Effect of Shell Closure on Neutron Multiplicity

Varinderjit Singh[1]*, B.R. Behera[1], D. Siwal[2], S. Goyal[2], Maninder Kaur[1], P. Sugathan[3], K.S. Golda[3], A. Jhingan[3], A. Kumar[1], A. Saxena[4], R.K. Bhowmik[3], S. Kailas[4]

[1]*Department of Physics, Panjab University, Chandigarh -160014, INDIA.*
[2]*Department of Physics and Astrophysics, University of Delhi – 110007, INDIA.*
[3]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA.*
[4]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai, - 400085, INDIA.*
** email: Mangat_phy@yahoo.co.in*

Introduction:

In the last century the development of nuclear accelerator for the production of heavy ion beams opened an opportunity to study heavy ion induced fusion-fission reactions. The importance of dissipation in fusion-fission dynamics is well established from the study of light particle emission during heavy-ion induced fusion-fission reaction. 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]. Mainly, dissipation is observed at nuclear temperature between 1 and 2 MeV, also it is found that dissipation effect increases with excitation energy.

In the current scenario, one of the major objectives of nuclear reaction study is to explore the predicted Island of Super-Heavy elements and to find what will be the next Proton and Neutron magic nucleus beyond 82 and 126 respectively. However, different theoretical models predict proton and neutron shell closure at Z = 114, 120, 122, 124, 126 and N = 172, 184.

Knowledge of the existing shell closure is very important in order to achieve this. Back *et al.* [2] 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. It was concluded that nuclear dissipation has possible relation with neutron closed shell N_C=126. To explore the effect of shell closure on nuclear dissipation, 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 resulting in the formation of CN ^{213}Fr (N_c=126), ^{215}Fr (N_c=128) and ^{217}Fr (N_c = 130) systems. Here we are presenting the results of neutron multiplicity measurement for reactions of ^{19}F + ^{194,196,198}Pt at the excitation energy range of 52-67.5 MeV.

Experimental Arrangement:

The experiment was performed using 15UD pelletron and National array of Neutron Detectors (NAND) at IUAC, New Delhi. Pulsed beam ^{19}F (Energy Range = 98 – 115 MeV) at repetition rate of 250 ns with pulse width of 1.5 ns, was bombarded on targets of ^{194}Pt, ^{196}Pt and ^{198}Pt of thickness 1.75 mg/cm^2, 1.8mg/cm^2 and 2.15 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 17.7 cm and 17.0 cm from target position. Two silicon surface barrier detectors were also placed inside the chamber at ±16^o to beam direction out of the reaction plane for normalization purpose.

Out of 16 Neutron detectors (5" x 5"), 12 detectors were kept at 2 meter distance and remaining 4 detectors were kept at 1 meter distance from the target. These detectors were placed at different angles ranging from 30^o to 315^o around the target chamber in reaction plane. Hardware threshold of 0.5 MeV of neutron energy was applied using ^{137}Cs and ^{60}Co sources.

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 performed by using both time of flight technique and IUAC made pulse shape discrimination module.

Results and Discussions:

The raw neutron TOF spectra were converted to energy spectra for all the detectors.

These energy spectra have contribution from neutrons originated from three different 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. In order to obtain pre-scission and post-scission contributions energy spectra of all detectors are fitted simultaneously using chi-square minimization process, for different neutron-fission angle (Φ_{nf}) combinations, with watt expression:

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

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*.

The total neutron multiplicity $M_{total} = M_{pre} + 2 * M_{post}$. Here multiplicities were obtained by using M_{pre}, M_{post}, T_{pre}, and T_{post} as free parameters. Neutron multiplicities obtained from fitting for decay of ^{213}Fr, ^{215}Fr and ^{217}Fr at different excitation energies are given in Figure 1 and fitting plots are shown in Figure 2.

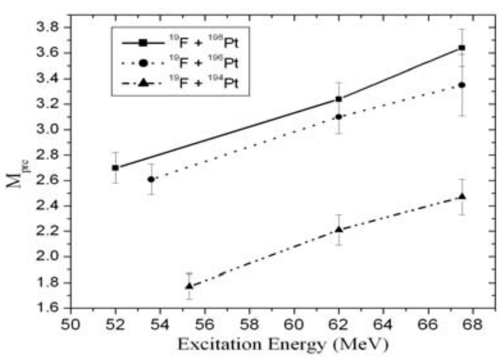

Figure 1: Variation of M_{pre} with excitation energy for different systems. Lines are only to guide the eye.

Statistical model calculation PACE2 was performed with a value of parameters obtained by fitting the measured fission and ER cross sections [3]. At the lowest excitation energy (52MeV) PACE2 calculation could reproduce the experimental results for pre-scission neutron multiplicity. However, at higher excitation energy the measured neutron multiplicity values

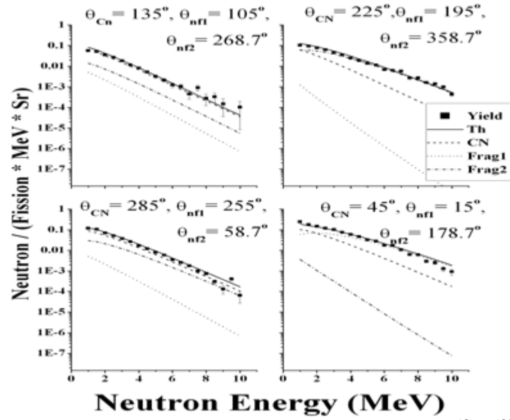

Figure 2: Neutron multiplicity (filled circle) for the ^{19}F+^{198}Pt system at E_{ex}=52.0 along with the fits for the pre-scission (dot curve) and post-scission from one fragment (dot dashed curve) and that from the other (dot dot dash curve). The solid curve represents the total contribution.

deviate considerably from the calculation. This is precisely due to the fact that delay is not included in the PACE2 calculation. However the deviation for the system ^{19}F+^{194}Pt is much less compared to other two systems. It may be perhaps due to the presence of neutron shell closure (N_c=126) in the former system. This also indicates that the threshold for dissipative effects is higher for ^{19}F+^{194}Pt system which is having N_c=126. Back et al. [2] has indicated that systems with N_c=126 may have higher excitation energy threshold, where fission delay effects are more pronounced. It is also interesting to compare the neutron multiplicity values at different excitation energies. As we go from ^{194}Pt to ^{198}Pt through ^{196}Pt target, there is a gradual increase of two neutrons. However, the measured multiplicity variation of ^{194}Pt to ^{196}Pt target is more as compared to the values for the ^{196}Pt to ^{198}Pt target. This discrepancy can also be attributed to the shell closure of N_C=126 in ^{19}F+^{194}Pt system. It clearly shows that in the observed excess pre-scission neutrons there is a competition between fission delay and effect of shell closure of the compound system.

References

[1] D. Hilscher et al. Ann. Phys. Fr.17, 471 (1992).
[2] B.B. Back et al. Phys. Rev. C60, 044602 (1999).
[3] K. Mahata et al. Phys. Rev C65, 034613 (2002).