Probing prompt-neutron multiplicity through Fission Fragment Spectroscopy

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Introduction and Measurement

According to our present understanding of the fission reaction mechanism, a fissioning nucleus traverses through a multidimensional valley of Potential Energy Surface (PES) during which its constituent nucleons undergo a collective rearrangement. During this course of rearrangement process, the fissioning nucleus passes through multiple saddle and scission points corresponding to different fission modes. At the scission point, the nucleus splits into two primary fission fragments (FFs) followed by emission of prompt-neutrons, and thereby forming the secondary FFs. The characteristics of the emitted prompt-neutrons are primarily dependent on the energy partition stage during the fission process. The scission of the nucleus takes place in several distinct pre-scission shapes and accordingly, the properties of the prompt-neutrons differ for different fission modes [1]. It is to be pointed out here that the prompt-neutrons are considered to be an important experimental observable to investigate the underlying fission dynamics during the partitioning of kinetic and excitation energies between the FFs, and a crucial parameter required for the future nuclear reactors as well.

The Fission Fragment Spectroscopy (FFS) measurement technique provides an indirect way to measure the total prompt-neutron multiplicity distribution of a fissioning nucleus. Since this technique is primarily based on the conservation of atomic (Z) and mass (A) numbers of the correlated fission fragments, a simultaneous measurement of the two correlated fragments can be carried out to determine the number of the emitted prompt-neutrons [2]. Here, we report the measurement of the total prompt-neutron multiplicity distribution for the fissioning system, ^{235}U(n_{th},f) using FFS technique. The high-fold prompt γ-ray coincidence data were collected during the EXILL campaign [2]. The measured total prompt-neutron multiplicity distribution corresponding to five complementary fission fragment pairs have been subsequently utilized to determine the variation profile of the average neutron multiplicity distribution with A. The mathematical formalism based on the Point-By-Point (PbP) model [3] has been extensively used for extracting the theoretical average neutron multiplicity distribution. The results have been further compared with the theoretical predictions based on (a) GEneral description of Fission (GEF), and (b) TALYS software packages [4].

Results and Discussions

In the PbP formalism, the Total Excitation Energy (TXE) corresponding to each complementary fission fragment pairs can be expressed as:

$$TXE = \nu_{pair}(<\epsilon> + <S_n>) + E_\gamma \quad (1)$$

where ϵ is the average prompt neutron energy of the fissioning nucleus in the center of mass system. The terms, ν_{pair}, S_n, and E_γ represent respectively the measured prompt neutron multiplicity, average neutron separation energy, and average prompt γ-ray energy related to the concerned FF pair. The FFS measurement technique has been extensively utilized to measure the ν_{pair} and E_γ correspond-

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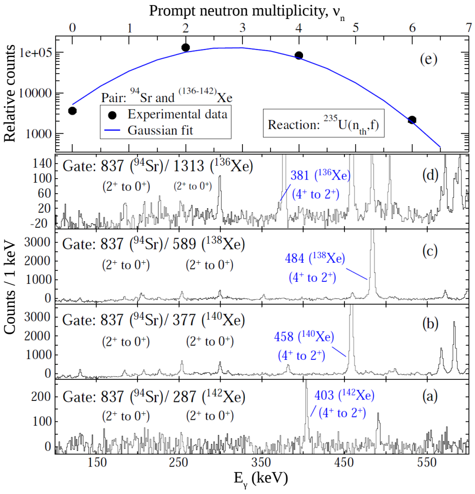

FIG. 1: Panels (a-d): Representative γ-γ coincidence spectra obtained by applying the simultaneous gates on the $2_1{}^+ \rightarrow 0_1{}^+$ transitions of ^{94}Sr and $^{136-142}$Xe, respectively. Panel (e): The prompt neutron multiplicity distribution corresponding to various $^{136-142}$Xe isotopes with respect to ^{94}Sr.

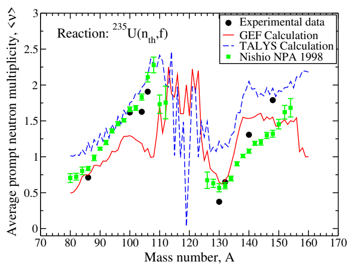

FIG. 2: The distribution profile of the average prompt neutron multiplicity versus fragment mass number as obtained from the present investigation following the reaction, ^{235}U(n_{th}, f).

ing to the different even-even FFs as shown in Fig.1 [5]. The TXE of the fully accelerated FFs can further be calculated as:

$$TXE = E^*_{F1} + E^*_{F2} \tag{2}$$

where $E^*_{F1,F2}$ represent the excitation energies of the correlated complementary FFs. According to the binary fragmentation dynamics, this TKE is shared among the two complementary FFs according to the following relation:

$$\frac{E^*_{F1}}{E^*_{F2}} = \frac{\nu_{F1}}{\nu_{F2}}, and \frac{E^*_{F1}}{E^*_{F2}} = \frac{a_{F1}}{a_{F2}} \tag{3}$$

where $\nu_{F1,F2}$ and $a_{F1,F2}$ denote respectively the average prompt neutron multiplicity and level density parameters of the concerned FFs. The level density parameters were calculated by using the Back-Shifted Fermi Gas (BSFG) model in the TALYS-v1.96 code [4] for the said reaction. Adopting the aforementioned mathematical formalism, the average prompt neutron multiplicity versus fragment mass number distribution profile has been extracted and the results are shown in Fig.2. In Fig.2, the estimated neutron multiplicity distribution profile obtained from the present study is also compared with the experimental data taken from Ref.[6]. The close resemblance between the two results suggests the validity of the present analysis procedure, and applicability of prompt FFS technique in unveiling the underlying fission dynamics of a particular fissioning system.

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