Determination of ^{236}Np(n,f) and ^{238}Pu(n,f) cross-sections using surrogate reactions

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Introduction

New Generation-IV nuclear reactors are going to utilize fast neutron induced fission as the source of energy, because of which fast neutron induced fission cross sectional data up to 20 MeV neutron energy are required. Neutron induced reaction cross-sections also play an extremely important role in astrophysical nucleo-synthesis. Often, direct (n,f) cross-section measurements are difficult because of short lived target nuclei or non- availability of mono-energetic neutron beam. Under this circumstances, Surrogate reactions [1] are very useful to determine the required (n,f) cross-sections.

Cross sectional data for ^{236}Np(n,f) reaction is not available for neutron energies beyond 4.32 MeV. In this work, we have determined the cross section of the above reaction for the neutron energy range E_n=10-18 MeV using 'Hybrid Surrogate Ratio' method via ^{235}U(^{6}Li,α)^{237}Np and ^{235}U(^{6}Li,d)^{239}Pu reactions. The cross sections for ^{238}Pu(n,f) reaction available in literature have been used as a reference for the above surrogate method. Following relation has been used to determine ^{236}Np(n,f) cross sections,

$$\frac{\sigma(^{236}Np(n,f))}{\sigma(^{238}Pu(n,f))} = \frac{\sigma_{cn}^{^{237}Np}}{\sigma_{cn}^{^{239}Pu}} \frac{N_{\alpha-f}}{N_\alpha} \frac{N_d}{N_{d-f}}. \quad (1)$$

Here, $N_{\alpha-f}$ and N_{d-f} correspond to the number of fission events measured in coincidence with outgoing direct reaction products α and d particles respectively. The inclusive α and d counts are denoted by N_α and N_d respectively. Compound nuclei formation cross-sections (σ_{cn}) are obtained from the code EMPIRE3.1.

The reference cross sections for the above measurement (i.e. ^{238}Pu(n,f) cross-sections) have also been determined using 'Surrogate Ratio' method via ^{235}U(^{6}Li,d)^{239}Pu and ^{232}Th(^{6}Li,d)^{236}U and compared with the literature data [2]. ^{235}U(n,f) cross sections which are available in the literature have been used as reference. The relation used is:

$$\frac{\sigma(^{238}Pu(n,f))}{\sigma(^{235}U(n,f))} = \frac{\sigma_{cn}^{^{239}Pu}}{\sigma_{cn}^{^{236}U}} \frac{N_{d-f}^{^{239}Pu}}{N_d^{^{239}Pu}} \frac{N_d^{^{236}U}}{N_{d-f}^{^{236}U}} \quad (2)$$

Here, $N_{d-f}^{^{239}Pu}$ and $N_{d-f}^{^{236}U}$ are the numbers of deuterons in coincidence with fission of compound nuclei ^{239}Pu and ^{236}U respectively. $N_d^{^{236}U}$ and $N_d^{^{239}Pu}$ are the respective inclusive deuteron counts.

The experiment

Measurements were carried out using 44.4 MeV ^{6}Li beam (from BARC-TIFR Pelletron), 1.6 mg/cm^2 thick ^{235}U target and 1.3 mg/cm^2 thick self-supported ^{232}Th target. ^{235}U target was prepared by electrodeposition method on 4.5 mg/cm^2 thick Ni-Cu backing. Two telescopes (ΔE-E) made of silicon surface barrier detectors, used to detect light charged particles, were kept at 70° and 80°. A large area silicon detector (with a solid angle $\sim$ 33 msr and an angular coverage of 154°-166°) was used to detect fission fragments. Two monitor detectors were placed at forward angles. To stop

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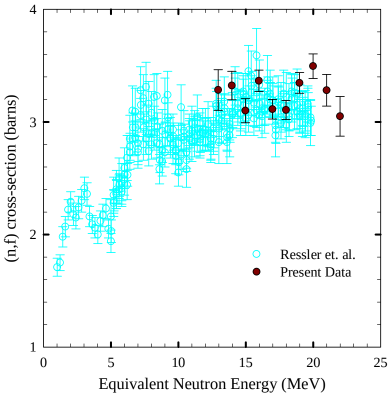

FIG. 1: Determined ^{238}Pu(n,f) cross-sections along with the data measured by Ressler et. al. [2].

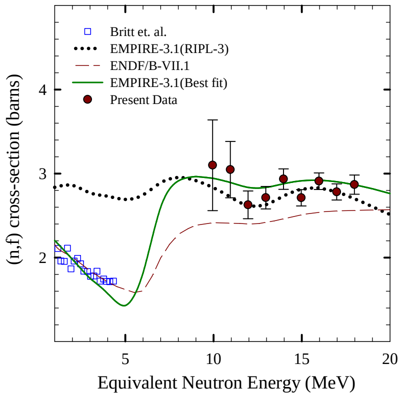

FIG. 2: Determined ^{236}Np(n,f) cross-sections along with the data measured by Britt et. al. [3], ENDF/B-VII.1 Predictions and EMPIRE calculations.

the fission fragments entering the ΔE detectors and prevent them from radiation damage aluminium foils (6.75 mg/cm^2) were placed in front of the particle telescopes. Energy loss in Ni-Cu backing and aluminium foil has been taken into account to reconstruct the energy of outgoing light charged particles.

Determination of ^{238}Pu(n,f) and ^{236}Np(n,f) cross-sections

From the two body kinematics, excitation energy of the compound nuclei has been obtained. The overlapping excitation energy region for surrogate reactions are 18.6 - 27.6 MeV and 16.6 - 24.6 MeV for 1st and 2nd cases respectively. Neutron separation energies from ^{237}Np and ^{239}Pu are 6.57 MeV and 5.64 MeV respectively. Total counts from two telescopes are used in Eqn. (1) and (2) to determine the required cross sections. The (n,f) cross-sections for two reactions determined in steps of 1.0 MeV along with the literature data and calculations are shown in (Fig. 1 and Fig. 2) respectively. Present ^{238}Pu(n,f) cross-sections are in good agreement with the literature data by Ressler et. al. [2] (Fig. 1). Thus it gives us confidence in using the literature data as well as present data for ^{238}Pu(n,f) cross-sections as reference reaction.

As shown in Fig 2 the ENDF/B-VII.1 evaluated ^{236}Np(n,f) cross-sections (dashed line) are in good agreement with the data (hollow squares) measured by Britt et. al. [3], but are slightly under-predicted compared to the present data (filled circles).

Results of EMPIRE-3.1 calculations including fissions up to 3rd chance are also compared. Here, the inner and outer fission barrier heights of a double humped fission barrier for all the isotopes have been taken from RIPL-3. The EMPIRE calculations (dotted and solid line) reproduce the present data for ^{236}Np(n,f) very well. However, the EMPIRE calculations (solid line) only with a reduced value of k quantum number, from 6.0 (default) to 2.5, of discrete transitional state of ^{236}Np nucleus could reproduce both low energy data of Ref. [3] as well as present data at higher energy.

References

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