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PROPERTIES OF STANDARD-I MASS CHANNEL IN FISSION OF Z-ODD NUCLEI

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ABSTRACT

Mass distributions of fission fragments in Am-243(n,f) reaction have been measured for incident neutron energy from 1 to 3.7 MeV. The data were analyzed along the Brosa model. The attention was paid to behavior of standard-I component which was observed to be strongly determined by excitation energy of the fissile system at the top of fission barrier. Results of the analysis showed that FF mass spectra of americium isotopes can be predicted for any incident neutron energy. The comparison with the data for other Am-nuclei measured is given.

INTRODUCTION

For Am-243 the FF-mass yields data are very scarce covering only thermal neutron energy point [1,2]. In addition the negligence of the Pu-239 ingrowth in the sample due to α,β- decay of Am-243 (α-7370 y, β^- - 2.355 d) can provide some mistakes. For example, fission cross section was measured accurately in [3], resulting in a value of 74 $\pm$ 4 mb, in complete contradiction with the value of 198 $\pm$ 4.2 mb reported in [4] by authors measured after that and FF mass distributions. Unfortunately they did not indicate how long before the start of experiment the americium target was fabricated. Therefore the data [1] and [2] will be compared with our results simultaneously. In the present work we performed systematic study of ^{243}Am FF mass spectra for different incident neutron energies from 1 MeV up to 3.7 MeV covering practically whole region of compound system excitation from the fission barrier top to (n,n'f) threshold. Well known 2-E method based on surface-barrier detectors was used like in [1,2]. Neutron energies were chosen to be 1.0; 2.0; 2.2; 2.7; 3.0; 3.4; and 3.7 MeV.

RESULTS AND DISCUSSION

Measured FF mass distributions for different E_n are represented in fig.1. Open symbols show the spectrum for E_n = 1 MeV with high statistics : 100.000 events. In comparison, in work [1] only 15.000 event were collected (362.000 [2]). Changes of Y

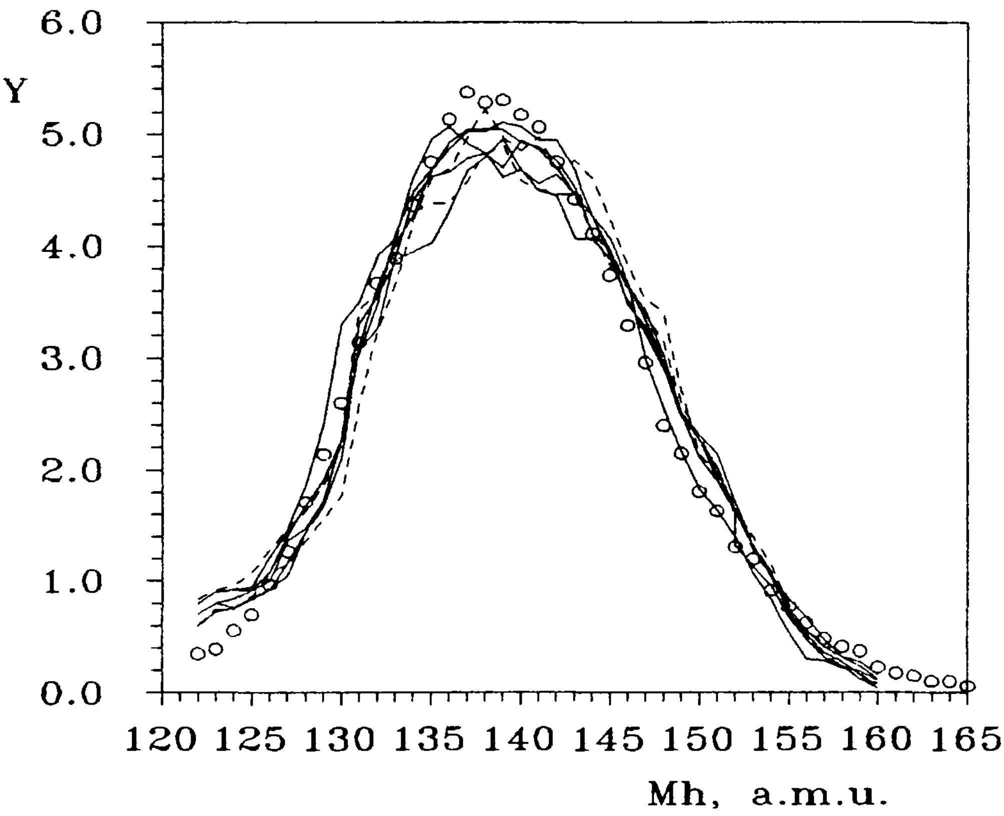

Fig.1. Set of FF mass-distributions of ^{243}Am for different E_n.

curve vs neutron energy are visible. The width of distribution comes up and mass-symmetric yield starting from 0.27 % (1 MeV) increases up to 1 % (3.7 %). So high Y_s is partly due to strong overlapping of Standard-I and Standard-II components and partly unperfect mass resolution. The last problem will be discussed later along the analysis of cold fragmentation (CF) spectrum.

Fig.2 shows a comparison of our data with the results [1,2]. In work [1] a fine structure of mass spectrum averaged over all FF kinetic energies available was indicated. For both our mass curve and Asghar's [2] one it is not visible. At the same time the smooth curves from [1] and [2] are in good agreement. We observed relatively broad less asymmetric distribution due to much higher contribution of the Standard-I component. It can be demonstrated via fitting procedure by set of Gaussians. It appears that the third mass-component around M_h = 153-155 a.m.u. should be added (Y_{as}). Table 1 represents the numerical results of spectra fitting. One can see that relative yield of Y_{as} is not high (1.5-4%) with approximately the same width σ_{MAS} as for

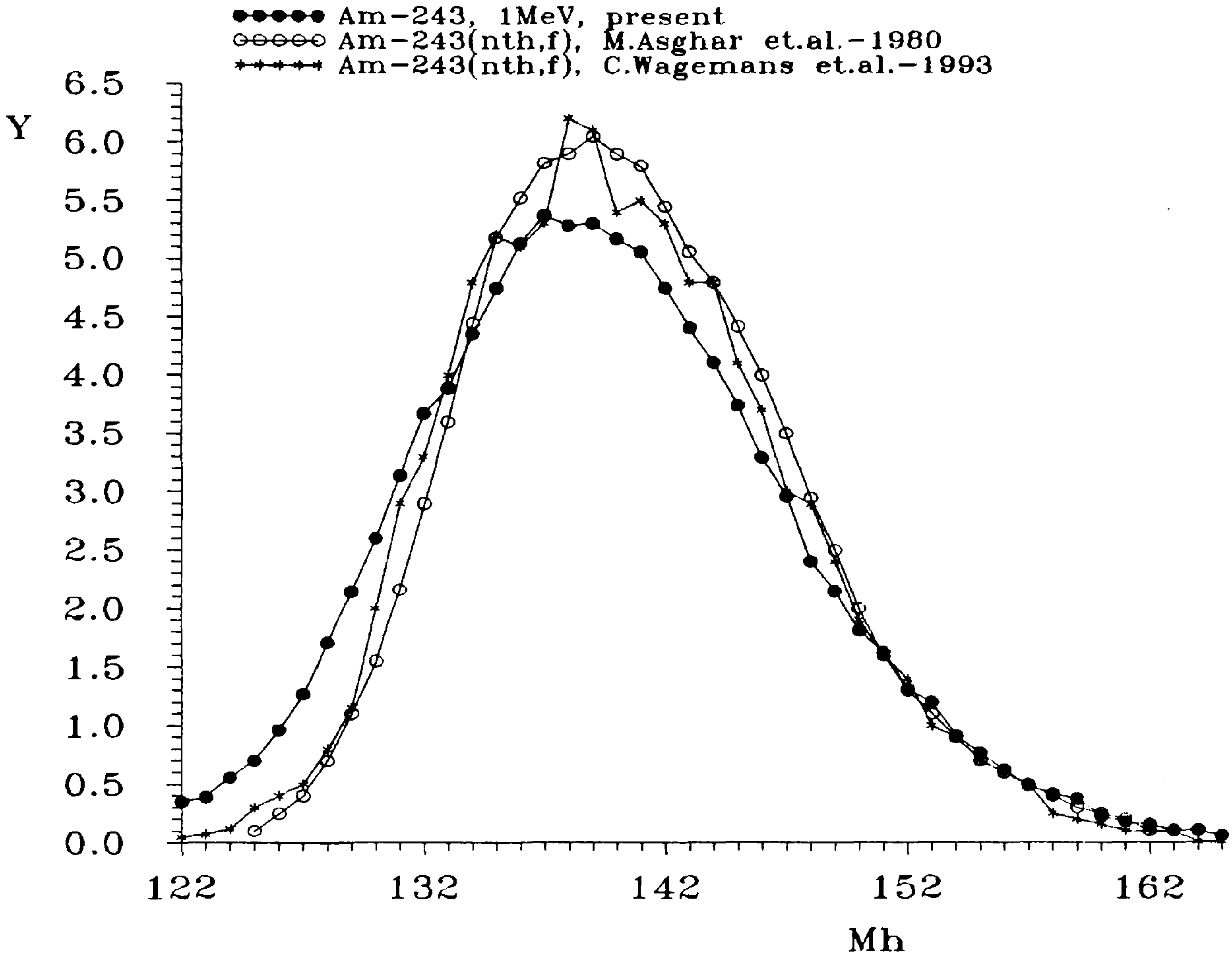

Fig.2. FF mass distributions for $^{243}Am(n,f)$ reaction with thermal and 1 MeV neutrons.

Standard-II component. Shortly before the existence of asymmetric component around the heavy fragment mass M_h = 154 a.m.u. was predicted theoretically for another odd-odd fissile system -^{238}Np [5]. Experimental studies showed very small but definite contribution of the asymmetric component named Standard-III associated with additional valley on the potential energy surface of neptunium. The calculations [5] were made with method developed by U.Brosa e.a. [6]. Present data together with [1,2] for ^{244}Am confirmed the existence of Standard-III mass-channel. Practically, it can be attributed to a high-asymmetric tale of the mass curve Y.

Fig.2 shows a high difference in mass spectra of the present work and [1,2] in the region of Standard-I component (see also

Table). For subbarrier fission Y_1 is much smaller relative to around barrier fission. It means that barrier penetration in different mass channels is different. It's important to remind that fission cross-section of americium is determined by inner barrier hump which is higher than outer one. Inner barrier is the same for all the mass channels because the bifurcation point locates at least at the second well of fission barrier.

TABLE.

Parameters of mass spectra fitting by a set of Gaussians.

isotopes	^{243}Am 1 MeV present	^{243}Am thermal [2]	^{243}Am thermal [1]	^{241}Am thermal [2]	^{242m}Am isomer [7]
Y1, % <M1> σ_{M1}	18.3 (.2) 134.1 (.6) 4.9 (.2)	11.4 (.4) 135.3 (.5) 2.8 (.1)	15.2(.4) 135.0(1.3) 3.5(.1)	24.0(.4) 134.8(1.8) 3.9(.1)	13.4(.5) 135.2(.7) 2.9(.1)
Y2, % <M2> σ_{M2}	76.7 (.9) 140.2 (.3) 7.0 (.1)	85.9 (.8) 140.9 (.2) 6.4 (.1)	83.9(.9) 140.9(.3) 6.6(.1)	73.1(.2) 140.2(.4) 6.2(.1)	82.8(.6) 139.6(.2) 6.1(.2)
YS, % σ_{MS}	1.0 (.1) 7.5 (3.)				
YAS <MAS> σ_{MAS}	4.1 (.2) 154.7(1.7) 6.1 (.5)	2.7 (.3) 155.9(1.8) 5.6(1.4)	1.4(.6) 156.2(1.2) 2.3(.5)	2.9(.3) 154.4(2.) 6.1(1.)	3.8(.3) 155.8(1.) 4.9(.7)

Obviously, observed contributions of Y_1 reflect fission barrier structure. Analogous feature takes place for other Am-isotopes. For example, yield of Standard-I fragments in thermal neutron induced fission of ^{241}Am [2] is much higher (24%) than in fission of shape isomer ^{242m}Am [7] (13.4%), populated via ^{241}Am(n,γ) reaction after γ-transition to ground state of second well of the barrier. In addition, the variance for both cases of ^{244}Am and ^{242}Am (fissile nuclei) increases with increasing of the excitation energy of compound system. Fig.3 represents mass distributions for reactions: ^{242m}Am(sf) [7], ^{242m}Am(nth,f) [8], ^{241}Am(d,pf) [7], and ^{241}Am(nth,f) [2]. The biggest differences can be observed again in the region of Standard-I component.

Adding to the data discussed above mass spectra obtained for fast neutrons up to 3.7 MeV one can present the yield of

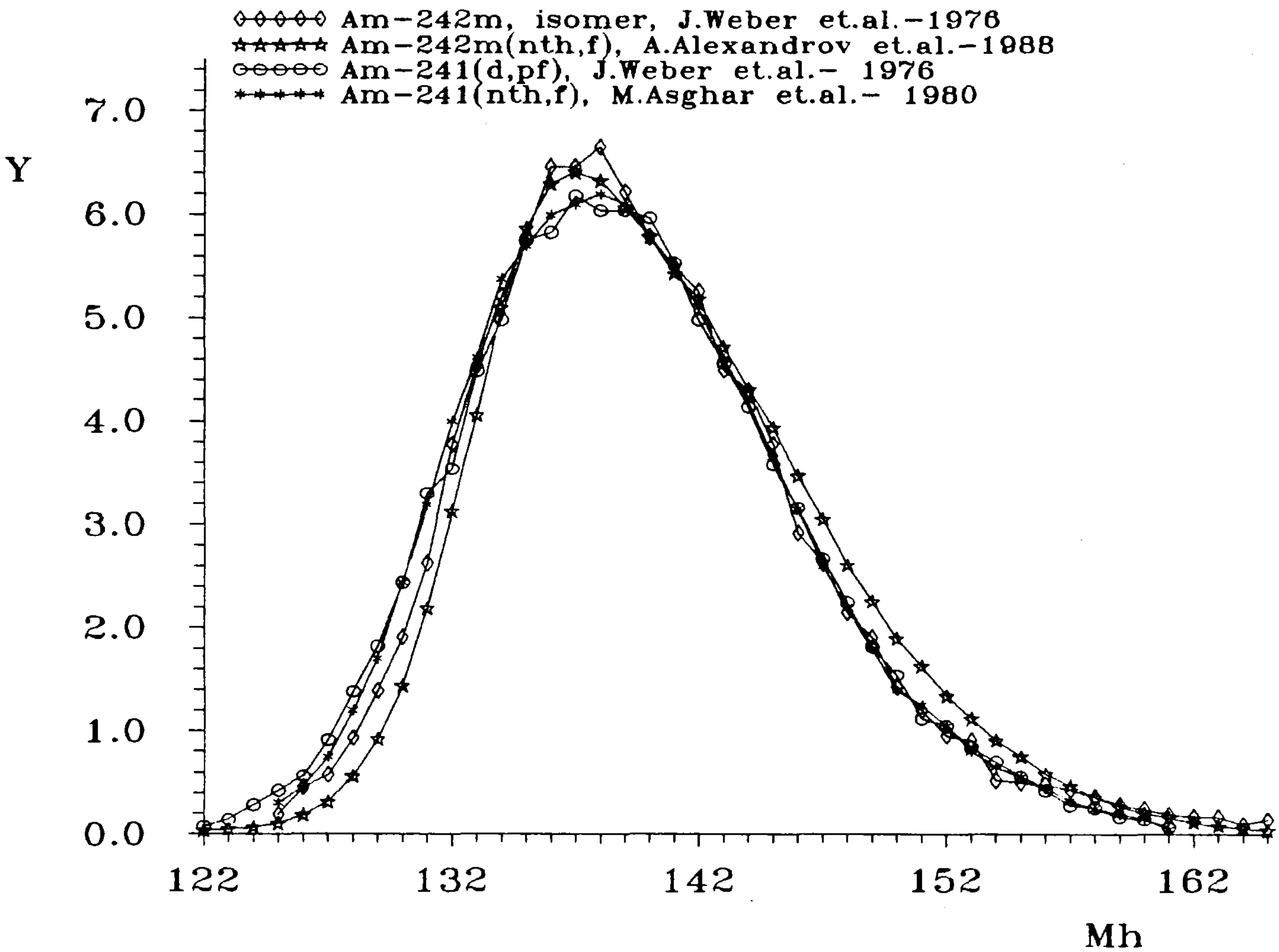

Fig.3. Fission fragment mass distributions for reactions: ^{242m}Am(sf) [7], ^{242m}Am(nth,f) [8], ^{241}Am(d,pf) [7], and ^{241}Am(nth,f) [2].

Standard-I vs excitation energy E^* at first saddle point. Parameters (neutron binding energies B_n and fission barrier heights B_f) were derived from [9]. Energy dependence $Y_1(E^*=E_n+B_n-B_f)$ is shown in fig.4. Insert shows analogous data for Np-237 [10]. One can see a maximum in $Y_1(E^*)$ for all odd-odd fissile nuclei investigated. Its location is the top of observable in σ_{nf} excitation functions fission barrier. A slope of $Y_1(E^*)$ for positive E^* is very sharp relative to that for uranium isotopes (e.g.U-235(n,f) [11]) in the same E^* region. This kind of behavior of Y_1 can explain a more rapid decrease of FF total kinetic energy with E^* for Np and Am than for U-233,234,235,236,238.

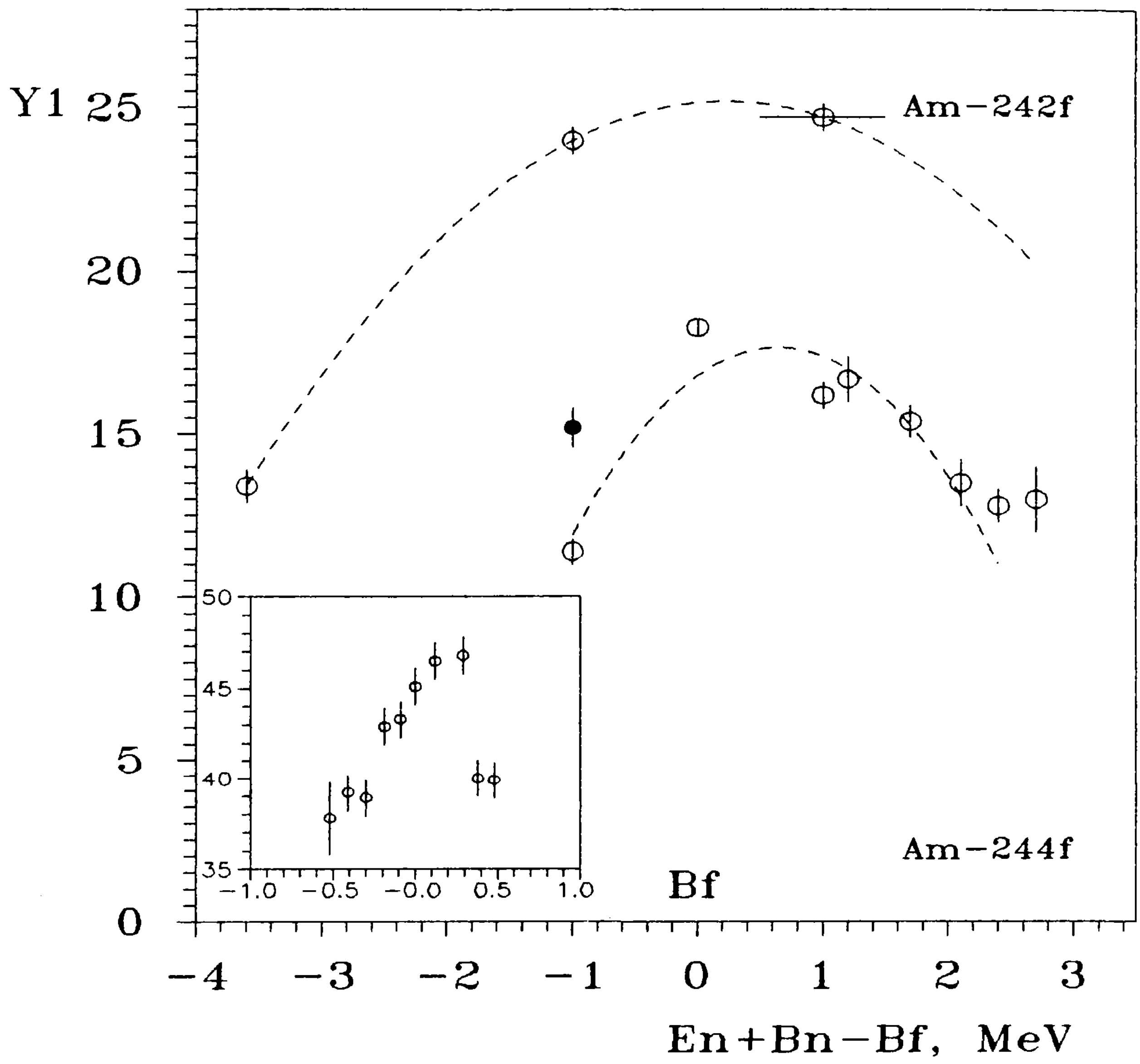

Fig.4. Energy dependence of Standard-I contribution (in % normalized to 100) to the mass spectrum of ^{242}Am and ^{244}Am fissile systems. Data for ^{241}Am(d,pf) [7] were averaged over (d,pf)-excitation function in the region, indicated in [7]. The black sign - [1]. Insert shows Y_1 for ^{237}Np(n,f) [10] in the same variables as for mane figure. Barrier parameters were derived from [9].

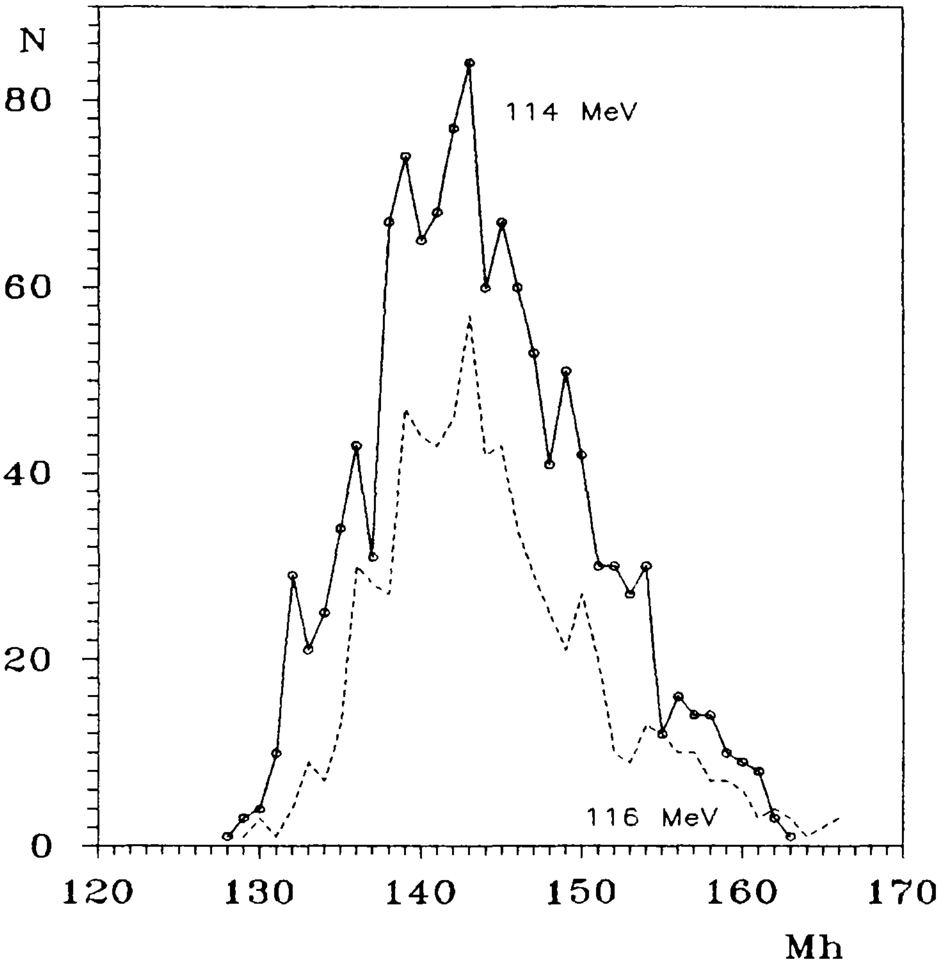

Fig.5. FF mass spectra for E_L = 114 and 116 MeV.

It was mentioned above that Wagemans e.a. [1] observed fine structure of FF mass-distributions which remains and repeats in selected light fragment's kinetic energies windows higher than 112 MeV. In fig.5 two our spectra are represented for E_L = 114 and 116 MeV (pseudo - cold fragmentation). One can see pronounced fine structure with the step of approximately 2.5 - 3 a.m.u. This kind of a periodicity was previously observed for the odd-odd fissioning systems ^{238}Np [12,13] and ^{232}Pa [14]. To explain this effect the idea was proposed [1] that one unpairing proton could be distributed between both fission fragments, as consequence of the Coulomb repulsion. It should be true for all scission points along the descent from saddle independently on free energy of the system and the contribution of dissipation. Fig.6 shows the spectrum for E_L = 121 MeV far from average value equal to 104 MeV. The structure definitely exists. For all of E_L -windows the

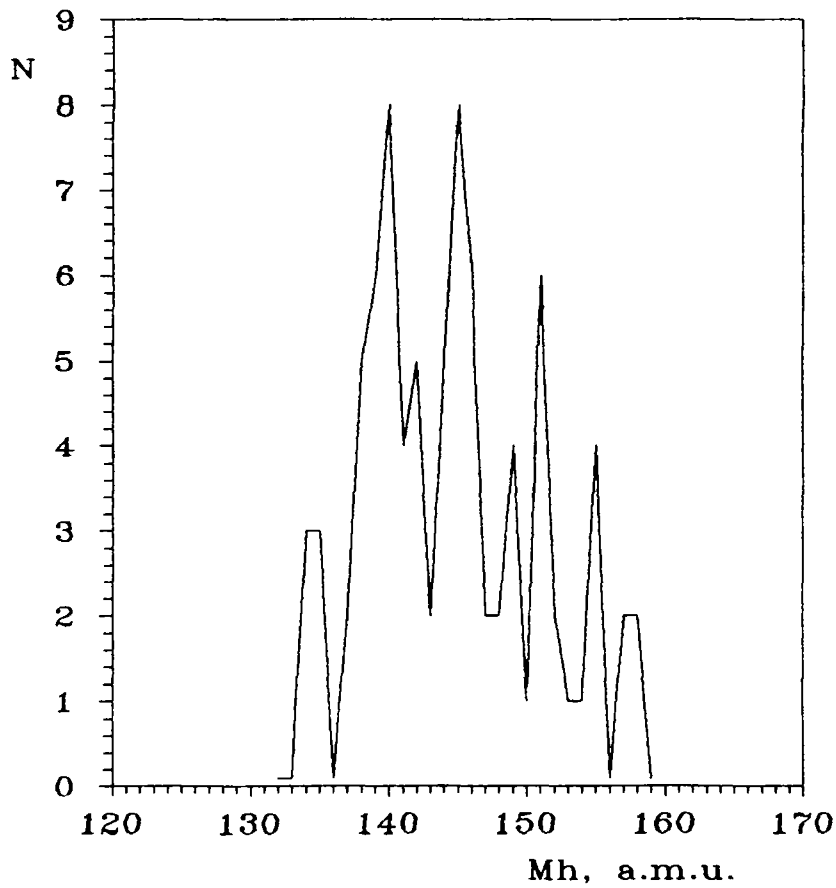

Fig.6. Cold fragmentation spectrum for E_L = 121 MeV.

contribution of Standard-I component is obviously low.

Mass resolution in our work was good enough to resolve fine structure. It means that relatively high mass-symmetric yield should be associated with the penetration of respective fission barrier and instrumentation problems in FF spectrometry are not essential in our case.

Observed energy dependence $Y(E^*)$ can be directly used for evaluation of americium FF mass spectra for any incident neutron energy E_n. A transformation to the fission product yield data needs prompt neutron emission probabilities, this is a subject of future analysis.

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