Chapter 5

Summary and Conclusions

Excitation functions for 15 reaction residues were measured in the reaction of $^{14}N + {}^{103}Rh$ system up to 400 MeV and a detailed description of the same is given in Chapter 2. The present theoretical analysis was performed by using the HMS model using three different forms of the nuclear level density, namely, OB, KR, and backshifted FG. In the HMS model the decay of the composite system is initially followed in terms of nucleon-nucleon collisions. Unlike previous versions, there are no adjustable parameters in ALICE2014 for this phase of the reaction. After the system cools sufficiently, the usual statistical model is applied, and in this phase the nuclear level density plays a crucial role in deciding the final population of the residues. At each step of the statistical decay, particle emission rates depend on the ratio of level densities of the residual and parent systems.

The overall trends of the predicted excitation functions are satisfactory. The absolute values generally agree well with the experimental data for lighter isotopes and at energies above 200 MeV with the OB level density. The latter region is the one where pre-equilibrium emission of nucleons and light clusters dominates and is therefore a more important region for the test of the present pre-equilibrium model. Considering the various options for the level densities, it was observed that the Kataria-Ramamurthy level densities lead to predictions very far from the data. In general it may be concluded that the calculations with the HMS model (ALICE2014) with the OB level densities has qualitative trends similar to the data and reasonable quantitative agreement at the higher energies. The OB level density gives a fairly good description of the excitation functions for the observed isotopes of Cd, Ag, Pd, Rh, Ru, and Tc in that the general features are reproduced. The new code ALICE2014, which incorporates pre-equilibrium multinucleon and cluster emissions in addition to the emission of single nucleons, satisfactorily describes the underlying mechanism for the production of heavy residues induced by medium-mass ions at intermediate energies.

In general, it may also be concluded that the present experimental and theoretical calculations are in close agreement with those obtained earlier for the $^{12}C + ^{103}Rh$ system.

In the next experiment, we have made an experimental measurement of neutron spectra in ^{19}F-induced reactions for three targets, description of which is given Chapter 3. The trend of the data is well reproduced by ALICE2014 calculations. A comparison with PACE4 calculations, which includes only statistical evaporation, brings out the contributions arising from breakup and pre-equilibrium effects. Both arise at forward angles; however, the former contributes to the low-energy part of the spectra,while the latter contributes at higher neutron energies. While calculations using the ALICE2014 model with OB level densities reproduce the data globally quite well, a few shortcomings have been pointed out. It may be remarked cautiously that the breakup comes at lower neutron energies and forward angles while pre-equilibrium comes at high neutron energies and forward angles. PACE does not include breakup. In our graphs it is seen in the low-energy part of the spectra that PACE underestimates while ALICE2014 does better. This may be because the breakup of light particles is included in the ALICE2014 code. From the present study it may also be concluded that the target mass dependence on the reaction mechanism cannot be ignored. Some shortcomings of the ALICE2014 calculations are also brought out.

In the present work, we have measured experimental double differential cross-sections for the secondary alpha particles emitted from the reactions $^{14}N + ^{59}Co$ and $^{14}N + ^{93}Nb$ at an incident beam energy of 250 MeV and compared them with theoretical predictions obtained using the modified PACE code, in order to probe alpha-particle emission in the pre-equilibrium mode. From the study of the present results it can be inferred that at such a high incident energy, significant contribution to the alpha particle emission comes from direct reactions and re-emission of alpha after incomplete fusion and these mechanisms are dominant in forward angles. Towards larger emission angles the contributions from non-equilibrium and evaporation processes increase and start competing with direct reactions. There is a large amount of underestimation seen at forward angles and overestimation in some cases at backward angle. The modified PACE code used for comparison still needs inclusion of other reaction mechanisms to explain the experimental data in a better way, as it still under predicts the data by a large amount in certain regions. Hence further modifications are required on the code so that we can have a better nuclear model code that can predict the outcomes of heavy ion induced reactions for the incident particle energies above 200 MeV. In fact, it is expected that the obtained experimental results are the basis for continuing research on the over production of alpha

particles in heavy-ion induced reactions for the higher incident particle energies reactions.

Future Plans

In the present work the experimental study was performed using ^{14}N and ^{19}F beams. But in future we would like to perform these kind of studies using other light and heavy ion beams like ^{12}C, ^{13}C, ^{16}O, ^{18}O and ^{28}Si to study the effect of projectile structure in the emission of neutrons and alpha particles. Main focus will be to separate out the contribution from pre-equilibrium, break-up and evaporation reaction mechanism and also to check the performance of various nuclear model codes for these new systems. We also want to investigate the extent upto which α-clustering takes place in such reactions. We have put forward a proposal for the measurement of neutron cross-section in such heavy-ion reaction using Time-of-flight technique and to estimate multiplicity for neutrons and charged particles and pre-equilibrium emission. These kind of studies will be helpful for further refinement of the available nuclear model codes for heavy ion reactions.

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