Chapter 7

Summary and Conclusion

The study of fission of highly excited compound nuclei has emerged as a topic of great interest in recent years. Motivation of the present work was to study fission hindrance in presaddle region via two different probes and also to study the effect of entrance channel on fission hindrance. Time scale of fission for highly excited heavy nuclei resulting from heavy ion-induced fusion reactions has been extensively studied by measuring multiplicities of neutrons, charged particles, and giant dipole $\gamma$-rays. Very few measurements on evaporation residues (ERs) have been carried out to understand fission hindrance. As a fused system moves from equilibrium position to saddle point and then from saddle point to scission point, it keeps on emitting neutrons, charged particles, and gamma rays. Therefore, neutron, charged particle and gamma ray multiplicities are not very sensitive to whether the emissions occur before or after the traversal of saddle point. On the other hand, ER measurement is a more sensitive method to understand fission hindrance from equilibrium deformation point to saddle point because the evaporation probability from hot nuclei formed in heavy ion fusion reaction is sensitive to the dissipation strength inside the fission barrier. If there is any reduction in the fission width due to dissipation, then there is a strong probability for survival of the compound nucleus. This is manifested in the evaporation residue cross section which is larger than that predicted by the standard statistical model. The compound nucleus undergoing fission or surviving as an
ER is decided mainly within the saddle point. Hence the measurement of ER formation probability provides the desired separation between pre-saddle and post-saddle dissipation. ERs de-excite to the ground state by the emission of gamma rays (non-statistical in nature). These gamma rays carry valuable information on the spin distribution of ERs. Fission imposes the upper limit to the angular momentum carried by the evaporation residues from a heavy compound nucleus. If the fission branch is suppressed due to dissipation, then the spin population of ERs will be enhanced with the occurrence of higher spin values. Thus spin distribution is an additional parameter to study the dynamical competition between ER and fission channel. The combined study of evaporation residue cross section and spin distribution gives a better understanding of fusion-fission dynamics than what is obtained by studying only the total evaporation residue cross section. However, due to experimental difficulties there are very few measurements on evaporation residue cross section. Experimentally an energy threshold is observed from where the onset of dissipation takes place resulting in deviation from the standard statistical model. This energy threshold is not unique, rather it is different for different probes, especially in 200 mass region. Due to lack of ER cross section data, the threshold for this probe is not available. This discrepancy demands accurate and combined measurements involving different probes for better understanding of the physics of fusion-fission dynamics.

Evaporation residue cross section and spin distribution measurements were carried out for $^{16}$O+$^{184}$W and $^{19}$F+$^{181}$Ta reactions leading to the same compound nucleus $^{200}$Pb*. Excitation energy for both systems were matched. For $^{16}$O+$^{184}$W, measurements were performed at the laboratory beam energies of 84, 92, 100, 108, 116, and 120 MeV, whereas for $^{19}$F+$^{181}$Ta, measurements were done at laboratory beam energies of 82, 85, 89, 93, 97, 101, 104, 109, 114, 117.5, 121.5 and 125 MeV. Evaporation residues were selected with the recoil mass spectrometer, HIRA and detected using a 2D position sensitive silicon detector at its focal plane. Evaporation residue spin distributions were measured by detecting gamma rays with 14 elements BGO multiplicity filter. Total fusion cross
section was obtained by summing presently measured evaporation residue cross section and fission cross section (for both the systems) from the literature. Evaporation residue cross sections and spin distributions at various energies were compared with statistical model calculations.

For $^{16}O + ^{184}W$ system the standard statistical model (with no nuclear dissipation effects, i.e., $\gamma = 0$) cannot reproduce the systematic trend of evaporation residue cross section and spin distribution over the range of excitation energies considered here. Our analysis shows that a value of $\gamma = 3$ for the dissipation coefficient is required to fit evaporation residue cross section along with spin distribution. The present study therefore provides evidence for fission hindrance in $^{200}$Pb in the measured energy range. It is further demonstrated in the present work that evaporation residue spin distribution measurement provides another sensitive tool to investigate fission hindrance in 200 mass region. Calculation for this system was again carried out using a new version of the statistical model code where charged particle decay widths were also incorporated. A slightly higher value of nuclear viscosity parameter ($\gamma = 5$) was required to reproduce total evaporation residue cross section and spin distribution.

In case of $^{19}F + ^{181}Ta$ system, calculations were carried out using an improved version of the statistical model code. Standard statistical model ($\gamma = 0$) underestimates the experimental results. Whereas a value of $\gamma$ in the range of 1 to 3 was required to fit evaporation residue cross section, spin distribution and moments of spin distribution. But the shape of spin distribution beyond beam energy 117.5 MeV were not very well reproduced. Experimental yields at lower $l$ values were less than statistical model predictions. Spin distribution at lower $l$ values beyond this energy was found to be independent of nuclear viscosity parameter. This analysis clearly indicates the need for dynamical model calculation for this system. Which will be done in near future.

To understand the effect of entrance channel on fission hindrance in 200 mass region, the two systems were chosen such that they lie on either side of the Businaro-Gallone mass...
asymmetry point. $^{16}O + ^{184}W$ lies on the higher side of Businaro Gallone mass asymmetry whereas $^{19}F + ^{181}Ta$ lies on the lower side. Experimental evaporation residue cross sections as a function of excitation energy were compared for both the systems. ER cross section for $^{16}O + ^{184}W$ is almost twice the cross section for $^{19}F + ^{181}Ta$ showing the direct evidence of entrance channel effect. Similarly, first three moments were also compared for both systems. The first moment does not show any difference but as we compare higher moments, which are more sensitive to higher spin population, entrance channel effect is observed. From these experimental observations, one can conclude that in case of $^{19}F + ^{181}Ta$, pre-equilibrium fission events are more due to which there is reduction in evaporation residue cross section. Such kind of study has been carried out for the first time to the best of our knowledge.

Future scope of present work

From the present study it is established that spin distribution is also a sensitive probe for studying fission hindrance in 200 mass region. It is therefore expected that more extensive measurements of evaporation residue cross section and spin distribution at higher excitation energies would lead to a better understanding of fission dynamics. Such extensive measurements in heavy mass region will give information about the energy threshold from where onset of dissipation takes place resulting in deviation from the standard statistical model prediction. Present work also emphasizes on the need for dynamical model calculation which will be done in near future. In this work, entrance channel effect has been observed through evaporation residue cross section and spin distribution measurements. More such combined measurements, for different projectile and target combinations leading to the same compound nucleus and lying on either side of BG point, are required for better understanding of pre and post-compound nuclear dynamics in heavy ion fusion-fission reactions. There is also scope to study entrance channel effect for the present systems using probes other than ER cross section and spin distribution.
In support of present experimental observations on entrance channel effect, theoretical calculations will be carried out in near future.