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PARAMETRIZATION OF MASS CURVE OF NEUTRON-INDUCED ACTINIDE FISSION PRODUCTS

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Regardless of advances in the theory of fission, the description of mass fragment yields is at a comparatively low level, which in particular manifests itself in the design mass dispersions being essentially less than those observed for neutron-induced fission of actinides /1/. This results in significant errors of predicting independent yields essential for practical purposes. Certain approaches to the evaluation of isotopic and energy dependences of actinide fission fragment mass distributions will be discussed below.

MASS DISPERSION (σ_m^2)

Fig.1 shows the values σ_m^2 for fragments of fissile systems from thorium to plutonium depending on the neutron energy E_n /2-5/. All the results have been obtained whwithin a single technique (2-E method) and it is specified by the same mass resolution ($\Delta E_n \sim$ 0,1 MeV, $\Delta M \sim 3 - 4$ a.m.u.). As follows from the figure, with the growth of E_n, σ_m^2 is rising linearly. This allows the value of dispersion to be estimated at any energy of compaund nucleus excitation (up to the N,N'F-threshold). Taking into account the fact, that the fissile nuclei in the mass yield distribution formation region, e.g. in the actual scission point, are heated due to collective energy dissipation into internal degrees of freedom, rather an abrupt isotopical

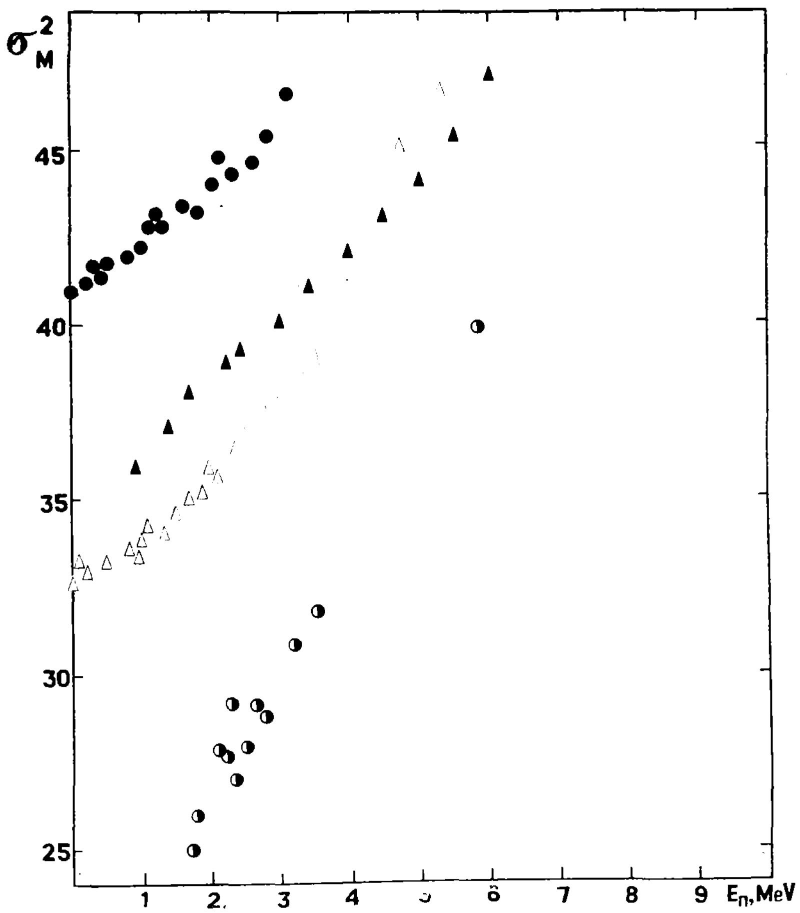

Fig.1. Dispersions of nuclear fission fragment yields depending on neutron energy : ● - ^{239}Pu /2/ ; ▲ - ^{235}U /3/ ; △ - ^{238}U /4/ ; ◑ - ^{232}Th /5/ .

dependence σ_m^2 can be expected with the fixed excitation in the saddle point E_{sp}. This situation is shown in Fig.2, where the systematics of mass dispersion on the fissility parameter Z^2/A for the induced (E_{sp}=2,0 MeV) and spontaneous actinide fission is given. First, the growth of σ_m^2 with Z^2/A is worth notice, and second - the systematic discrepancies of dispersion for induced and spontaneous fission. The discrepancies are easily eliminated by reducing all the data tothe single excitation energy in the scission point (a straight line in fig.2). The values from Ref./8/ are adopted for the dissipation energy E_{diss} ,which were obtained as a result of analyzing even-odd differences of light group fragment chage yields and mass-symmetric fragments yields analizing. It also follows from fig.2, that the observable

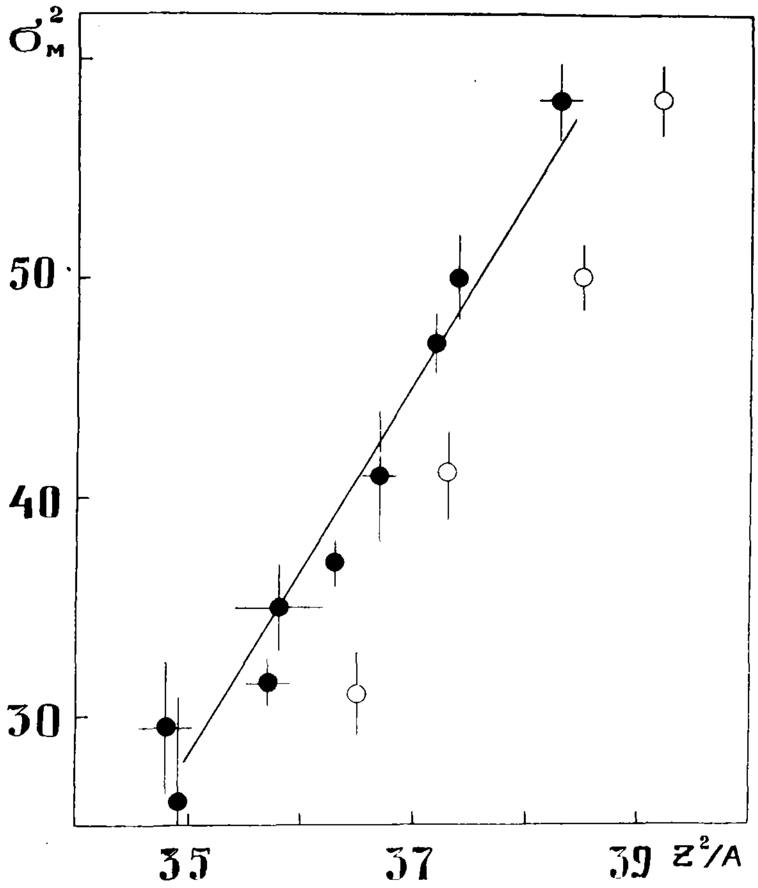

Fig.2. Dependence of mass distribution width on the parameter Z^2/A : ● - induced fission ; ○ - spontaneous fission. The data from reviews /6,7/.

values of dispersion can be a measure of fissile system heating on various stages of descent from the saddle to scission. For the quantitative evaluations σ_m^2 of nuclear fission fragments from isomeric (in the intermediate minimum of fission barrier), ground states and those above the barrier must be compared. The results of this analysis are given in fig.3. The value :

$$R = \frac{\Delta E_{diss}}{\Delta E_{def} - 2\delta},$$

is plotted on the Y-axis, where : ΔE_{diss} is extracted from the data on mass dispersions taking into account its energy dependences, $\Delta Edef$ - is the variation of system potential energy in the section of descent from the saddle under consideration (see fig.3),

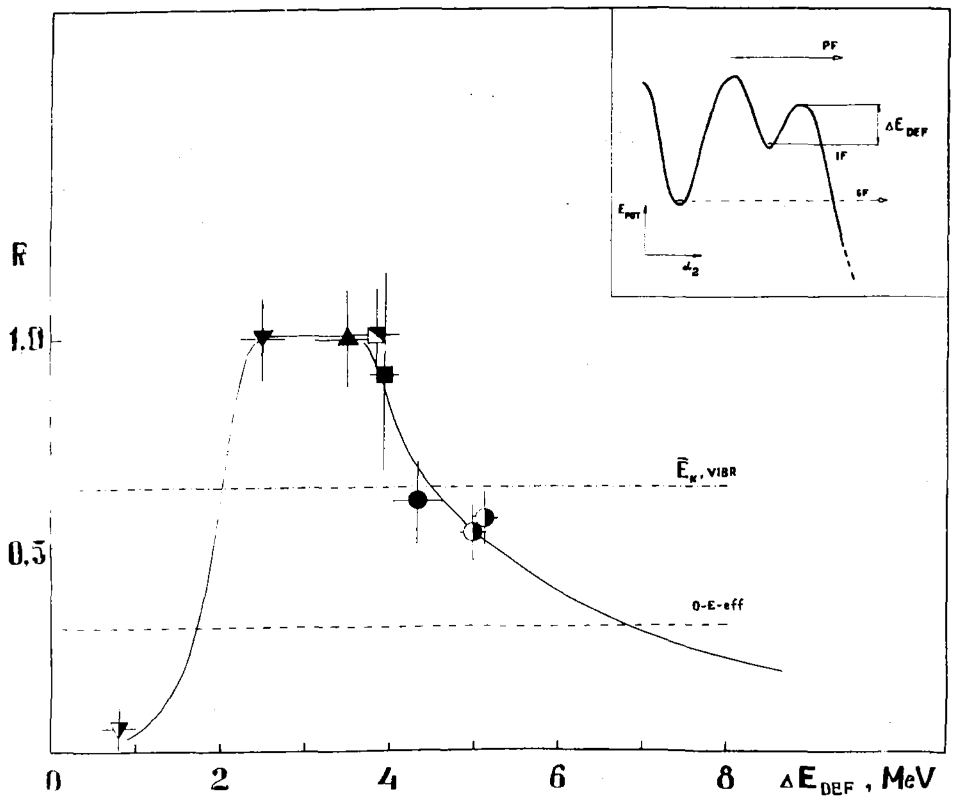

Fig.3. Relation R of fissile system excitation energy and deformation energy variation when the nucleas moves from the saddle point to the scission point :

▼ - comparison of data of the reactions $^{241}Am(n,f)$ and $^{242}Am^{m}_{sf}$;

▲ - $^{249}Cf(n,f)$ - $^{250}Cf(SF)$; ◪ - $^{250}Cf(t,pf)$ - $^{252}Cf(SF)$;

■ - $^{238}U^{m}(SF)$ - $^{238}U(SF)$; ● - $^{245}Cm(n,f)$ - $^{246}Cm(SF)$;

◐ - $^{239}Pu(n,f)$ - 240Pu(SF) ; ◑ - $^{241}Pu(n,f)$ - $^{242}Pu(SF)$.

- - -, -·-·-·- - average level of dissipation energy from the data of Ref./8/, and from the data on local variations of fission fragment kinetic energy around vibrational resonances.

$2\delta = 2$ MeV is an energy for "ignition" of the processes of energy exchange between the collective and single-particle nuclear degrees of freedom. R reflects a portion of energy released due to variation of the deformation energy dissipating to heat. As it follows from the figure, the initial stage of post-saddle motion to scission involve an essential nuclear viscosity. Whereas the final stage of the process represents virtually non-viscous rolling-down along the fission valley. The intermediate mean level for $\langle R \rangle$ over the whole length of the descent according to /8/ is about 40%. The upper limit for $\langle R \rangle$ obtained from the analysis of local variations of mean total kinetic of the fragment for uranium fission via vibrational resonances /9/ of barrier penetration is about 60%. The above properties of $\langle R \rangle$ can be employed when selecting an adequate theory of nuclear viscosity to increase the reliability of fission fragment mass yields calculation at any assigned excitation energy. It is noteworthly that the information on charge distribution of fragments should also be subjected to such an analysis.

STRUCTURE OF MASS CURVE

Numerous experimental data are indicative of the "degree of structure" of the mass curve, and in the dependence on nuclear composition and excitation energy of a fissile nucleus. Thus , the Y_m structure manifests itself most strikingly with the near-barrier thorium-232 fission by neutrons /10/ (Fig.4). As the excitation energy grows, the Y_m curve form undergoes considerable variations /10/ : the peak in the region $M_h = 134$ a.m.u. is attenuated, σ_m^2 grows. The mass curves Y_m for various nuclei have a different number of components, which can be interpreted

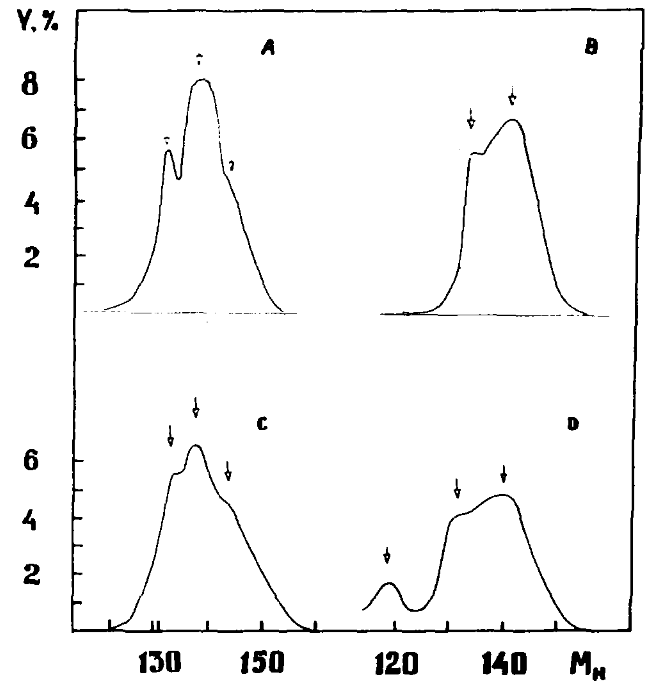

Fig.4. Mass yields for the reactions : A - ^{232}Th(n,f), E_n=1,6 MeV /10/ ; B - ^{235}U(n_{th},f) /3/ ; C - ^{238}U (n,f) E_n=2MeV /15/ ; D - ^{235}U(n,f), E_n= 9,6 MeV /9/ ((n,n'f)-channel background is taken into account).

within model /11/ as an effect of multi-valley character of a potential fission surface. Figs.4B and 4C show the comparison of Y_m for ^{235}U and ^{238}U neutron-induced fission. The curve of yields for the second nucleus is known /12/ to be even more complex : the components of Y_m were observed in the vicinity of M_h= 175 a.m.u. Systematization of the data on the structure of mass curves Y_m and working out the technique of its evaluation can appear rather tedious, which is concerned with insufficiency and sometimes inconsistency of the experimental data. Therefore the calculations of the type /11/ and their verification on the fissile systems carefully analyzed appear most promissing. However, individual components of the estimate order can be taken into account. In particular, like in Ref./13/, where the method of Y_m mass curve asymmetry consideration for a wide range of fissile nuclei is reported.

In the course of developing the evaluation of independent highly-excited nuclei fission yields the contribution of fission prosesses with a pre-neutron emission must be taken into consideration, and to do so it is a good idea at least to have a correct expansion into chances of the fission cross-section σ_f. Currently this procedure can be performed most reliably for the reaction $^{235}U(n,f)$ in the region of second fissile chance (n,n'f) /14/. In this case the information on the properties and contribution of mass-symmetric component (Fig.4D) in the range of compound nucleus excitation energies in the saddle point E_{sp} = 11 MeV becomes available.

A whole mixture of mass distributions is observed in the experiment at high excitation energies, which requires the research on fission fragment properties not only of the main fuel nuclei , but also a great number of minor ones built up as a result of successive capture ore emission of neutrons.

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