

ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

BB

CERN LIBRARIES, GENEVA



SCAN-9704106

E7-96-414

Sw 9716

NATURE AND PROPERTIES OF THE FISSION
MODES OF THE NEUTRON DEFICIENT
 $^{220,224,226}\text{Th}$ NUCLIDES

Submitted to the International Symposium «Large-Scale Collective
Motions of Atomic Nuclei», October 15-19, 1996, Brolo (Messina), Italy

1996

M.G.Itkis, N.A.Kondratiev, E.M.Kozulin, Yu.Ts.Oganessian, V.V.Pashkevich,
I.V.Pokrovsky, A.Ya.Rusanov, V.S.Salamatin

JINR, Dubna

L.Calabretta, C.Maiolino, K.Lukashi, C.Agodi, G.Bellia

LNS-INFN, Catania, Italy

G.G.Chubarian, B.Hurst, D.O'Kelly, R.Schmitt

Texas A&M University, USA

F.Hanappe

ULB, Brussels, Belgium

E.Liatard

INS, Grenoble, France

L.Stuttge

CRN, Strasbourg, France

Introduction

During the past 10 years, investigations of the mass and the energy distributions in the vicinity of ^{208}Pb using relatively light projectiles have yielded two important conclusions ¹. First of all, it is possible to circumvent the natural obstacle associated with the lack of stable *Po-Fr* target nuclei. Second, overcoming this hurdle makes it possible to study the evolution of the mass asymmetry mode in the fission of lighter nuclei so that one can delineate the physical boundary associated with multimodal fission phenomena.

The parameters of the measured mass-energy distributions of the fragments appear to be in good agreement with the theoretical calculations of V.V.Pashkevich ². This suggests that one can probe a new property in fission physics - the valley structure of the barrier. Experimental studies of this property will make it possible to trace out the evolution of the fissioning nucleus between its two critical shapes - the transition state (saddle point) and the scission point. Following this evolution from beginning to end will provide new insights into the mechanism by which the mass and energy distributions are formed. However, this time it is being applied to a significantly expanded region of nuclei. Work by Hulet *et al.* ³ in the $Z=100$ region has revealed peculiarities in the fission mass and energy spectra which are also suggestive of bimodal structure. These observations can be interpreted as being due to the influence of the valley structure (produced by shell effects) during the descent from saddle to scission.

An obvious question arises in connection with the above results. Is the phenomenon of multimodal fission associated with special circumstances characteristic of the regions around *Pb* and *Fm*, or is it a universal property of fission?

The region of transitional nuclei from *At* to *Th* offers virgin territory for further explorations of multimodal fission phenomena. In this range of nuclei, one can expect dramatic changes in the fission properties as the nucleonic composition and the excitation energy are varied. The transition from mass-symmetric to mass-asymmetric fission and the accompanying changes in the barrier heights and the transition times from saddle to scission for the different fission modes will strongly influence observables such as the fission mass, energy and charge distributions, the fission cross sections, the angular distributions, the pre- and post-fission neutron multiplicities, and the γ -multiplicities. Experimental data on these properties will provide critical testing grounds for theories of both the static and dynamical aspects of the fusion-fission process.

The first experiments on studying the low-energy fission of transition nuclei were started 3 years ago at the FLNR of JINR ⁴ and then continued in Catania by

employing sub-barrier fusion-fission reactions and at GSI by employing fission reactions on secondary beams of radioactive nuclei ⁵.

The paper presents the results of studying the modal structure of mass and energy distributions of the fission fragments of neutron deficient nuclides ²²⁰Th, ²²⁴Th and ²²⁶Th produced in reactions with ¹⁶O and ¹⁸O ions at energies near and below the Coulomb barrier.

It is worth noting that these data do not cover the whole material collected up to date and, first of all, the measurement results concerning the multiplicities of pre- and post-fission neutrons and gamma-quanta in relation to mass fission asymmetry, which are to be presented in future on their analysis being completed.

Experiment

The central problem with studying the low-energy fission ($E^* < 20\text{-}30$ MeV) of transition nuclei in reactions with heavy nuclei is that the fusion cross section, σ_{fus} , decreases exponentially, and, along with it, so does the fission cross section, σ_f at ion energies below the Coulomb barrier.

For the reaction $^{208}\text{Pb} + ^{16}\text{O} \rightarrow ^{224}\text{Th}$ the experiment ⁶ shows that over the range of excitation energies, near and below the Coulomb barrier, $E^* = 20\text{-}30$ MeV ($E_f = 72\text{-}83$ MeV), being of interest to us, the fission cross section changes by a factor of five orders of magnitude from 10^2 mbarn to 10^{-3} . This places definite, sufficiently severe constraints on the techniques of the experiment and the energy characteristics of an ion beam. While studying the fission modes over the discussed region of nuclei another important point is reaching a compromise between the necessity of employing the maximal possible intensity of an ion beam and a high requirement to the resolution of a spectrometer measuring the masses and energies of fission fragments, pre- and post-fission neutron emissions and gamma-multiplicity.

Basing on this consideration, the experiments on measuring the mass and energy distributions of fission fragments which were started on the U-400 accelerator in Dubna and employed the DEMAS fission spectrometer were then continued on the tandem in Catania. For these experiments the new DEMAS-3 spectrometer was developed and produced. It is intended for measuring the mass, energy and angular distributions of fission fragments in coincidence with neutrons and gamma-quanta by a method based on the time-of-flight registration of the correlated reaction products. The diagram of the facilities is shown in figure 1.

Its basis is formed by a two-armed time-of-flight spectrometer of fission fragments. The spectrometer comprises 4 wide-aperture position sensitive avalanche counters, PSACs, utilized as stop detectors and 2 plane-parallel avalanche counters, PPACs, utilized as start detectors in each channel.

The angular and energy characteristics of neutron emission were measured by 8 neutron detectors of the DEMON facility. The detectors were installed 129 cm away from the target at different angles.

Measuring the multiplicity of gamma-quanta was carried out by six 63×63 mm NaJ gamma-detectors being at 14 cm distance away from the target centre.

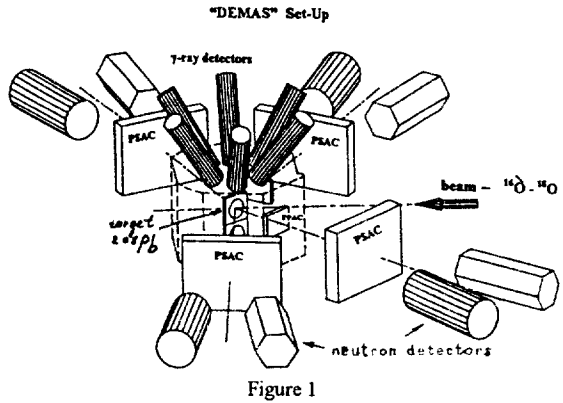


Figure 1

Results and analysis

Presented in Table 1 are the principal characteristics of the investigated reactions and the experimental first moments of the total energy and mass distributions of fission fragments: where E_i is ion energy, E^* - the excitation energy of a compound nucleus, E_f - the fission barrier height, E_{sp}^* - the excitation energy of a fissioning nucleus at the saddle point, $\langle E_k \rangle$ - the mean kinetic energy of fission fragments, σ_E^2 and σ_M^2 - the dispersions of energy mass distributions of fission fragments.

Table 1

| Nucleus | E_i , MeV | E^* , MeV | E_f , MeV | E_{sp}^* , MeV | E_k , MeV | σ_E^2 , MeV ² | σ_M^2 (exp), (amu) ² | $\Sigma Y_f / \Sigma Y_g$ |
|-----------------------------------|----------------|----------------|----------------|---------------------|----------------|------------------------------------|-------------------------------------------|---------------------------|
| $^{208}\text{Pb} + ^{18}\text{O}$ | 78 | 26.1 | 7.0 | 18.1 | 165.4±1.1 | 137±6 | 280±15 | 4.1±0.5 |
| | 75 | 23.3 | | 16.3 | 165.2±2.0 | 150±11 | 291±22 | 2.7±0.8 |
| $^{208}\text{Pb} + ^{16}\text{O}$ | 108 | 53.8 | 7.2 | 46.6 | 162.4±1.0 | 137±9 | 224±15 | - |
| | 85 | 32.4 | | 25.2 | 164.0±1.1 | 114±7 | 193±13 | 8.0±1.0 |
| | 77 | 25.0 | | 17.8 | 163.6±1.2 | 98±6 | 187±12 | 4.8±0.5 |
| | 75 | 23.2 | | 15.9 | 164.7±1.4 | 94±6 | 202±13 | 3.3±0.4 |
| $^{204}\text{Pb} + ^{16}\text{O}$ | 108 | 55.6 | 8.8 | 46.8 | 162.1±1.0 | 151±10 | 236±15 | - |
| | 85 | 34.3 | | 25.5 | 163.1±1.2 | 118±7 | 188±12 | 7.6±0.8 |
| | 77 | 26.9 | | 18.1 | 163.6±1.2 | 102±6 | 166±11 | 6.0±0.7 |
| | 75 | 25.0 | | 16.2 | 163.7±1.4 | 103±6 | 162±11 | 6.3±1.0 |

Shown in figure 2 are the outline plots of $TKE-M$ for ^{220}Th , ^{224}Th , ^{226}Th . They show that, at the same excitation energy, the contribution of the asymmetric fission increases significantly with the number of neutrons in a fissioning nucleus.

An interesting peculiarity about the obtained dependencies, $Y(M)$, $TKE(M)$ and $\sigma_f^2(M)$ for ^{224}Th and ^{226}Th , is the presence of a structure in the region of $M > 130$ related to two asymmetric fission modes appearing: a_0 and a_1 of the mean masses $M_{a0} = 132$ and $M_{a1} = 140$. To estimate the contributions of each mode (the symmetric mode and two asymmetric modes) of the integral mass distributions, the three-component analysis was carried out assuming the partial distributions, $Y_i(M)$, being of the Gaussian form.

The results of the three-component analysis of the ^{220}Th , ^{224}Th and ^{226}Th fragment mass distributions are presented in Table 1 and in figure 3.

The dependence of ratio Y_a'/Y_s' on the excitation energy of the fissioning nuclei at the saddle point E_{sp}^* is shown in figure 4. Together with our experimental data the analysis

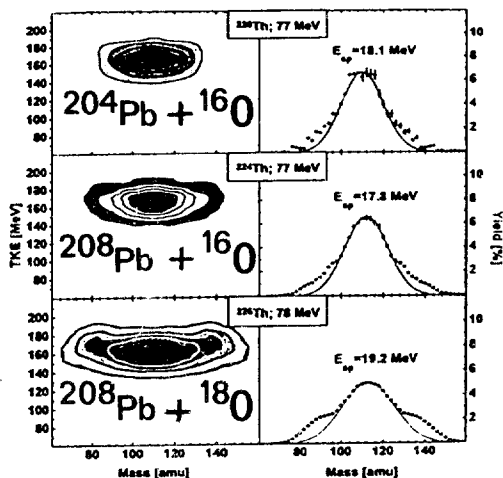


Figure 2

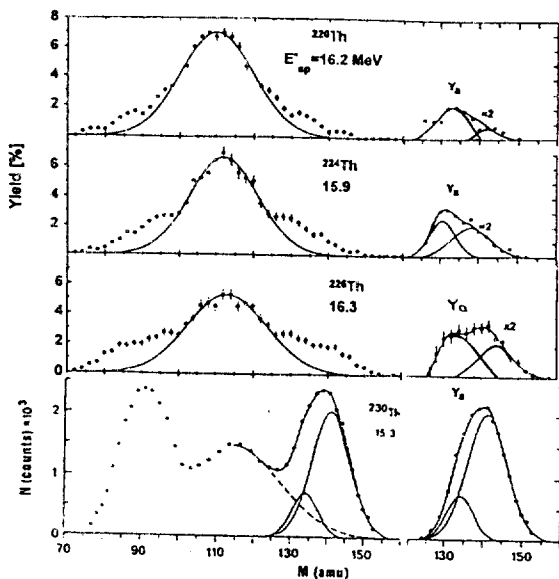


Figure 3

results of the mass distributions for heavier *Th*-isotopes studied in the reactions with neutrons, γ -quanta and ${}^4\text{He}$ -ions are also shown. The values Y'_s/Y'_a for all studied nuclei at the same excitation energy $E^*_{sp} \approx 16$ MeV are shown on insert in figure 4.

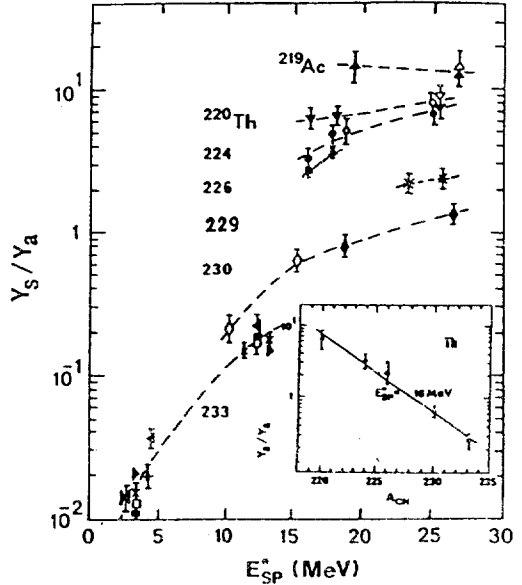


Figure 4

At the changing of free energy of the fissioning nucleus Q - TKE , i.e. at selection fission events for different intervals of TKE very important properties of fragment mass distributions are manifested. Figure 5 shows the differential mass distribution of ${}^{224}\text{Th}$ and ${}^{226}\text{Th}$ at the excitation energy $E^* = 26$ MeV. It is easily observed that in the case of ${}^{226}\text{Th}$ at changing total kinetic energy TKE from 146 MeV

up to 194 MeV a strong transformation of mass distributions from a symmetric shape, through the three-hampered one, into the asymmetric one with relation peak-valley > 3 takes place. On the other hand, for ${}^{224}\text{Th}$ the symmetric fission mode dominates up to most high TKE values. So, if the nucleon composition of a fissioning nucleus is changed by two neutrons, the transition is observed from symmetric to asymmetric fission at free energy Q - TKE striving for zero. Obviously, that observed effect is of the same scale as that of the spontaneous fission of ${}^{256}\text{Fm}$ and ${}^{258}\text{Fm}$ nuclei ($\Delta N=2$). It means that in spite of the excitation energy being high enough ($E^* = 26$ MeV), peculiarities of potential energy deformation surface for each of these *Th*-isotopes are to very strongly affect the formation of fragment mass and energy distributions on the whole and fission modes in particular.

In order to understand the nature and the properties of fission modes the analysis of the differential spectra of total kinetic energy as function of mass asymmetry parameter is very important. For this purpose we have analyzed the experimental spectra $N(TKE)$ of ${}^{226}\text{Th}$ ($E_f = 78$ MeV) which are shown in figure 6 for three regions of mass split $M=A/2=112-114$, $M=132(134)$ and $M=142$. It is seen, the spectra are differed by their parameters, namely, by the average total kinetic energy TKE and its dispersion δ_{TKE} . When one of the fission modes is dominant in the total spectrum, for instance, symmetric ($M=112$) or asymmetric a_0 ($M=142$), the

gaussian shape and essentially smaller dispersion δ_{TKE} are present in comparison to the $M=132$ or 134 a.u.m. spectrum where the contributions of all fission models (s , a_0 and a_1) are comparable.

The analysis of the former spectra ($M=134$) has been performed and its results are shown in figure 6 and given in Table 2. As seen from Table 2 the components are essentially differed in the mean total kinetic energies and its dispersions and, consequently, by their configurations at the scission point. This observation is a strong proof of the phenomenon of the independent fission modes.

Fission modes differ not only in the shape of partial mass distributions $Y^i(M)$ and the value of the average total kinetic energy of fragments TKE_i , but also they must have

different saddle points^{2,7} in the corresponding valleys of potential energy surface which are responsible for the origin of this phenomenon. It means that mass-symmetric and mass-asymmetric fission modes, their corresponding yields Y_i^f , contributions to the total fission cross section T_f or fission probability P_f and their energy dependences will be defined by the fission barrier with different parameters, first of all the height of barrier E_f^i . For some transitional nuclei near β -stability (Ra , Ac , At) the difference between E_f^s and E_f^a has been observed experimentally^{1,8}.

In our case the method of the transition state (Bohr-Wheeler formula) can be used for description of the ratio $Y_i^f(E^*)$ or, which is the same, of the ratio of the

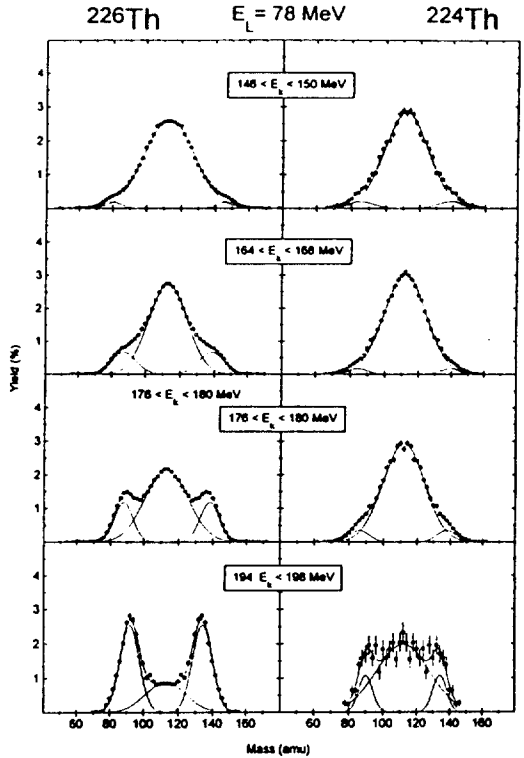


Figure 5

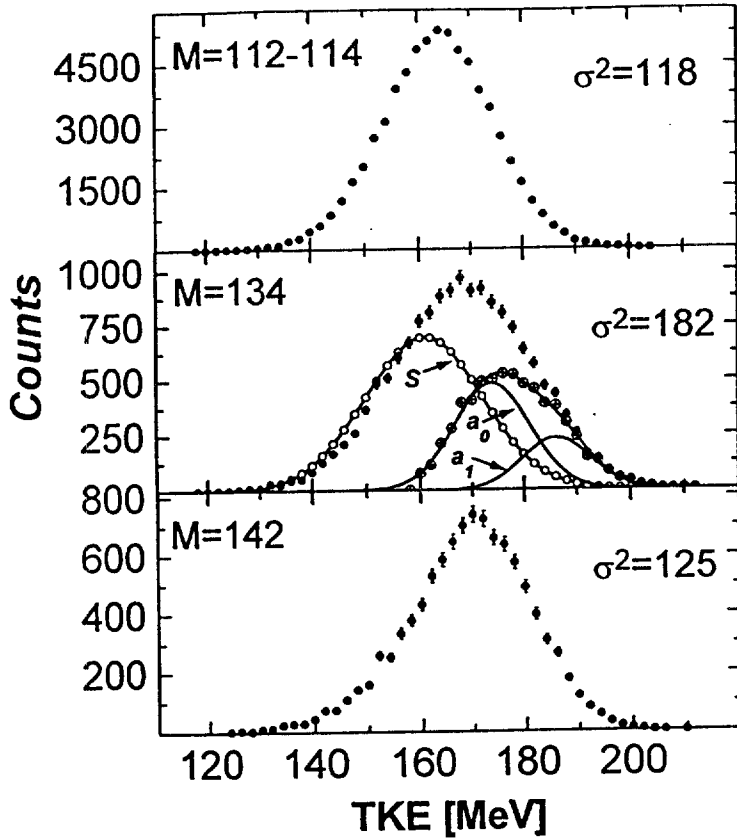


Figure 6

Table 2

| | $M=132$ | | | $M=134$ | | |
|-----------------------------|---------|-------|-------|---------|-------|-------|
| | s | a_0 | a_1 | s | a_0 | a_1 |
| $TKE, \text{ MeV}$ | 161 | 173.9 | 188.5 | 160 | 173.8 | 186.2 |
| $\sigma_{TKE}, \text{ MeV}$ | 26.0 | 16.5 | 15.3 | 26.0 | 14.6 | 13.1 |
| $Y_s^t, \%$ | 0.67 | 0.26 | 0.7 | 0.6 | 0.28 | 0.12 |

average fission widths for distinct fission modes $\Gamma_j^i(E^*)$ and for definition of the value $E_j^s - E_j^a$

$$Y_a^i(E^*) / Y_s^i(E^*) = \frac{\Gamma_j^a(E^*)}{\Gamma_j^s(E^*)} = \frac{\int_0^{E^* - E_j^s} \rho_a(u) du}{\int_0^{E^* - E_j^a} \rho_s(u) du} \quad (1)$$

For $E^* = \text{const}$ we have the following approximation

$$Y_a^i / Y_s^i \cong \frac{K_{rot}^a}{K_{rot}^s} \exp\left(\frac{E_j^s - E_j^a}{T}\right) \quad (2)$$

where K_{rot} is the rotating coefficients of the collective enhancement of level density, $\rho(u)$ - internal level density of a nucleus for which in (1) the constant temperature is used, T - nuclear temperature.

The values of $E_j^s - E_j^a$ deduced from relation (2) for different coefficients $C_l = K_{rot}^a / K_{rot}^s$ are given in Table 3. It can be concluded that the quantity (difference of the symmetric and asymmetric fission barriers) for $C_l = 0.7$ (axial and mirror symmetries are contained) and $C_l = -3.3$ (not rotating symmetry) are not in agreement with the experiment because in the first case symmetric fission is predicted to dominate up to ^{230}Th which is not correct, in the second case asymmetric fission is predicted to dominate for all nuclei which is not also correct. So, we conclude that only values $E_j^s - E_j^a$, deduced with parameter $C_l = -1.9$, corresponding to the pear shapes of Th nuclei in the ground state, are in agreement with the experiment.

Table 3

| Compound nucleus | $(E_j^s - E_j^a)^{\text{exp.}}$, MeV | | | $(E_j^s - E_j^a)^{\text{theor.}}$, MeV |
|---------------------|---------------------------------------|-------------|--------------|--------------------------------------------|
| | $C_l = -1.9$ | $C_l = 0.7$ | $C_l = -3.3$ | |
| ^{220}Th | -0.3 | -2.57 | 1.3 | -1 |
| ^{224}Th | +0.8 | -2.2 | 2.4 | +0.9 |
| ^{226}Th | 1.15 | -1.95 | 2.75 | +1.2 |
| ^{230}Th | 2.6 | -0.4 | 4.2 | +2.9 |
| ^{232}Th | 3.2 | 0.6 | 4.8 | +3.1 |
| ^{233}Th | 3.7 | 1.1 | 5.3 | |

Discussion of the results

As is mentioned above, the key concept underlying the understanding of fission modes is a potential energy of deformation as function of the nuclear shape. To describe qualitatively the results of the symmetric and asymmetric yields of the mass distributions of the thorium isotopes fission fragments the potential energy surfaces were considered in the space of deformation parameters which specify the nuclear shape in the coordinate system associated with Cassinian ovals². In this parametrization the liquid-drop model shapes along the fission path are described as a fast convergent series.

In the calculation taking into account, the shell correction the higher harmonics of up to the 7th order were used.

The barrier structures in ^{220}Th and ^{226}Th can be seen in figure 7, where the potential energy surface as a function of the elongation parameter α and the asymmetry parameter α_3 is depicted. At each point of the surface the minimization with respect to the parameters $\alpha_4 - \alpha_7$ was carried out.

Neither the ground state and the second minimum, nor the barrier between them which is usually called the barrier A are shown in these figures. The fission valley ascends from the mirror symmetrical second minimum to the barrier B which becomes visible at considerable asymmetric shapes in both parts of figure 7 in the depth of the figures and then passes through a very shallow third minimum which has been experimentally observed in the heavier thorium isotopes. The surface is completely symmetrical with respect to a changing sign of α_3 so that only one of the two valleys corresponding to asymmetric shapes of different space orientation is explicitly discussed here. Details of the landscape in the vicinity of barrier C are not seen from the position chosen in figure 7 and are different for various isotopes. During the descent a shift of the valley to the smaller asymmetry is seen for ^{220}Th and even the existence of the two valleys with a very small ridge between them is seen for ^{226}Th .

A symmetrical-shape valley is seen to begin at $\alpha_2 = 0.7$. It is running almost parallel to the asymmetric-shape valley. Still another shallow minimum exists in its course to the separated fragments for ^{226}Th . The valley may be populated only from the asymmetric valley over a pass on a very thin ridge that separates the two valleys. That ridge is apparently due to the shell effects and should disappear soon with the heating resulting in a dramatic increase in the symmetrical yield as it is known for the heavier nuclei.

The same type of the potential energy surface was analyzed for all thorium isotopes beginning from ^{220}Th to ^{232}Th . All of them have analogous barrier structures, the difference being only in the details of the landscape on the bottoms of the asymmetric and symmetrical valleys and in the relative height of the third

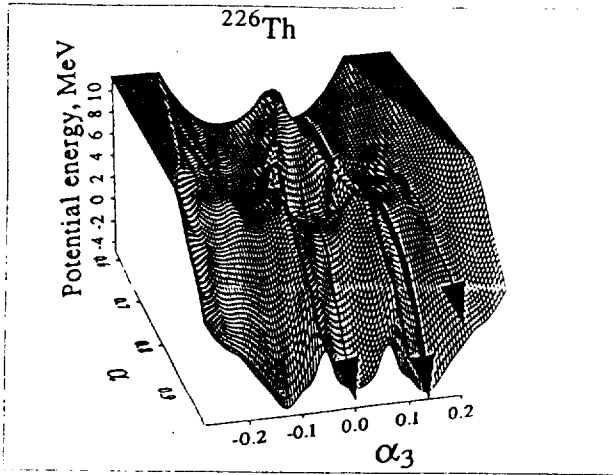
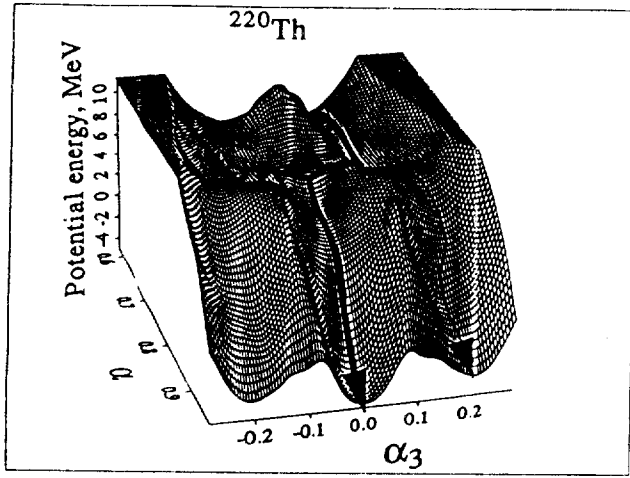


Figure 7

fission barrier E_c beyond the asymmetric valley and the pass E_s from asymmetric to symmetrical valley. That quantity is crucial for the fission fragments mass distribution and determines the ratio of the symmetrical yield to the asymmetric one. The height of the fission barrier E_c with respect to the pass from the asymmetric to symmetrical valley E_s is shown in figure 8. It is seen to be positive for the light isotopes and negative for the heavier ones which qualitatively and quantitatively (see also Table 3) explains the transition from the symmetrical to

asymmetric fission fragment mass distribution observed for these isotopes and described in the previous section. The exact position of the transition point between the predominantly symmetrical to predominantly asymmetric fission is expected to be sensitive to the excitation energy of the compound nucleus, as is mentioned earlier.

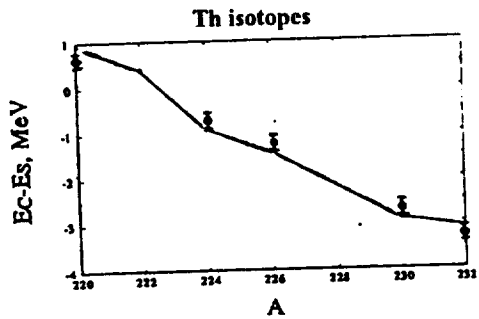


Figure 8.

Conclusion

The experimental and theoretical research of the characteristics of low-energy fission of the neutron deficient isotopes ^{220}Th , ^{224}Th , ^{226}Th , the results of which are given in the present paper, was the first successful attempt to employ subbarrier fusion reactions of heavy ions and nuclei for this purpose.

The analysis of the experimental data obtained by these investigations allowed one to reveal essential characteristics of the mass and energy distributions of fragments in relation to the excitation energy and nucleonic composition of fissioning nuclei. It was established that each fission mode (the symmetric mode s and the two asymmetric modes, a_0 and a_1) has its own definite set of characteristics: Y_b , TKE_b , σ_{TKE}^i , E_f^i . These results give a sufficiently rigorous physical proof of fission modes being independent and genetically related to the corresponding valleys on the potential energy deformation surface of the nuclei under study.

References

1. M. Itkis *et al*, *Z. Phys.* **A320**, 433 (1985); *Nucl. Phys.* **A502**, 343 (1989); *Europhys. Lett.* **4**, 275 (1987).
2. V.V.Pashkevich, *Nucl. Phys.* **A169**, 275 (1971).
3. E.K. Hulet *et al*, *Phys. Rev. Lett.* **56**, 313 (1986).
4. M.G. Itkis *et al*, *JINR Rapid Commun.* **3**, 19-29 (1994).
5. K.-H. Schmidt *et al*, *Phys. Lett.* **B325**, 313 (1994).
6. Yu.Ts. Oganessian *et al*, *JINR Rapid Commun.* **1(75)**, 123 (1996).
7. P. Moeller, J.R. Nix and W.J. Swiatecki, *Nucl. Phys.* **A492**, 349 (1989).
8. H.J. Specht, *Nukleonika* **20**, No.7-8, 717 (1975).
9. S. Bornholm, O. Bohr, B.R. Mottelson, *Phys. and Chem. of Fission* (Proc. Symp. Roshester 1973), Vienna *IAEA* **1**, 361 (1974).

Received by Publishing Department
on November 5, 1996.

**SUBJECT CATEGORIES
OF THE JINR PUBLICATIONS**

| Index | Subject |
|--------------|-----------------------------------------------------------|
| 1. | High energy experimental physics |
| 2. | High energy theoretical physics |
| 3. | Low energy experimental physics |
| 4. | Low energy theoretical physics |
| 5. | Mathematics |
| 6. | Nuclear spectroscopy and radiochemistry |
| 7. | Heavy ion physics |
| 8. | Cryogenics |
| 9. | Accelerators |
| 10. | Automatization of data processing |
| 11. | Computing mathematics and technique |
| 12. | Chemistry |
| 13. | Experimental techniques and methods |
| 14. | Solid state physics. Liquids |
| 15. | Experimental physics of nuclear reactions at low energies |
| 16. | Health physics. Shieldings |
| 17. | Theory of condensed matter |
| 18. | Applied researches |
| 19. | Biophysics |

На ускорителях У-400 в ЛЯР ОИЯИ и Тандеме (Катанья) с помощью двухплечевого спектрометра DEMAS были измерены массово-энергетические распределения осколков деления, эмиссия пред- и постделительных нейтронов и γ -множественность ядер $^{220,224,226}\text{Th}$, полученных в реакциях $^{204,208}\text{Pb}(^{16}\text{O}, f)$ с энергиями $E_{^{16}\text{O}} = 75, 78, 85, 108$ МэВ и $^{208}\text{Pb}(^{18}\text{O}, f)$ с энергиями $E_{^{18}\text{O}} = 75, 78$ МэВ.

Диапазон энергий возбуждения в седловой точке для этих ядер составил $E^*_{sp} = 16-40$ МэВ. Вклад асимметричной моды деления характеризуется полным отношением Y_a/Y_s , резко возрастающим для более тяжелых изотопов тория. Такое поведение Y_a/Y_s находится в качественном согласии с теоретическими расчетами, предсказывающими преимущественно симметричное деление для легчайших изотопов и преимущественно асимметричное — для более тяжелых при низких E^*_{sp} . Разделенная асимметричная мода деления $Y_a = Y_{a1} - Y_{a2}$ имеет сложную структуру, характеризующуюся двумя компонентами $Y_a = Y_{a1} - Y_{a2}$ со средними массами M_{a1} 132 и M_{a2} 139 для всех изученных изотопов. Энергетические характеристики осколков: кинетическая энергия E_k и ее дисперсия σ^2_E для наиболее низких E^*_{sp} также имеют определенные нерегулярности, характеризующие мульти-модальность деления ядер — увеличение E_k и пик в σ^2_E в области, где Y_a проявляет себя.

Работа выполнена в Лаборатории ядерных реакций им.Г.Н.Флерова ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1996

On the U-400 accelerator of FLNR and the Tandem (Catania) by means of a double arm DEMAS spectrometer were measured the mass-energy distributions of fission fragments, the emission of pre- and post-fission neutrons and γ -multiplicity of $^{220,224,226}\text{Th}$ nuclei produced in the reactions $^{204,208}\text{Pb}(^{16}\text{O}, f)$ with energies $E_{^{16}\text{O}} = 75, 78, 85, 108$ MeV and $^{208}\text{Pb}(^{18}\text{O}, f)$ with energies $E_{^{18}\text{O}} = 75, 78$ MeV. The range of excitation energies at the saddle point for these nuclei was $E^*_{sp} = 16-40$ MeV. The contribution of the asymmetric fission mode characterized by the total yields ratio Y_a/Y_s increases sharply for heavier isotopes of thorium. Such a behaviour of Y_a/Y_s is in qualitative agreement with theoretical calculations predicting predominantly symmetric fission for the lightest thorium isotopes and predominantly asymmetric — for heavy ones at low E^*_{sp} . The sorted out asymmetric fission mode $Y_a = Y_{a1} - Y_{a2}$ for all studied isotopes has a complex structure characterized by two components $Y_a = Y_{a1} - Y_{a2}$ with average masses M_{a1} 132 and M_{a2} 139. The energy characteristics of fragments: kinetic energy E_k and its dispersion σ^2_E for the lowest E^*_{sp} also have certain irregularities which are characteristics of the multimodal fission of nuclei — increase of E_k and a peak in σ^2_E in the region where Y_a manifests itself.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1996

Макет Т.Е.Попеко

**Подписано в печать 16.01.97
Формат 60 × 90/16. Офсетная печать. Уч.-изд.листов 1,13
Тираж 325. Заказ 49645. Цена 1356 р.**

**Издательский отдел Объединенного института ядерных исследований
Дубна Московской области**