

## Survival probabilities of heavy nuclei Cm to Lr

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### Introduction

In heavy-ion fusion reactions, survival probability  $P_{sur}$  is the probability that an excited compound nucleus will de-excite by the emission of neutrons, protons, or gamma rays instead of undergoing fission [1]. For heavy and superheavy nuclei, Qiao and Pei [2] studied first-chance survival probability. Liu and Bao [3] predicted cross-sections of the order of pb for the fusion reaction of  $^{50}\text{Ti}+^{250,251}\text{Cf}$  during 3n and 4n evaporation channel. Aritomo et al., [4] showed that the diffusion model, including statistical fluctuations, can describe the fusion–fission process in systems with or without pockets. Xia et al., [5] studied stability of superheavy nuclei against neutron emission and fission in the atomic number range  $100 \leq Z \leq 134$ . Swiatecki et al., [6] have studied the transition-state treatment of the ratio  $\Gamma_n/\Gamma_f$  in excited nuclei, pointing out errors due to improper shell correction handling and providing a unified transition-state-based derivation for fission and nucleon evaporation widths.

Manjunatha et al., [7] have studied the survival probability of heavy-ion fusion leading to the formation of superheavy nuclei and proposed an empirical formula to estimate it at the optimal beam energy. The dinuclear system (DNS) model is considered one of the most effective approaches to explain the mechanism of heavy-ion fusion [8]. Most previous studies on survival probability have primarily focused on superheavy compound nuclei, aiming to understand their stability and synthesis mechanisms. This concentration of work on the superheavy region has motivated us to extend the investigation toward heavy-ion compound nuclei.

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In the present study, we examine the survival probability of heavy-ion compound nuclei in the atomic number range  $96 \leq Z \leq 103$ .

### Theory

The evaporation residue cross section is evaluated using DNS model as follows [8],

$$\sigma_{ER} = \sum_{j=0}^{j_{max}} \sigma_C(E_{cm}, J) P_{CN}(E^*, J) P_{sur}(E_{cm}, J) \quad (1)$$

here  $\sigma_C$  is the capture cross-section at center of mass energy  $E_{cm}$  and spin  $J$ ,  $P_{CN}$  is the compound nucleus formation probability,  $E^*$  is the excitation energy and  $P_{sur}$  is the survival probability of the excited nucleus.

The empirical formulae for survival probability at an optimal energy is expressed as follows [7]

$$\ln P_{sur} = \delta_3 x^3 + \delta_2 x^2 + \delta_1 x + \delta_0 \quad (2)$$

Where  $\delta_0, \delta_1, \delta_2$  and  $\delta_3$  are the fitting constants and  $x$  is the function as follows

$$x = \left( \frac{E_{cm}}{V_B} \right)^n \left( \frac{Z^2}{A} \right) \exp \left( \frac{B_f - E_n}{T} \right)^n \quad (3)$$

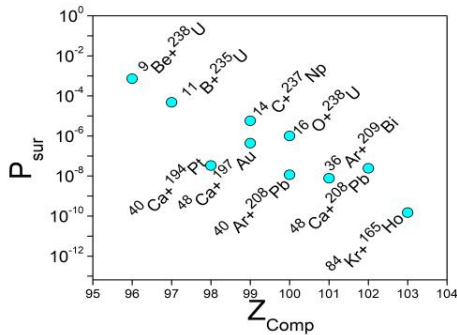
where  $V_B$  is the fusion barrier height and  $a$  is the level density parameter,  $B_f$  and  $B_n$  are the fission barrier and neutron separation energy respectively.  $T$  is defined as  $(E^*/a)^{1/2}$ .

### Results and Discussions

In the present work, we have analyzed different projectile–target combinations leading to the synthesis of heavy elements from Cm to Lr. The study considers various types of nuclear deformations, namely spherical–spherical (S–S), spherical–deformed (S–D), deformed–spherical (D–S), and deformed–deformed (D–D) systems. For these combinations, the survival probability and evaporation residue cross sections have been systematically evaluated.

Fig. 1 illustrates the variation of the survival probability ( $P_{sur}$ ) at optimal excitation energy as a function of the atomic number of the compound nucleus ( $Z_{Comp}$ ). It is evident from the plot that  $P_{sur}$  exhibits a general decreasing trend with increasing  $Z_{Comp}$ . For lighter compound nuclei ( $Z_{Comp} \approx 96-98$ ), the survival probability is relatively higher, reaching values close to  $10^{-4}-10^{-5}$ . However, as  $Z_{Comp}$  increases beyond 100,  $P_{sur}$  systematically decreases by several orders of magnitude, approaching values as low as  $10^{-10}$ .

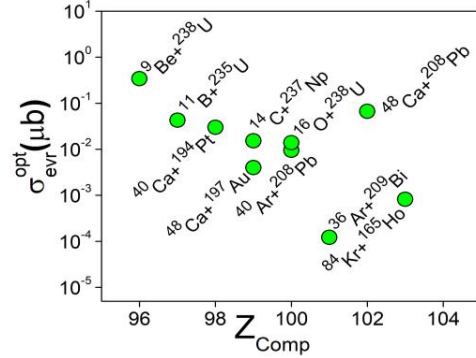
This reduction in survival probability with increasing atomic number can be attributed to the enhanced fission competition in heavier systems. As the Coulomb repulsion becomes stronger with increasing proton number, the fission barrier decreases, making the compound nucleus less stable against fission and thereby reducing the likelihood of survival against neutron evaporation.



**Fig. 1** A plot of survival probability ( $P_{sur}$ ) as function of atomic number of compound nucleus ( $Z_{Comp}$ ).

Fig. 2 depicts the variation of the evaporation residue cross section ( $\sigma_{evr}$ ) at optimal excitation energy as a function of the atomic number of the compound nucleus ( $Z_{Comp}$ ). Similar to the survival probability shown in Fig. 1, the evaporation residue cross section generally decreases with increasing  $Z_{Comp}$ . For lighter compound nuclei ( $Z_{Comp} \approx 96-98$ ), relatively larger cross sections are observed in the range of  $10^0-10^2 \mu b$ . However, as  $Z_{Comp}$  increases beyond 100,  $\sigma_{evr}$  rapidly decreases by several orders of magnitude, approaching values as low as  $10^{-4} \mu b$  for superheavy systems. A notable exception is the  $^{48}\text{Ca}+^{208}\text{Pb}$  system, where shell effects from

the doubly magic projectile and target enhance stability and lead to a comparatively larger cross section than expected.



**Fig. 2** Variation of an evaporation cross-section at optimal energies with atomic number of compound nucleus.

### Conclusions

The study demonstrates a systematic decrease in both survival probability and evaporation residue cross section with increasing atomic number of the compound nucleus, particularly beyond  $Z_{Comp} \approx 100$ , where fission strongly suppresses stability. A notable exception is the  $^{48}\text{Ca}+^{208}\text{Pb}$  system, where the doubly magic nature of the interacting nuclei enhances the cross section compared to the general trend. These findings highlight the interplay of Coulomb repulsion, fission barrier reduction, and shell stabilization in the formation of heavy and superheavy nuclei.

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