Determination of the ^{241}Pu(n,f) reaction cross sections by surrogate ratio method

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Introduction:

Many nuclei in the actinide region which are produced by successive neutron capture in fast reactors possess short radioactive decay half life. The cross sections for reactions of neutrons and light, charged particles with such nuclei taking place at energies from several KeV to tens of MeV are required for nuclear astrophysics, national security and nuclear energy applications [1,2]. Not all relevant data can be directly measured in the laboratory or easily determined by calculations. The direct measurement on neutron induced fission (*n,f*) cross section for these nuclei is not possible, because of their too short decay half life to serve as target. Also the sufficient flux of neutrons beam of required energy regime is often inaccessible. In recent years, the surrogate reaction method in various forms have been employed to get the indirect estimate of the neutron induced fission cross sections of many compound systems in actinide region that are relevant U-Pu fuel cycle and nuclear waste incineration.

In a recent work [3], direct measurement of neutron induced fission cross section of ^{241}Pu($T_{1/2} = 14.1$yrs), has been carried out using neutron time of flight. Differences between the reported experimental measurement and evaluation by standard libraries exceeds by 30%, thus it is suggested to carry out further confirmatory measurements on ^{241}Pu(*n,f*) cross sections[4]. In this paper, we report the use of ^{238}U(^{6}Li,d)^{242}Pu and ^{232}Th(^{6}Li,d)^{236}U transfer reactions as surrogate of ^{241}Pu(*n,f*) and ^{235}U(*n,f*) compound nuclear reactions respectively. By employing the surrogate ratio method (SRM) and taking ^{235}U(*n,f*) as reference, the ^{241}Pu(*n,f*) cross sections have been determined in the equivalent neutron energy range of 11.0 MeV-16.0 MeV.

Measurement and Analysis:

The self supporting ^{238}U and ^{232}Th targets of thicknesses 2.3 mg/cm^2 and 1.3 mg/cm^2 were bombarded with ^{6}Li beam at projectile energies 39.6 MeV and 39.0 MeV to populate the compound nuclei ^{242}Pu and ^{236}U via ^{238}U(^{6}Li,d)^{242}Pu (surrogate of ^{241}Pu(*n,f*)) and ^{232}Th(6Li,d)^{236}U, (surrogate of ^{235}U(*n,f*)) transfer reactions respectively. One ΔE-E telescopes was kept $\theta_{lab} = 85^0$ with respect to beam direction around the transfer grazing angle to identify the PLFs. A large area solid state detector was placed at backward angle 160^0 to detect fission fragment in coincidence with PLFs. The ground state Q-values (Q_{gg}) for ^{238}U(^{6}Li,d)^{242}Pu and ^{232}(^{6}Li,d)^{236}U are -6.458 MeV and -6.047 MeV respectively. Hence the ^{242}Pu and ^{236}U compound systems can be populated at overlapping excitation energies, this enables us to use SRM to determine ^{241}Pu(*n,f*) cross section. The projectile-like fragments (PLFs)-singles and coincidence between PLFs and fission fragment measurements were carried out to determine the fission decay probabilities of the ^{242}Pu and ^{236}U compound nuclei produced in the transfer reactions stated above by dividing the number of PLF-fission coincidence event (N_{d-f}) by associated PLF-singles N_d as follows:

$$\Gamma_f^{CN}(E_{ex}) = \frac{N_{d-f}}{N_d} \quad . \tag{1}$$

The relative fission probabilities of the compound nuclei are then multiplied by the ratio of neutron induced compound nucleus formation cross sections of corresponding surrogate reactions to obtain the ratio of the neutron induced fission cross section as follows [5]:

$$\frac{\sigma_f^{n+^{241}Pu \to ^{242}Pu}(E_{ex})}{\sigma_f^{n+^{235}U \to ^{236}U}(E_{ex})} = R(E_{ex})$$

$$= \frac{\sigma^{CN}_{n+^{241}Pu}(E_{ex})}{\sigma^{CN}_{n+^{235}U}(E_{ex})} \times \frac{\Gamma_f^{^{242}Pu}(E_{ex})}{\Gamma_f^{^{236}U}(E_{ex})} \tag{2}$$

The n + $^{235}U \to$ ^{236}U $\to$fission cross section which is well measured has been used as reference monitor to determine n + ^{241}Pu $\to$ ^{242}Pu $\to$ fission from the R(E_{ex}) measurement.

Results and Discussion:

The ratios of coincidence to singles counts i.e., fission decay probabilities were determined in steps of 1.0 MeV excitation energy bins over the excitation energy range 15.0 MeV-21.0 MeV for both ^{242}Pu and ^{236}U compound nuclear systems. The corresponding fission decay probabilities were then substituted in Eq.2 to determine ^{241}Pu(n,f) cross section for each excitation energy bins using n+^{235}U $\to$ ^{236}U $\to$ fission reaction cross section as reference. The ratio of neutron capture cross section values for ^{241}Pu and ^{235}U are taken as ratio of corresponding mass numbers in Eq.2. The excitation energy was scaled down to the equivalent neutron energy by subtracting the neutron separation energy of ^{242}Pu (6.34 MeV). The experimental ^{241}Pu(n,f) cross sections as a function of equivalent neutron energy, along with direct measurement by F.Tovesson *et al.*[3] and EMPIRE-3.1[6] predictions are shown in Fig.1. The experimental cross section values are observed to be consistent with the direct measurement on $^{241}Pu(n,f)$ cross section data of Tovesson *et al*. The EMPIRE-3.1 predictions on $^{242}Pu(n,f)$ cross section values with first, second and third chance fission barriers corresponding to RIPL-1 fission barrier library[7], are about 30% higher in comparison to experimental (both by the direct and indirect surrogate methods) cross section values. The present experimental results along with results of Tovesson *et al.* suggest that the EMPIRE-3.1 library needs revaluation for ^{241}Pu(n,f) cross section data.

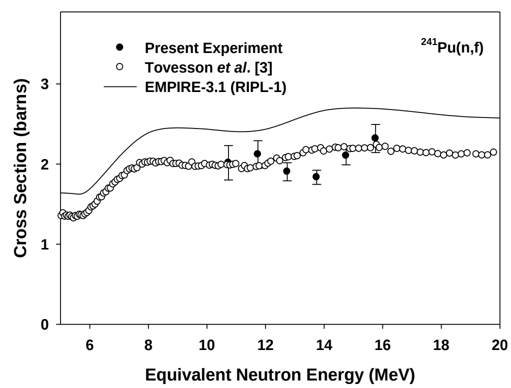

Fig.1: Neutron induced fission cross sections for ^{241}Pu by the surrogate ratio method (present experiment) along with the $^{241}Pu(n,f)$ cross section data from the direct measurement (F. Tovession *et al*.[3]) and the evaluated data using EMPIRE-3.1 RIVOLI code.

References:

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