Determination of ^{234}Pa(n,f), ^{239}Np(n,f) and ^{240}Np(n,f) reaction cross sections by hybrid surrogate ratio method

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Introduction:

The neutron induced fission (*n,f*) cross section data are important for their applications in nuclear energy, national security and nuclear astrophysics [1]. Unfortunately for large number of nuclear species from actinide region, the relevant data cannot be measured directly in laboratory or reliably predicted by calculations. The (*n,f)* cross section data on many actinide nuclei which are produced in the nuclear fuel cycles such as Pa in Th-U fuel cycle or Np, Cm, Pu, Am in U-Pu fuel cycle, are not readily available. The direct measurement of (*n,f*) cross section on these unstable isotopes is particularly affected since the relevant nuclei are difficult to produce by present day experimental techniques or too short lived to serve as target. Calculations are highly nontrivial since they typically require a thorough understanding of both direct and statistical mechanism and detailed knowledge of the nuclear structure involved.

In recent years, the surrogate reaction method in various forms have been employed to get indirect estimate of the neutron induced fission reaction cross sections of many compound nuclei systems in actinide region, which are not accessible for direct experimental measurements. In this present work, we have employed the hybrid surrogate ratio method to determine (*n,f*) cross section for ^{234}Pa ($T_{1/2}$= 6.8hrs) ^{239}Np($T_{1/2}$=62 min) and ^{240}Np($T_{1/2}$= 2.4days) systems. The hybrid surrogate ratio method involves the aspects of both absolute and ratio surrogate method, introduced by Nayak *et al.*[2] in their earlier work to determine ^{233}Pa(*n,f*) cross sections measurement. The hybrid surrogate ratio method is accomplished by taking the ratio of fission probabilities of two simultaneous surrogate reactions performed on same target. The details of the formalism to determine the neutron induced fission cross section for the above isotopes are same as given in [2].

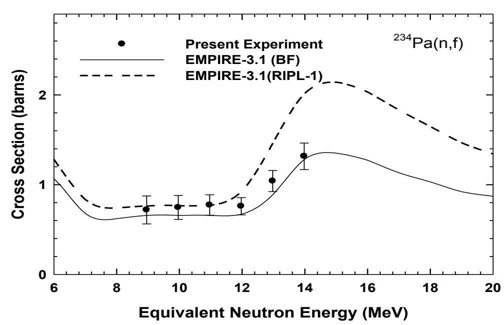

Fig.1: Experimental ^{234}Pa(*n,f*) cross sections along with the EMPIRE-3.1 code predictions with fission barriers obtained from Barrier formula (solid line) and RIPL-1 fission barrier library (dotted line).

Measurements and analysis:

A single self supporting ^{232}Th target of thickness 1.3 mg/cm^2 was bombarded with ^{7}Li beam of energy E_{lab} = 39.5 MeV from 14MV Palletron accelerator at Mumbai, to populate the compound nuclei ^{235}Pa and ^{236}U via ^{232}Th(^{7}Li,α)^{235}Pa (surrogate of ^{234}Pa(*n,f*)) and ^{232}Th(^{7}Li,t)^{236}U, (surrogate of ^{235}U(*n,f*)) transfer reactions respectively . The two solid state ΔE-E telescopes with ΔE detectors 200μm and 150μm and 1.0 mm E- detectors were kept at

$\theta_{lab} = 85^\circ$ and $\theta_{lab} = 105^\circ$ respectively with respect to the beam direction around transfer grazing angle to identify projectile like fragments (PLFs). A large area solid state detector was placed at back angle $\theta_{lab} = 160^\circ$ to detect fission fragment in coincidence with the PLFs. The time correlation between PLFs and fission fragment was recorded through a time-to-amplitude converter (TAC). The ^{234}Pa(*n,f*) cross section measurement was accomplished by taking the ratio of fission decay probabilities of ^{235}Pa and ^{236}U compound nuclei in the overlapping- excitation energy range 15.0 - 21.0 MeV. The experimental ^{234}Pa(*n,f*) cross section as a function of equivalent neutron energy along with the EMPIRE-3.1[3] predictions with fission barrier used from barrier formula(BF)[4] and RIPL-1 libraries[5] are shown in Fig.1.

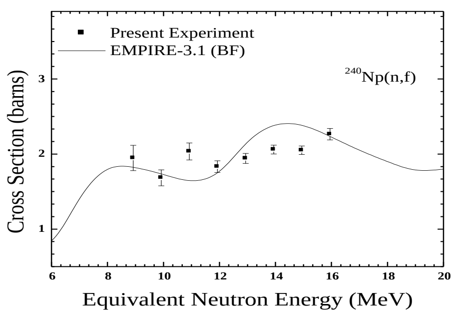

Fig.2: Experiment ^{240}Np(*n,f*) cross sections and EMPIRE-3.1 code predictions.

The ^{240}Np(*n,f*) cross section was derived by measuring the fission decay probabilities of ^{241}Np and ^{242}Pu compound nuclei. A self supporting ^{238}U target of thickness 2.3 mg/cm^2 was bombarded with ^{7}Li beam of energy 42.0 MeV to populate these nuclei via ^{238}U(^{7}Li,α)^{241}Np (surrogate of ^{240}Np(*n,f*)) and ^{238}U(^{7}Li,t)^{242}Pu (surrogate of ^{241}Pu(*n,f*)) transfer reaction channels. The remaining experimental arrangement was same as discussed above. The neutron induced fission cross sections for ^{240}Np have been obtained over the equivalent neutron kinetic energy range 9.0 MeV- 16.0 MeV. The experimental ^{240}Np(*n,f*) cross section as a function of equivalent neutron energy along with the EMPIRE-3.1 predictions using fission barriers from barrier formula(BF) calculations are shown in Fig.2.

The ^{239}Np(*n,f*) cross section was derived from the measurement of ratio of fission decay probabilities of ^{240}Np and ^{242}Pu compound nuclei over the overlapping excitation energy range 17.0 - 24.0 MeV via ^{238}U(^{6}Li,α)^{240}Np (surrogate of ^{239}Np(*n,f*)) and ^{238}U(^{6}Li,d)^{242}Pu, (surrogate of ^{241}Pu(*n,f*)) transfer reaction channels respectively. The experimental ^{239}Np(*n,f*) cross section as a function of equivalent neutron energy along with the EMPIRE-3.1 predictions using fission barriers from barrier formula(BF) calculations are shown in Fig.3.

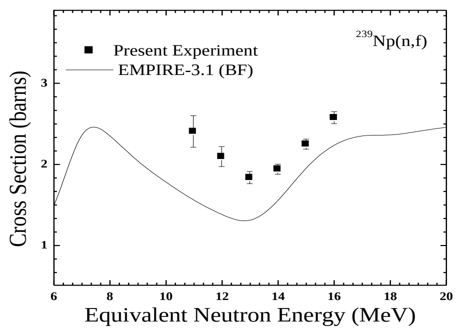

Fig.3: Same as Fig.2 for ^{239}Np(*n,f*) reaction.

Our experimental results for ^{234}Pa(*n,f*) and ^{240}Np(*n,f*) cross sections as a function of neutron kinetic energy shown in Figs.1 and 2 are in good agreement with the EMPIRE-3.1 predictions. The experimental ^{239}Np(*n,f*) cross section values are higher in comparison to the predictions of EMPIRE-3.1 code which require further investigations.

References:

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