Statistical Model Calculations of Pre-scission Neutron Multiplicity from ^{28,30}Si+^{232}Th Reactions

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Introduction

Using the heavy ion fusion reactions, superheavy elements in the range Z = 104-118 have been produced and their properties are being investigated [1]. As cross-sections for formation of superheavy nuclei are of the order of picobarns (pb), it is difficult to produce such nuclei. The multinucleon transfer reaction around the barrier energies would produce neutron-rich heavy nuclei. The compound nucleus formed in heavy ion reactions is responsible for the formation of superheavy nuclei. The compound nucleus is formed in the excitation energy in the range of 30-60 MeV can emits neutrons, charged particles and high energy γ-radiations and these particles can be used as a probe to understand the dynamics of fused system [2].

In the present work we have calculated pre-scission neutron multiplicity (M_{pre}) and total neutron multiplicity (M_{tot}) for the ^{260}Rf and ^{262}Rf compound nuclei at excitation energy 48-116 MeV and these compound nuclei are formed by ^{28}Si+^{232}Th and ^{30}Si+^{232}Th systems respectively. With the best knowledge of the authors there are no experimental neutron multiplicity data for ^{260}Rf and ^{262}Rf in the above excitation regions till date. However A. Saxena et al. [3] have measured the (M_{pre}) for ^{260}Rf at excitation energy of 218 MeV and observed pre-scission and post-scission neutron multiplicities (M_{post}) are 8.7 ± 2.0 and 9.4 ± 2.0 respectively. In the present work we have used statistical code [4] to determine (M_{pre}) and (M_{tot}) for ^{260}Rf and ^{262}Rf compound nuclei at excitation energy 48-116 MeV. Using the same code we have also determined the M_{pre} and M_{post} for ^{260}Rf compound nucleus at excitation energy 218 MeV and found that our values closely agree with the experimental values of A. Saxena et al.

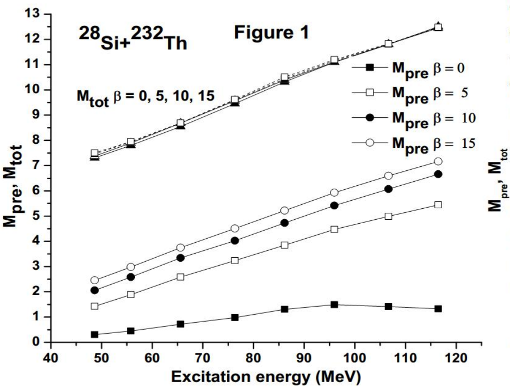
Statistical code analysis

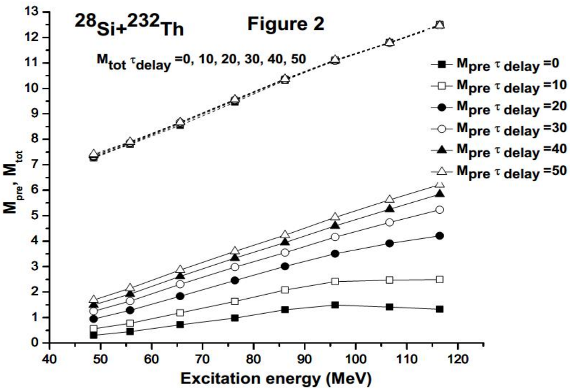
In the present study we have selected ^{28}Si, ^{30}Si beam incident on ^{232}Th to form ^{260}Rf and ^{262}Rf compound nuclei. It is important to mention that ^{28}Si is oblate nucleus with deformation β = -0.478 (^{30}Si is a spherical nucleus and ^{232}Th is a prolate nucleus having deformation β = 0.207). In the present study, we aim to explore the range of neutron multiplicities which might be expected in an experimental run which we plan to undertake shortly to this end, we have calculated (M_{pre}) and (M_{post}) (and hence $M_{tot} = M_{pre} + M_{post}$) using the statistical model code VECSTAT [4] in which the shell corrections to both level density parameter and fission barrier, the K-orientation effect and the effect of collective enhancement of level density parameter (CELD) in all decay channels and fission are included [5].

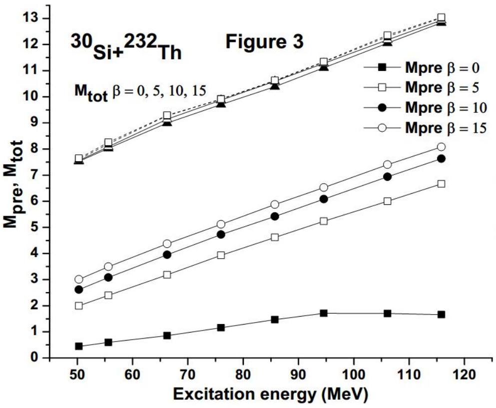
The statistical model code VECSTAT calculates the neutron multiplicity in all the stages since from formation of a fully equilibrated compound nucleus. For a fission event, first the number of neutrons emitted by the compound nucleus till it crosses the saddle point is calculated. This number is controlled by the fission width which is taken as [6],

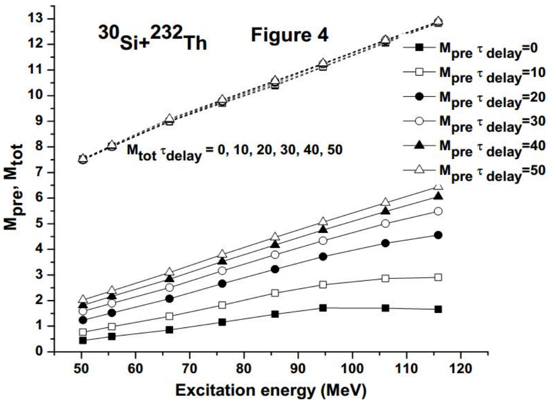
$$\Gamma_k = \Gamma_{BW}\,[\{1+(\beta/2\omega_s)^2\}^{1/2} - (\beta/2\omega_s)] \qquad [1]$$

where Γ_{BW} is the Bohr-Wheeler fission width, β is the nuclear dissipation function and ω_s is the frequency of a harmonic oscillator potential which approximates the saddle region. The code next calculates the number of neutrons evaporated during the following time interval τ_{ss} taken by the compound nucleus to evolve from









-saddle to scission [7],

$$\tau_{ss} = \tau_{ss}^{0}\ [\{1+(\beta/2\omega_s)^2\}^{1/2} - (\beta/2\omega_s)] \qquad [2]$$

where τ_{ss}^{0} is the time interval when there is no dissipation. The neutrons emitted in the above two stages are added to obtain M_{pre}. Finally the number of evaporated neutrons (M_{post}) from the fission fragments is calculated assuming symmetric fission. In order to get an idea about the time scales of neutron emission, calculations are also performed with $\beta = 0$ and using a delay time τ_{delay} in place of τ_{ss} in the saddle to scission sector. Calculations are performed for different values of β and the corresponding $\tau_{ss,}$ or keeping $\beta = 0$ and various values of τ_{delay}.

Using VECSTAT code we have calculated M_{pre}, M_{tot} for various nuclear viscosity parameter (β) and fission delay time (τ_{delay}) for ^{28}Si+^{232}Th leads to ^{260}Rf and ^{30}Si+^{232}Th leads to ^{262}Rf. These are given in the figures 1, 2, 3, 4 respectively. From figures 1- 4 we notice that M_{pre} for ^{28}Si+^{232}Th and ^{30}Si+^{232}Th systems increases with increasing the β and τ_{delay} as a function of excitation energy. However for ^{28}Si+^{232}Th and ^{30}Si+^{232}Th systems M_{tot} increases with excitation energy but independent of β and τ_{delay} . The analyses of the above data are under progress.

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