Entrance channel effects on the deexcitation ways of
the same compound nucleus at a fixed excitation
energy

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Abstract. The investigation of various properties of deexcitation of the same 220Th compound
nucleus (CN), formed by the different mass (charge) asymmetric 16O+208Pb, 40Ar+180Hf,
82Se+138Ba and 96Zr+124Sn reactions is presented. The effective fission barrier \( < B_{\text{fis}} > \)
value, as a function of the excitation energy \( E^*_{\text{CN}} \), determined for each intermediate excited
nucleus reached along the deexcitation cascade of the CN obtained by the four considered
reactions is strongly sensitive to the various orbital angular momentum \( L=\ell \hbar \) distributions of
CN formed with the same excitation energy \( E^*_{\text{CN}} \) by the various entrance channels. Therefore,
the competition between the fission and evaporation of light particles (neutron, proton, and
\( \alpha \)-particle) processes along the deexcitation cascade of CN is dependent on the orbital angular
momentum distribution of CN. In fact, the ratio between the evaporation residue cross sections
obtained when also the charged particles are emitted and the ones obtained after neutron
emission only for the same CN with a fixed excitation energy \( E^*_{\text{CN}} \) is sensitive to the mass
(charge) asymmetry of the entrance channel.

1. Introduction
It is well known to the scientific community that in heavy ion collisions, at low energies, the
complexity of processes preceding the formation of reaction products strongly influences the
properties and nature of these final products, and that due to very transient characteristics of
these processes it is impossible to observe how they occur. Moreover, in the reactions there are
products that are strongly determined by the first stage of the collision between the projectile and
the target nuclei leading to the capture of reactants and then to the evolution of the dinuclear
system (DNS) [1] up to the formation of products of the quasifission process in competition
with the ones of the complete fusion process. In this last case, the complete fusion stage can
lead to the fast fission products (for angular momentum values \( \ell > \ell_{\text{cr}} \)) and reaction products
determined by the deexcitation of the compound nucleus (CN) that leads to the fission fragments
in competition with the evaporation residue (ER) nuclei after light particle emissions surviving fission [2–6]. In this complex context, many quasifission, fast fission and fusion-fission products are overlapped, and many ER nuclei can not be detected and identified to cause of concrete limits of experimental apparatus and/or analysis of data. Therefore, in the analysis of experimental data there are unavoidable uncertainties on the identification and separation of the products that are formed in each step of the reaction process. Of course, also in calculation of the theoretical models there are serious uncertainties on the obtained results due to the assumptions made in the procedures and use of phenomenological models. In this paper, we present a detailed analysis and comparison of calculated results obtained by the study of the $^{16}\text{O}+^{204}\text{Pb}$, $^{40}\text{Ar}+^{180}\text{Hf}$, $^{82}\text{Se}+^{138}\text{Ba}$ and $^{96}\text{Zr}+^{124}\text{Sn}$ reactions leading to the same $^{220}\text{Th}$ CN. Since the products of reactions at deexcitation of CN are the evaporation residues after neutrons and charged particle emissions, and the fission fragments produced in competition with the light particle emission along the various steps of the deexcitation cascade of CN, it is possible to analyze the effects related to the various modes of deexcitation of the same formed CN with the same excitation energy $E_{\text{CN}}^*$ but characterized by a different angular momentum distribution with respect to the various mass (charge) asymmetry in the entrance channel.

2. Method

The study of heavy ion collisions near the Coulomb barrier energies is based on calculations of the incoming path of projectile nucleus and finding the capture probability, taking into account the possibility of interaction with different orientation angles of the axial symmetry axis of deformed nuclei [4]. Also, the surface vibration of the nuclei, which are spherical in the ground state and deformed shape in the first excited $2^+$ state, is taken into consideration. The final results are averaged over all orientation angles the axial symmetry axis of deformed nuclei or vibrational states of the spherical nuclei. These procedures are presented in the Appendix A and Appendix B of the paper [2].

The capture of the projectile by the target is characterized by the full momentum transfer of the relative momentum into the intrinsic degrees of freedom and shape deformation. The capture occurs if the following necessary and sufficient conditions are satisfied. The necessary condition of capture is overcoming the Coulomb barrier by projectile nucleus to be trapped in the potential well of the potential energy surface (PES). The collision dynamics is calculated by the solution of the equations of the relative distance $R$ and angular momentum $L$ [2].

The condition of sufficiency for capture is the decrease of the relative kinetic energy due to dissipation by friction forces up to values lower than the depth of the potential well [7–9]. The potential well is formed due to the competition of the short range nuclear attractive and the Coulomb and centrifugal repulsive potentials. This condition depends on the values of the beam energy and orbital angular momentum, the size of the potential well and intensity of the friction forces that cause dissipation of the kinetic energy of the relative motions to internal energy of two nuclei. So, the trapping of the collision path in the well means that the capture has occurred and the DNS is formed. The lifetime of the DNS is determined by its excitation energy $E_{\text{DNS}}^*$ and by the size of the potential well. The height of the inner barrier of the potential well is called the quasifission barrier $B_{\text{qfis}}$ in our approach. This definition is related to the quasifission process: in this case the DNS decays without reaching the equilibrated shape of a compound nucleus [8–10]. The alternative to the quasifission process in the evolution of DNS is the complete fusion of its constituent fragments. According to this scenario the partial capture cross section $\sigma_{\text{cap}}^\ell$ for a given relative energy in the center-of-mass system $E_{\text{c.m.}}$ and angular momentum value $\ell$ is the sum of the partial complete fusion $\sigma_{\text{fus}}^\ell$ and quasifission $\sigma_{\text{qfis}}^\ell$ cross sections [11];

$$
\sigma_{\text{cap}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2) = \sigma_{\text{fus}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2) + \sigma_{\text{qfis}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2).
$$

(1)

The capture cross section is determined by the number of partial waves which lead the path
of the total energy of colliding nuclei to be trapped in the well of the nucleus-nucleus potential after dissipation of a sufficient part of the initial kinetic energy. The size of the potential well decreases with increasing orbital angular momentum $\ell$. Therefore, the capture cross section is calculated by the formula

$$
\sigma_{\text{cap}}(E_{\text{c.m.}}; \alpha_1, \alpha_2) = \frac{\lambda^2}{4\pi} \sum_{\ell=0}^{\ell_d(E_{\text{c.m.}})} (2\ell + 1) \times P_{\text{cap}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2),
$$

(2)

the fusion cross section is obtained as

$$
\sigma_{\text{fus}}(E_{\text{c.m.}}; \alpha_1, \alpha_2) = \sum_{\ell=0}^{\ell_d(E_{\text{c.m.}})} \sigma_{\text{cap}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2) \times P_{\text{CN}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2),
$$

(3)

and the quasifission cross section is obtained as

$$
\sigma_{\text{qfis}}(E_{\text{c.m.}}; \alpha_1, \alpha_2) = \sum_{\ell=0}^{\ell_d(E_{\text{c.m.}})} \sigma_{\text{cap}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2) \times [1 - P_{\text{CN}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2)],
$$

(4)

for details see [3].

Here $\lambda$ is the de Broglie wavelength of the entrance channel and $P_{\text{capture}}^\ell(E_{\text{c.m.}}, \ell; \alpha_1, \alpha_2)$ is the capture probability which depends on the collision dynamics: is 1 at $\ell_{\text{min}} \leq \ell \leq \ell_d$, while is 0 if $\ell < \ell_{\text{min}}$ or $\ell > \ell_d$.

That means the possible values leading to capture can form a “window” of angular momentum values and consequently the friction coefficient is not so strong to trap the projectile in the potential well. Moreover, the maximal value of partial waves ($\ell_d$) leading to capture is calculated by the solution of the equations of the relative motion of nuclei [7,8,12], and $\ell_{\text{min}}$ is the minimal value of $\ell$ leading to capture.

3. Role of the angular momentum on the CN formation and its deexcitation

The role of the angular momentum distribution of the entrance channel on the capture and fusion cross sections and consequently on the evaporation residue products are widely discussed in our previous papers [2,3]. Here, we like to discuss about the possibilities offered by our codes [2,3] to calculate for each step of reaction the main properties of various processes. We obtain that:

(i) The competition between the quasifission and complete fusion at the deexcitation of DNS is strongly sensitive to the characteristics of reactants in the entrance channel and the orbital angular momentum distribution; the main role is played by the values of the $B_{\text{fus}}^*$ intrinsic fusion barrier and $B_{\text{qfis}}$ quasifission barrier that are both sensitive to the angular momentum $\ell$ values [13–15].

(ii) The contributions of the fast fission process and the compound nucleus formation are sensitive to the entrance channel through the angular momentum distribution characterizing the excitation functions of the related cross sections.

(iii) The contributions of products formed along the deexcitation cascade of CN through the competition between the processes: evaporation of light particles (that can lead to the formation of ER nuclei with $Z_i$ and $A_i$ values not very different from the $Z$ and $A$ numbers of CN), and fission process (that lead definitively to two nuclear fragments with $Z_i$ and $A_i$ values near $Z/2$ and $A/2$, where $Z$ and $A$ are the atomic and mass number of CN, respectively).
Therefore, starting from the CN we calculate for each intermediate excited nucleus formed along the deexcitation cascade the $\Gamma_n$, $\Gamma_p$, $\Gamma_\alpha$, and $\Gamma_{fis}$ widths that are dependent on the values of the separation energies of emitted particles and the fission barrier, respectively, as well as the level densities of the successive excited intermediate nuclei and the produced evaporation residues, or the obtained fission fragments. The shell corrections in the fission barriers and the level densities are damped with the excitation energies $E^*$ of nuclei and with the orbital angular momentum $\ell$. For details see [2,3] and references therein.

The method of our study for the deexcitation of CN does not use free parameters that can be changed for each reaction, but it is rigorously applied to all reactions and at any explored excited energy range.

4. Results on reactions leading to the $^{220}$Th CN

We study some properties of the deexcitation of the $^{220}$Th CN formed by four very different mass (charge) asymmetry and almost symmetric reactions in the entrance channel ($^{16}$O+$^{204}$Pb, $^{40}$Ar+$^{180}$Hf, $^{82}$Se+$^{138}$Ba and $^{96}$Zr+$^{124}$Sn reactions presented in panels a), b), c) and d), respectively.

![Figure 1](image-url)

**Figure 1.** The effective fission barrier $< B_{fis} >$ for the excited $^{220}$Th* CN and some of its isotopes $^{219,218,217,216}$Th* formed after the successive neutron evaporation processes by the $^{16}$O+$^{204}$Pb, $^{40}$Ar+$^{180}$Hf, $^{82}$Se+$^{138}$Ba and $^{96}$Zr+$^{124}$Sn reactions presented in panels a), b), c) and d), respectively.

In Fig. 1 panel a), we present the effective fission barrier $< B_{fis} >$ versus the excitation energy $E_{CN}$ obtained for the investigated $^{16}$O+$^{204}$Pb very asymmetric reaction at first step of the deexcitation of $^{220}$Th* (full line), at deexcitation of $^{219}$Th* (dashed line) after 1 neutron emission from the $^{220}$Th CN. Moreover, we present the excitation function of $< B_{fis} >$ for $^{218}$Th* (dotted line), $^{217}$Th* (dash-dotted line), and $^{216}$Th* (dash-double-dotted line) after one neutron emission from $^{219}$Th*, $^{218}$Th*, and $^{217}$Th* respectively.
The effective fission barrier \(< B_{\text{fis}} >\) value of an intermediate excited nucleus is obtained as the weighted average on the partial production cross section \(\sigma^\ell_{\text{fus}}\) [16] of all possible \(B_{\text{fis}}(\ell, T)\) values defined as:

\[
B_{\text{fis}}(\ell, T) = cB_{\text{fis}}^m - h(T)q(\ell)\delta W
\]

where \(c = 1\), while \(h(T)\) and \(q(\ell)\) represent the damping functions of the nuclear shell correction \(\delta W\) by the increase of the excitation energy \(E^*\) and angular momentum \(\ell\), respectively. The nuclear temperature \(T\) is defined as \(\sqrt{E^*/a}\), where \(a\) is the intrinsic level density parameter [3,17].

Analogously, we present in Fig. 1 panels b), c), and d) the excitation functions of \(< B_{\text{fis}} >\) for the \(^{40}\text{Ar}+^{180}\text{Hf}\) asymmetric reaction, \(^{82}\text{Se}+^{138}\text{Ba}\) almost symmetric reaction, and \(^{96}\text{Zr}+^{124}\text{Sn}\) symmetric reaction, respectively.

In panels a), b), c), and d) of Fig. 2 are presented the calculated results of excitation functions \(\Gamma_n/\Gamma_{\text{tot}}\) neutron emission probability from the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(216\text{Th}^*\) excited nuclei for the \(^{16}\text{O}+^{204}\text{Pb},\ 40\text{Ar}+^{180}\text{Hf},\ 82\text{Se}+^{138}\text{Ba}\) and \(^{96}\text{Zr}+^{124}\text{Sn}\) very different entrance channels, respectively.

In panels a), b), c), and d) of Fig. 3 are reported the results of \(\Gamma_{\text{fis}}/\Gamma_{\text{tot}}\) excitation functions representing the fission probability from the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(216\text{Th}^*\) excited nuclei for the above-mentioned reactions.

By observing the values and trends of the \(< B_{\text{fis}} >,\ \Gamma_n/\Gamma_{\text{tot}}\), and \(\Gamma_{\text{fis}}/\Gamma_{\text{tot}}\) excitation functions versus \(E_{\text{CN}}\) reported in Figs. 1, 2, and 3, respectively, for the four investigated reactions leading to the same \(^{220}\text{Th}^*\) CN, it is possible to ascertain the variations of single values and the complete interval of the obtained excitation function for the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(216\text{Th}^*\) excited nuclei along the five steps of the deexcitation cascade of CN. In order to have a clearer

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**Figure 2.** The excitation functions of \(\Gamma_n/\Gamma_{\text{tot}}\) at the deexcitation of the \(^{220}\text{Th}^*\) CN and the \(^{219,218,217,216}\text{Th}^*\) intermediate excited nuclei for the reactions and panels as indicated in Fig. 1.

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In panels a), b), c), and d) of Fig. 2 are presented the calculated results of excitation functions \(\Gamma_n/\Gamma_{\text{tot}}\) neutron emission probability from the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(^{216}\text{Th}^*\) excited nuclei for the \(^{16}\text{O}+^{204}\text{Pb},\ 40\text{Ar}+^{180}\text{Hf},\ 82\text{Se}+^{138}\text{Ba}\) and \(^{96}\text{Zr}+^{124}\text{Sn}\) very different entrance channels, respectively.

In panels a), b), c), and d) of Fig. 3 are reported the results of \(\Gamma_{\text{fis}}/\Gamma_{\text{tot}}\) excitation functions representing the fission probability from the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(^{216}\text{Th}^*\) excited nuclei for the above-mentioned reactions.

By observing the values and trends of the \(< B_{\text{fis}} >,\ \Gamma_n/\Gamma_{\text{tot}}\), and \(\Gamma_{\text{fis}}/\Gamma_{\text{tot}}\) excitation functions versus \(E_{\text{CN}}\) reported in Figs. 1, 2, and 3, respectively, for the four investigated reactions leading to the same \(^{220}\text{Th}^*\) CN, it is possible to ascertain the variations of single values and the complete interval of the obtained excitation function for the \(^{220}\text{Th}^*,\ 219\text{Th}^*,\ 218\text{Th}^*,\ 217\text{Th}^*,\) and \(^{216}\text{Th}^*\) excited nuclei along the five steps of the deexcitation cascade of CN. In order to have a clearer
observation and comparison of results, we choose and indicate in figures by vertical lines the values of 35, 46, and 61 MeV of excitation energy of CN and we compare the obtained values of the studied functions related to the considered excited nuclei. It is easy to see that the values found for the various excited nuclei $^{220,219,218,217,2016}\text{Th}^*$ are significantly different for the four reactions studied (and presented in panels a), b), c) and d), respectively) at 35, 46 and 61 MeV. In fact, in Fig. 1 where are reported the values of the effective fission barrier $<B_{\text{fis}}>$ vs $E_{\text{CN}}^*$, in panel a) related to $^{16}\text{O}+^{204}\text{Pb}$ reaction, at $E_{\text{CN}}^* = 35$ MeV $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ is 4.3 MeV while for the last studied step of $^{216}\text{Th}^*$ the value of $<B_{\text{fis}}>$ is 8.6 MeV, in panel b) related to the $^{40}\text{Ar}+^{180}\text{Hf}$ reaction, $<B_{\text{fis}}>$ for $^{220}\text{Th}^*$ is 5.5 MeV while for $^{216}\text{Th}^*$ is 8.8 MeV; analogously, in panel c) for the $^{82}\text{Se}+^{138}\text{Ba}$ reaction $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ CN is 4.9 MeV while for $^{216}\text{Th}^*$ is 8.73 MeV, and in panel d) for the $^{96}\text{Zr}+^{124}\text{Sn}$ reaction, $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ CN is 3.7 MeV while for $^{216}\text{Th}^*$ is 8.6 MeV. It is possible to verify that also for other intermediate excited nuclei $^{219,218,217}\text{Th}^*$ the corresponding $<B_{\text{fis}}>$ are generally different for the considered reactions at the same excitation energy $E_{\text{CN}}^*$. These results are determined by the different angular momentum distributions of the partial fusion cross section for the four different entrance channels, even when the excitation energy $E_{\text{CN}}^*$ is the same (see figure 4 at $E_{\text{CN}}^* = 35$, 46 and 61 MeV for the excitation energies of the formed CN by the four considered reactions in the entrance channel).

An analogous behavior is ascertained at $E_{\text{CN}}^* = 46$ MeV: in panel a), for the reaction induced by $^{16}\text{O}$, the $<B_{\text{fis}}>$ value for $^{220}\text{Th}^*$ is 2.35 MeV while for $^{216}\text{Th}^*$ is 7.2 MeV; in panel b), for the reaction induced by $^{40}\text{Ar}$, $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ CN is 4.1 MeV while for $^{216}\text{Th}^*$ is 6.9 MeV; in panel c), for the reaction induced by $^{82}\text{Se}$, $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ CN is 4.6 MeV while for $^{216}\text{Th}^*$ $<B_{\text{fis}}>$ is 7.3 MeV; in panel d), for the reaction induced by $^{96}\text{Zr}$, $<B_{\text{fis}}>$ for the $^{220}\text{Th}^*$ CN is 3.2 MeV while for $^{216}\text{Th}^*$ $<B_{\text{fis}}>$ is 7.3 MeV.

![Figure 3](image-url)

**Figure 3.** As Fig. 2 but for the fission probability $\Gamma_{\text{fis}}/\Gamma_{\text{tot}}$. 

Finally, at $E_{CN}^*\approx 61$ MeV we obtain: in panel a), $<B_{fis}>$ for $^{220}\text{Th}^*$ is 1.5 MeV while for $^{216}\text{Th}^* < B_{fis} >$ is 5.2 MeV; in panel b) $<B_{fis}>$ for the $^{220}\text{Th}^*$ CN is 2.25 MeV while for $^{216}\text{Th}^*$ is 5.0 MeV; in panel c), $<B_{fis}>$ for the $^{220}\text{Th}^*$ CN is 4.5 MeV while for $^{216}\text{Th}^* < B_{fis} >$ is 5.5 MeV; in panel d), $<B_{fis}>$ for the $^{220}\text{Th}^*$ CN is 2.6 MeV while for $^{216}\text{Th}^* < B_{fis} >$ is 5.3 MeV.

Similar considerations can be made by observing the values of neutron emission probabilities $\Gamma_n/\Gamma_{tot}$ reported in Fig. 2 and the values for the fission probabilities $\Gamma_{fis}/\Gamma_{tot}$ reported in Fig. 3, at any fixed excitation energy value of $E_{CN}^*$ when the $^{220}\text{Th}$ CN is formed by the four very different reaction in the entrance channel. Since the effective fission barrier $<B_{fis}>$ values are significantly different for the excited nuclei $^{220}\text{Th}^*$, $^{219}\text{Th}^*$, .... $^{216}\text{Th}^*$ along the deexcitation cascade at any fixed excitation energy value of the formed $^{220}\text{Th}$ CN, also the competition between the neutron emission probability $\Gamma_n/\Gamma_{tot}$ value and the fission probability $\Gamma_{fis}/\Gamma_{tot}$ value is different for any excited nucleus reached along the deexcitation cascade, even when the excitation energy $E_{CN}^*$ of the $^{220}\text{Th}$ CN is the same but the mass (charge) asymmetry of reaction in the entrance channel is different. For this reason, we also report in all panels a), b), c) and d) of Fig. 2 and Fig. 3, three vertical lines at 35, 46 and 61 MeV values of excitation energy of the $^{220}\text{Th}$ in order to easier observe the variations of $\Gamma_n/\Gamma_{tot}$ and $\Gamma_{fis}/\Gamma_{tot}$ values for the same reached excited nucleus $^{220}\text{Th}^*$, $^{219}\text{Th}^*$, .... $^{216}\text{Th}^*$ when any individuated excited nucleus is formed by the four above-mentioned different entrance channels.

5. Conclusion

The present study on heavy ion reactions with various mass (charge) asymmetry parameters points out the effects of the entrance channel on the CN formation and the consequent different ways of its deexcitation cascade even when the formed CN is characterized by the same $Z$
and A values and has the same excitation energy $E_{CN}^\ast$. The reason of this different way of deexcitation is due to the different orbital angular momentum distribution of reactants in the entrance channel to cause of different mass (charge) asymmetry parameter of reacting nuclei, of the specific shapes (oblate, prolate or spherical), and also of the eventual deformation parameters of these beam and target nuclei, even when the CN is formed with the same $Z, A$ and $E_{CN}^\ast$ values. Moreover, the effective fission barrier $<B_{fis}>$ of each intermediate excited nucleus reached at each step of the deexcitation cascade of the same formed CN with the same $E_{CN}^\ast$ but by various entrance channels, is affected by the various angular momentum distributions for the four considered reactions forming the $^{220}$Th CN; moreover, the damping function of the fission barrier $B_{fis}$ determines different effects on the deexcitation of CN to cause of the different range of the angular momentum $\ell$ for the considered reactions. Therefore, the competition between $\Gamma_n/\Gamma_{tot}$ and $\Gamma_{fis}/\Gamma_{tot}$ for each considered intermediate excited nucleus reached along the deexcitation cascade of CN is affected by the type of reaction in the entrance channel and the excitation energy $E_{CN}^\ast$ too. In addition, we can anticipate the information that at each $E_{CN}^\ast$ value the formation of evaporation residue nuclei ERs –formed after neutrons emission only along the deexcitation cascade of CN and the ones formed by the charged emission too– is strongly sensitive to the type of reaction in the entrance channel and to the complete reaction mechanism that is specific of each reaction also when it leads to the same CN for A, Z and $E_{CN}^\ast$ values.

Therefore, by considering also the emission of charged particles proton and $\alpha$ together with neutron emission along the deexcitation cascade of the $^{220}$Th CN the results of calculation show that the total ER evaporation residue nuclei cross sections contributed by the intermediate excited nuclei after charged particle emission too (with $Z < 90$) along the complete deexcitation cascade of CN are greater than the ER yields obtained by the excited nuclei after neutron emission only (with $Z = 90$) [2]. For example, at $E_{CN}^\ast = 46$ MeV, the ratio $\text{ER}(Z < 90)/\text{ER}(Z = 90)$ values are 8.2, 6.0, 10.1, and 8.7 for the reaction induced by the $^{16}$O, $^{40}$Ar, $^{83}$Se, and $^{96}$Zr, respectively. This additional preliminary result on the evaporation residue production furtherly confirms that the deexcitation of the same CN with the same excitation energy $E_{CN}^\ast$ formed by various reactions with different mass (charge) asymmetry parameter is strongly sensitive to the effects of the entrance channel and to the complete reaction mechanism that is specific for each reaction.

By our procedure it is also possible to determine the excitation function of the neutron emission multiplicities $\nu_{\text{pre}}$ overcoming the fission process as a function of the excitation energy $E_{CN}^\ast$, and we also observe for the $\nu_{\text{pre}}$ determination the effect of the entrance channel on the related excitation functions.

References
[1] Volkov V V et al. 1993 Phys. Lett. B 319 425, 1995 Phys. Rev. C 51 2635
[2] Kim K et al. 2015 Phys. Rev. C 91 064608
[3] Giardina G et al. 2018 Nucl. Phys. A 970 169
[4] Fazio G et al. 2008 J. Phys. Soc. Jpn. 77 124201
[5] Mandaglio G et al. 2009 Phys. At. Nucl. 72 1639
[6] Mandaglio G et al. 2012 Phys. Rev. C 86 064607
[7] Fazio G et al. 2005 Phys. Rev. C 72 064614
[8] Nasirov A K et al. 2005 Nucl. Phys. A 759 342
[9] Fazio G et al. 2005 Mod. Phys. Lett. A 20 391
[10] Back B B et al. 1985 Phys. Rev. C 32 195
[11] Nasirov A K et al. 2010 Phys. Lett. B 686 72
[12] Fazio G et al. 2003 J. Phys. Soc. Jpn. 72 2509
[13] Antonenko N V et al. 1993 Phys. Lett. B 319 425
[14] Antonenko N V et al. 1995 Phys. Rev. C 51 2635
[15] Fazio G et al. 2004 Eur. Phys. J. A 22 75
[16] Anastasi A et al. 2015 Acta Phys. Pol. B 8 583
[17] Ignatyuk A V et al. 1975 Sov. J. Nucl. Phys. 21 255