

Fission barriers of superheavy nuclei

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An analysis of the available experimental data on the fusion and fission of the nuclei of $^{286}112$, $^{292}114$, and $^{296}116$, produced in the reactions $^{48}\text{Ca} + ^{238}\text{U}$, $^{48}\text{Ca} + ^{244}\text{Pu}$, and $^{48}\text{Ca} + ^{248}\text{Cm}$, as well as experimental data on the survival probability of those nuclei in evaporation channels with three- and four-neutron emission, enables the quite reliable conclusion that the fission barriers of those nuclei are really quite high, which results in their relatively high stability. The lower limits that we obtained for the fission barrier heights of $^{283-286}112$, $^{288-292}114$, and $^{292-296}116$ nuclei are 5.5, 6.7, and 6.4 MeV, respectively.

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I. INTRODUCTION

The fission barrier is a fundamental characteristic of heavy atomic nuclei. Many heavy nuclei decay mainly by spontaneous fission, and it is the fission barriers that are responsible for the lifetimes of those nuclei. On the other hand, the probability of superheavy nucleus formation in a heavy-ion fusion reaction is also directly connected to the height of its fission barrier. The fission barrier depends on the way in which the intrinsic energy of the nucleus changes as its shape varies. The intrinsic energy of the nucleus undergoes a significant change as its spherically symmetrical configuration turns into a strongly deformed configuration of two nuclei in contact at the scission point. It can be separated into two parts: a macroscopic (collective) component, which is a measure of an averaged change in the Coulomb and nuclear energy [1–3], and a microscopic component, which is a function of a change in the shell structure of the deformed nuclear system [4,5]. The macroscopic component of the fission barrier (commonly calculated within the framework of the liquid drop model) declines rapidly with the increasing atomic number due to the Coulomb energy increasing in importance (proportional to $Z^2/A^{1/3}$) as compared to the surface energy (proportional to $A^{2/3}$). For $Z > 105$, the simple liquid drop model predicts fission barriers of less than 1 MeV, which suggests that the fission properties and existence itself of those nuclei depend mainly on shell effects (Fig. 1).

Determining the heights of fission barriers is a challenging experimental problem. Only for sufficiently long-lived isotopes, which can be used as target materials, can the fission barriers be reliably deduced from measured excitation functions of such reactions as (n, f) , (d, pf) , etc. Details and appropriate references can be found in review work [7]. For nuclei with $Z > 100$, such measurements are not possible.

Calculating the fission barrier for the atomic nucleus (mainly its microscopic component) is also a very complicated problem, involving with the necessity of solving a many-body quantum problem. The exact solution to this problem is currently unobtainable, and the accuracy of the approximations in use is rather difficult to estimate. As a result, the fission barriers for superheavy nuclei calculated within the framework of different approaches differ greatly (Fig. 2). However, in spite of the quantitative distinctions, many models predict that shell effects should grow sharply

in the region of nuclei with $Z \sim 114$ and $N \sim 184$, whose fission barriers are in fact devoid of a macroscopic component. Any experimental information about the fission properties of those nuclei seems to be highly valuable.

Note that spontaneous fission of a heavy nucleus, and its half-life, depend not only on the height of the fission barrier but also on its shape. At the same time an important property of the fission barrier is that it has a pronounced effect on the survival probability of an excited nucleus in its cooling by emitting neutrons and γ rays in competition with fission. It is this property that may be taken advantage of to make an estimate of the fission barrier of a superheavy nucleus if the fission barrier is impossible to measure directly. More sensitivity may be obtained if such a competition is tested several times during an evaporation cascade. To deduce the experimental value of the survival probability of the superheavy nucleus, it is necessary to measure the cross section of weakly excited compound nucleus production in the near-barrier fusion of heavy ions as well as the cross section for the yield of a heavy evaporation residue. It was experiments of this kind that were carried out at Flerov Laboratory of Nuclear Reactions (JINR, Dubna) recently, as part of a series

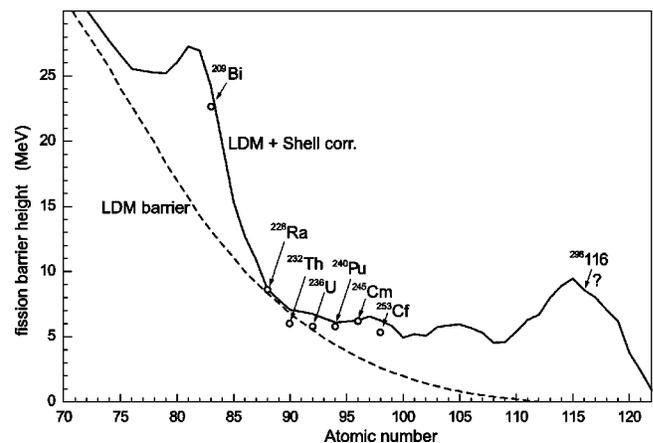


FIG. 1. Heights of the fission barriers calculated for heavy nuclei along the drip line. The dashed curve represents the macroscopic component of the fission barrier [3]; the solid curve takes account of the shell correction for the ground state of the nuclei [6]. For some nuclei, measured values of the fission barrier are presented [7].

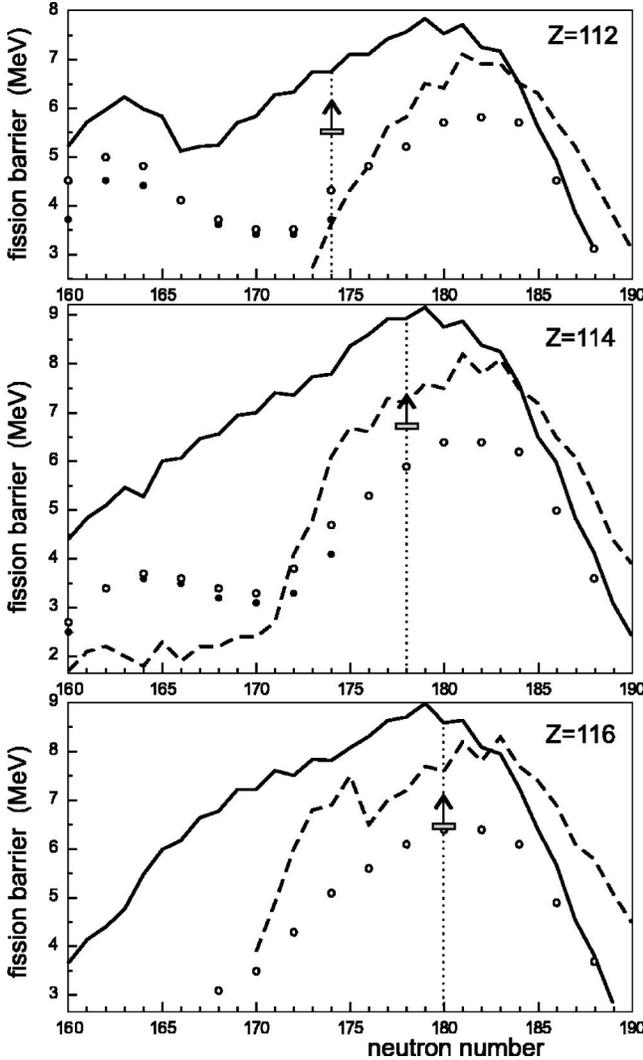


FIG. 2. Predicted heights of fission barriers for some isotopes of nuclei with $Z=112$, 114 , and 116 . The solid curves correspond to the barriers obtained by summing the liquid-drop component calculated according to Ref. [3], and the shell correction for the ground-state energy of the nucleus [6]. The dashed curves show the calculated fission barriers from Ref. [8]. The circles correspond to the calculations done in Ref. [9] (solid circles are so-called static barriers, and open circles are dynamic barriers). The rectangles with arrows show the estimates of the lower boundary of the fission barriers of nuclei of $^{286}_{112}$, $^{292}_{114}$, and $^{296}_{116}$ (see below).

of experiments on the production of nuclei with $Z=112$, 114 , and 116 [10–12]. In Ref. [13], the yield of fission fragments was measured for a number of near-barrier heavy-ion fusion reactions, including the reactions $^{48}\text{Ca}+^{238}\text{U}$, $^{48}\text{Ca}+^{244}\text{Pu}$, $^{48}\text{Ca}+^{248}\text{Cm}$, successfully employed in Refs. [10–12] to produce nuclei of $^{283}_{112}$, $^{288}_{114}$, and $^{292}_{116}$, formed in $3n$ and $4n$ evaporation channels. A careful analysis of the whole body of data obtained allows one to deduce certain information about the values of the fission barriers of the nuclei produced.

II. THEORETICAL MODEL

To analyze the available experimental data, we applied the approach formulated in Refs. [14,15]. Here we just outline

this approach. The production cross section of a heavy residue nucleus B , produced as a result of neutron evaporation and γ emission from the excited compound nucleus C formed in a fusion reaction of two heavy nuclei $A_1+A_2 \rightarrow C \rightarrow B+n, p, \alpha, \gamma$ at the energy close to the Coulomb barrier in the entrance channel, can be decomposed over partial waves and represented as

$$\sigma_{ER}^{A_1+A_2 \rightarrow B}(E) \approx \frac{\pi \hbar^2}{2\mu E} \sum_{l=0}^{\infty} (2l+1) T(E, l) P_{CN}(A_1+A_2 \rightarrow C; E, l) P_{ER}(C \rightarrow B; E^*, l). \quad (1)$$

Here $T(E, l)$ is the probability that the colliding nuclei will penetrate the entrance channel potential barrier and reach the contact point $R_{cont}=R_1+R_2$ (R_1, R_2 are the radii of the nuclei), which is normally 2–3 fm less than the radius of the Coulomb barrier R_C^B . P_{CN} defines the probability that the system will go from the configuration of two nuclei in contact into the configuration of a spherical (or near-spherical) compound mononucleus. When thus evolving, a heavy system is in principle likely to reparate into two fragments without producing a compound nucleus (quasifission), so $P_{CN} \leq 1$. Finally, $P_{ER}(C \rightarrow B)$ defines the probability that the cold residue B will be produced in the decay of the compound nucleus C with the excitation energy $E^*=E-Q_{gg}^{fus}$, where E is the center-of-mass energy of the colliding nuclei; $Q_{gg}^{fus}=M(C)c^2-M(A_1)c^2-M(A_2)c^2$, and $M(C)$, $M(A_1)$, and $M(A_2)$ are the ground state nuclear masses. That Eq. (1) is not an exact equation accounts for the fact that here the single process of the production of the final nucleus B is in fact divided into three separate steps; though interconnected, these are considered and calculated separately.

It should be noted that in the case of the production of superheavy nuclei, describing all the three steps of the reaction [i.e., calculating the values $T(E, l)$, P_{CN} and P_{ER}], presents certain difficulties. Things get much better if there are independent experimental data on the so-called capture cross section defined as $\sigma_{capt}(E)=(\pi \hbar^2/2\mu E) \sum_{l=0}^{\infty} (2l+1) T(E, l)$ and the fusion cross section $\sigma_{fus}(E)=(\pi \hbar^2/2\mu E) \sum_{l=0}^{\infty} (2l+1) T(E, l) P_{CN}(E, l)$. In this situation, the quantities $T(E, l)$ and P_{CN} can be calculated (or parametrized) in such a way as for the energy dependence of the corresponding reaction cross sections to be described adequately.

$T(E, l)$ was calculated considering the coupling between the relative motion of the nuclei, their surface oscillations (dynamic deformations), and rotation (for nonzero static deformation). Use was made of the semiphenomenological barrier distribution function method. This allowed the capture cross section to be quite adequately described in the entire near-barrier energy region. To describe the interaction of two deformed nuclei, the proximity potential, which has no additional fitting parameters other than nuclear radii, was chosen. This approach was successfully applied to describe the capture cross sections of a number of mass asymmetric nuclear reactions [14,15].

The production of a compound nucleus, which occurs in fierce competition with quasifission, is the least understood

reaction stage. To describe this process and to calculate the value of P_{CN} , a few theoretical approaches, some of which are contradictory to each other, were proposed [14,16,17]. Here a simple parametrization of the probability of compound nucleus production is used:

$$P_{CN}(E^*) = P_0 \left/ \left[1 + \exp\left(\frac{E^* - E_0}{\Delta E}\right) \right] \right.$$

The parameters P_0 , E_0 , and ΔE were chosen in such a way as for the corresponding fusion cross section to be reproduced (see below).

The survival probability of a cooling excited compound nucleus is calculated following a statistical model [18]. It can be expressed as [15]

$$\begin{aligned} P_{ER}(C \rightarrow B + xn) &= \int_0^{E_0^* - E_n^{sep(1)}} \frac{\Gamma_n}{\Gamma_{tot}}(E_0^*, J_0) P_n(E_0^*, e_1) de_1 \\ &\times \int_0^{E_1^* - E_n^{sep(2)}} \frac{\Gamma_n}{\Gamma_{tot}}(E_1^*, J_1) P_n(E_1^*, e_2) de_2 \dots \\ &\times \int_0^{E_{x-1}^* - E_n^{sep(x)}} \frac{\Gamma_n}{\Gamma_{tot}}(E_{x-1}^*, J_{x-1}) P_n(E_{x-1}^*, e_x) \\ &\times G_{N\gamma}(E_x^*, J_x \rightarrow g.s.) de_x. \end{aligned} \quad (2)$$

Here Γ_n is the partial decay width for neutron evaporation, and Γ_{tot} is the sum of all the partial decay widths. $E_n^{sep}(k)$ and e_k are the binding and kinetic energies of the k th evaporated neutron, $E_k^* = E_0^* - \sum_{i=1}^k [E_n^{sep}(i) + e_i]$ is the excitation energy of the residual nucleus after the emission of k neutrons, $P_n(E^*, e) = C \sqrt{e} \exp(-e/T(E^*))$ is the probability for the evaporated neutron to have an energy e , and the normalization coefficient C is determined from the condition $\int_0^{E^* - E_n^{sep}} P_n(E^*, e) de = 1$. The quantity $G_{N\gamma}$ defines the probability that the remaining excitation energy and angular momentum will be taken away by γ emission after the evaporation of x neutrons [15].

For heavy nuclei $\Gamma_n/\Gamma_{tot} \approx \Gamma_n/\Gamma_f$, and this relationship depends strongly on the fission barrier height, or more exactly, on the ratio between neutron separation energy and the barrier height. The calculated neutron separation energies for superheavy nuclei also have a certain error; however, its value is no more than 0.4 MeV. For nuclei close to the beta stability line, this error is still less [6]. Thus, having experimental data on the capture cross section $\sigma_{capt}(E)$ and the compound nucleus production cross section $\sigma_{fus}(E)$, the value of the fission barrier for this nucleus can be assessed by comparing the measured values of the cross section for the yield of a heavy evaporation residue with those calculated in Eqs. (1) and (2). Unfortunately, decay widths also depend on a number of other factors (such as the level density parameter, the shell correction damping parameter, the collective enhancement factor, etc), whose exact values are currently unknown [15]. Nevertheless, a careful analysis of a great number of reactions associated with the production of

heavy and superheavy nuclei, whose fission barriers are either known or have very close predicted values in different models, allows a sufficiently narrow range for values of those factors to be reliably found by examining experimental data of interest.

It should be noted that the proposed procedure for determining the fission barrier is to be the most efficient in analyzing so-called hot fusion reactions, in which the final nucleus is produced by evaporating several neutrons. In this case, the cross section $\sigma_{ER}^{xn}(E)$, which is proportional roughly to $(\Gamma_n/\Gamma_f)^x$, happens to be more sensitive to the value of the fission barrier since it increases in importance by a factor of x .

III. ANALYSIS OF EXPERIMENTAL DATA

The decay properties of the nobelium isotopes ($Z=102$) produced in $^{48}\text{Ca} + ^{204-208}\text{Pb}$ reactions are very close to those of superheavy nuclei. Here the macroscopic component (1.2 MeV) is only small part of the whole fission barrier, which is predominantly determined by the shell correction. Thus in this case the role of shell effects and the way they fall off with increasing excitation energy can be well established by considering a vast body of available information on the yields of heavy evaporation residues in different channels of the reaction. It should be noted that here the excitation function should be described in several xn channels simultaneously for several reactions, i.e., the decay widths of many nobelium isotopes $^{250-256}\text{No}$ involved in evaporation cascades are calculated and used simultaneously in describing several reactions. This to a great extent abridges freedom in changing the parameters used.

Figure 3 presents the capture cross sections for the reaction $^{48}\text{Ca} + ^{208}\text{Pb}$, measured from the total yield of fission fragments [19], in comparison with the calculated results obtained according to the approach proposed in Ref. [14]. For this reaction, the quasifission probability is not high, $P_{CN} \sim 1$, and the fusion cross section is practically the same as the capture cross section. Using the same interaction parameters and changing only the radii of the nuclei, we calculated the capture cross sections in the fusion reactions $^{48}\text{Ca} + ^{204,206,207,208}\text{Pb}$, as well as the yield of evaporation residues for all the reactions in the $2n$ channel, which was measured in Ref. [20] (Fig. 3). Figure 4 presents a comparison of the calculated and measured cross sections of the yields of heavy evaporation residues in the $1n-4n$ channels in the reaction $^{48}\text{Ca} + ^{206}\text{Pb}$.

The survival probabilities for all the reactions were calculated with experimental values of separation energies for light particles (n, p, α) [21], and the fission barriers calculated according to the formula $B_f(J=0) = B_{LD} - \delta W e^{-\gamma_D E^*}$, where B_{LD} is the liquid drop fission barrier (≈ 1.2 MeV for the nuclei under consideration) [3]; δW is the shell correction for the ground-state energy [6]; γ_D is the damping parameter, which accounts for the fact that shell effects fall off as the excitation energy of the compound nucleus increases. The value of this parameter is especially important in the case of superheavy nuclei, whose fission barriers are mainly determined just by the shell corrections

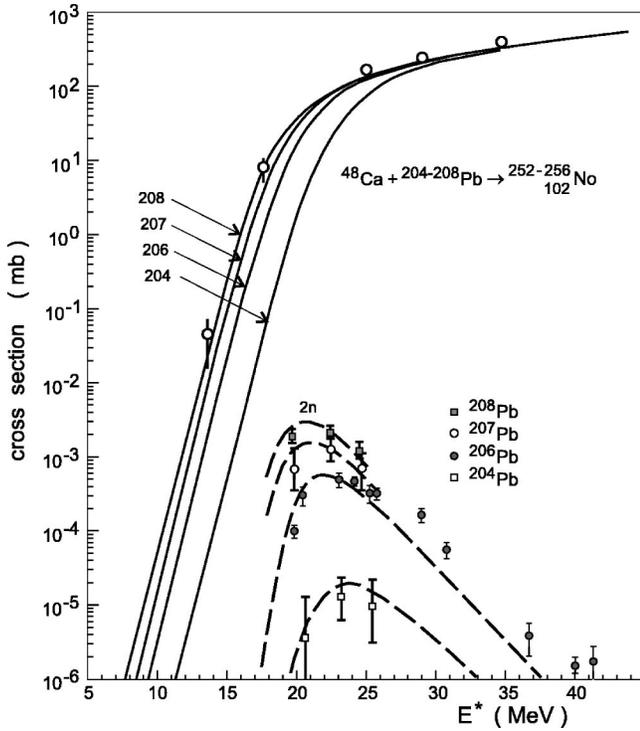


FIG. 3. Capture cross sections and cross sections of the evaporation residue (ER) production in the $2n$ channel in the $^{48}\text{Ca} + ^{204-208}\text{Pb}$ fusion reactions. The experimental data for the capture cross sections in the $^{48}\text{Ca} + ^{208}\text{Pb}$ fusion reaction are from Ref. [19]. The experimental data for the $2n$ ER channels are from Ref. [20].

for their ground states. In the literature one can find close but slightly different values for the damping parameter, and we paid special attention to the sensitivity of the calculated cross sections to this parameter. Figure 4 shows how sensitive the cross section for the $4n$ channel is to a change in the damping parameter. A simultaneous analysis of a great number of hot fusion reactions used for producing heavy elements allows the conclusion that the value of this parameter lies in the range $\gamma_D^{-1} = 14\text{--}18$ MeV. The values of the other parameters required for calculating the survival probability, including the collective enhancement factor, which plays an important role in the decay of heavy spherical nuclei, can be found in Ref. [15].

As already mentioned, in fusion reactions of superheavy nuclei, having overcome the Coulomb barrier, a nuclear system evolves with high probability into quasifission channels, i.e., $P_{CN} < 1$ and $\sigma_{fus} < \sigma_{capt}$. In quasifission at low energies, the role played by the energy gain (Q value) is great, which results in a sharply asymmetric fragment mass distribution concentrated in the region of $A \sim 208$ and the complementary fragment [13]. A distribution of this type allows one to separate quasifission products from deep inelastic scattering products (which are concentrated in the region of the projectile and target masses) and from regular fission products, which are more or less symmetric in mass. Thus in the case of a mass-asymmetric reaction, the capture cross section $\sigma_{capt}(E)$ can be found by measuring the total yield of all the fission fragments of the nuclear system, which are different from deep inelastic scattering products. The fusion cross sec-

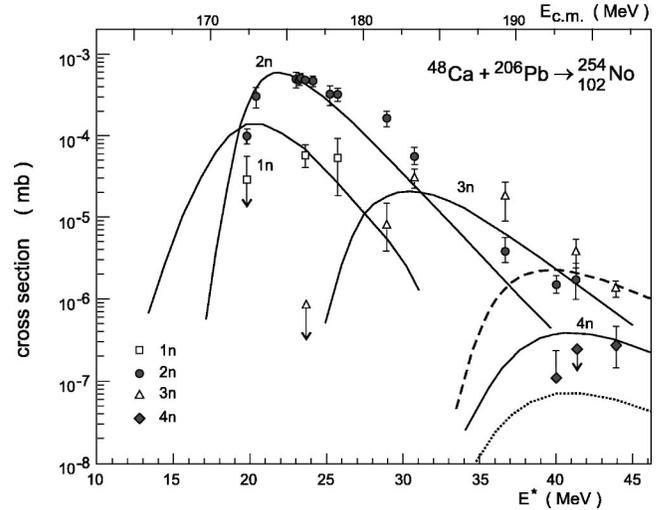


FIG. 4. Cross sections of the ER production for different xn -channels in the $^{48}\text{Ca} + ^{206}\text{Pb}$ fusion reaction. The experimental data are from Ref. [20]. The solid lines correspond to the calculations with the damping factor $\gamma_D = 0.06$ MeV $^{-1}$, whereas the dashed and dotted curves for the $4n$ -channel are calculated with $\gamma_D = 0.05$ and 0.08 MeV $^{-1}$, respectively.

tion can be found by measuring the yield of near-symmetric mass fragments in the region $A \sim A_{CN}/2 \pm 20$, i.e., by measuring the yield of fragments that show all the properties of regular fission fragments.

Measurements of this kind were carried out in Refs. [13,19] for a great number of fusion reactions. Three of those reactions are considered in this work: $^{48}\text{Ca} + ^{238}\text{U}$, $^{48}\text{Ca} + ^{244}\text{Pu}$, and $^{48}\text{Ca} + ^{248}\text{Cm}$. An experimental two-dimensional total kinetic energy (TKE) mass plot for the $^{48}\text{Ca} + ^{248}\text{Cm}$ fusion-fission reaction is shown in Fig. 5 along with the corresponding potential energy surface [14] determining evolution of the nuclear system. After the nuclei have come into contact, the nuclear system typically evolves in the asymmetric quasifission channels: path number 1 in Fig. 5(a), which populates the area of fragment masses near $A = 208$ in Fig. 5(b). The asymmetric quasifission channels are closer to the initial state in the configuration space of collective degrees of freedom as compared with the configurations through which the system has to pass on the way to the compound nucleus configuration, and the fusion cross section turns out to be far less than the capture cross section. The distinction between $\sigma_{fus}(E)$ and $\sigma_{capt}(E)$ becomes still more evident at low excitation energies.

Approximating the mass distribution of the quasifission fragments [area 1 in Fig. 5(b)] by a Gaussian shape, we may easily single out the events in the symmetric region of fission fragments [$(A_{CN}/2) \pm 20$, area of dashed quadrangle in Fig. 5(b)] which correspond to a regular fission. For the $^{48}\text{Ca} + ^{248}\text{Cm}$ fusion-fission reaction, the tail of Gaussian gives no more than 20% of all the events in this region (see the details in Ref. [13]). A mass distribution corresponding to the symmetric region of fission fragments [$(A_{CN}/2) \pm 20$; area of dashed quadrangle in Fig. 5(b)] is shown in Fig. 5(c), com-

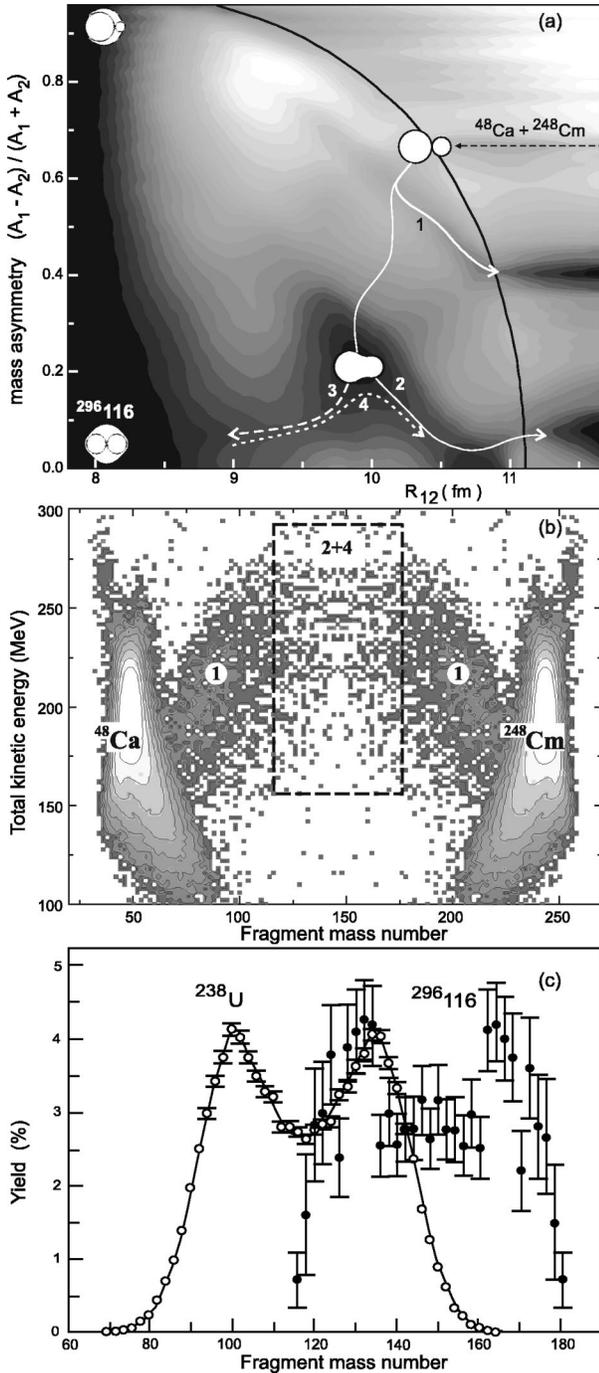


FIG. 5. (a) Driving potential as a function of mass asymmetry and distance between centers of two nuclei with zero deformations [14]. The black solid curve corresponds to the contact configurations. Paths 1 and 2 lead the system to the asymmetric and near-symmetric quasifission channels, whereas paths 3 and 4 correspond to the compound nucleus formation and its regular fission, respectively. (b) Two-dimensional TKE mass plot. Different regions are numerated in accordance with the most probable trajectories (shown on upper panel) contributed to these regions. (c) Mass distribution of near-symmetric fission fragments [dashed quadrangle in panel (b)] detected in the $^{48}\text{Ca} + ^{248}\text{Cm}$ reaction at an excitation energy of $E^* = 33$ MeV, compared with the fission of ^{238}U measured at approximately the same excitation energy [22].

pared with the typical mass yield of ^{238}U fission fragments [22]. As can be seen, both distributions are quite similar. In the case of ^{238}U a two-humped fission mass distribution is regulated mainly by a doubly magic heavier fragment ^{132}Sn , which plays the role of a lighter fragment in the case of fission of a $^{296}116$ nucleus at low excitation energies. This means, that symmetric region of fission fragment masses $[(A_{CN}/2) \pm 20]$ seems to originate mainly from the regular fusion-fission process in the reaction $^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow ^{296}116$.

However, as shown in Ref. [14], evolving from the initial configuration of two nuclei in contact into the state of spherical or near-spherical compound nucleus [path number 3 in Fig. 5(a)], the system goes through the same configurations through which a compound nucleus goes in regular fission [path number 4 in Fig. 5(a)], i.e., configurations close to the saddle point. When in such a configuration and in a state of complete thermodynamic equilibrium, the nuclear system is much likely to go into the fission channel [path number 2 in Fig. 5(a)], without overcoming the saddle point, and producing a spherically symmetric compound nucleus. A process of this kind results in fragments that are practically not different from regular fission fragments, since in both cases the system follows the same path from the saddle point to the scission point. This means that among all the events resulting in the system going in regular near-symmetric fission channels, there are such events in which the system does not produce a true spherically symmetric compound nucleus, whose survival probability $P_{ER}(C \rightarrow B + xn + N\gamma; E^*, l)$ is calculated within the framework of a standard statistical model. To put this another way, if a compound system is assigned all the configurations from which it goes into an ordinary fission channel, then the survival probability of this nucleus should be greatly decreased. If an ordinary statistical model is used for calculating $P_{ER}(C \rightarrow B + xn + N\gamma; E^*, l)$, then the compound nucleus configuration space should be considerably narrowed down and its production probability should be taken to be less than $\sigma_{fus}^{expt} / \sigma_{capt}^{expt}$, where σ_{fus}^{expt} is the fusion cross section deduced from the total yield of near-symmetric fission fragments.

Another peculiarity of the reactions under discussion is that the target nuclei possess a rather great static deformation. Coulomb barrier, which colliding nuclei are to penetrate, depends strongly on the orientation of a deformed nucleus. The barrier heights of the nose-to-nose (B_1) and side-by-side (B_2) ultimate configurations differ from each other by 14–16 MeV. On the one hand, this results in the capture cross section being diffused as compared with the fusion of spherical nuclei (compare Figs. 3 and 6). On the other hand, it should be expected that after the nuclear surfaces are in contact in the nose-to-nose configuration (low barrier and correspondingly low excitation energies), the system is more likely to go in a quasifission channel than when in the side-by-side configuration. This must cause the probability of compound nucleus production to decrease further at low excitation energies, which in its turn causes the production cross section for evaporation residues for the $1n$ and $2n$ channels to decrease, and makes an analysis of those channels still difficult.

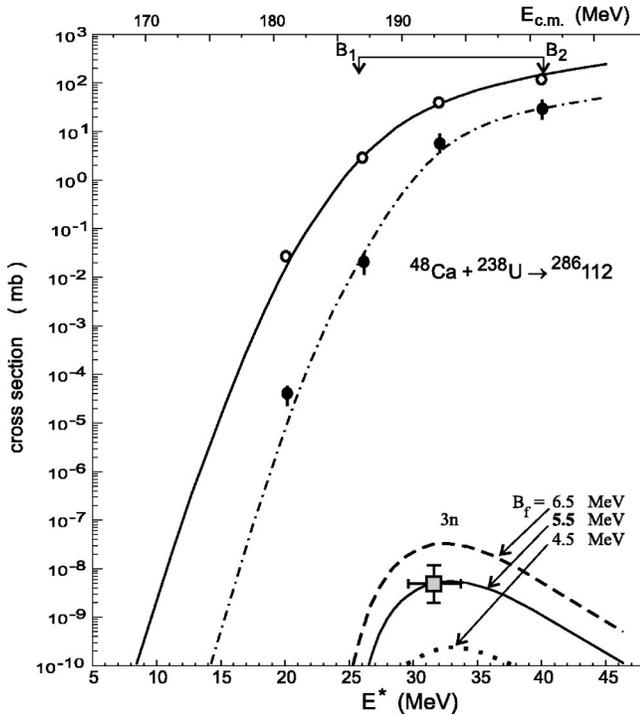


FIG. 6. The capture cross section (all fission fragments, open circles), the total yield of near-symmetric fission fragments with $A = A_{CN}/2 \pm 20$ (solid circles), and the ER production cross section in the $3n$ channel of the $^{48}\text{Ca} + ^{238}\text{U} \rightarrow ^{286}_{112}$ reaction. The arrows show the Coulomb barriers for two ultimate orientations of the deformed target nucleus: nose-to-nose (B_1) and side-by-side (B_2) configurations. The cross section of evaporation residue formation was calculated with fission barrier of 4.5 MeV (dotted curve), 5.5 MeV (solid curve), and 6.5 MeV (dashed curve).

After calculating the value of $T(E, l)$ in such a way that the measured capture cross section is reproduced, and parametrizing the compound nucleus production probability P_{CN} in such a way that σ_{fus}^{expt} is reproduced, fission barriers for the nuclei of the evaporation cascade were chosen in such a way that the corresponding measured cross section of the yield of a heavy evaporation residue nucleus was reproduced with the help of Eq. (1). The calculated results are shown in Fig. 6 for

TABLE I. The lower limits of the heights of fission barriers.

Nucleus	E^* (MeV)	σ_{capt}	σ_{fus}, \leq	σ_{ER} (pb)	$\langle B_f \rangle, \geq$
$^{286}_{112}$	31.5	40 mb	5 mb	$5.0 (3n)_{-3.2}^{+6.3}$	5.5 MeV
$^{292}_{114}$	36.5	30 mb	4 mb	$0.5 (4n)_{-0.3}^{+0.8}$	6.7 MeV
$^{296}_{116}$	34.8	30 mb	2 mb	$0.5 (4n)_{-0.3}^{+0.8}$	6.4 MeV

the case of the $^{48}\text{Ca} + ^{238}\text{U} \rightarrow ^{286}_{112}$ fusion reaction. Taking account of the fact that fission barriers vary little from nucleus to nucleus in an evaporation cascade (see Fig. 2), as well as making the procedure for assessing them simpler, the same value B_f was used for these nuclei. The typical sensitivity of the calculated production cross section for the evaporation residue to a change in the value of the fission barrier is shown in Fig. 6. It is the fact that this sensitivity is high which allows one to expect the value of the fission barrier to be deduced to an accuracy of the order of ± 0.5 MeV, with allowance made for the experimental error in measuring this cross section and the uncertainty of some parameters used in the calculations [15]. Since, as established above, the production probability for a true compound nucleus may really be less than the value of $\sigma_{fus}^{expt}/\sigma_{capt}^{expt}$, then comparing the measured and calculated cross sections for the evaporation residues allows one to deduce the lower limits of the fission barriers of the corresponding nuclei. The final results are presented in Table I.

The analysis of the available experimental data on the fusion and fission of nuclei of $^{286}_{112}$, $^{292}_{114}$, and $^{296}_{116}$, produced in the reactions $^{48}\text{Ca} + ^{238}\text{U}$, $^{48}\text{Ca} + ^{244}\text{Pu}$, and $^{48}\text{Ca} + ^{248}\text{Cm}$ [13], as well as experimental data on the survival probability of those nuclei in evaporation channels of three- and four-neutron emission [10–12], enables us to reach the quite reliable conclusion that the fission barriers of those nuclei are really quite high, which results in their relatively high stability. The lower limits that we obtained for the fission barriers of nuclei of $^{283-286}_{112}$, $^{288-292}_{114}$, and $^{292-296}_{116}$ are 5.5, 6.7, and 6.4 MeV, respectively.

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