Study on reaction mechanism by analysis of kinetic energy spectra of light particles and formation of final products

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Abstract. The sensitivity of reaction mechanism in the formation of compound nucleus (CN) by the analysis of kinetic energy spectra of light particles and of reaction products are shown. The dependence of the $P_{CN}$ fusion probability of reactants and $W_{surv}$ survival probability of CN against fission at its deexcitation on the mass and charge symmetries in the entrance channel of heavy-ion collisions, as well as on the neutron numbers is discussed. The possibility of conducting a complex program of investigations of the complete fusion by reliable ways depends on the detailed and refined methods of experimental and theoretical analyses.

1. Introduction

The study of nuclear reactions in heavy-ion collisions continues to be of great interest in the scientific community to better understand the reaction dynamics from the stage of capture of the projectile by target up to the formation of the final products. Nevertheless, in literature there are still present relevant unclear discrepancies between experimental and theoretical results. Uncertainties also exist among various theoretical results and incomprehension also among various experimental results. The differences between theoretical results by different models are related to the assumptions made in the procedures of theoretical calculations and use of simplified phenomenological models unsuitable to describe the reaction dynamics. In fact, the use of free parameters can lead to an apparent acceptable agreement between the calculated results and data but actually these results can not prove the effectiveness of the procedures used to obtain the experimental results. Analogously, the procedure of obtaining the best values of free parameters used in the phenomenological model which leads to results of calculation in good agreement with the obtained experimental results can not demonstrate by a clear and unambiguous way the understanding of the reaction dynamics. The main reason for the differences in the experimental fusion and capture cross sections is related to the ambiguity of the procedures at the separation of the events corresponding to deep-inelastic collisions (DICs), quasifission (QF) and fusion-fission (FIS) processes. The quasifission is the decay of the dinuclear system (DNS) into two...
fragments without formation of CN. There is still no definite understanding the nature of full momentum transfer reactions at the experimental analysis of the deep-inelastic collisions and quasifission events to estimate capture cross sections. The overlap of the mass and/or angular distributions of the quasifission and fusion-fission products causes ambiguity in the estimation of the experimental fusion cross sections. The $P_{CN}$ fusion probability of reactants in the heavy ion collisions is estimated as a ratio of the complete fusion ($\sigma_{fus}$) and capture ($\sigma_{cap}$) cross sections:

$$P_{CN} = \frac{\sigma_{fus}}{\sigma_{cap}} = \frac{\sigma_{fus}}{\sigma_{fus} + \sigma_{qfis}}.$$  \hspace{1cm} (1)

The theoretical value of the capture cross section is determined by the estimation of the range of the orbital angular momentum leading to the full momentum transfer in the entrance channel of collision. The evolution of the excited dinuclear system (DNS) formation can lead to complete fusion in competition with quasifission. The details of this model are present in many of our papers (see, for example, [1–11]).

The model takes into account the dependence of the capture cross section on the range of the orientation angles of nuclei at the initial stage of nuclear collision, the mass asymmetry parameter of reactants in the entrance channel, the considered $E_{c.m.}$ energy range for the investigated reaction. The orbital angular momentum range is needful to consider the evolution of each reaction from the contact of reactants to the compound nucleus formation, until to obtaining the final products of deexcitation of CN.

It is obvious the differences between the values of $P_{CN}$ extracted from the measured data of the capture and complete fusion events depend on how are correctly estimated capture and fusion cross sections from the measured data. Therefore, the reliable experimental determinations of $P_{CN}$ and consequently the understanding the entrance channel effect on the $P_{CN}$ values are strongly related to the choice of assumptions for the data analysis.

The competition between the complete fusion of nuclei in DNS and quasifission (decay of DNS into two fragments) processes decreases the value of the fusion cross section [12,14,15]:

$$\sigma_{fus}(E_{c.m.}) = \sum_{\ell=0}^{\ell_d(E_{c.m.})} (2\ell + 1)\sigma_{cap}(E_{c.m.}, \ell)P_{CN}(E_{c.m.}, \ell).$$ \hspace{1cm} (2)

The maximum value of $\ell$ leading to capture $\ell_d(E_{c.m.})$ depends on the beam energy and it is calculated by the solution of the radial motion equations (see ref. [15]). Since the capture cross section is equal to the sum of the complete fusion and quasifission cross sections, $\sigma_{cap} = \sigma_{fus} + \sigma_{qfis}$, the quasifission cross section is calculated by the expression

$$\sigma_{qfis}(E_{c.m.}) = \sum_{\ell=0}^{\ell_d} (2\ell + 1)\sigma_{cap}(E_{c.m.}, \ell)(1 - P_{CN}(E_{c.m.}, \ell)).$$ \hspace{1cm} (3)

It should be stressed that quasifission of dinuclear system can take place at all angular momentum values from $\ell = 0$ to $\ell_d$. Another binary process which leads to the formation of two fragments similar to those of fusion-fission and quasifission is the fast fission (FF). The fast fission occurs only if there is not a fission barrier for the being formed compound nucleus due to the large values of the angular momentum, $\ell > \ell_f$. According to the rotating liquid drop model (see [16]) a rotating nucleus with the angular momentum $\ell_f$ breaks down immediately. Therefore, FF is determined as the disintegration of the fast rotating mononucleus into two fragments, through DNS survives quasifission to be transformed into CN. In the case of the superheavy nuclei, the fission barrier providing their stability against fission appears only due to shell effects in their binding energy because there is no barrier connected with the liquid-drop
model (see ref. [17]). The damping of the shell effects decreases the possibility of the deformed mononucleus of reaching the CN equilibrium shape, and the mononucleus breaks down into two fragments without reaching the CN stage. Therefore, the fast fission cross section $\sigma_{ff}$ is calculated by summing the contributions of the partial fusion cross sections with $\ell$ values corresponding to the range $\ell_f < \ell < \ell_d$ leading to the formation of the mononucleus,

$$\sigma_{ff}(E_{c.m.}) = \sum_{\ell=\ell_f}^{\ell_d} (2\ell + 1) \sigma_{cap}(E_{c.m.}, \ell) P_{CN}(E_{c.m.}, \ell).$$

(4)

As the advantage of our modular system of nuclear reaction codes we stress the possibility to include into calculation explicitly the effect of the orbital angular momentum on the capture, fusion and survival probability. This fact allows us to analyze the role of the entrance channel effects on the evaporation residue cross section [7].

2. Fusion probability $P_{CN}$ determinations
As discussed in Introduction by regarding the use of formula (1) for the determination of $P_{CN}$ values of many kinds of nuclear reaction, the reason for the relevant discrepancy between the measured data and theoretical values of $P_{CN}$ is connected with the experimental difficulties in the identification of the fusion-fission fragments produced by fission of the compound nucleus to determine the fusion cross section. The mass distribution of the fast fission and sometimes quasifission processes overlaps with the mass symmetrical fusion-fission product distributions. The ability of the correct extraction of the fusion-fission cross section from the mixed data of the reaction products decreases due to intensive population of the mass-symmetric region by the fast fission or/and the quasifission fragments by the increase of $E_{CN}^*$. Therefore, the extraction of the fusion cross section from the experimental data is strongly affected by the underestimation of contribution of the fast fission and quasifission fragments. This problem is inherent to all kinds of reactions, leading to the formation of superheavy nuclei, when experimentalists selecting only mass symmetric fragments with the mass numbers in the range $A_{CN}/2\pm20$, assume such products belong only to the fusion-fission process. In fact, this assumption is completely doubtful because the yield of mass symmetric fragments produced by the quasifission and fast fission processes are competitive and often some orders of magnitude higher than the ones produced by the fusion-fission process (see for example, refs. [12, 13]).

**Figure 1.** (Color on-line) The $P_{CN}$ fusion probability as a function of the angular momentum $\ell$ for the $^{16}O+^{186}W$ very asymmetric reaction at excitation energy $E_{CN}^*=75$ MeV (dashed line) of the $^{202}Pb$ CN is shown; in the same figure, the $P_{CN}$ values vs $\ell$ for the $^{48}Ca+^{154}Sm$ less asymmetric reaction at excitation energies $E_{CN}^*=49$ and 63 MeV, respectively (dotted and full lines), are also reported.

Moreover, in order to show the sensitivity of the $P_{CN}$ with the angular momentum $\ell$ at two different excitation energies of 49 and 63 MeV (dotted and full lines, respectively) of the formed $^{202}Pb$ compound nucleus, we present in Fig. 1 our results obtained for the $^{48}Ca+^{154}Sm$ less
asymmetric reaction. We also present in the same figure the $P_{CN}$ values vs $\ell$ obtained for the $^{16}$O+$^{186}$W very asymmetric reaction, leading to the same $^{202}$Pb CN at $E_{CN}^{*}=63$ MeV (dashed line). This figure clearly shows the strong dependence of the $P_{CN}$ results on the excitation energy $E_{CN}^{*}$ and/or of the beam-target combination in the entrance channel.

Therefore, the comparison of the $P_{CN}$ values for different conditions of reactions can be made and understood only if somebody is able to explain the reasons for different results and trend due to the entrance channel effects and/or characteristics of the reaction mechanism (for details see [11]).

3. Survival probability $W_{sur}$ determinations and ER residual nuclei formation

Another important problem in the analysis of the experimental data is related with the determination of the reliable $B_{nis}$ fission barrier values of excited nuclei reached along the deexcitation cascade of CN in order to correctly estimate the overall $W_{sur}(E_{CN}^{*})$ survival probability against fission which is used to calculate the total ER cross section vs $E_{CN}^{*}$. Indeed, the experimental determinations of the ERs values may be uncertain whether any of $\alpha$-decay lifetime of reached nuclei along the deexcitation cascade is less than few $\mu$s. The uncertainty in determination of the ERs values appears even more strongly when the process of the deexcitation of CN by the evaporation of the charged particles is neglected in comparison with the evaporation of neutral particles. In fact, in many heavy-ion reactions leading to formation of the heavy and superheavy compound nuclei, the total evaporation residue cross sections (when the charged particles are taken into account too) are much higher than the ones obtained for the evaporation of neutral particles. For example, the $\sigma_{ERot}/\sigma_{ER-xn}$ ratio is 5–8 times for the $^{26}$Mg+$^{248}$Cm and $^{36}$S+$^{238}$U reactions (leading to the same $^{274}$108 CN called $^{274}$Hs*) and it can reach even 1 or 2 orders of magnitude for some other reactions (see for example [7, 18]). Therefore, neglecting the contribution of the charged particles in the determination of evaporation residue nuclei without the possibility of knowing the effect on the final results is doubtful. We can conclude here that the complete evaporation residue cross section $\sigma_{ERot}$ can be determined correctly if there is a possibility of full detection of all the total evaporation residue nuclei in the reaction.

The evaporation residue cross sections at the given values of the CN excitation energy $E_{x}^{*}$ at each step $x$ of the deexcitation cascade by the advanced statistical model [9]

$$\sigma_{ER}^{(x)}(E_{x}^{*}) = \Sigma_{\ell=0}^{P}(2\ell+1)\sigma_{ER}^{(x)}(E_{x}^{*}, \ell), \tag{5}$$

where $\sigma_{ER}^{(x)}(E_{x}^{*}, \ell)$ is the partial cross section of ER formation obtained after the emission of particles $\nu(x)n + y(x)p + k(x)\alpha + s(x)$ (where $\nu(x)$, $y$, $k$, and $s$ are numbers of neutrons, protons, $\alpha$-particles, and $\gamma$-quanta) from the intermediate nucleus with excitation energy $E_{x}^{*}$ at each step $x$ of the deexcitation cascade by the formula (for more details, see papers [2, 9, 11, 14]):

$$\sigma_{ER}^{(x)}(E_{x}^{*}, \ell) = \sigma_{ER}^{(x-1)}(E_{x-1}^{*}, \ell)W_{sur}^{(x)}(E_{x-1}^{*}, \ell). \tag{6}$$

In calculation of the $W_{sur}^{(x)}(E_{x-1}^{*}, \ell)$ the fission barrier is used as a sum of the parametrized microscopic fission barrier $B_{fis}^{m}(\ell)$ depending on the angular momentum $\ell$ [16] and the microscopic (shell) correction $\delta W = \delta W_{sad} - \delta W_{gs}$ due to shell effects; by considering the large deformation of a fissioning nucleus at the saddle point, $\delta W_{sad}$ is much smaller than the $\delta W_{gs}$ value and the microscopic shell correction $\delta W$ to the fission barrier can be expressed by the relation $\delta W \cong -\delta W_{gs}$. Therefore, an effective fission barrier, as a function of $\ell$ and $T$ for each excited nucleus formed at various steps along the deexcitation cascade of CN, is calculated by the expression

$$B_{nis}(\ell, T) = c B_{fis}^{n}(\ell) - h(T) q(\ell) \delta W, \tag{7}$$
where the factor $c$ was set to 1 in all our calculations and $h(T)$ and $q(\ell)$ represent the damping functions of the nuclear shell correction (usually it is $\delta W < 0$) with the increase of the excitation energy $E^*$ and $\ell$ angular momentum, respectively [9]:

$$h(T) = \left\{1 + \exp[(T - T_0)/d]\right\}^{-1}$$

(8) and

$$q(\ell) = \left\{1 + \exp[(\ell - \ell_{1/2})/\Delta\ell]\right\}^{-1},$$

(9) where, in Eq. (8), $T = \sqrt{E^*/a}$ represents the nuclear temperature depending on the excitation energy $E^*$ and the level density parameter $a$, $d = 0.3$ MeV is the rate of washing out the shell corrections with the temperature, and $T_0 = 1.16$ MeV is the value at which the damping factor $h(T)$ is reduced by 1/2. Analogously, in Eq. (9), $\Delta\ell = 3h$ is the rate of washing out the shell corrections with the angular momentum, and $\ell_{1/2} = 20h$ is the value at which the damping factor $q(\ell)$ is reduced by 1/2.

By regarding the determination of intrinsic level density $\rho_{\text{int}}$ which takes into account the density of the intrinsic excitations, the nucleus is considered as a system made up to non-interacting Fermi gases (proton gas and neutron gas) at the same thermodynamic temperature $T$. It is supposed that each of the two gases is in thermodynamic equilibrium and that the excitation energy $E^*$ is distributed in a statistical way between two gases. In this context for the intrinsic level density parameter $a$ we use the general expression [19] especially tailored to account for the shell effects in the level density

$$a(E^*) = \tilde{a} \left\{1 + \delta W \left[\frac{1 - \exp(-\gamma E^*)}{E^*}\right]\right\}$$

(10)

where $\tilde{a} = 0.094 \times A$ is the asymptotic value that takes into account the dependence on the mass number $A$, and $\gamma =0.0064$ MeV$^{-1}$ is the parameter which accounts for the rate at which shell effects wash out with excitation energy for neutron or other light particle emission. The general expression (10) works well also for deformed prolate or oblate nuclei. Physically, the disappearance of the shell effects with $E^*$ excitation energy may be seen as a rearrangement of the shell-model orbitals in such a way that the shell gap between orbitals close to the Fermi energy vanishes. The value of the $\gamma$ parameter was obtained [19] by fitting the observed density of neutron resonances.

In order to determine the $a_{\text{fis}}$ level density parameter in the fission channel we use the relation $a_{\text{fis}}(E^*) = a_n(E^*) \times r(E^*)$ found in [20] where $r(E^*)$ is given by the relation

$$r(E^*) = \frac{[\exp(-\gamma_{\text{fis}} E^*) - (1 + E^*_{\text{fis}})]}{[\exp(-\gamma E^*) - (1 + E^*_{\text{fis}})]}$$

(11)

with $\gamma_{\text{fis}} = 0.024$ MeV$^{-1}$.

To calculate the intrinsic level density $\rho_{\text{int}}(E^*, \ell)$ we use the general expression

$$\rho_{\text{int}}(E, J) = \frac{1}{16\sqrt{6\pi}} \left[\frac{h^2}{J_r}\right]^{1/2} a^{-1/4} \times \sum_{k=-J}^{J} \left[E - E_{\text{rot}}(k)\right]^{-5/4} e^{2[a|E-E_{\text{rot}}(k)|]^{1/2}}$$

(12)

The collective level density $\rho_{\text{coll}}$ calculated in the adiabatic approach, valid at low excitation energies, takes into account in addition to the intrinsic excitations also the rotational and vibrational excitation states by the collective enhancement factor $K_{\text{coll}}(E^*)$:
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where $K_{\text{coll}}(E^*)$ is given by the simple multiplication of the two $K_{\text{rot}}(E^*)$ and $K_{\text{vibr}}(E^*)$ enhancement factors; therefore, $\rho_{\text{coll}}(E^*, J)$ is determined (for more details see Appendix B) as

$$\rho_{\text{coll}}(E^*, J) = \rho_{\text{int}}(E^*, J) \times K_{\text{coll}}(E^*) \times K_{\text{rot}}(E^*) \times K_{\text{vibr}}(E^*). \quad (13)$$

In the cited paper [11] we give many other details regarding the intrinsic $\rho_{\text{int}}$ and collective $\rho_{\text{coll}}$ level density determinations, the fission $\Gamma_{\text{fis}}$ and particle-x $\Gamma_x$ decay widths, and we show the sensitivity of the model on final reaction products by using mass asymmetric and almost symmetric reactants in the entrance channel.

Figure 2. (Color on-line) The $W_{\text{sur}}$ survival probability against fission along the deexcitation cascade for the $^{16}\text{O}+^{204}\text{Pb}$ reaction (a) and the $^{124}\text{Sn}+^{96}\text{Zr}$ reaction (b), both leading to the $^{220}\text{Th}$ CN, as a function of the $E_{\text{CN}}^*$ excitation energy.

By comparing the $W_{\text{sur}}$ values obtained for two very different entrance channels leading to the formation of the $^{220}\text{Th}$ CN at excitation energies $E_{\text{CN}}^*$=30, 40 and 50 MeV, it is possible to observe the different effects of the angular momentum distribution on the surviving probability excitation functions. The $W_{\text{sur}}$ values for the CN formed in the almost symmetric $^{124}\text{Sn}+^{96}\text{Zr}$ reaction are greater than the $W_{\text{sur}}$ values corresponding to the one in the very asymmetric $^{16}\text{O}+^{204}\text{Pb}$ reaction by factors of 3.5, 4.2, and 4.5 times at the $E_{\text{CN}}^*$=30, 40 and 50 MeV, respectively. Certainly the increase of the beam energy $E_{\text{CM}}^*$ leads to an increase of the excitation energy $E_{\text{CN}}^*$ of CN and to an extension of the angular momentum distribution of the CN formed in these reactions. But the behavior of the extension of the angular momentum distribution is different for the two reactions. The $\ell$ angular momentum range is larger for the $^{220}\text{Th}$ CN obtained in the very asymmetric $^{16}\text{O}+^{204}\text{Pb}$ reaction than for the CN obtained in the almost symmetric $^{124}\text{Sn}+^{96}\text{Zr}$ reaction at the same considered $E_{\text{CN}}^*$ excitation energy. This difference in the angular momentum $\ell$ interval increases with the increase of $E_{\text{CN}}^*$ since the size of the potential well in the nucleus-nucleus interaction for the almost symmetric $^{124}\text{Sn}+^{96}\text{Zr}$ reaction is smaller than the one for the very asymmetric reaction like $^{16}\text{O}+^{204}\text{Pb}$. Therefore, the number of the angular momentum $\ell$ contributing to fusion in the $^{124}\text{Sn}+^{96}\text{Zr}$ reaction is smaller. Moreover, the fusion probability $P_{\text{CN}}$ strongly decreases by increasing the angular momentum due to the increase of the $B_{\text{fus}}^*$ intrinsic fusion barrier and due to a decrease of the $B_{\text{qf}}$ quasifission barrier.
for the symmetric reaction (see for example ref. [21]). The quasifission barrier is the depth of the potential well in the nucleus-nucleus interaction.

Obviously, the fusion cross section at a considered \( E_{\text{CN}}^* \) value of CN for the \(^{124}\text{Sn} + ^{96}\text{Zr} \) symmetric reaction is smaller than the one of the \(^{16}\text{O} + ^{204}\text{Pb} \) very asymmetric reaction, but with a smaller \( \ell \) interval of the formed CN by the symmetric reaction has a greater \( W_{\text{sur}} \) survival probability to fission in comparison with the very asymmetric reaction.

Moreover, as discussed in our paper [18], it is difficult to estimate the \( \sigma_{\text{ERTot}} \) cross section in experiment, when the emission of charged particles present also, because not all of residue nuclei can be identified. Therefore, apart from the uncertainties which are inherent to the theoretical predictions, there are ambiguities in the estimation of the fusion cross sections by the analysis of experimental data.

In our code the fission and particle decay widths \( \Gamma_{\text{fis}} \) and \( \Gamma_x \) are calculated by the formulas

\[
\Gamma_{\text{fis}}(E, J) = \frac{1}{2\pi \rho(E, J)} \int_0^{E - E_{\text{sad}}(J)} \rho_{\text{fis}}(E - E_{\text{sad}}(J) - \epsilon, J) \times T_{\text{fis}}(E - E_{\text{sad}}(J) - \epsilon) d\epsilon, \tag{14}
\]

and

\[
\Gamma_x(E, J) = \frac{1}{2\pi \rho(E, J)} \sum_{J' = 0}^{\infty} \sum_{j = |J' - J|}^{J' + J} \int_0^{E - B_x} \rho_x(E - E_x - \epsilon, J') T_{\text{x}}^{\ell,j}(\epsilon) d\epsilon, \tag{15}
\]

where the subscript \( \text{fis} \) and \( x \) refer, respectively, to the fission process and particle-\( x \) emission channels (neutron, proton, \( \alpha \), and \( \gamma \)), and primes are used to mark an intermediate excited nucleus after particle emission and \( E_{\text{sad}}(J) \) is the energy of the decaying nucleus at the saddle point with angular momentum \( \ell \) and total spin \( J \).

Formulas (14) and (15) \( \rho, \rho_{\text{fis}} \) and \( \rho_x \) represent the collective level densities of the formed excited nucleus, the level density of the excited nucleus at the saddle point configuration for orbital angular momentum \( \ell \), and the level density of the reached subsequent excited nucleus after particle-\( x \) emission for orbital angular momentum \( \ell \), respectively. \( T_{\text{fis}}^{\ell,j} \) is an optical-model transmission coefficient for particle-\( x \) with angular momentum \( \ell \) coupled with particle spin to give \( j \), and the fission transmission coefficient \( T_{\text{fis}} \) in the Hill-Wheeler approximation is given by \( T_{\text{fis}} = \left\{ 1 + \exp\left[-2\pi(E^* - E_{\text{sad}}(J) - \epsilon)/\hbar\omega\right]\right\}^{-1} \), with \( \hbar\omega = 1 \) MeV.

It is useful to observe that in formula (14) the calculation of \( \Gamma_{\text{fis}} \) width is characterized by the level density \( \rho_{\text{fis}} \) of the excited nucleus that reaches the saddle point state with angular momentum \( \ell \) and total spin \( J \) - weighted by the transmission coefficient \( T_{\text{fis}} \) - and in the denominator by the level density \( \rho(E, J) \) of the same excited and rotating nucleus at the statistical equilibrated state with energy \( E \) and spin \( J \), while in (15) the calculation of the \( \Gamma_x \) width for particle-\( x \) emission - weighted by the \( T_x \) transmission coefficient - is characterized in the nominator by the level density \( \rho_x(E - B_x - \epsilon, J') \) of the intermediate excited nucleus.

In order to calculate the collective level density in the non-adiabatic approach \( \rho_{\text{coll}}^{\text{non-adiab}}(E^*, J) \) - necessary when the CN is formed at higher \( E_{\text{CN}}^* \) excitation energies - we used a damped collective enhancement function \( q(E^*, \beta) \) with the aim to account the coupling of the collective to intrinsic degrees of freedom due to the nuclear viscosity because while it is acceptable to treat collective modes within the adiabatic approximation at low energies, it is rather unlikely that at high energies the adiabatic assumption still holds, due to the coupling of the elementary modes to the collective ones. So we introduce a certain general function for damping collective effects in the level density, depending strongly on the excitation energy.
and deformation of the nucleus. This is expressed in a decrease of the collective enhancement coefficient $K_{coll}^{non-adiab}(E^*)$ when the excitation energy increases; therefore, the following expression was assumed [22, 23]

$$K_{coll}^{non-adiab}(E^*) = \left\{ \left[ K_{rot}^{adiab}(E^*) - 1 \right] q(E^*, \beta) + 1 \right\} \times \left\{ \left[ K_{vibr}^{adiab}(E^*) - 1 \right] q(E^*, \beta) + 1 \right\}$$  \hspace{1cm} (16)

where

$$q(E^*, \beta) = \exp[-E^*/E_1(\beta)].$$  \hspace{1cm} (17)

The expression of damping function is used in the fission and neutron (or other light particles) emission channels in the same way [24]. In formula (17) the following expression for $E_1(\beta)$ was assumed

$$E_1(\beta) \cong 170 \times A^2 \beta^2$$  \hspace{1cm} (18)

in order to reach the better agreement between calculated values of fission cross sections and experimental ones for a wide set of nuclear reactions leading to compound nuclei lighter than lead, preactinide and actinide compound nuclei, and also for nuclei with $Z > 100$. At the same time, the comparison between theoretical estimation of evaporation residue cross sections and experimental determinations have contributed to the choice of the damping function $q(E^*, \beta)$ to the $K_{coll}$ collective enhancement coefficient given in formula (17) together with the expression (18). The consequence of the quadratic dependence of $E_1(\beta)$ on $\beta$ (see relation (18)) is that the damping at the saddle point ($\beta \approx 0.6 - 0.8$) is negligible in the high $E^*$ excitation energy region, while the deviations of $q(E^*, \beta)$ from unity are already considerable for the neutron channel ($\beta \approx 0.2 - 0.3$) at low $E^*$ excitation energy values.

4. Analysis of ER excitation functions for the $^{82}$Se+$^{138}$Ba reaction

We analyze and present the ER excitation functions for the $^{82}$Se+$^{138}$Ba almost mass symmetric ($\eta = 0.255$) reaction since it is possible to explore the low excitation energy range starting from the value $E_{CN}^{*} = 12$ MeV that corresponds to the threshold energy for the $^{220}$Th CN formation. In comparison with the fusion excitation functions obtained for the mass asymmetric $^{16}$O+$^{204}$Pb ($\eta = 0.855$) and $^{40}$Ar+$^{180}$Hf ($\eta = 0.636$) reactions, the maximum value of the fusion excitation function for the reaction induced by the $^{82}$Se beam is about two orders of magnitude lower than the value obtained for the reaction induced by the $^{16}$O beam, and about one order of magnitude lower than the value obtained for the reaction induced by the $^{40}$Ar beam (see Fig.6 in [7]). The strong difference in the fusion excitation functions is related to the size of the potential well in the nucleus-nucleus interaction at the capture stage. The increase of the beam energy from near the Coulomb barrier energies leads to increase of number of partial waves contributing to capture and complete fusion. The Coulomb repulsion is stronger for the almost symmetric reactions in comparison with the one for the asymmetric reactions. Therefore, strong repulsion forces make the potential well shallower, reducing consequently the maximum number of the partial waves [$l_d(E)$] leading to capture; consequently, the capture cross section decreases. This effect is related to the dependence of the fusion barrier $B_{fus}$ and quasifission barrier $B_{qf}$ on the angular momentum values.

Fig.3 shows in panels (a), (b), (c) and (d) the experimental values obtained in ref. [25] for the individual $\sigma_{ER,xn}$ cross sections after 3n, 4n, 5n, and 6n+7n neutron emission, respectively. In order to compare our calculated results for the above individual $\sigma_{ER,xn}$ excitation functions vs
$E_{CN}^*$ with the available measurements, we also report in the above panels dashed lines representing the values obtained by our code. The results of the theoretical calculations are in good agreement with experimental measurements for all panels.

![Graphs](image_url)

**Figure 3.** (Color on-line) The individual ER cross sections after 3n (panel (a)), 4n (b), 5n (c), and 6n+7n (d) neutron emission vs. $E_{CN}^*$ for the $^{82}\text{Se}^+1^{38}\text{Ba}$ reaction leading to the $^{220}\text{Th}$ CN. The points represent the experimental values taken from ref. [25]. In each panel, the dashed line represents the related theoretical excitation function obtained by our code.

Fig. 4 shows in panels (a), (b), (c) and (d) the experimental values given in ref. [25] for the individual ER cross sections after $\alpha 1n+1n$, $\alpha 2n+2n$, $\alpha 4n+\alpha 5n$ and $\alpha 6n+\alpha 7n$ emissions, respectively. Also in this case we report in the above panels the dashed lines representing the theoretical values obtained by our code. The related results of calculation for the indicated individual channels are in good agreement with the experimental measurements in all panels.

Moreover, Fig. 5 shows in panels (a), (b), (c), and (d) the experimental values given in ref. [25] for the individual ER cross sections after $p3n$, $p4n$, $p5n$, and $p6n+p7n$ emissions, respectively. Analogously, also in this case, we report in the above panels by dashed lines the theoretical results obtained by our code; we register still a good agreement of these results with the experimental ones given in the above-mentioned panels.

The comparison made on the results presented in Figs. 3, 4, and 5 ensures the goodness of the experimental determinations and the reliability of the results obtained by our theoretical procedures, but unfortunately the complete final result is that the experimental determinations cover only a partial set of the possible charged particle emissions in the investigated $^{82}\text{Se}^+1^{38}\text{Ba}$ reaction. In fact in our theoretical calculations we have extended the determination of other
Figure 4. (Color on-line) As Fig. 3 but for the $\alpha n+1n$ (panel (a)), $\alpha 2n+2n$ (b), $\alpha 4n+\alpha 5n$ (c), and $\alpha 6n+\alpha 7n$ (d) channels.

relevant contributions of charged particle emissions as for example the $\alpha$p$\alpha$n, $2\alpha$x$n$, $2\alpha$p$\alpha$n, $3\alpha$x$n$, and $3\alpha$p$\alpha$n channels leading to the formation of other various ER evaporation residue nuclei.

At last, in Fig. 6 we report by dashed line the total contribution of ER cross sections after neutron emission only, by thin full line the contribution of ER cross section when also the $\alpha$x$n$, and $p$z$n$ channels (considered in ref. [25]) are included, and by thick full line when also the other $\alpha$p$\alpha$n, $2\alpha$x$n$, $2\alpha$p$\alpha$n, $3\alpha$x$n$, and $3\alpha$p$\alpha$n channels are considered. Therefore, this last line represents the true total ER excitation function vs $E_{CN}^*$ obtained in the $^{82}$Se+$^{138}$Ba reaction. Moreover, in the insert of Fig. 6 we report the $W_{sur}$ survival probability excitation function vs $E_{CN}^*$ for the $^{220}$Th CN formed by the considered reaction in the entrance channel. At $E_{CN}^* >40$ MeV $W_{sur}$ decreases by 2-3 orders of magnitude to cause of the dominant fission process. From this figure it is possible to observe that in the about $E_{CN}^*$ 27-30 MeV of excitation energy range the ratio between the yield of the total ER cross section (contributed by evaporation of all possible charged and neutral particles) and the yield of the ER cross section obtained for evaporation of neutrons only, is about a factor 20 confirming the decisive role of emission of charged particles along the deexcitation cascade of CN in order to form the residual nuclei. Moreover, it is possible to observe in the same figure that the true total ER cross section obtained for possible contributions of evaporation of charged and neutron particles (represented by the thick full line) is at least a factor 2-4 higher than the sum of the ER cross sections given in ref. [25] in the 27-70 MeV $E_{CN}^*$ energy range.
Therefore this study demonstrates that many times, because of the intrinsic limitations of the experimental apparatus to identify all real contributions [25], or simplified assumptions are made in the analysis of experimental results, or when one adopts calculation procedures based on parameter-free phenomenological models, the obtained ER results are inconsistent and unreliable.

Moreover, in order to demonstrate the sensitivity of the method and the relevant effect of the entrance channel on the fusion probability $P_{CN}$ values for two very close reactions, we present in Fig. 7 the results for the $^{26}$Mg+$^{248}$Cm and $^{25}$Mg+$^{248}$Cm reactions leading to the $^{274}$Hs CN and $^{273}$Hs CN, respectively, different only for one neutron.

Fig. 7 (a) shows the capture, fusion and quasifission excitation functions for the reaction induced by the prolate deformed (0.363) $^{25}$Mg beam; panel (b) shows the same mentioned excitation functions for the reaction induced by the deformed oblate (-0.309) $^{26}$Mg beam.

To a simple visual recognition of the lines reported in panels (a) and (b) show the presence of a small difference of 2 MeV in the threshold energy value and some quite similar appreciable difference in the trend of quasifission, but from Fig. 8 (that shows the fusion probability excitation function $P_{CN}$) appears instead to have a complete different trend of the $P_{CN}$ excitation function for the two mentioned reactions vs the collision energy $E_{cm}$-$E_B$ as compared with the Bass barrier.

This example demonstrates the importance of the type of deformation (oblate for the $^{26}$Mg beam, prolate for the $^{25}$Mg beam) for a nucleus (beam or target) in the entrance channel and
Figure 6. (Color on-line) The ER excitation functions vs $E^*_{CN}$ calculated by our code for the $^{82}\text{Se}+^{138}\text{Ba}$ reaction leading to the $^{220}\text{Th}$ CN: dashed line represents the ER contribution after neutron emission only considered in Fig.3; thin full line represents the sum of ER contributions after $xn$, $pxn$, and $\alpha xn$ particle emissions considered in Fig.3, 4, and 5; thick full line represents the sum of ER contributions considered in Figs.3, 4, 5, with in addition the above-mentioned $2\alpha xn$, $2p\alpha xn$, $3\alpha xn$, and $3p\alpha xn$ contributions. In the insert, the dotted line represents the excitation function vs $E^*_{CN}$ of the real $W_{sur}$ survival probability calculated by our code when the total ER contributions represented by the thick full line is considered.

Figure 7. (Color on-line) Comparison of the capture, fusion, and quasifission excitation functions calculated for: (a) the $^{25}\text{Mg}+^{248}\text{Cm}$ reaction leading to the $^{273}\text{Hs}$ CN; (b) the $^{26}\text{Mg}+^{248}\text{Cm}$ reaction leading to the $^{274}\text{Hs}$ CN.

how this strongly influences the reaction mechanism and the determination of the reaction final products. The present specific case (by comparing some results of the $^{25,26}\text{Mg}+^{248}\text{Cm}$ reactions leading to the $^{273,274}\text{Hs}$ compound nuclei, respectively) was already presented in our paper [11] and we discussed about the unreliable result found in paper [26] on the value $\Gamma_n/\Gamma_{total} = 0.89 \pm 0.13$ for the probability of neutron emission at first step of deexcitation of the $^{274}\text{Hs}$ CN with $E^*_{CN} = 63$ MeV of excitation energy (and consequently a value of $\Gamma_{fis}/\Gamma_{total} \simeq 11$ for the fission probability) by using the formula (7) of ref. [26] ($\Gamma_n/\Gamma_{total} = 1/1 + \nu_{274}^2/\nu_{274}$).

But, in [26] the authors affirmed that “For the range of the $B_{fis}$ values predicted by current
models, there is very little sensitivity of $B_{\text{fis}}$. To get values of $\Gamma_n/\Gamma_{\text{total}}$ similar to the measured value, one must invoke values of $B_{\text{fis}} \sim 11$ MeV, a number not consistent with current theoretical models for superheavy nuclei.  

Moreover, the above-mentioned formula (7) of ref. [26] was obtained by assuming that the fission-neutron emission competition of the reaction induced by the $^{26}\text{Mg}$ beam on the $^{248}\text{Cm}$ target after 1 neutron emission from the $^{274}\text{Hs}$ CN with excitation energy $E^{*}_{\text{CN}}=63$ MeV reaches the intermediate excited nucleus $^{273}\text{Hs}$ with excitation energy of 53 MeV, it is similar in all the characteristics to the $^{273}\text{Hs}$ CN obtained in the reaction induced by the $^{26}\text{Mg}$ beam of appropriate energy on the same $^{248}\text{Cm}$ target in order to reach the $^{273}\text{Hs}$ CN with the same excitation energy of $E^{*}_{\text{CN}}=53$ MeV. By realizing this condition for the two above-mentioned reactions induced by the $^{26}\text{Mg}$ and $^{25}\text{Mg}$ beams on the $^{248}\text{Cm}$ target, the authors [26] affirmed that the following deexcitation cascade from the $^{273}\text{Hs}$ intermediate excited nucleus with the excitation energy of 53 MeV formed by the $^{26}\text{Mg} + ^{248}\text{Cm}$ reaction after 1 neutron emission from the $^{274}\text{Hs}$ CN at $E^{*}_{\text{CN}}=63$ MeV is completely the same for the $^{273}\text{Hs}$ CN at $E^{*}_{\text{CN}}=53$ MeV formed by the $^{25}\text{Mg} + ^{248}\text{Cm}$ reaction.

Instead, in [11] was explained that this assumption in data analysis [26] does not hold, for two reasons: a) in the $^{25}\text{Mg} + ^{248}\text{Cm}$ reaction, the $^{273}\text{Hs}$ CN formation has a certain excitation energy $E^{*}_{\text{CN}}$ (for example $E^{*}_{\text{CN}}=53$ MeV) with respect to a certain $^{25}\text{Mg}$ energy beam; the energy spread (of some hundred keV) of $E^{*}_{\text{CN}}$ for the $^{273}\text{Hs}$ CN is only related to the determination of the energy beam and also to the thickness of the target. Analogously, in the $^{26}\text{Mg} + ^{248}\text{Cm}$ reaction, the $^{274}\text{Hs}$ CN formation has a certain excitation energy $E^{*}_{\text{CN}}$ (for example $E^{*}_{\text{CN}}=63$ MeV) with respect to a certain $^{26}\text{Mg}$ energy beam and related energy resolution, but the formation of the intermediate excited $^{273}\text{Hs}$ nucleus, reached after 1 neutron emission from the $^{274}\text{Hs}$ CN, is characterized by a broader excitation energy peak (of some MeV) with respect to the kinetic energy distribution of the neutron emitted from the $^{274}\text{Hs}$ CN.  

b) In the present specific case of the $^{25}\text{Mg}$ and $^{26}\text{Mg}$ induced reactions, the dynamic deformation of the $^{25}\text{Mg}$ and $^{26}\text{Mg}$ beams are very different at collision with the $^{248}\text{Cm}$ target, because the $^{25}\text{Mg}$ nucleus has a prolate static deformation (+0.363) while $^{26}\text{Mg}$ has an oblate static deformation (-0.309). These different conditions of the entrance channel affect the dynamic deformation of the $^{274}\text{Hs}$ CN and $^{273}\text{Hs}$ CN formed by the two $^{26}\text{Mg} + ^{25}\text{Mg} + ^{248}\text{Cm}$ reactions, and the intermediate excited nucleus $^{273}\text{Hs}$ (for example at $E^{*}=53$ MeV of excitation energy) reached after 1 neutron emission from the $^{274}\text{Hs}$ CN is dynamically different with respect to the $^{273}\text{Hs}$ CN (at $E^{*}_{\text{CN}}=53$ MeV) formed by the $^{25}\text{Mg} + ^{248}\text{Cm}$ reaction. Moreover, the result we obtained for the probability of neutron emission $\Gamma_n/\Gamma_{\text{total}} =0.17$ for the $^{274}\text{Hs}$ CN at $E^{*}_{\text{CN}}=63$ MeV is completely different from the

![Figure 8](image-url)
value $\Gamma_n/\Gamma_{\text{total}} = 0.89 \pm 0.13$ deduced in experiment [26]. Instead, our result ($\Gamma_n/\Gamma_{\text{total}} = 0.17$) allows us to affirm that the fission probability $\Gamma_{\text{fiss}}/\Gamma_{\text{total}} = 0.83$ at first step of deexcitation of the $^{274}\text{Hs}$ CN at $E_{\text{CN}}^* = 63$ MeV is the dominant process to cause of the small effective fission barrier $B_{\text{fiss}} = 0.72$ MeV contributed only by the shell correction value that is damped by the nuclear temperature $T$ (namely the related excitation energy $E^*$) and the angular momentum $\ell$, since the contribution to the macroscopic rotating liquid drop model is zero. Following this procedure we calculate for the ER cross section about 0.6 pb at $E_{\text{CN}}^* = 63$ MeV of the $^{274}\text{Hs}$ CN by the $^{26}\text{Mg}+^{248}\text{Cm}$ reaction.

This last result is consistent with the results obtained in ref. [27], while by assuming the value $\Gamma_n/\Gamma_{\text{total}} = 0.89$ given in [11] we estimate to reach a ER value of about $10^{-3}$mb that is at least 6 orders of magnitude higher than the experimental determination [27]. Moreover, the determinations of $\nu_{\text{pre}}^{274}$ and $\nu_{\text{pre}}^{273}$ values and the use of formula (7) of ref. [26] is not a reliable way to determine the $(\Gamma_n/\Gamma_{\text{total}})_1$ value since the method and procedures do not take into account the detailed dynamic effects of reactions. In fact, if for example one uses the values of $\nu_{\text{pre}}^{274} = 1.7, 2, 2.7, 3$, and 4 at $E^*(^{274}\text{Hs}) = 63$ MeV with the corresponding of $\nu_{\text{pre}}^{273} = 1.37, 1.61, 2.17, 2.42, \text{and 3.22 at } E^*(^{273}\text{Hs}) = 53$ MeV that assure the same $\nu_{\text{pre}}^{274}/\nu_{\text{pre}}^{273}$ ratio of the neutron multiplicities values reported in Table I of paper [26], corresponding to the above-mentioned excitation energies for the two reactions (induced by the $^{26}\text{Mg}$ and $^{25}\text{Mg}$ beams respectively), the neutron emission probability ($\Gamma_n/\Gamma_{\text{total}})_1$ at first step of the $^{274}\text{Hs}$ CN, should be 72%, 77%, 85%, 88%, and 94%, respectively. This kind of result leads to the conclusion that for the $^{26}\text{Mg}+^{248}\text{Cm}$ reaction at $E_{\text{CN}}^*(^{274}\text{Hs}) = 63$ MeV of excitation energy, if the prescission neutron multiplicity $\nu_{\text{pre}}^{274}$ is a very low value as 1.7 or a very high value as 4, the probability to emit neutron at first step of the deexcitation cascade of the $^{274}\text{Hs}$ at $E_{\text{CN}}^* = 63$ MeV is high as 72% - 94% against the fission that always should remain a shortly competitive process at decay of CN in comparison with the neutron emission, while on the contrary it is fission the dominant process at first step of the $^{274}\text{Hs}$ CN decay since the effective fission barrier $B_f = 0.72$ MeV in comparison with the binding neutron energy that is 6.51 MeV. Therefore, the method and procedures adopted in ref. [26] is clearly unreliable, and the result of formula (7) of ref. [26] is not sensitive to the reaction mechanism of the entrance channel.

We return again to discuss in the present paper about the $\Gamma_n/\Gamma_{\text{total}}$ value of about 0.9 at $E_{\text{CN}}^* = 63$ MeV found in the analysis of [26] for the $^{26}\text{Mg}+^{248}\text{Cm}$ reaction because the authors affirmed that such a relevant value of the probability of neutron emission $\Gamma_n/\Gamma_{\text{total}}$ suggests the interpretation that the fission process of a high excited nucleus, to cause of the strong effect of the nuclear viscosity delays of reaching the saddle point, and only approaching about the last step of the deexcitation chain the intermediate excited nucleus can go into fission. Such a result of $(\Gamma_n/\Gamma_{\text{total}})_1$ and the related interpretation of delay of the fission process led to other inspections in experiments assuming that the result [26] and the competition of the neutron emission against fission is considered as a reliable result. In fact, in paper [28] the $\Gamma_n$ value and its related interpretation were considered welcome with the words “Recently, it has been experimentally demonstrated that $\Gamma_1$ is dominant over $\Gamma_f$ in the first chance fission of $^{274}\text{Hs}$ produced in the $^{26}\text{Mg}+^{248}\text{Cm}$ reaction at $E^* = 63$ MeV [57].”

But unfortunately the authors of [28] do not found results as they argued before in their investigations, and affirmed that “results should stimulate future measurements of both fission fragments and evaporation residues in reactions forming elements to understand fully the effects and properties of the slow quasi-fission that appears to be very important in ..........” and finally they affirmed that “ The development of parameter-free dynamical approaches to modelling heavy ion reactions is therefore desirable for a full predictive capability on how best to produce heavy and superheavy elements and their isotopes.”
5. Analysis of kinetic energy spectra of emitted light particles
As an example of sensitivity and possibility supplied by our code, we present in Fig.9 the calculated neutron energy spectra of some emitted neutrons at various steps of the deexcitation cascade of the $^{288}114\;CN^*$ formed at $E_{\text{CN}} = 35.89$ MeV of excitation energy in the $^{48}\text{Ca}+^{240}\text{Pu}$ reaction: thick full line represents the kinetic energy spectrum of neutron evaporated from excited $^{288}144\;CN$, dashed line is for neutron emitted from excited $^{287}114^*$, dotted line is for neutron emitted from excited $^{288}144^*$, and thin full line is for neutron emitted from excited $^{289}114^*$.

At various steps of the deexcitation cascade of the formed CN, each intermediate excited nucleus surviving fission and reached after evaporation of one neutron, has a lower excitation energy $E^*$ with respect to the $E_{\text{CN}}^*$ value. Analogously to the various successive steps of the intermediate excited nuclei which survive fission along the deexcitation cascade, the yield of spectra of subsequent neutron emission is reduced of about two orders of magnitude and the correspondent kinetic energy range significantly decreases of about 5 MeV, respectively, after each neutron emission. In Fig.10 we present the calculated kinetic energy spectra of neutron, proton, and $\alpha$-particle emitted when one of these particles is emitted at first step of the above-mentioned $^{288}114\;CN$ at excited energy $E_{\text{CN}} = 40.06$ MeV. In this case the maximum yield of proton emission is reduced of about four orders of magnitude in comparison with the spectrum of the first neutron; for the emission of a charged particle from the internal part of CN exists a threshold for the evaporation of one charged particle. The maximum kinetic energy value of emitted proton is higher in comparison to the neutron emission to cause of the repulsive Coulomb force that appears on the charged particle after its emission from CN; in the case of the $\alpha$-particle emission, the threshold energy is higher than the one for the proton emission and the kinetic energy range for the $\alpha$-particle is much higher in comparison to the proton and neutron particle emissions.

In the present case of the $^{48}\text{Ca}+^{240}\text{Pu}$ reaction forming the $^{288}144\;CN$, the intermediate excited nuclei reached along the deexcitation cascade are $\alpha$-emitter and the maximum yield of $\alpha$-emission is about 1 order of magnitude higher than the one of proton-emission. Therefore, we can affirm that the experimental determinations of the kinetic energy spectra of $\alpha$ or/and proton emissions following the interaction of nuclei in the entrance channel can unambiguously contribute to verify that the CN has really been formed with excitation energy $E_{\text{CN}}^*$, and it is possible to observe the light charged particles evaporated from CN. Moreover, by also measuring the fusion-fission fragment cross sections vs. $E_{\text{CN}}^*$ and the neutron kinetic energy distribution it is possible to determine the fusion cross section and to characterize the main relevant decay widths $\Gamma_\alpha/\Gamma_{\text{total}}, \Gamma_{\text{fis}}/\Gamma_{\text{total}}, \Gamma_p/\Gamma_{\text{total}},$ and $\Gamma_\alpha/\Gamma_{\text{total}}$ as functions of the excitation energy $E_{\text{CN}}^*$

6. Conclusion
The reasons leading to uncertainties of the experimental and theoretical values of the fusion probability $P_{\text{CN}}$ in heavy ion collision at lower energies are discussed. It should be stressed that there are two important reasons causing the uncertainties of the experimental values $P_{\text{CN}}$. The first reason is related to the ambiguity in identification of the reaction products formed by the true capture and fusion events. In the analysis of experimental data with full momentum transfer, events with masses around the values of light initial nucleus and conjugate nucleus are not usually taken into consideration.

The second reason is the ambiguity in the separation of the fusion-fission events in the analysis of fission-like products containing quasi-fission or/and fast fission products. Therefore, the number of events seem to be larger than true fusion events due to consideration of the part of quasi-fission and fast fission events as fission events of compound nucleus which has not formed in the reaction. Certainly the extracted fusion probability $P_{\text{CN}}$ will be larger than its correct
value.

Due to difference in the spin distribution probability of the heated and rotating nucleus the survival probability $W_{\text{sur}}$ is strongly sensitive to the type of reactions in the entrance channel even if these reactions lead to the same CN formation with the same $E_{\text{CN}}^*$ excitation energy.

The characteristics of our model and procedure used for calculation are based on the possibility to analyze the effect of the entrance channel on the nuclear reactions mechanism. Moreover, in the model all properties of reaction which are responsible for the evolution of reactants with formation of intermediate states and final products (mass asymmetry and type of deformations of interacting nuclei, potentials, barriers, excitation function, reaction mechanisms, competition of processes, cross sections, etc.) are considered as a function of the energy and angular momentum. We have shown that the consistent description of the fission cross section reached by consideration of the fade-out of the shell correction to the fission barrier with increasing temperature and angular momentum is very important for a reliable estimation of the final reaction products. This result is of crucial importance for the synthesis of the superheavy elements, since it extends the stabilizing effects of the shell structure to higher temperatures, but this stabilizing effect, however, will be partially removed by the decrease of the shell correction with the increasing angular momentum.

Moreover, in the present paper we propose to use the kinetic energy spectra of charged particles ($\alpha$ and/or proton) emission from the formed compound nucleus in order to obtain by an unambiguous way information on the characterization of formed excited nuclei. This methodology

**Figure 9.** (Color on-line) Energy spectra of neutrons emitted at various steps of the deexcitation cascade starting from the $^{288}114$ CN at $E_{\text{CN}}^* = 35.89$ MeV of excitation energy by the $^{48}\text{Ca} + ^{240}\text{Pu}$ reaction: thick full line for the first neutron emitted from $^{288}114$ CN*, dashed lines for the first neutron emitted from $^{287}114$*, dotted line for the first neutron emitted from $^{286}114$* and thin full line for the first neutron emitted from $^{285}114$*.

**Figure 10.** Energy spectra of $n$, $p$, $\alpha$ emitted from the $^{288}114$ CN* at $E_{\text{CN}}^* = 40.06$ MeV of excitation energy by the $^{48}\text{Ca} + ^{240}\text{Pu}$ reaction: full line for the first emitted neutron, dotted line for the first emitted proton, dashed line for the first emitted $\alpha$-particle.
proves to be even more useful when, as the mass asymmetry of reacting nuclei in the entrance channel decreases, the reaction cross section is smaller than fraction of pb (picobarn) or even of fmb (femtobarn). In the case of reactants with $Z_1 \times Z_2 > 2500$ the very low values of $P_{CN}$ and $W_{sur}$ functions lead to an estimation of evaporation residues lower than the fmb (femtobarn) to cause of high contributions of DNS decay into quasifission and to decay of CN into fission.

But, in any case, the possibility to form compound nuclei by collisions between nuclei with the $Z_1 \times Z_2$ value much higher than 5000 and by almost mass symmetric reactions it is a very unrealistic dream to obtain ERs because the reactants can not even reach the stage of capture. Therefore, without capture it is not possible to obtain fusion and then to reach the CN formation considered as a statistically equilibrated system from which it is possible to obtain ER nuclei by evaporation of light particles along the deexcitation cascade of CN.

Therefore the absence of a refined analysis with appropriate procedures as also the use of assumptions without estimation of effects on the final results can not contribute to a correct and useful understanding of the reaction mechanism that one wants to investigate.

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