Neutron multiplicity measurements for $^{19}F + ^{194,198}Pt$ systems at high excitation energy to understand the fission dynamics

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Introduction:

From the study of light particles emitted in heavy-ion induced fusion-fission reaction, the importance of dissipation in fission-fusion dynamics is well established. Experimental signature of large dissipation is observed through large excess in pre-fission neutrons, gamma ray multiplicities from compound nucleus giant dipole resonance (GDR), light charged particles and evaporation residue [1-4]. Mainly dissipation is observed at nuclear temperature between 1 and 2 MeV, also it is found that dissipation effect increases with excitation energy.

From the systematic analysis, Thoennessen et al. found that dissipation starts at temperature $T > 0.26\ B_f(T)$, where T is nuclear temperature and $B_f(T)$ is temperature dependent fission barrier [3]. In a recent study, Back *et al.* reported that in order to reproduce evaporation residue cross-sections for ^{224}Th and ^{216}Th nuclei, a larger dissipation strength was required for ^{224}Th. They have concluded that nuclear dissipation has possible relation with neutron closed shell N_C=126 [4]. It is to be noted that this conclusion was drawn from one observable sensitive to nuclear dissipation. So it is desirable to do consistent analysis for other observables like pre-scission neutron multiplicity, fission and ER cross section to establish the role of neutron shell closure in the dissipation strength. With this motivation in our mind, we have decided to perform a simultaneous analysis of neutron multiplicity, fission cross-section and evaporation residue cross-section for $^{19}F+^{194,196,198}Pt$ (N_c = 126, 128, 130) systems. Here we report the results of neutron multiplicity measurement for reactions of $^{19}F + ^{194,198}Pt$ at excitation energy of 92.2 MeV.

Experimental Arrangement:

The measurements were carried out at IUAC New Delhi. Pulsed beam of ^{19}F at energies 140.8 and 137.2 MeV delivered by Pelletron plus Ist module of LINAC, was bombarded on targets of ^{194}Pt and ^{198}Pt of thickness 530 μg/cm^2 and 1.45 mg/cm^2 respectively. Targets were located at centre of a thin walled spherical scattering chamber of 60 cm diameter. Fission fragments were detected by a pair of Multi-wire proportional counter (MWPC) (5" x 3") kept at fission fragment folding angle at distance of 24 cm from target position. Two silicon surface barrier detectors were also placed inside the chamber at $\pm16^o$ to beam direction out of reaction plane for normalization purpose.

24 Neutron detectors (NE213 and BC501) were kept at 2 meter distance from target, at different angles ranging from 30^o to 315^o around the target chamber. Out of these 24 detectors, 16 detectors (5" x 5") were kept in reaction plan and remaining 8 detectors (5" x 3") were kept at 15^o up and down out of reaction plan. Hardware threshold of 0.5 MeV of neutron energy was applied using ^{137}Cs and ^{60}Co sources. In order to reduce gamma background beam dump was extended 3m downstream from target and beam line was shielded with paraffin and lead bricks. The beam width from the LINAC was continuously measured and it was found to be approximately 400 psec.

The trigger of data acquisition was generated by Logical OR of cathode signal of two MWPC ANDed with RF of the beam pulse.

Neutron gamma discrimination was done using IUAC made Pulse Shape Discrimination module.

Results and Discussions:

Neutrons detected in coincidence with fission fragments were fitted with three moving sources (compound nucleus evaporation and two fission fragments). The compound nucleus contribution (pre-scission) and contribution from fission fragments (post-scission) were assumed to be isotropic. Further, post-scission neutron multiplicity and temperatures are assumed to be same for both fragments. Hence the total neutron multiplicity $M_{total} = M_{pre} + 2 * M_{post}$. The raw neutron TOF spectra are converted to energy spectra for all 16 in plane detectors. In order to obtain pre-scission and post-scission contributions spectra of 16 detectors are fitted simultaneously for 32 different neutron-fission angle (Φ_{nf}) combinations, using watt expression:

$$Y(E_n) = \sum_{i=1}^{3} \frac{M_n^i \sqrt{E_n}}{2(\pi T_i)^{3/2}} \times \exp\left[\frac{-(E_n - 2\sqrt{\varepsilon_i E_n} Cos\, \Phi_i + \varepsilon_i)}{T_i}\right]$$

Where ε_i, T_i and M_n^i are energy per nucleon, temperature and multiplicity of neutron source *i*. E_n is lab energy of neutrons and ϕ_i is neutron detection angle with respect to source *i*.

Neutron multiplicities obtained from fitting for decay of ^{217}Fr and ^{213}Fr are given in Table [1] and fitting plots are shown in figure 1.

Table-01

CN	M_{pre}±Err	$2M_{post}$±Err	M_{total}±Err
^{217}Fr	4.62± 0.30	2.24±0.34	6.86±0.45
^{213}Fr	3.46± 0.24	2.16±0.28	5.62±0.37

Here multiplicities were obtained by using by fixing pre-fission temperature (equal to $T_{pre} \approx \frac{11}{12}\sqrt{\frac{E^*}{a}}$, where E^* excitation energy and a is level density parameter $A_{cn}/10$). Other parameters (M_{pre}, M_{post} and T_{post}) were made free.

Total neutron multiplicity obtained for both the systems roughly matches with the systematic given by Hinde et al. for a wide range of systems with various fissility and excitation energies [5].

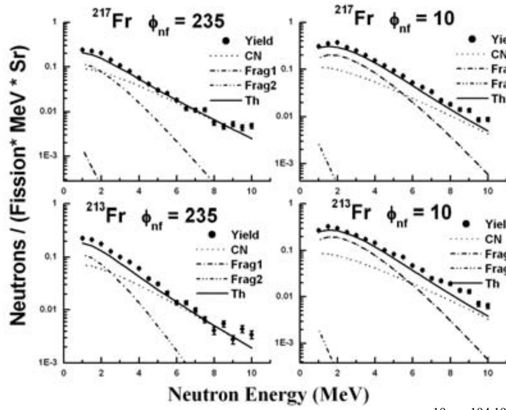

Fig.1: Neutron multiplicity (filled circle) for the ^{19}F+^{194,198}Pt system at E_{ex}=92.2 along with the fits for the pre-scission (dot curve) and post-scission from one fragment (dot dashed curve) and that from the other (dot dot dash curve). The solid curve represents the total contribution.

The pre-scission neutron multiplicity for ^{217}Fr is larger compared to ^{213}Fr at similar excitation energy of 92.2 MeV. ^{217}Fr has four neutrons more compared to ^{213}Fr. Statistical model PACE2 calculation was performed with a reasonable value of parameters obtained from the fitting of the fission and ER excitation function for the systems under study [6]. A pre-scission neutron multiplicity value of 1.03 and 0.70 was obtained for ^{217}Fr and ^{213}Fr respectively. In PACE2 calculation dissipation effects are not included. It is also interesting to note that ^{213}Fr has N_C= 126 and ^{217}Fr has N_C= 128. According to Back et al. [4] neutron shell closed nuclei will have higher threshold for dissipation and one may expect less neutron multiplicity for shell closed nuclei. However, a detail consistent analysis including all observables sensitive to dissipation is warranted.

References

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