On how $\langle P_{\rm CN} \rangle$ behaves with mass-asymmetry in heavy nuclei

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The heavy evaporation residue (ER) production cross-section can be factorised as

$$\sigma_{\rm ER} = \sum_{J=0}^{J_{\rm max}} \sigma_{\rm cap} P_{\rm CN} W_{\rm sur} \quad (1)$$

where, $\sigma_{\rm cap}$ is the capture cross section at center of mass energy ($E_{\rm c.m.}$) and spin J, $P_{\rm CN}$ is the probability of forming the compound nucleus (CN) and $W_{\rm sur}$ is the fission survival probability of the CN. Here, $P_{\rm CN}$ (or $P_{\rm fus}$, the fusability) is the least known quantity.

Following have been reported about $P_{\rm CN}$:

- $P_{\rm CN}$ does not depend much on the charge of the CN, but mainly on the combination of fusing nuclei [1].
- $P_{\rm CN}$ demonstrates a sharp energy dependence. It increases with the excitation energy E^* [1].
- For the more asymmetric hot combinations, the $P_{\rm CN}$ is usually much higher than for the cold combinations leading to the same elements [2].
- Systems with similar effective fissility, can have $P_{\rm CN}$ values differing by as much as an order of magnitude [3].

$P_{\rm CN}$ can be extracted by analysing the shape of the fission-fragment (FF) angular distribution or the FF mass distribution. However, these methods are not robust and are yet to have predictive power. There are a few theoretical estimations and systematics of $P_{\rm CN}$ too. It has been reported that $P_{\rm CN}$ is approximately constant at energies above the barrier [4, 5]. A global systematics of $P_{\rm CN}$ will also aid super-heavy element (SHE) synthesis.

Sahm et al. [6] defined the angular momentum-averaged fusability as

$$\langle P_{\rm CN} \rangle = \frac{\sigma_{\rm ER}}{\sigma^0_{\rm ER}} \quad (2)$$

where, $\sigma^0_{\rm ER}$ is the maximum limit of the ER cross section ($\sigma_{\rm ER}$) at a given E^* which corresponds to $P_{\rm CN} = 1$. Therefore, it can be calculated by a statistical model without considering fusion hindrance. Sagaidak [7] also followed a similar approach for estimating $P_{\rm CN}$ for a number of heavy and super-heavy nuclei.

In the present work, we have calculated $P_{\rm CN}$ using Eq. (2) to study its behavior as a function of mass-asymmetry (η). We have performed calculation for a number of systems forming three CNs having well separated mass numbers, namely ^{200}Pb, ^{210}Rn and ^{220}Th.

First, we calculated $\sigma_{\rm cap}$ for these systems using the coupled-channels code CCFULL [8]. Proper rotational and vibrational couplings to the targets and projectiles were considered in the calculation. Akÿuz-Winther parametrization of Woods-Saxon potential was used in the input. The spin-distribution generated by the CCFULL was fed to the input of a statistical model (SM) code [9]. The code considers evaporation of neutrons, protons, α-particles and statistical giant dipole resonance (GDR) γ-rays as the decay channels of an excited CN in addition to fission. Shell-effect in level-density and shell-correction to the barrier height were included in the calculation. Fission barrier was not scaled and dissipation strength was not taken into account.

While comparing with experimental $\sigma_{\rm ER}$, calculated $\sigma_{\rm ER}$ is overestimated in all cases except for the system ^{16}O+^{184}W. Shidling et al.

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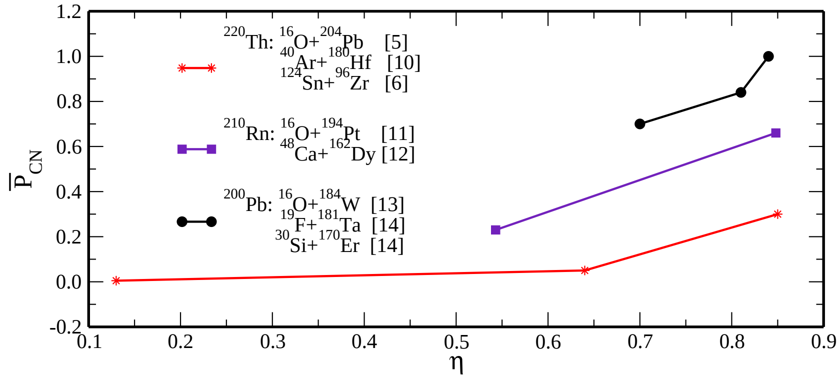

FIG. 1: $P_{\rm CN}$ as a function of η. Experimental $\sigma_{\rm ER}$ have been taken from Refs. [5, 6, 10–14].

[13] reported presence of dissipative forces in this system. Hence, we considered $P_{\rm CN} = 1$ for this reaction. For all other reactions, $P_{\rm CN}$ was estimated by scaling down the calculated $\sigma_{\rm ER}$ onto the experimental $\sigma_{\rm ER}$. It is clear from Fig. 1 that $P_{\rm CN}$ decreases with decreasing η. In other words, fusability decreases for symmetric combinations. Also, $P_{\rm CN}$ goes down with increase in mass number of the CN.

Hinde et al. [5] obtained $P_{\rm CN}$ for a number of reactions, all leading to the CN ^{224}Th, by comparing measured xn $\sigma_{\rm ER}$ without using model calculations. Sahm et al. [6], on the other hand, estimated $P_{\rm CN}$ by comparing experimental $\sigma_{\rm ER}$ with calculated $\sigma_{\rm ER}$. One may argue that such calculations are susceptible to errors due to improper choice of parameters in the statistical model. Liang et al. [15] reported estimation of fusion probability for neutron-rich Sn-induced reactions, in which statistical model calculation was performed by the code PACE2 [16]. Statistical model parameters were varied within reasonable limits to study the uncertainties in the calculated $\sigma_{\rm ER}$. It was demonstrated that the dependence of $P_{\rm CN}$ on the effective fissility parameter was not sensitive to the choice of parameters in the calculation. However, the magnitude of $P_{\rm CN}$ differed with the choice of statistical model parameters by a few percents.

We plan to carry out such calculations for more systems in the heavy mass region to gain a more complete understanding of $P_{\rm CN}$ with η.

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