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Importance of the inner potential barrier in nuclear spontaneous cold fission processes

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The relevance of the inner part of the potential barrier in an effective model to describe the pre-scission phase in nuclear disintegration processes is discussed under the assumption of spherical fragments. Although for alpha decay process the inner part of the potential barrier can be neglected, this is not the case for heavier cluster radioactivity and spontaneous cold fission processes. For the latter one, we remark that the dinuclear phase may contribute with the major part to Gamow's penetrability factor in cold fission yield calculations.

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Alpha decay, cluster radioactivity, and cold fission processes have been extensively investigated in the last decade, both from the theoretical and experimental point of views [1–19]. In order to unify these processes many attempts have been carried out by using models which projects the multiparametric fragmentation path into the one-dimensional motion to allow calculation of Gamow's penetrability factor.

Recently, cold fission processes have called attention to researchers, since these processes can provide new insight about the nuclear structure (energy levels density, deformation, etc.), giving information about the fission path from the saddle point to the scission point [6–12]. Since the spontaneous cold fission of ^{248}Cm isotope was observed [4], other new cases of cold fission events for the fissioning systems ^{230}Th [5], ^{233}U [5], ^{234}U [3], ^{240}Pu [5], ^{242}Pu [19], and ^{252}Cf [2,18] have been detected.

The models available in the literature consider the separating dinuclear system as two (spherical or deformed) fragments, and Gamow's penetrability factor used to calculate the yield (or the half-life) has been obtained by regarding the one-dimensional motion of the dinuclear system. There are different procedures of calculating the nuclear fission barrier, but in all cases this barrier can be separated into an internal part (when separation between the nascent fragments is smaller than the external touching distance), and an external one (for fragment separation greater than the touching distance), where in this latter case only the Coulomb interaction has influence on kinetic energy of the fragments. For the external part of the potential, the inertia coefficient of the two product nuclei is clearly given by the reduced mass of the two-body system, $\mu = (m_1 \times m_2)/(m_1 + m_2)$. However, for the internal part of the potential, the inertia coefficient should be obtained in terms of the geometrical configuration of the system. Werner-Wheeler's coefficient has been already employed in [16, 20, 21] by regarding a cylindrical parameterization for the dynamics of the nuclear flow. On the other hand, we have shown that an effective inertia coefficient can be obtained when the multidimensional problem is reduced to the one-dimensional one. We deduced the expression for the inertia coefficient by imposing appropriate constraint relations for the parameters which describe the evolution of the nuclear shape [13].

The aim of this brief report is to discuss the relevance of the inner potential barrier in calculating the penetrability factor for spontaneous cold fission processes. In some models it has been assumed that the inner part of the potential barrier can be neglected in yield calculations of cluster radioactivity and cold fission processes [7, 12]. The present calculation shows that the extent of the inner part of the potential barrier increases with the mass of the emitted cluster, being the most significant contribution to the penetrability factor when one deals with cold fission processes. In order to stress the importance of the inner part of the potential barrier in Gamow's penetrability factor,

$$\mathcal{P} = exp\left\{-\frac{2}{\hbar}\int_{r_1}^{r_2}\sqrt{2\mu[V(r)-Q]}\mathrm{d}r\right\},$$

we present in Fig. 1 (shaded area) the inner part of the barrier for alpha decay (Fig. 1-a), the exotic ^{28}Mg decay (Fig. 1-b), and a cold fission event from ^{234}U parent nucleus (Fig. 1-c). In the shaded region, a configuration-dependent inertia coefficient, μ, should be used, and the inner and outer turning points are obtained from the Q-value of the process $[V(r_1) = V(r_2) = Q]$. Here, the total potential includes the Coulomb and surface potentials, as was done in our previous works [13, 14]. As shown in Fig. 1-a, in the case of alpha decay the contribution from the dinuclear phase is small when compared with the whole extension of the barrier. In the case of the heavy cluster emission mode $^{234}\mathrm{U}\rightarrow^{28}\mathrm{Mg} + ^{206}\mathrm{Hg}$ (Fig. 1-b) the contribution from the inner the part of the potential barrier becomes significant. Particularly, in the case of the cold fission process shown in Fig. 1-c the inner potential barrier is even larger, representing almost 85% of the total extension of the potential barrier.

In Fig. 2 we present the inner part of the potential barrier in the calculation of Gamow's penetrability factor for the most recent detected cold fission events. The fission products were taken from references [6–8]. It is clearly seen in Fig. 2 that the contribution from the inner potential cannot be neglected for the cold fission processes mentioned. Such a procedure can be considered as a reasonable approximation only in cases for light cluster emission (helium and carbon radioactivity), which leads to satisfactory results for the corresponding observed half-lives [22]. We call attention to the fact that the inner part of the potential barrier is essential when trying to describe light, intermediate, and heavier nuclear cluster emission modes by a unified model, as has been shown in our previous works [13, 14]. The relevance of the inner potential barrier should be manifested also in the case where the nascent fragments are to be considered as deformed ones.

Finally, we wish to point out that the configuration-dependent inertia coefficient used to treat cold fission processes may change Gamow's penetrability factor. Thus, during the evolution of the nuclear system from the saddle to scission point, the inertia coefficient should be taken into account properly. The study of the influence of different configuration-dependent inertia coefficients to the decay yield in spontaneous cold fission processes is in progress.

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Figure Captions

FIG. 1 – Potential barrier for three decay modes of ^{234}U. a) shows the internal part of the potential (shaded area) for the alpha decay process; the same is shown for ^{28}Mg cluster emission (b), and the cold fission mode $^{234}\mathrm{U} \rightarrow {}^{100}\mathrm{Zr} + {}^{134}\mathrm{Te}$ (c). The horizontal dashed line represents the Q-value in each case.

FIG. 2 – The same as in Fig. 1 for cold fission of ^{242}Pu (a), ^{248}Cm (b), and ^{252}Cf (c) fissioning systems.

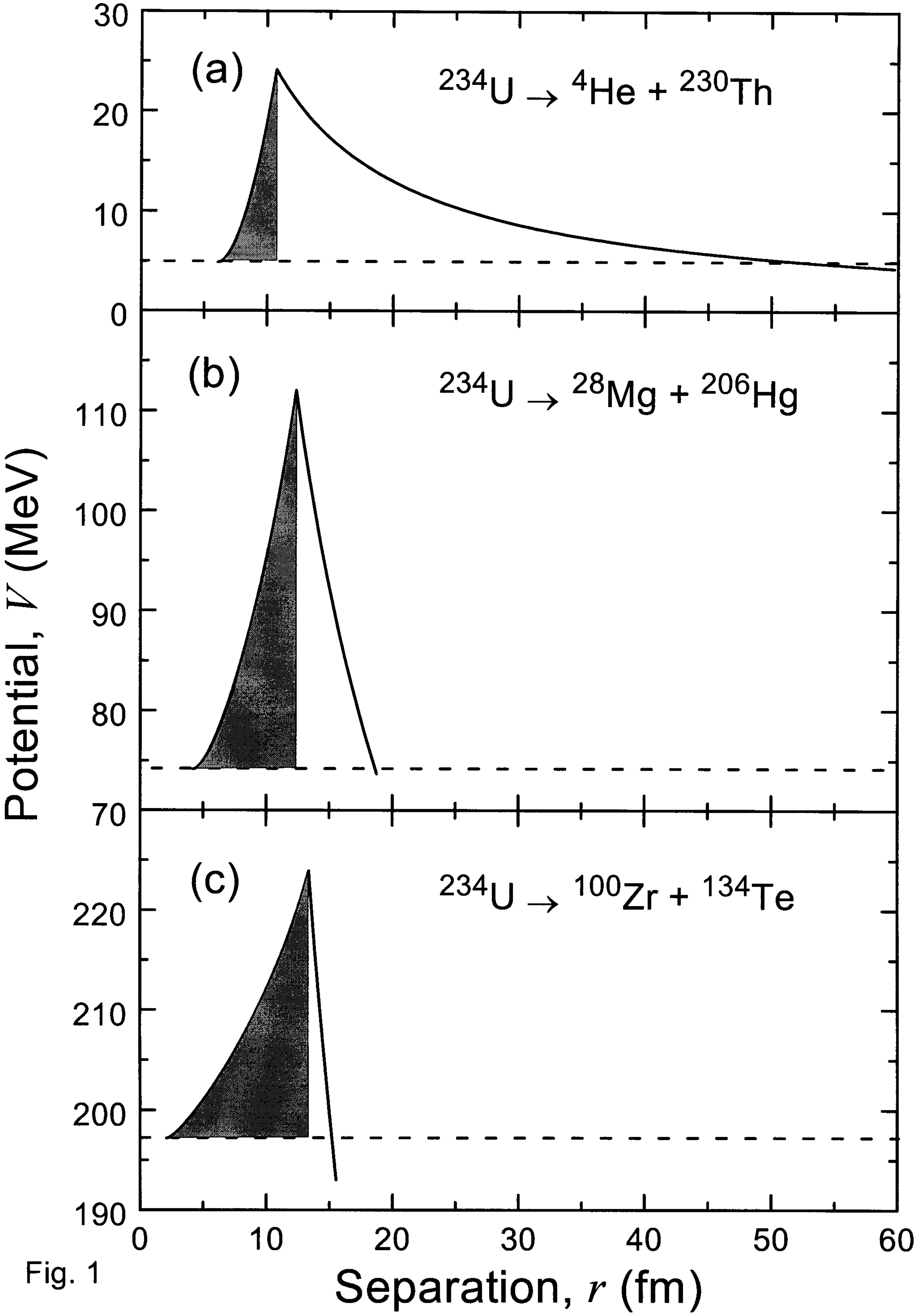
(a)
$^{234}U \rightarrow {}^{4}He + {}^{230}Th$
(b)
$^{234}U \rightarrow {}^{28}Mg + {}^{206}Hg$
(c)
$^{234}U \rightarrow {}^{100}Zr + {}^{134}Te$
Potential, V (MeV)
Separation, r (fm)
0
10
20
30
70
80
90
100
110
190
200
210
220
0
10
20
30
40
50
60

Fig. 1

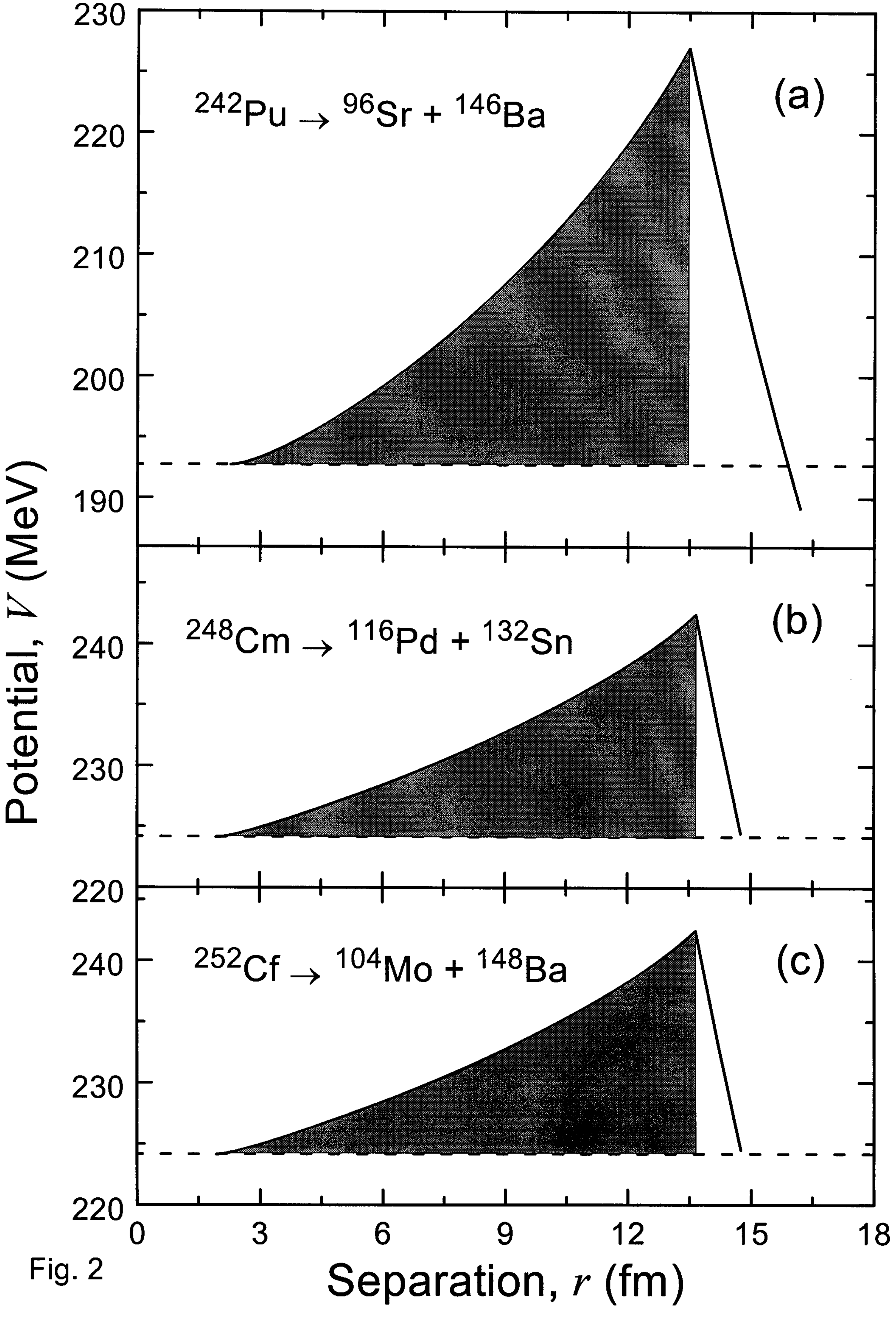
^{242}Pu → ^{96}Sr + ^{146}Ba
(a)
^{248}Cm → ^{116}Pd + ^{132}Sn
(b)
^{252}Cf → ^{104}Mo + ^{148}Ba
(c)
Potential, V (MeV)
Separation, r (fm)
230
220
210
200
190
240
230
220
240
230
220
0
3
6
9
12
15
18

Fig. 2

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