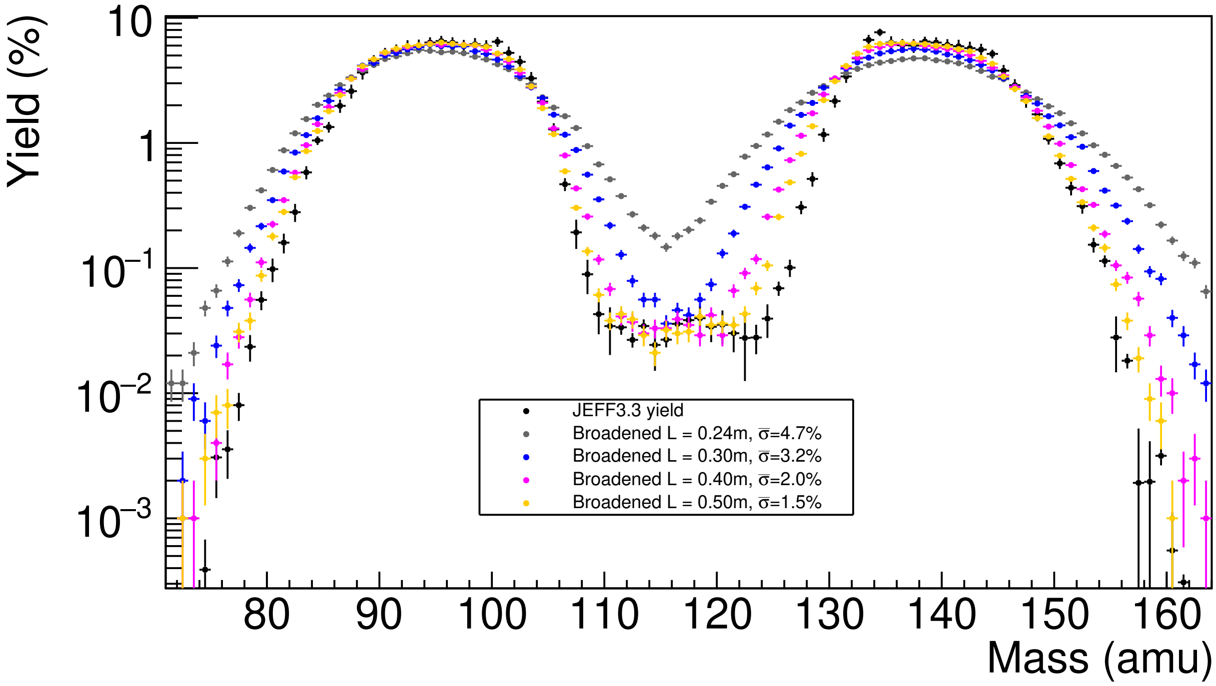

Figure 3: JEFF3.3 ^{235}U mass yields for 400-keV incident neutron energies (in black) convolved with expected system resolution for several flightpath lengths indicated in the legend. Expected mass resolution is expressed as a standard deviation in legend as well. Velocity of 3% of the speed of light was assumed for all fragments.

In order to test flightpath effects on mass resolution and to investigate maximum neutron energies attainable with FiFI (accounting for effects of the gamma-flash at n_TOF), a test at EAR2 is needed. 7×10^{17} protons on target will provide around 1000 to 2000 signals in the 500 keV - 10 MeV neutron-energy range, which can be investigated to address the energy limits and mass resolution. For 0.01-100 eV region, mass yields can be calculated, as yields are not expected to vary substantially in this interval, particularly given the dominance of 0.02-0.2 eV flux increase in this region. Total counts for the the aforementioned neutron energy cuts are shown as a function of FF mass and flightpath L in Fig. 4. Therefore, a test with FiFI at EAR2 is proposed here for a particular flightpath choice (likely 30 or 40 cm), using 7×10^{17} protons on target with a thick-backing ^{235}U target.

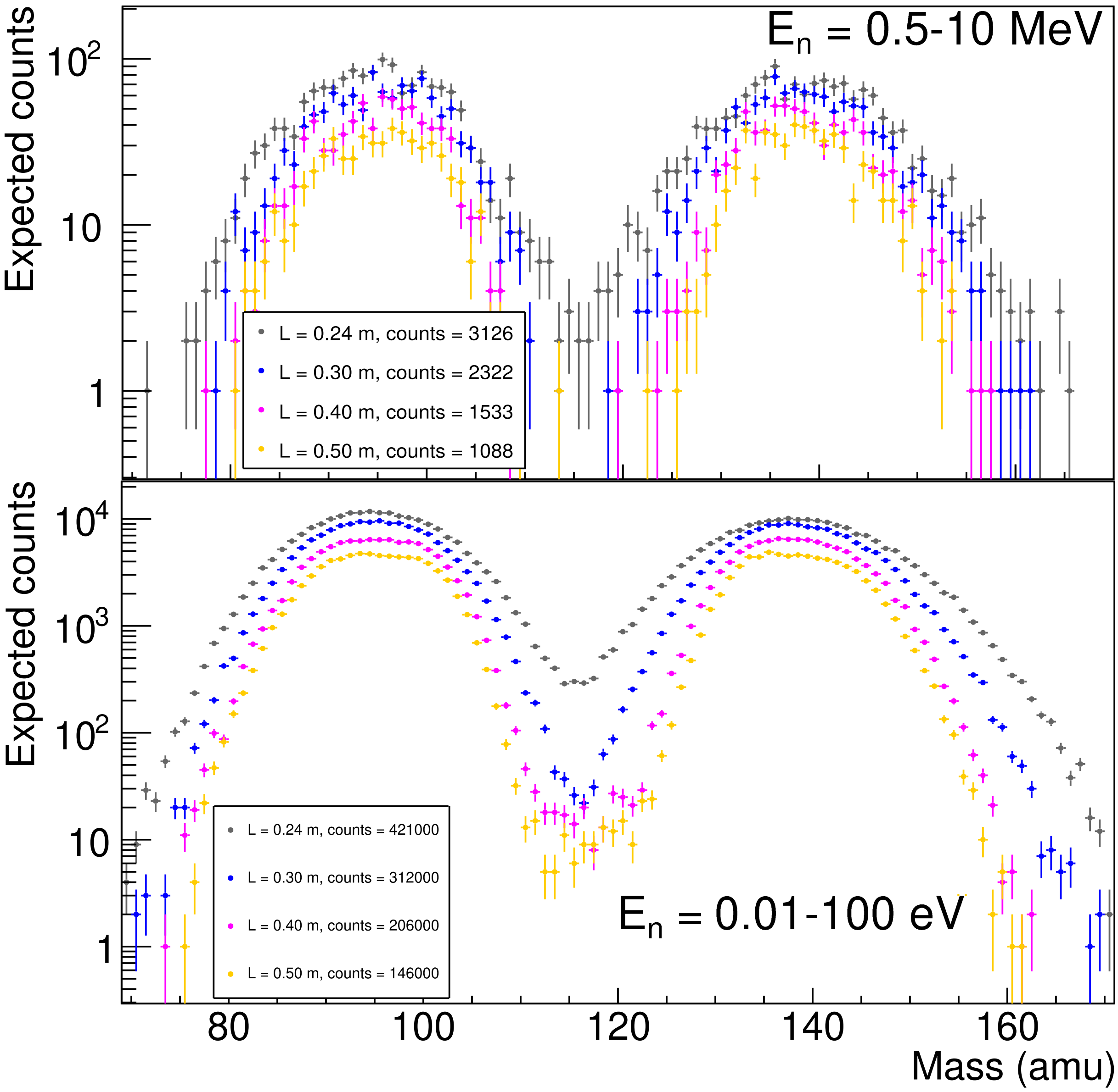

Figure 4: Expected counts in 0.5-10 MeV (top panel) and 0.01-100 eV (bottom panel) neutron energy regions for 7×10^{17} protons-on-target per FF isobar based on resolutions and JEFF3.3 evaluation presented in Fig. 3.

Summary of requested protons: 7×10^{17}.

References

[1] Measurement of the fission cross-section of ^{243}Am at EAR-1 and EAR-2 of the CERN n_TOF facility, 2020, CERN-INTC-2020-048, `https://cds.cern.ch/record/`

2730930/files/INTC-P-566.pdf

[2] T. Sasa, NEA Nuclear Data High Priority Request List, HPRL, 2008, https://www.oecd-nea.org/dbdata/hprl/hprlview.pl?ID=433

[3] N. Otuka *et al.*, Towards a More Complete and Accurate Experimental Nuclear Reaction Data Library (EXFOR): International Collaboration Between Nuclear Reaction Data Centres (NRDC), Nucl.Data.Sheets 120, 272-276, 2014, DOI: https://doi.org/10.1016/j.nds.2014.07.065

[4] Commissioning of a Double Frisch-grid Bragg Detector for Fission Measurements and Determination of n-induced Background at EAR1 and EAR2, 2021, CERN-INTC-2021-051, https://cds.cern.ch/record/2782319/files/INTC-I-236.pdf?version=1

[5] PN1 (Lohengrin) - an exotic-isotope spectrometer, 2024, https://www.ill.eu/users/instruments/instruments-list/pn1/description/instrument-layout/

[6] A.J.M. Plompen *et al.*, The Joint Evaluated Fission and Fusion Nuclear Data Library JEFF-3.3, Eur.Phys.J. A 56, 181, 2020, DOI: https://doi.org/10.1140/epja%2Fs10050-020-00141-9