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503

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ABSTRACT. -

Energy spectra and angular distributions with respect to the light fragment flying direction have been measured for ^{4}He and ^{6}He particles emitted in the thermal neutrons induced fission of ^{239}Pu. The particle identification and energy measurements have been performed by using solid state detectors. The gaussian fits of the obtained distributions are reported with the experimental data. The most probable angles θ_k and the relative FWHM result

$$\theta_k = 84^\circ \qquad \theta_k = 86^\circ$$

$$\mathrm{FWHM} = 24^\circ \qquad \mathrm{FWHM} = 23^\circ$$

for ^{4}He and ^{6}He angular distributions respectively. Comments are made about the characteristics of the achieved angle/energy correlation.

1. - INTRODUCTION. -

It is known that in the fission of the heavy elements, in addition to the normal binary fragments, the emission of long-range light particles is verified with a rather low frequency(1). At first these particles have been identified as ^{4}He ions and more recently the emission of Hydrogen and Helium isotopes has been pointed out with some other rarer nuclei having $Z > 2$(2-7).

The unusual high energy and the angular distribution sharply peaked at about 90° with respect to the fragments direction have suggested that these long-range light particles are released from the neck of the deformed nucleus at instants very close to the fragments separation. Due to the place and moment of the emission, the correct knowledge of the light particle and correspondent fission fragments features can supply new information about the dynamical and geometrical conditions of fissioning system, indications can be obtained about the open question if the fission is a slow (statistical) rather than a fast process.

Recently we prepared a computing program that, by assuming a three-sferical-charge model, is able to evaluate the conditions of the fissioning system at the moment of the scission(8). Contrary to other preceding works it does not act as a fitting of assumed distributions but it is rather a technique for achieving the initial conditions of the considered problem from the experimental measurements, except the angular distribution. In particular the weights in the distributions of the various initial parameters are deduced from the measured energy spectrum of the light particle and the reliability of the calculated results are obtained by comparing the measured angular distribution with that derived from the calculations.

There was up now no experimental angular distribution relative to the light fragment direction regarding long-range particle other than alphas. In fact in the preceding works regarding ^{235}U (9-11), ^{238}U (12) and ^{252}Cf fission(12-16), the experiments have been performed without the identification of the light particles or with referring to the light and heavy fragment irrespectively. The second procedure can give informations just about the symmetry of the distribution.

We report in this article for the first time the angular distributions of ^{4}He and ^{6}He identified particles relative to the light fragment direction as obtained in the ^{239}Pu n-thermal fission.

2. - EXPERIMENTAL PROCEDURE -

The neutron beam used in the experiment has been extracted from the Triga Mark II reactor of the University of Pavia. In order to minimize the nuclear noise on the detectors the beam has been collimated on a 2 cm^2 surface by a collimator having an optically polished internal Ni surface; so, in addition to accurate collimation, due to the total reflection under limit angle, an enrichement in the thermal component of the beam was obtained(17). Along the neutrons path, just the ^{239}Pu target was interposed.

The identification of the light particles has been obtained by using a solid state DE. E telescope consisting of two silicon detectors; the first one had a thickness of 20 μm and the second detector, 500 μm thick, was able to stop all the transmitted ^4He and ^6He ions. A Ni absorber 11.6 mg/cm^2 thick was placed between the target and telescope in order to prevent the fission fragments and the natural alpha-particles from reaching the DE detector.

The fission fragments have been contemporaneously detected by five low-resistivity surface barrier detectors connected in parallel and each one placed at the same angle with respect to the direction between the centres of the DE detector and target.

The pulses from the detectors were fed into three low-noise FET preamplifier - delay line non overloading amplifier systems. At last the signals in triple coincidence with a resolution time of 40 nsec were analysed by a three parameters PHA constructed in our laboratory and recorded by a tape paper punch.

The experimental analysis chain, conventionally equipped, is shown in Fig. 1 that is almost self-explanatory.

For the energy calibrations a precision pulser and the alpha particles from the natural decay of ^{241}Am were used.

The experiment has been performed in four different runs each corresponding to an angle between the directions of the two segments whose extremes were the centres of the target, DE and fragment detectors.

The analysed angles are 68, 88, 108, 129 degrees. The normalization of the data has been obtained by counting during each run the uncorrelated binary fission fragments through the same detectors and an independent system that fed a 512 channel pulse-height analyser.

The triple coincidence of the pulses deriving from the telescope and single fragment detectors and the recording of the energies DE, E, F (see Fig. 1) event by event have allowed to derive the identification and energy spectra of the light particles with the energy distributions of the associate fission fragments simultaneously.

The common angular width of the DE and fragment detectors relative to the target centre was ± 5 degrees.

The target consisted of a layer of ^{239}Pu acetate enriched to 98,8% and electrosprayed on a 8 mg cm^{-2} Ni disk while the neutron current at the beam-hole exit was 3 x 10^{9} cm^{-2} sec^{-1}.

The extremely low counting rate has made the experiment accomplished in more than one year.

The achieved data have been elaborated in the following way: in a first time we considered the angular distributions of the particles without distinguishing the light from the heavy fragment directions. Due to the recoil fragments angle, the two distributions appear simmetrical with respect to an angle $\theta \neq 90$ degrees. The angle

$$\overline{\theta}_r = 2 (\theta - 90)$$

can be considered as the measured average recoil angle of the fragments.

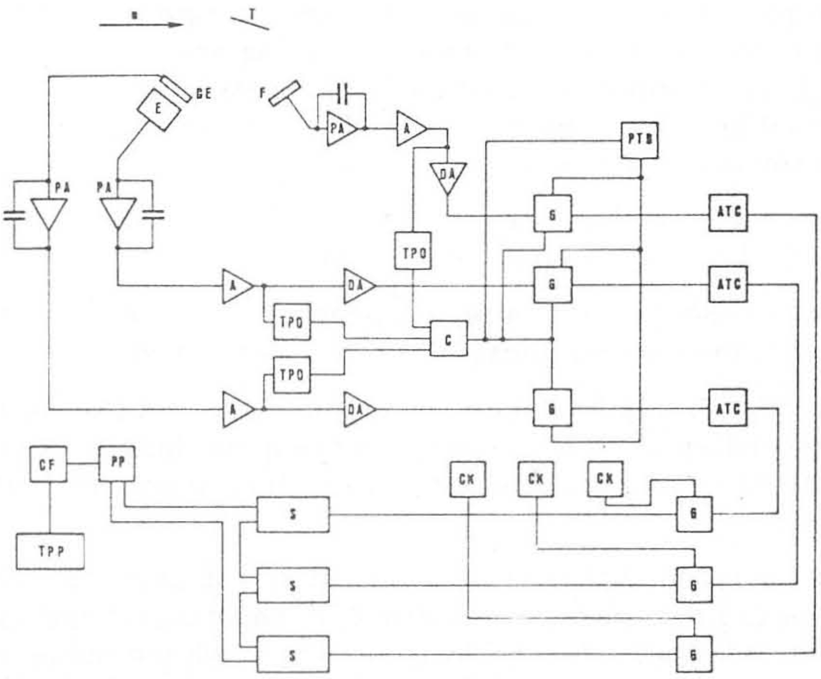


FIG. 1 - Schematic diagram of electronic system. The various parts are as follows : n - neutron beam; T - target; DE - thin detector; E - thick detector; F - fission detector; PA - FET preamplifier; A - delay-line amplifier; C - triple fast coincidence; G - linear gate; PTB - printing time black; TPO - time pick-off; DA - delay amplifier; ATC - amplitude to time converter; CK - clock; S - scaler; PP - printing programmer; CF - codifier; TPP - tape paper punch.

With regard to the distributions referred to the light fragment flight direction, we considered that the run relative to a given angle θ included informations about two different angles: θ when the fragment detected in coincidence with the particle was related to the light component of the fragments spectrum and the angle $(180 - \theta + \overline{\theta}_r)$ when the detected fragment was heavy; consequently the experimental points in each distribution are double with respect to the number of the runs performed. Nevertheless we have not considered the data corresponding to some angles where, due to the extreme low yield, a very bad statistics resulted.

The described experimental procedure has allowed to obtain the light particles energy-spectra in correspondence of each analysed angle and the angular distributions relative to various energy intervals in the particles spectra.

3. - RESULTS AND COMMENTS. -

In Fig. 2 the alpha and ^{6}He particles angular distributions relative to the single fragment direction are shown. In addition to the experimental points, reported with the estimated indeterminations due to the detectors and target finite dimensions, the gaussian fits are indicated as they have been obtained by a least squares program.

In Table I the gaussian parameters resulting from our measurements are compared with some preceding data achieved with various techniques for ^{238}U (12) and ^{252} Cf (12, 14, 15, 16) fission. All the reported peak angles lie in an interval of 3 degrees and this is an obvious consequence of the fact that they are correlated only to the fragments recoil angles. For the distributions amplitude, the standard deviation obtained in the present experiment is consistent with the values included in the table.

The average recoil angles result:

$\overline{\theta}_r$ = 6 degrees for ^{4}He accompanied fission
$\overline{\theta}_r$ = 8 degrees for ^{6}He accompanied fission

With regard to the distributions referred to the light fragment flight direction, Fig. 3 reports the experimental points with the fitted gaussian curves, while in Table II the gaussian parameters are shown in comparison with those resulting from previous experiments(9, 10, 11, 13, 15).

Our peak-angle of 84° relative to the alpha-particles distribution is very close to the values obtained in the case of ^{235}U analysis(9-11).

In Table II the results concerning the alpha-particles angular

TABLE I - Gaussian parameters of ^{4}He and ^{6}He particles angular distributions with respect to the single fragments. Light and heavy fregments are not distinguished.

^{4}He PARTICLES				
Target	ref.	Technique	Peak angle	σ
^{238}U+p	12	Semiconductors	95^{o}	14.7^{o}
^{252}Cf	12	Semiconductors	94^{o}	12^{o}
^{252}Cf	16	Semiconductors	92^{o}	15^{o}
^{252}Cf	14	Semiconductors	92^{o}	14.5^{o}
^{252}Cf	15	Semiconductors	---	16^{o}
^{239}Pu	Present work	Semiconductors	93^{o}	15^{o}
^{6}He PARTICLES				
^{252}Cf	16	Semiconductors	93^{o}	15^{o}
^{239}Pu	Present work	Semiconductors	94^{o}	14^{o}

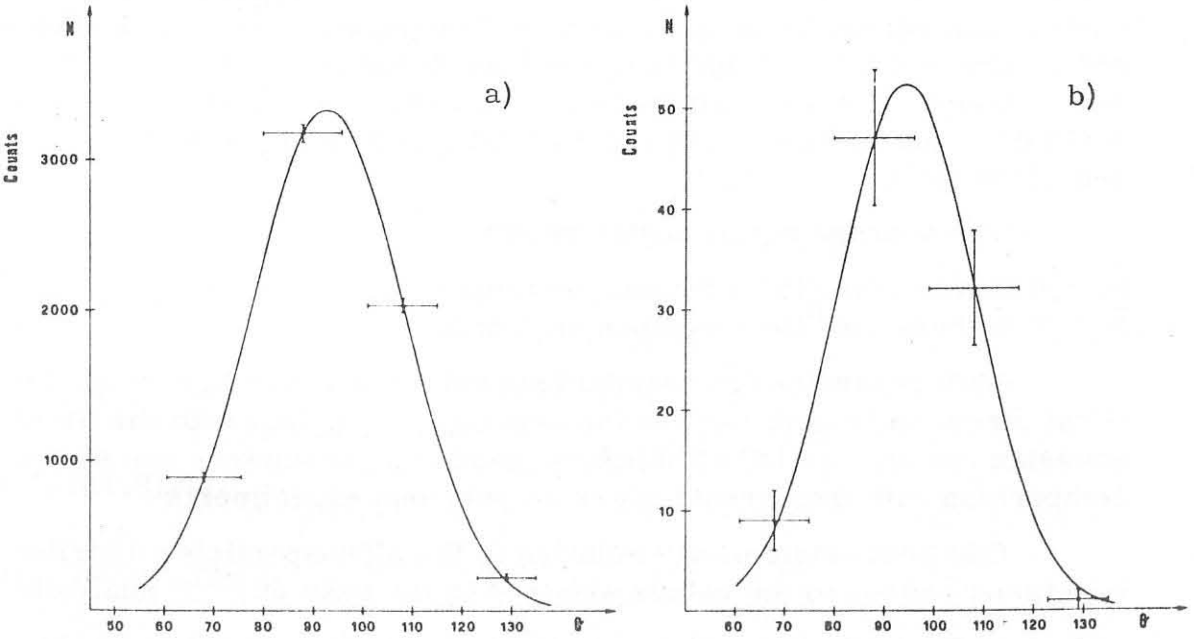


FIG. 2 - Alpha (a) and ^{6}He (b) particles angular distributions with respect to the single fragment direction. Light and heavy fragments are not distinguished.

TABLE II - Gaussian parameters of alpha and ^{6}He particles angular distributions with respect to the light fragment direction.

^{4}He PARTICLES				
Target	Ref.	Technique	Peak angle	FWHM
^{235}U	11	Semiconductors	~ 82°	23°
^{235}U	10	Nuclear emulsion	83°	29°
^{235}U	9	Nuclear emulsion	82°	30°
^{252}Cf	13	Semiconductors	81°	32.5°
^{252}Cf	15	Semiconductors	~ 83°	23.5°
^{239}Pu	Present work	Semiconductors	84°	24°
^{6}He PARTICLES				
^{239}Pu	Present work	Semiconductors	86°	23°

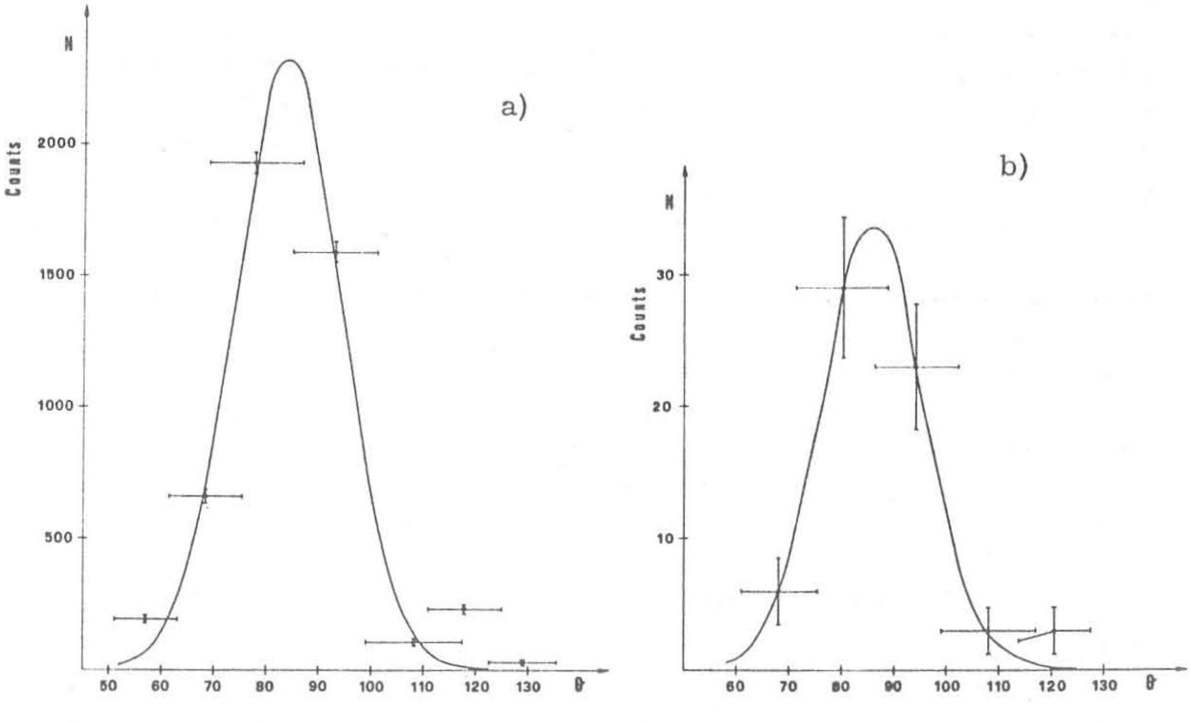


FIG. 3 - Alpha (a) and ^{6}He (b) particles angular distributions with respect to the light fragment direction.

distribution amplitude in ^{252}Cf fission show a substantial difference of about 10 degrees; the reason of this disagreement is not known, nevertheless the FWHM (24°) resulting from our work lies, with the other considered data, in the interval characterized by the two reported extreme values.

No comparison is possible with the data referring to the ^{6}He particles. The features of the obtained angular distribution clearly prove that the modalities of the ^{6}He release are the same as in the alpha-particles emission.

The energy spectra of the alpha particles identified at various angles are the subject of Fig. 4 and Table III. The reported distributions are referred to the angles where a sufficient particle statistics has been obtained. In Fig. 5a and Fig. 5b the resulting curves of the most probable energy in function of the angle can be observed for both alpha and ^{6}He emission. More precisely for the latter isotope the average energy of the particles at each angle has been used.

In Fig. 6 at least the alpha particles angular distributions relative to five energy intervals are displayed. A progressive flattening of the curves with the increasing energies is pointed out.

TABLE III

Alpha-particles energy spectra parameters at various angles.

Experimental angle	Energy distribution peak (MeV)	Standard Deviation (MeV)
68°	16.1	4.16
78°	15.2	3.72
88°	15.3	3.29
98°	16.6	3.41
118°	17.3	4.30

From the given results we can deduce the following conclusions:

i) The curve of Fig. 5a, in agreement with ref. (13), indicates that the points of minimum peak energy correspond to angles of maximum alpha particle yields; this feature is a decisive suggestion to

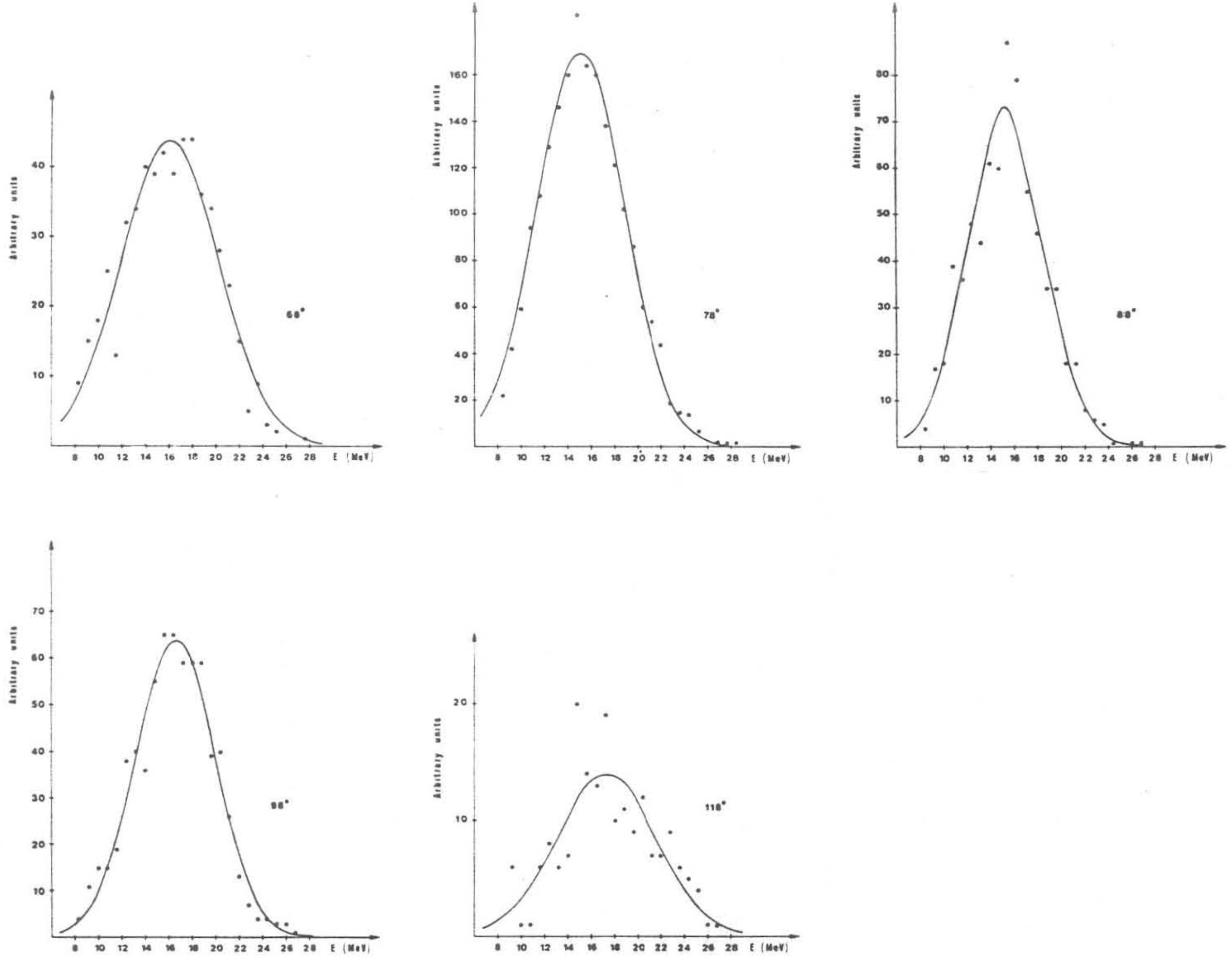
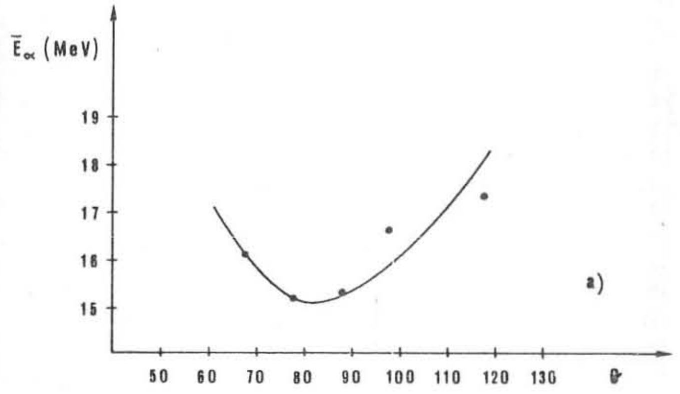
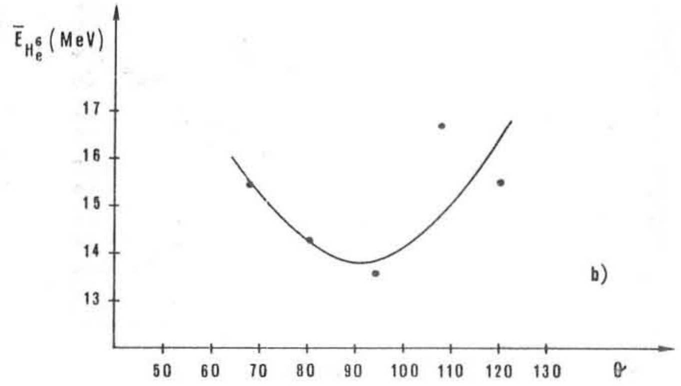


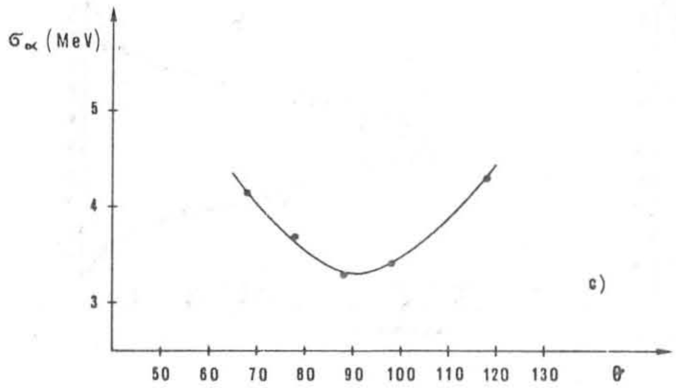
FIG. 4 - Alpha particles energy spectra at various angles referred to the light fragment direction.



Average energy of alpha particles spectra Vs. angles



Average energy of ^{6}He particles spectra Vs. angles



Standard deviation of alpha particles spectra Vs. angles.

FIG. 5

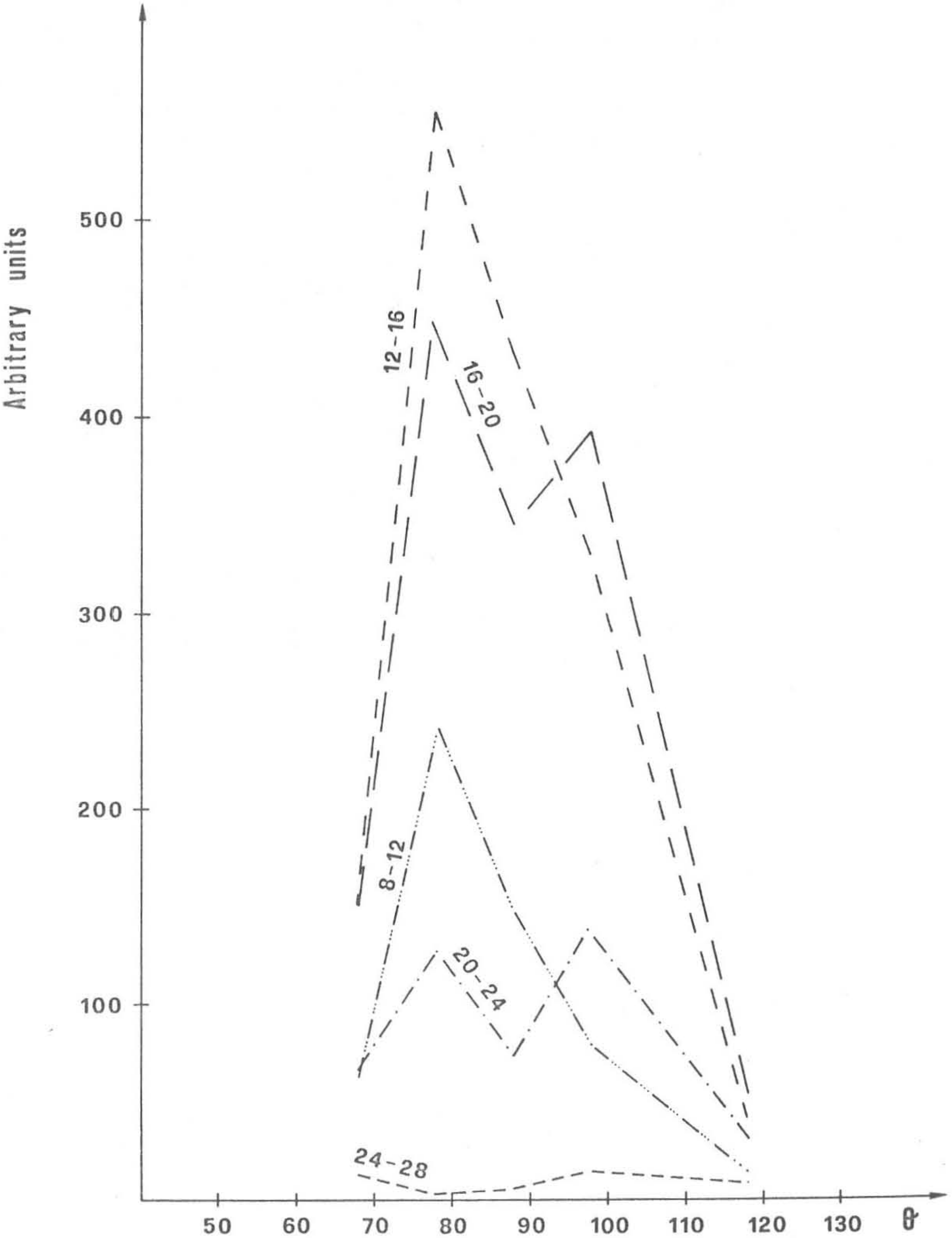


FIG. 6 - Angular distributions of alpha particles in five energy intervals (MeV).

consider the potential-energy minimum as the most probable emission point of these particles. We note here that a distribution around this point has been obtained in ref. (8) for the particle emission coordinates.

ii) The behaviour of the average particle energy versus asymptotic angles concerning ^{6}He particles emission (Fig. 5b), seems to indicate that the most probable angle does not correspond to the potential-energy minimum. One can explain this trend by considering the average release point of ^{6}He nearer one of the two fragments than that relative to the alpha particles; in these conditions the transfer probability of nucleons from the fragment to the forming particle would be increased.

iii) The uncertainty principle and the consideration of Fig. 5c, where the alpha spectra standard deviation versus angle is considered, can provide us with the idea that the particles observed at various angles are derived from different states where the largest mean-lives are attributable to the states corresponding to the angles of maximum yield (and minimum mean energy).

iv) We interpret the progressive flattening of the particles angular distributions as their energy is increased (see Fig. 6) as a consequence of a smaller influence of the initial emission angles at the highest energies and as indication of the anisotropy of the process of the light particles emission.

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REFERENCES -

(1) - E.K. Hide, The nuclear properties of the heavy elements, (Prentice-Hall, 1964), vol. III, p. 135.
(2) - S.W. Cosper, J. Cerny and R.C. Gatti, Phys. Rev. 154, 1193 (1967).
(3) - M. Cambiaghi, F. Fossati and T. Pinelli, Nuovo Cimento 59 B, 236 (1969).
(4) - M. Dakowski, J. Chwaszewska, T. Krogulski, E. Piaseki and M. Sowinski, Phys. Letters 25 B, 213 (1967).
(5) - T. Krogulski, J. Chwaszczewska, M. Dakowski, E. Piaseki, M. Sowinski and J. Tys, Nuclear Phys. A 128, 219 (1969).

(6) - W.N. Andreiev, V.G. Nedopekin and V.I. Rogov, Theoretical and Experimental Physics, Institute of the State Comitee for Atomic Energy Use U.R.S.S., Report nº 609, Moscow (1968).

(7) - M. Cambiaghi, F. Cavallari, F. Fossati, F. Jappelli, C. Petronio and T. Pinelli, Nuovo Cimento, 11A, 716 (1972).

(8) - F. Cavallari, F. Fossati and T. Pinelli, Lett. Nuovo Cimento 2, 1217 (1971).

(9) - N.A. Perfilov and Z.I. Slov'eva, Soviet Phys. - JETP 10, 824 (1960).

(10) - C. Carles, M. Asghar, T.P. Doan, R. Chastel and C. Signarbieux, Proc. 2nd Symp. on the Physics and Chemistry Fission, Vienna 1969) (IAEA, 1966), p. 119.

(11) - E. Piasecki, M. Dakowski, T. Krogulski, J. Tys and J. Chwaszczewska, Phys. Letters 33 B, 568 (1970).

(12) - T.D. Thomas and S.L. Whetstone Jr., Phys. Rev. 144, 1060 (1966).

(13) - Z. Fraenkel, Phys. Rev. 156, 1282 (1967).

(14) - V.M. Adamov, L.V. Drapchinskii, S.S. Kovalenko, K.A. Petrzhak and I.I. Tyutyugin, Sov. J. Nuclear Phys. 13, 540 (1971).

(15) - M. Rajagopalan and T.D. Thomas, Phys. Rev. C 5, 2064 (1972).

(16) - G.M. Raisbeck and T.D. Thomas, Phys. Rev. 172, 1272 (1968).

(17) - M. Cambiaghi, F. Fossati and T. Pinelli, Nuclear Instr. and Meth. 62, 233 (1968).