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DISPERSION OF THE ENERGY DISTRIBUTION AS A FUNCTION OF FISSION–FRAGMENT MASSES

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ABSTRACT

Once again, the width of the total kinetic energy distribution for thermal neutron induced fission of ^{235}U and ^{239}Pu was measured as a function of the fragment mass - ratio. Datawere obtained by meens of the "double energy method" with a experimental lay-out specifically designed to eliminate possible error sources. An appropriate Monte-Carlo procedure was used to correct the raw data for all dispersion effects induced by prompt neutron emission. These "corrected" data clearly demonstrate that most, of the sharp variation in the observed width, $\sigma_{E_K}(\mu)$ previously interpreted as having some real physical origin, are in fact generated by the "uncorrected" raw data as such. Similarly treated data, obtained with the Lohengrin mass-spectrometer, are also discussed.

RESUMEN

DISPERSION DE LA DISTRIBUCION DE ENERGIA EN FUNCION DE LA MASA DE LOS FRAGMENTOS DE FISION

Una vez más, el ancho de la distribución de energía cinética total para la fisión del ^{235}U y ^{239}Pu inducida por neutrones términos ha sido medida como una función de la razón de masas de los fragmentos. Los datos fueron obtenidos por medio del "método de doble energía" con un dispositivo experimental diseñado para eliminar las posibles fuentes de errores. Un metodo apropiado de procedimiento Monte-Carlo ha sido usado para corregir los datos de todo efecto de dispersión inducido por la emisión de neutrones inmediatos. Estos datos "corregidos" demuestran claramente que muchas, de las variaciones abruptas en el ancho observado, $\sigma_{E_K}(A)$, previamente interpretadas como que tienen un origen físico, son de realidad generadas por los datos "no corregidos". Se discute similarmente los datos obtenidos con el espectrómetro Lohengrin.

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The Experimental part of this work was carried out by M. Dakowski, C. Guet, M. Montoya, P. Perrin and C. Signarbeiux.

1. INTRODUCTION

In low-energy fission, many final-fragment characteristics can be explained in terms of a static scission model of two coaxial juxtaposed deformed spheroidal fragments, provided shell effects, affecting the deformation energy of the fragments, are also taken into account. These shell corrections, determined by the Strutinsky prescription, and discussed in some detail by Dickmann and Dietrich /1/ and more recently by Wilkins et al /2/, subsequently generate-secondary minima in the total potential energy surface of fragments having some particular neutron and (or) proton shell configurations. If the final fragment characteristics were governed by the properties of the fragments themselves, a basic argument in any statistical theory, one would the expect an increase in the width of the total kinetic energy distribution curve, σE_K (A), for fragment masses, A, having the above mentioned special neutron and (or) proton shell arrangements.

Experimental results obtained by the "double energy" method /9/ seemed to confirm these theoretical predictions to a remarkable extent, since sharp variations in the σE_K (A), curve were in fact observed. Unfortunately, most of the experimentally observed "peaks" were found in the low yield region, where the "double-energy" method, is known to be strongly contaminated by spurious events coming from the high-yield region. Morever, no corrections were for the dispersion effect on the yield data, created by the emission of prompt neutrons, thus casting further doubts upon the physical origin of the observed variations in σE_K (A). Finally, these effects could become particularly strong in the symmetry region where the fragment mass yield as well as the mean EK value vary strongly with the fragment mass.

In order to test the physical reality of the experimentally observed variations in σE_K (A), we therefore understood, once again, to remeasure the fragment mass-energy distributions for thermal neutron induced fission of 235U and 239Pu. The experimental design and the data evaluation techniques used were specifically adapted to verify the validity range of the above cited criticisms and particular care was paid to the rejection of spurious events and the corrections required by the prompt neutron emission. These later corrections, applied to this type of experiment, turn out to be rather complex and let us adapt Monte–Carlo fitting procedures to the case at hand. We will discuss this problem quantitatively for the low energy or spontaneous asymmetric fission of ^{235}U, ^{239}Pu and ^{252}Cf.

2. EXPERIMENTAL PROCEDURE

The usual double-energy method /4/ has been used with a geometric arrangement especially designed to eliminate spurious events created when one of the complementary fragment is inelastically scattered by the collimator edges placed in front of each detector. As shown in fig. 1, two solid state detectors are placed in pronounced assymmetrical positions with respect to the fission sourse.

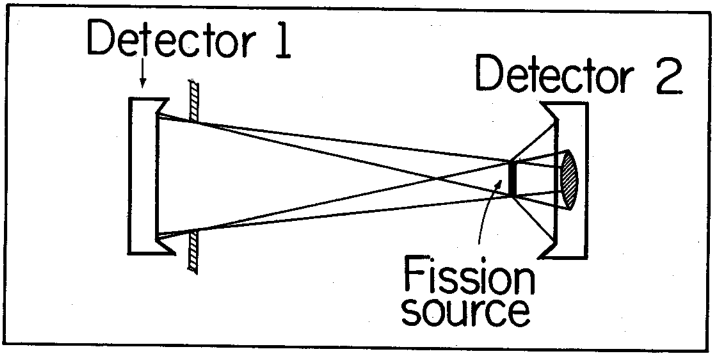

Figure 1: Schematic diagram of experimental geometry used for rejecting of spurious events.

Such a lay-out has the following characteristics:

i) For a source area smaller than the detector 1, the fragment-fragment coincidence requirement acts as a physical collimator for detector 1.

ii) By comparing measured with theoretical time of flight results for fragment detector 2, one can reject all events whose energies have been degraded by the edges of the collimator.

iii) Whenever detector 2, counts a fragment, the complementary fragment must necessarily be counted in detector 1, thus making the system efficiency strictly independent of prompt neutron emission. This particular condition is not quite satisfied in a symmetric lay-out.

So as to minimize energy losses in the target, a very thin and homogenous layer of 5 ugr. cm^{-2} fissile material was deposited on a backing of 20 μgr. cm^{-2}. The Grenoble High Flux Reactor provided us with a thermal neutron beam of roughly $5 \cdot 10^9$ neutrons cm^{-2}. sec^{-1}, giving approximatel y $3 \cdot 10^6$ detectable events. Raw data were analyzed event by event in a conventional manner /5/.

Pulse heights from the detectors are converted into kinetic energy E_k and provisional or pseudo-masses, μ, by using mass and momentum conservation together with a mass dependent energy calibration procedure proposed by Schmitt et al /4/.

For each event of pseudo-mass μ, one then calculates the time of-flight, ΔT_C, and compares it with its measured counterpart ΔT_m. If one now defines the difference in these time-of flight results as $\Delta T = (\Delta T_m - \Delta T_C)$, then the distribution of ΔT for a given μ, will allow for a "time window" in which all events can be considered valid. As an example, fig, 2. shows such a ΔT distribution for $\mu = 118$. Once these ΔT stablished, one proceeds to the second stage of the data evaluation procedure by rejecting all events falling outside the above mentionned time window. The remaining valid data then provides us with the mean value and the R.M.S. deviation $\sigma \varepsilon_K (\mu)$ of the ε_K distribution as a function of the pseudo mass.

3. EXPERIMENTAL RESULTS

The results of this experiment for the distribution of ε_K for ^{236}U and ^{240}Pu are presented, and compared with the published data on fig. 2. The decreasing of the dispersion in the symmetric regiǿn is observed for the consecutive experiments.

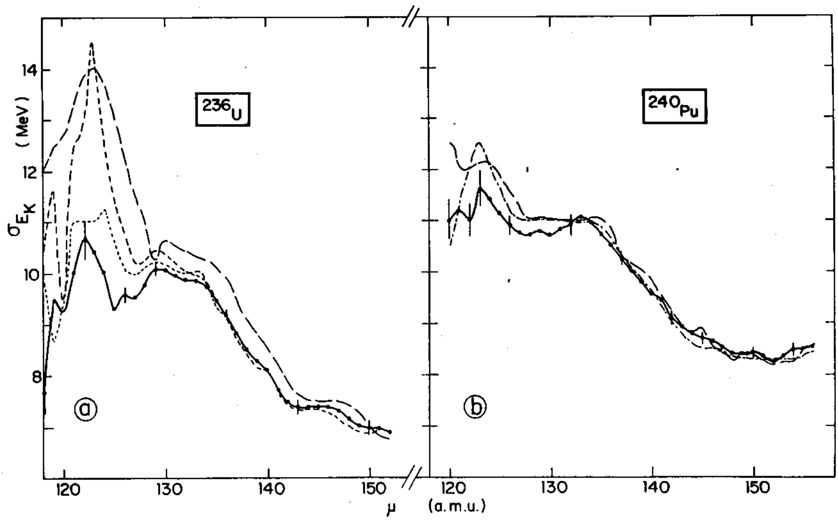

Figure 2: Comparison of published data on the dispersions ($\sigma \varepsilon_K$) of total kinetic energy distributions as a function of pseudo-mass μ:

a) For ^{236}U. Data: Long dashed line from Schmitt et al /4/; short-dashed line from Asghar et al /7/;dotted line from Asghar et al /8/;full line — this experiment.

b) For ^{240}Pu Data: Long-dashed line from Neiler et al /6/ dot-dashed line from Asghar et al /7/ full line — this experiment.

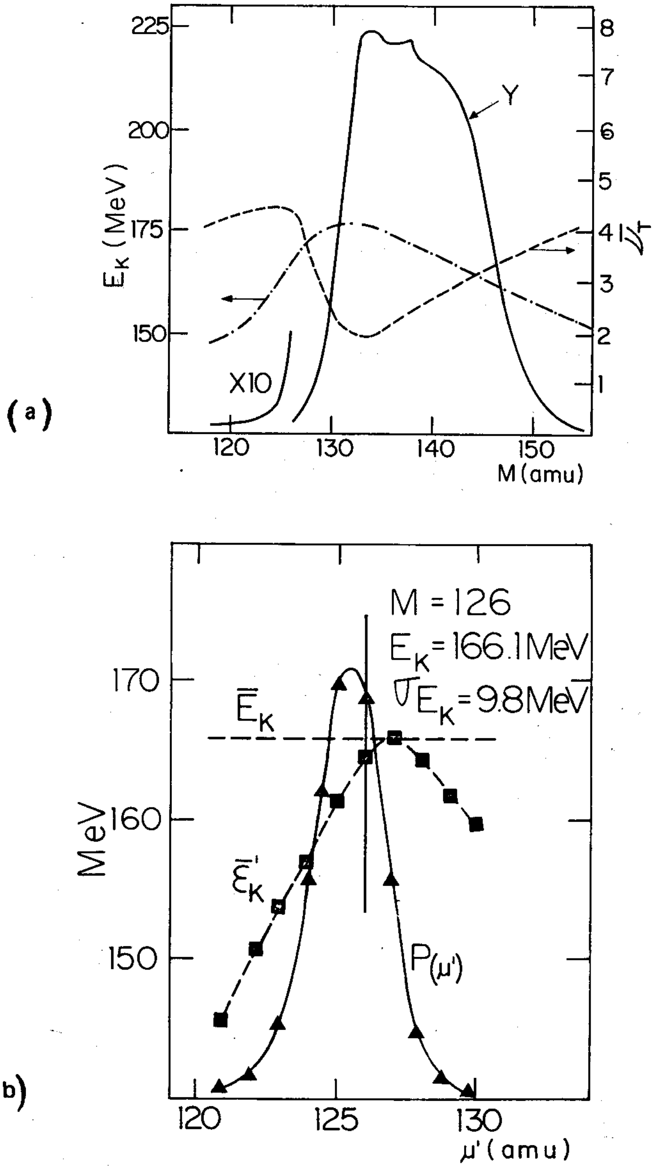

Figure 3: Qualitative explanation of dispersion corrections by Monte Carlo method. a) Schematic representation of input data for ^{235}U: kinetic energy E_K, yield Y /9/ and ν as a function of fragment mass M/10/b) Dispersión of μ' and ε_K' from the input data M = 126, E_K = 166.1 MeV. σE_K = 9.8 MeV. Notice that ε_K could be 15 MeV lower than E_K.

This fact is attributed to the improvements in the rejection of spurious events. As it was discussed above, the proposed method seems to reject all the spurious events, so the systematic change of the discussed curve, by this effect, should be expected in the future.

In order to measure the effects of prompt neutron emision it is used a Monte Carlo code to simulate neutron evaporation. The primary fragment kinetic energy distributions are obtained substracting the neutron emisi6n effect from the final measured distributions.

Let us the case of ^{235}U. The data input were the following:

- The mass yield curve. Y, and the neutron multiplicity, ν (A), are from/9/ and /10/, respectively.

- The multiplicity ν is a linear function of energy with the conditions $\nu(E_A) = \nu$ (A) with a $\frac{\partial \nu}{\partial E_K}$ from /11/

- The average total kinetic energy, E_K (A) of complementary fragments in function of initial mass and the dependance of root square width σ_{EK} (A) with initial mass are taken from smooth curves of experimental data.

In fig. 3a it is presented, schematically, the data input for Monte Carlo simulation for ^{236}U. Notice the rapid variation of ν_T (A), E_K (A) and Y (A) in the region A $\cong$ 126. The influence of this variation on K (u) for the input data M – 126 and E_K – 166.1 Me V and $\sigma E_K = 9.8$ MeV is schematically presented in fig. 3b. The value of $\varepsilon_{K'}$ for u' = 122 is approximately 15 MeV lower than E_K. Similar dispersion and rapid variation of Y (A) are at origin of the abrupt variation of $\sigma_{\varepsilon K'}$ which can be seen on the curve of the Monte Carlo correction Δ for experimental data $\sigma_{\varepsilon K}$. This correction was obtained by the following procedure:

At first the σE_K = const was assumed as a function of initial mass, M. The Monte Carlo program was executed and the difference between the output and input dispersion was established.

$$\Delta_0 = \sigma \varepsilon'_K - \sigma E_K$$

This quantity (see fig. 4) is subtracted from the experiment result $\sigma \mu(\varepsilon K)$ in order to obtain a first approximation for the curve of a physical quantity σE_K. This new curve is the input for a second simulation from which it is obtained a second approximation of σE_K.

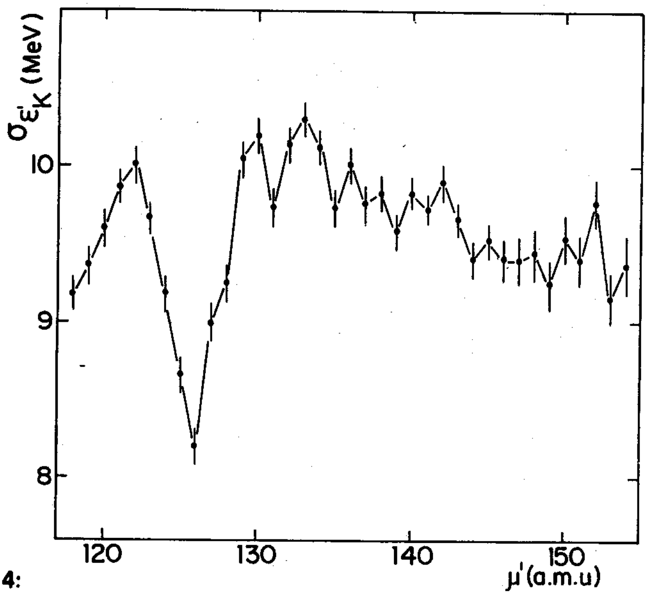

Figure 4:
Results of Monte Carlo calculations of dispersion for kinetic energy distributions ($\sigma \varepsilon'_K$ (u) for ^{236}U) for σ_{in} = 9 MeV.

Some discontinuities in the necessary interpolations of the input data (eg. multiplicity as a function of mass) caused minor oscillations seen eg. in the results for ^{236}U and ^{240}Pu. (see fig. 5a and 5b respectively). It is why the next two iterations were not necessary to improve the final precision of the difference between input and output data, called Δ and presented on fig. 5. The input data for Monte Carlo simulation for ^{240}Pu were from /6/ and /10/.

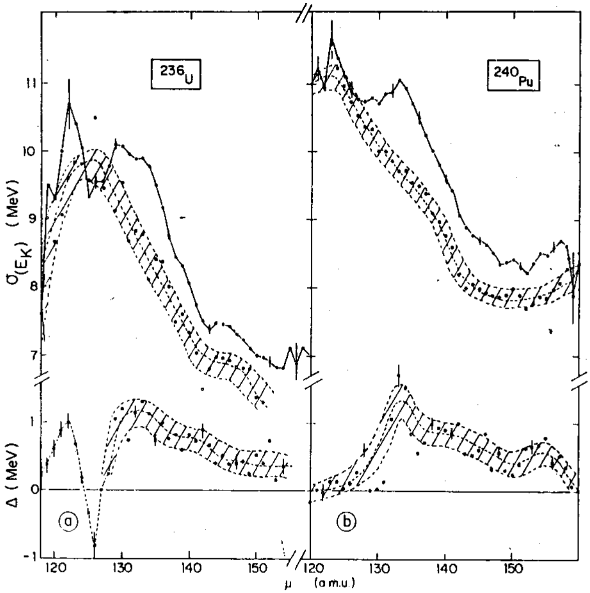

Figure 5:
Dispersions (σ) of kinetic energy distributions without and with Monte Carlo corrections: $\sigma_\mu(\varepsilon'_K)$ – thin line: raw experimental results. $\sigma_{M'}(E'_K)$ – open circles in corridor – data after Monte Carlo correction.
$\Delta = \sigma out_{\mu'} - \sigma in_M$: difference between $\sigma\, in_M (E_K)$, input width as a function of "real" primary mass of heavy fragment, and $\sigma\, out_{\mu'}(\varepsilon'_K)$ the output width as function of pseudo-mass. Estimated errors of Δ are about ± 0.5 MeV in the symmetry region and ± 0.2 MeV for the rest of the curve. a) for ^{236}U, b) for ^{240}Pu.

The corridor width of errors in this curve (Δ) is estimated to be 0.5 MeV in the symmetric region and 0.3 MeV for the next of the curve. These errors were estimated varing slightly the input data of Monte Carlo program in the "reasonable" limits of possible experimental deviations. The scatter of calculated points was taken into account too.

4. DISCUSSION AND CONCLUSIONS.

The discrepancies between different data reported, and the big peaks present in the raw data for dispersion curves (in the regioss: $\mu = 122, 123$ and 130 – 134 for ^{236}U, as well as in regions $\mu = 120 - 130$ for ^{240}Pu), are caused by the spurious events discussed in sect. 2 and removed in this experiment.

The remaining smaller peaks and dips seem to be caused by the interplay of fragment yield, kinetic energy and neutron multiplicity as a function of pseudo-mass. Monte Carlo evaporations model (and program) reproduces most of these structures for the double energy method as well as for the magnetic spectrometer method (Lohengrin)

The dispersion curves corrected for this effect are smooth, in the limits of experimental and computational errors. So any speculations about the deformations and/or deformabilities of the fragments /1/, or about the shapes of potentials for fissioning systems /2/, seem to be a bit premature ones.

The presented Δ functions (fig. 6) can be used as the correction factors also for the future experiments for the mentioned nuclides. They serve to transform the measured dispersions in ε_K (as a function of the pseudo-masses) to the physically meaningful values (as a function of calculated primary mass M'). The input data for Monte Carlo simulation were from /11,12/ for ^{234}U and /6, 13/ for ^{252}Cf.

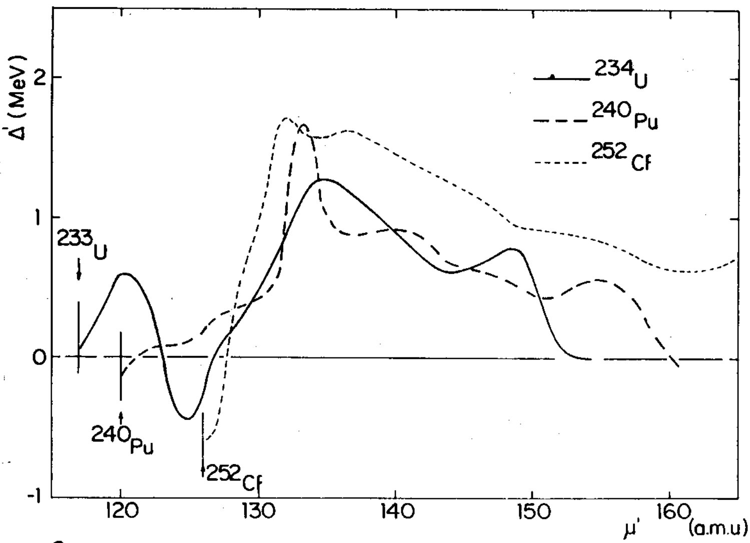

Figure 6:

Results of Monte Carlo calculations for correcting factors (Δ) between raw measured double energy dispersions σ_{μ} (ε_k) and calculated "primary" dispersions on the basis of existing data. ("universal" curves of neutron emission corrections). The lines are drawn only to guide the eyes. a) solid line - for ^{234}U. b) broken line - for ^{240}Pu, c) dotted line - for ^{252}Cf.

In the mass separator Lohengrin at the Grenoble High Flux Reactor it was measured the kinetic energy in function of final fragment mass in the symmetric region of ^{235}U /14/ and ^{233}U /15/. While by the double energy method it is measured the energy of two complementary fragments in order to calculate the pseudo mass (μ), at the Lohengrin separator it is measured the mass, m, and kinetic energy ε_k of one fragment after neutron emission. In the fig. 7a it is shown the effects neutron emission on the width of ε_K distribution in function of m for ^{236}U. This effect is evident on the diference Δ , between the results for simulation. The peak around m' = 110 can be explained very well by neutron emission effects. It is not the same for the peak at m' = 125 (see fig. 3 ref. /14/) Nevertheless, the rapid variation of the yield and average kinetic energy in function of mass suggests that could be necessary to pay attention to possible effects of not very well known data on the indicated region.

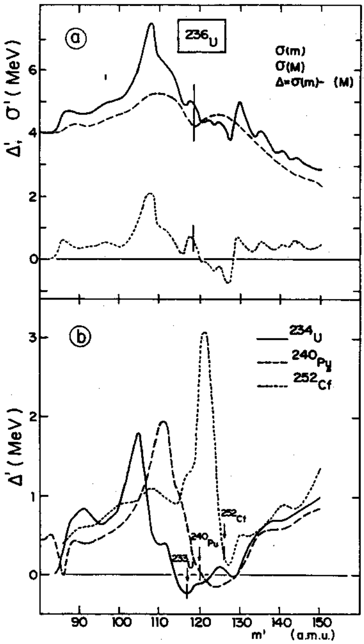

Figure 7:

Monte Carlo calculation results for the energy dispersion of one fragment as a function of mass mesured after neutron evaporation. a) for ^{236}U: broken line – input data (σ_M E_K) extracted from the corrected results presented on fig 5 a; solid line – dispersion $\sigma_{m'}$ (E_K) after introducing the neutron evaporation corrections; dotted line - difference $\Delta = \sigma_{m'}(E_k) - \sigma_M(E_k)$ b) Monte Carlo calculated functions $\Delta = \sigma_{m'} - \sigma_M$ (as defined in caption to fig 6) for: solid line: ^{234}U, broken line: ^{240}Pu, dotted line: ^{252}Cf.

In the fig. 7b it is presented the Δ in function of fragment mass for thermal neutron induced fission of ^{233}U, ^{239}Pu and for spontaneous fission of ^{252}Cf A very high peak on the light mass side of the width of kinetic energy is obtained for Δ (m) which must be taken into account to analyse the eventual similar experimental results.

Experimental and part of interpretation of results of this were carried out by M. Dakowski, C. Guet, M. Montoya, P. Perrin and C. Signarbeiux /16/

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