Angular momentum distribution for the formation of ERs in the reaction ^{19}F+^{184}W near the Coulomb barrier

S. Nath[1,2],* J. Gehlot[1], E. Prasad[3], Jhilam Sadhukhan[4], P.D. Shidling[5],† N. Madhavan[1], S. Muralithar[1], K.S. Golda[1], A. Jhingan[1], T. Varughese[1], P.V. Madhusudhana Rao[2], A.K. Sinha[6], and Santanu Pal[4]

[1] *Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi 110067, India*
[2] *Department of Nuclear Physics, Andhra University, Visakhapatnam 503003, India*
[3] *Department of Physics, Calicut University, Calicut 673635, India*
[4] *Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, India*
[5] *Department of Physics, Karnatak University, Dharwad 580003, India and*
[6] *UGC-DAE CSR, Kolkata Centre, 3/LB-8, Bidhan Nagar, Kolkata 700098, India*

Angular momentum distribution in fusion reactions has mostly been studied for light and medium compound systems. For increasing mass of the compound system, fission comes into play as a relevant reaction channel. In particular, for the production of the heaviest elements the competition between fission and particle evaporation is decisive for the survival of the evaporation residue (ER). In this context, it is interesting to study the limits of angular momenta which lead to the formation of ERs. Only a handful of studies have been carried out so far in the compound mass region $A \sim 200$ and above [1, 2]. A systematic study of the angular momentum dependence of the survival of ERs against fission with increasing mass can also reveal the role of closed shells in stabilizing the compound system [3].

We have performed ER-gated angular momentum distribution measurements for ^{19}F + ^{184}W $\rightarrow$ ^{203}Bi above the Coulomb barrier. The experiment was performed at the 15UD Pelletron accelerator facility of IUAC, New Delhi. A pulsed ^{19}F beam with 4 μs pulse separation was bombarded onto a 210 μg/cm^2 ^{184}W target with 110 μg/cm^2 carbon backing. Measurements were performed at beam energies (E_{lab}) of 89.2, 94.2, 99.2, 104.3 and 109.3 MeV using the HIRA[4]. ERs were unambiguously identified by simultaneous measurement of energy and time of flight. A multiplicity filter, consisting of 14 BGO crystals, was placed around the target to detect γ-rays from ERs. The multiplicity filter covered 48% of the total 4π solid angle. 14 time-to-digital converter (TDC) spectra were recorded with ER arrival time at the focal plane as the common start and individual BGO timing signals, delayed suitably, as the stop. Experimental γ-fold distribution was constructed offline from these TDC spectra using the code CANDLE [5].

The γ-multiplicity distribution was assumed to have the shape of a Fermi function:

$$P(M_\gamma) = \frac{2M_\gamma + 1}{1 + exp(\frac{M_\gamma - M_{\gamma 0}}{\Delta M_\gamma})} \quad (1)$$

where $M_{\gamma 0}$ is the mean multiplicity and ΔM_γ is the diffuseness in the multiplicity distribution.

The fold distribution was generated from the multiplicity distribution following the relation used in Ref. [6]:

$$Q(p) = \binom{N}{p} \sum_{l=0}^{p} (-1)^{p-l} \binom{p}{l} [1 - (N-l)\Omega] P(M_\gamma) \quad (2)$$

where $\binom{N}{p}$ denotes the number of ways p combinations are possible out of N numbers and Ω is the efficiency of each identical BGO detector. The parameters in Eq. (1) were chosen to produce the best fit for the measured fold distribution at each E_{lab}.

The multiplicity to angular momentum ($M_\gamma \rightarrow l$) transformation was accomplished by the following prescription [7, 8]:

$$l(M_\gamma) = (M_\gamma - \overline{M}_{\gamma S})\overline{\Delta l}_{\gamma NS} + \overline{M}_{\gamma S}\overline{\Delta l}_{\gamma S} + \overline{M}_n \overline{\Delta l}_n \quad (3)$$

*Electronic address: subir@iuac.res.in
†Present address: Cyclotron Institute, Texas A&M University, College Station, TX 77843-3366, USA

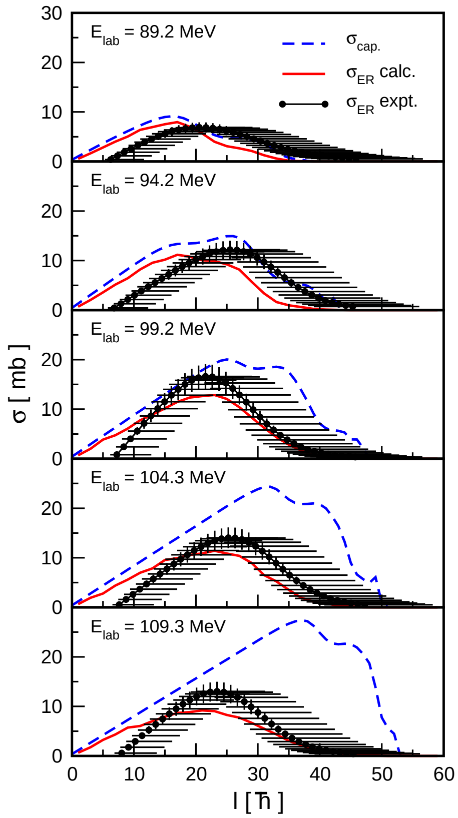

FIG. 1: Measured angular momentum distributions for the formation of ERs in the reaction ^{19}F + ^{184}W at the five laboratory energies. Capture cross sections from CCFULL and angular momentum distributions calculated using statistical model are also shown.

Here $(M_\gamma - \overline{M}_{\gamma S})$, $\overline{M}_{\gamma S}$ and $\overline{M}_n$ are the average multiplicities of non-statistical γ-rays, statistical γ-rays and evaporated neutrons, respectively. $\overline{\Delta l}_{\gamma NS}$, $\overline{\Delta l}_{\gamma S}$ and $\overline{\Delta l}_n$ represent the average amount of angular momentum carried off by each type of transition.

The values of $\overline{M}_{\gamma S}$, $\overline{\Delta l}_{\gamma S}$, $\overline{M}_n$ and $\overline{\Delta l}_n$ were estimated from statistical model calculation [9]. The angular momentum distribution of the fused compound nuclei, which is used as an input to the statistical model calculation, was generated by the coupled-channels code CCFULL [10]. Angular momenta carried off by evaporated protons and α-particles were insignificant and hence not considered in Eq. (3). We assumed that $\overline{\Delta l}_{\gamma NS} = 1.1$ as most of the non-statistical γ-transitions in the final ERs are of M1-type. This assumption together with the non-zero ground state spin and the presence of isomeric states in the ERs add to the uncertainty in the deduced l-values. Fig. 1 shows the experimental angular momentum distribution together with the results of statistical model calculation.

We must point out that the procedure followed here for $M_\gamma \rightarrow l$ transformation does not take into account the fact that the various evaporation channels are not uniformly distributed over the whole range of l. This is the main reason for the discrepancy between the measured and calculated distributions, particularly for low values of l, as mentioned in Ref. [11]. Therefore, one must exercise caution in taking the absolute values of angular momenta. However, the data quite reliably show the extent of the angular momentum distribution at the higher end ($\sim 40\hbar$). This value is $\sim 10\hbar$ less than that for the compound system ^{194}Hg [1] at similar beam energies. Further measurements are needed to ascertain whether this observation is related to the stabilizing effect of the $Z = 82$ shell, as was concluded in Ref. [12] for the survival of ERs.

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