SUMMARY & CONCLUSIONS

The study of nuclear reactions is of paramount importance to gain an understanding of the nature of nuclear forces and of nuclear structure. Unlike the electromagnetic interaction, the exact law governing nucleon-nucleon interaction is unknown. Therefore, a precise mathematical description of a nuclear reaction which is a many-body nuclear interaction, is impossible. As an alternative, the "BLACK BOX" or "MODEL" approach is used in which a simple mathematically solvable model is proposed on reasonable assumptions which is guided by experimental observations, without really solving the dynamics of the many-body system. The model is used to predict the reaction cross sections, its variation with energy, which is called the excitation function and also the distribution of energy between the outgoing particles, which is known as particle spectrum. The agreement between these predictions and experimental observations is a test on the success of the model and helps our understanding of the physics of the nucleus.

For a long time two extreme models of nuclear reactions have received particular attention and enjoyed commensurate success in explaining the experimental observation at low energies. The physics of the two extreme models is quite transparent. They are (i) direct reaction model which occurs on a time scale $\sim 10^{-22}$sec. i.e a much faster process and (ii) compound nucleus process which occurs on a time scale $\sim 10^{-16}$sec. So in the low energy studies, bulk of the particle emission can be attributed to the one of these processes.

But as the projectile energy increases, several complications begin. There is enough experimental evidence pointing out to some new types of processes which lie in complexity between the two well established nuclear reaction theories. The nuclear reaction is envisioned to proceed through such intermediate states which inherits partly some coherent effects which are characteristic of direct processes as well as statistical aspects dominant in compound nuclear reactions. This third mechanism in modern parlance is known as a "preequilibrium" emission.

It is important to obtain some understanding of the relative role played by the preequilibrium processes, which grow in importance with increasing excitation energy. In order to explain the preequilibrium phenomena, several models based on classical, semi-classical and quantum mechanical ideas were proposed during the past three decades. All these models deal with the nuclear matter calculation. So they embody few of the details of nuclear structure. They employ more general properties of nuclei such as mean free path of nucleons in nuclear matter, densities of particle-hole states at different excitation, emission rates of nucleons from a highly excited nuclear system etc.

Several revisions and refinements have taken place during the past three decades in the development of the preequilibrium theories. There is a growing demand for a systematic and accurate experimental data on the excitation functions to test the latest preequilibrium theories. On the experimental side, most of the measurements were carried out using poor resolution detectors and the reported cross sections were ambiguous. In some cases, there were no further measurements, since last one decades or so. In some cases, extensive experimental data are available using Ge detector, but, there is a large mutual discrepancies in these measurements. Adequate care was not exercised to take the isobaric contributions (if any) into account.

So, in the present work, a systematic study of twenty three alpha induced reactions were carried out on typical elements ^{197}Au, $^{121,123}Sb$, $^{113,115}In$ and ^{56}Fe using high resolution 120 cc HPGe detector (2.0 keV FWHM for 1332 keV photons). Of these, two reactions were measured for the first time. Experimental data were updated in seven reactions using high resolution HPGe detector, which were measured with scintillation detector and others. The cross sections of fourteen reactions were reinvestigated using high resolution HPGe detector which were earlier measured with Ge detectors and others having large mutual discrepancies in the cross section values.

Irradiations were performed at 50 MeV alpha energies using the national facility at Variable Energy Cyclotron Centre (VECC), Calcutta, India. The standard stacked foil activation technique and gamma ray spectroscopy were employed in the measurements of γ-activities. Alpha particle flux was determined with the help of the current integrator. Alpha particle flux was also measured using the well known standard (monitor) reaction cross section. In general, the two values agreed within 5%. The overall projected error of the measurements less than 8% which do not include the uncertainties of the nuclear data used in the analysis.

Finally, a comparison is made between experimental results obtained in the present investigations and the theoretical predictions. For the comparison of excitation functions, the semi-classical model such as Hybrid model, on account of their simplicity is used. It provides closed form expressions, which inherently includes integration over the emitted particle energy and angular distribution, so that integral cross section at each energy and its variation with energy can be readily calculated in the form of theoretical excitation function. A crucial parameter used in the model is the initial exciton number n_0, which governs the entire cascading process of binary collisions. In the present work the initial exciton number n_0 is varied between 4 and 6 to obtain best fit with the experimental data.

The following general conclusions were drawn from the overall comparison of the theoretical and experimental results for the (α.xn), (α,pxn) and (α,αxn) reactions in light, medium and heavy nuclei studied in the present work.

1) Essentially the same basic mechanism governs the emission of neutrons from light, medium and heavy nuclei.

2) For bombarding energies within about 10-15 MeV from the reaction threshold, single as well as multiple emission of neutron is governed by the well known compound nucleus evaporation mechanism and is adequately accounted for by simple or multistep Weisskopf-Ewing formalism.

3) At increasing energies the unambiguous evidence for increasing non-compound contributions in (α,xn) reactions particularly for decreasing neutron multiplicity.

4) The emission of neutrons from nuclear systems at excitation energies beyond a few tens of MeV is caused by the preequilibrium decay of the system in a time much shorter than the time for evaporation from an equilibrated compound nucleus. This is rather indirectly indicated by the "high energy tails" of the experimental excitation functions which signify a less rapid fall of the cross section than predicted by compound nucleus model.

5) The shape of the excitation functions in the preequilibrium dominated regions of energy is well reproduced by the improved version of Hybrid model. As far as the magnitudes of the cross sections are concerned, there is a reasonable agreement with the predictions of this model using an initial exciton configuration n_0=4(4p0h) i.e pure particle state.

6) The above initial configuration justifiable implies the assumption that following the first projectile-target interaction only four excitons share the excitation energy, they being naturally the four nucleons of the α-particle projectile. This view is quite consistent with the basic physics of the preequilibrium mechanism that only a few degrees of freedom is initially excited in a nuclear reaction at moderate energy.

7) There is a shift in the energy between theoretical and experimental compound nucleus peaks of few reactions (such as Au[(α,2n);(α,3n)] and In(α,2n)). Generally such shifts are ascribed due to complete neglect of angular momentum effects in the Weisskopf-Ewing theoretical calculations provided in the code. Compound systems attained with incident particles of different masses have appreciably different angular momenta when excited to the same excitation energy. Thus, in principle, can lead to differences in the excitation function. If, in the last stages of nucleon deexcitation, high angular momentum inhibits particle emission more than it does γ-ray emission, then the peak of the excitation function corresponding to the particle emitting mode, will be shifted to higher energy side. Such shifts could also be produced if the mean energy of the evaporated particles increases with increasing nucleon spin. Blann and Merkel have indicated that inclusion of angular momentum effects broadens the excitation function. The order of magnitude of this shift can be obtained from nuclear rotational energy.

8) It has been observed that reaction yields of nuclides with closed or nearly closed shells are predicted well with shell dependent level density option [in the case of ^{56}Fe(α,xn)]. It means that these nuclides show nuclear structure effects.

9) The cross sections for (α,pxn) type of reactions are, in general, one order of magnitude smaller than those of (α,xn) type of reactions and shapes of excitation functions are significantly different for the two types of reactions.

10) Due to the limitation of the projectile energy (E_α) and the large effective thresholds energies of these reactions [except for $^{56}Fe(\alpha,pn)$ reaction], only the predominantly compound nucleus part of the excitation function could be investigated in the present work.

11) The cross sections for $^{56}Fe(\alpha,pxn)$; x=2,3 reactions are significantly higher than that of $^{56}Fe(\alpha,xn)$;x=3,4 reactions respectively. This indicates that reaction yields are sensitive to nuclear structure. The isotopes $^{56,57}Ni$ produced through (α,xn) reactions are corresponding to the closure of the $f_{7/2}$ shell for protons in ^{57}Ni isotope and for both protons and neutrons in ^{56}Ni isotope, where as isotopes $^{56,57}Co$ produced through (α,pxn) reactions are nearer to closure of $f_{7/2}$ shell.

12) The preequilibrium model, when applied to $(\alpha,xnyp)$ type of reactions, drastically failed to account for the magnitude and shape of the observed excitation function by considering Fermi gas level density. However, as observed earlier they do much better when applied to (α,xn) type of reactions, where an equivalent number of neutrons instead of protons and neutrons are emitted.

13) The magnitude as well as shapes of observed excitation function for $Fe(\alpha,xnyp)$ reactions are fairly well reproduced by considering the shell dependent level density instead of Fermi gas level density. This observation indicates that nuclear shell structure has a profound effects on the level density of excited nuclei.

14) The difference in shape which is conspicuous in the lower energy part of the excitation function, can be attributed to the negative influence of Coulomb barrier on the emission of charged particles.

15) The excitation functions for (α,αxn) type of reactions i.e. (α,αn) reaction on the typical heavy element gold shows slowly rising structureless shape indicative of direct reaction effects. In this specific case, there is supplementary evidence from the study of recoil ranges of the residual nuclei, to which only about one tenth of the linear momentum is transferred in the interaction. This is much less than what the residual nucleus might receive in the case of preequilibrium reaction. A cautious inference that can be drawn from the above observation, can be that such reactions on heavy nuclei proceed through direct inelastic scattering of alpha particles followed by neutron evaporation.

16) The preequilibrium fraction (f_{PE}) has been calculated for ^{56}Fe, ^{113}In, ^{115}In, ^{121}Sb, ^{123}Sb and ^{197}Au isotopes as a function of bombarding energy E_{α}. It is observed that preequilibrium fraction increases quickly with the increase of incident alpha particle energy. The threshold for preequilibrium emission is higher for the lower mass number. It is also observed that the value of f_{PE} is higher for the system of higher mass number at a given alpha particle energy.