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FRAGMENT ENERGY DISTRIBUTION IN THE SPONTANEOUS FISSION OF CURIUM242

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FRAGMENT ENERGY DISTRIBUTION IN THE SPONTANEOUS FISSION OF CURIUM^{242}

Richard L. Shuey

October 18, 1950

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FRAGMENT ENERGY DISTRIBUTION IN THE SPONTANEOUS FISSION OF CURIUM^{242}

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October 18, 1950

ABSTRACT

The energy distribution of the spontaneous fission fragments of Cm^{242} has been measured. Both fission fragments from a binary fission were measured simultaneously. The experimental method consisted of photographing the pulses from a double ionization chamber.

The topological features of the distribution are the same as for slow neutron fission. The fission is more symmetrical than uranium or plutonium slow neutron fission. The total kinetic energy of the fragments is greater than for slow neutron fission of plutonium. Specifically, the low and high energy peaks are at 78 and 105 Mev, respectfully. The error in these values is probably 5 Mev and it is believed that they are high by this amount. Curves of the three dimensional energy distribution, the single fragment energy distribution, total energy distribution, calculated mass yield curve, and uranium slow neutron fission calibration are presented in the text. A comparison is made with previous work in slow neutron and spontaneous fission.

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INTRODUCTION

The observations resulting from the experimental study of the fission process have lead to a better understanding of the nucleus. Meitner and Frisch[1] first pointed out the analogy between the division of a liquid droplet into two nearly equal parts and the fissioning of a heavy nuclei. Bohr and Wheeler[2] in their classical paper on "The Mechanism of Fission" performed a detailed analysis of the fission process based upon this so-called liquid drop model of the nucleus. Present and Knipp,[3] Metropolis and Frankel,[4] and others have extended the Bohr-Wheeler calculations by considering in more detail the nuclear distortions leading to fission. The results have been in fair agreement with experimental evidence except for the observed asymmetry of fission. To be specific, the liquid drop analysis indicates that the most probable fission mode should be one in which the nucleus splits into two equal parts and that this mode should result in the greatest total kinetic energy; these conclusions are not in agreement with observed facts.

Another approach to the theory of fission is to take the experimental data on the division of charge, mass, and energy between the fragment and try to deduce the mechanism of the fission process from them. Using this type of approach, the fission process has been examined in some recent papers. The known mass and fragment energy yield

curves combined with the information on fragment decay chains are useful in developing a consistent theory by such an analysis. The analyses of Way and Wigner,[5] Present,[6] Coryell, Glendenin and Edwards,[7] Kingdon,[8] and Burton[9] are of this type, but based upon different assumptions. Unfortunately, no one of these analyses seems to give a completely satisfactory result. The complexity of fission may well be such that no simple, adequate explanation exists. Nevertheless, it is evident that the understanding of the fission process would be increased if more experimental results were available.

It is believed that fission induced by a particle or gamma-ray is really the spontaneous fissioning of the nucleus after the particle or gamma-ray is absorbed.[2] In other words, the compound nucleus is actually formed and exists for a finite period of time. This nucleus is excited by the kinetic energy it has absorbed from the incident particle and the binding energy of that particle; in the case of gamma-ray induced fission, the energy of excitation is equal to the gamma-ray energy. The excitation energy leads to large distortions of the nucleus that result in fission with a very short half-life. For example, when U^{235} absorbs a slow neutron, it becomes U^{236} in an excited state and the energy of excitation is equal to the approximately 6.5-Mev binding energy of the neutron. If the excitation energy of the compound nucleus is sufficiently great, Bohr[2] has suggested that the nucleus may boil off neutrons before the fission takes place; Jungerman and Wright[10] have found some experimental evidence indicating that this mechanism exists in fission induced by high energy particles.

It is interesting to examine how the energy, mass, and charge distributions of the fragments from heavy element fission change with

the excitation energy of the nucleus. A good deal of work in the field of induced fission has already been reported by other workers. As indicated above, the nucleus in spontaneous fission is in the ground state, and the results might be quite different from that of induced fission. The present work is concerned with the energy distribution of the fragments resulting from spontaneous fission.

Jentsche[11] and others have determined the mass and energy distributions of the fragments resulting from slow neutron induced fission. The most accurate mass yield curves are those of the plutonium project staff[12] and Katcoff, Miskel, and Stanley.[13] The most recent work on the energy distribution of fragments resulting from slow neutron fission of uranium is that of Burton and Hanna,[14] and on fission fragments of plutonium, Burton and Thompson.[15] The former is a particularly comprehensive report and the authors make detailed comparisons of their results with those of the previous workers. The results of these experiments indicate that both the mass yield and energy distribution curves follow the familiar double peaked shape. In disagreement with the Bohr-Wheeler theory, practically no symmetrical fission exists and the maximum kinetic energy release does not correspond to a symmetrical fission. As the atomic number of the fissioning nucleus is increased, the fission becomes more symmetrical. It should be noted that the mass yield curve is obtained by chemical means and thus is based on the masses existing after some radioactive decay of the fission fragments has taken place. The kinetic energy measurements are obtained from ionization chambers and give the kinetic energy of the actual fragments. It follows that a mass yield curve computed from the fragment energies should not agree perfectly with the chemical curve; however, the disagreement is more than expected.[14] Direct experimental data on the charge divisions are not

available, but estimates can be made from the observed decay chains.[5,9]

Newton[16] and Goeckermann and Perlman[17] have determined the mass yield curves resulting from fission induced by high energy particles. Jungerman and Wright[10] have measured the corresponding single fragment energy distribution. Rosen and Fowler[17] and others have measured the energy distribution for fast neutron fission. The above experiments indicate that as the kinetic energy of the incident particle increases, the fission becomes more symmetrical. It follows that as the nucleus in spontaneous fission is in the ground state, we might expect the resulting fission to be less symmetrical.

Because of the chemical difficulties resulting from the low spontaneous fission rates of all known isotopes, the mass yield curve of the fragments from spontaneous fission has never been determined. The single fragment energy distribution from the self-fission of Pu^{240} has been studied by Segrè and Wiegand,[19] and Whitehouse and Galbreith[20] have reported the single fragment distribution for the spontaneous fission of natural uranium. Neither of these experiments disclosed any difference between spontaneous fission and slow neutron fission of the same isotope. The work reported in the present paper describes the double fragment energy distribution resulting from the spontaneous fission of Cm^{242}. The high fission rate of curium makes it ideal for mounting on a thin film suitable for operation in a double ionization chamber. The apparatus used is suitable for less accurately performing the same experiment, with Pu^{240}, and it is hoped that this will be done.

EQUIPMENT

A detailed description of the design and construction of the equipment used is reported elsewhere.[21] The present description will consider only the more general operational features of the apparatus.

A general block diagram is shown in Fig. 1 and indicates that the equipment consists of a double ionization chamber and its associated electronic and recording equipment. Let us follow through on the diagram the effects resulting from a fission fragment in one side of the double ionization chamber.

The sample is mounted on a thin film in the center of the cathode (see Fig. 1). Conservation of momentum requires that the fragments resulting from a binary fission go in approximately opposite directions. A binary fission will be defined throughout this paper as the splitting of a nucleus into two major fragments and possible prompt neutrons and alpha-particles. The small effects of prompt neutrons, alpha-particles, and gamma-rays on the momentum balance will not be considered. Consider the fission fragment entering the upper part of the chamber. The fragment is stopped in the cathode (source)-grid region of the ionization chamber and while being stopped, ionizes molecules of the gass filling the chamber. The electrons resulting from this ionization are collected on the plate (collector) and constitute a current into the input of the preamplifier. The number of the electrons is very nearly proportional to the energy of the fission fragment and it follows that the voltage they develop across the grid-plate capacity of the chamber is proportional to the fragment energy. The output pulse of the pre-amplifier is clipped in time by a pulse forming network(PFN) and the result fed into the amplifier. One of the amplifier outputs is fed through a length of RG-65μ delay cable to the vertical deflection plates of a synchroscope. The other output is fed to a discriminator. If the input to the discriminator exceeds a fixed value, the output provides a synchronization pulse. The synchronization

pulse (a) intensifies the cathode ray tube, (b) initiates the synchroscope sweep, (c) trips a scaler, and (d) advances the film in the camera. The photographed deflection of the cathode ray tube sweep is proportional to the fission fragment energy. As all equipment is duplicated for the other side of the chamber, both fragment energies are determined simultaneously.

It is of interest to consider the performance specifications of some of the units on the block diagram. The dimensions of the double ionization chamber are indicated in Fig. 2; the electrical connections are shown in Fig. 1. The design of the grid follows the theory of Bunemann[22] and is such that all the electrons reach the collection plate. The top seal is lead, the spacers are ceramic and the feed-through insulations are of the kovar-glass type. A 96% Argon 4% carbon dioxide mixture, prepared at this laboratory from commercial gases, was used in the chamber. The gas was continuously circulated by means of a gear pump and passed through a hot copper reducer and calcium sulfate drier. It is difficult to see how the all metal-ceramic chamber could contaminate the counting gas, and a study of fission fragment distributions for different purification conditions verified this belief.[21] We are now convinced that with the metal-ceramic chamber, the gas circulation and purification system was not needed.

The preamplifiers and amplifiers used were built around the three tube cathode feedback circuits discussed by Elmore[23] and Watkins.[24] They were operated with a bandwidth of 2 mc/s. The pulse forming network was constructed by connecting lumped capacities to continuously wound inductances and had a clipping time of approximately one-half microsecond.

The amplifier outputs were connected directly to the deflection plates of two modified synchroscopes, type TS-28/UPN. The beam voltage

for these instruments was obtained from a regulated voltage supply. Type P-11 cathode ray tubes were photographed with Leica cameras using a relative aperature of f-2 and Eastman Super XX film. The shutter was left open at all times and the film advanced after each event. Fogging of the film by the cathode glow of the cathode ray tube was eliminated by the use of a corning type 5030 Blue filter. To permit alignment checks between the two channels, at set time intervals a small electric lamp would automatically light in front of each cathode ray tube.

The ionization chamber, preamplifiers, and amplifiers were all mounted in a well shielded box. All leads to the box except the amplifier outputs passed through LC filters. The discriminator utilizes a biased blocking oscillator as the selection unit. The unit will respond to a triangular shaped pulse 0.1 microsecond wide at its base. The output pulse is 0.5 microseconds wide and 60 volts in magnitude.

The resolution of the chamber, at least for alpha-particles, was checked with a sample containing Am^{241} and Cm^{242}. With the gas mixture used, the rise time of the ionization chamber was approximately 0.3 microseconds. The voltage plateau of the chamber for fission fragments was determined with slow neutron fission fragments from U^{235}. The operating point was more than 30% above the start of this plateau.

The gain of the over-all system was frequently checked by connecting a pulser to the cathode of the double ionization chamber and grounding the grids. The shielding of the grids is not perfect and some signal is picked up on the collection plates. These checks indicated that the gain of the equipment was constant. The energy calibration was accomplished by observing the pulse size distribution of the fragments resulting from the slow neutron fission of U^{235}.

The specifications of the curium sample used are given in Fig. 3. The sample was made in the following fashion.

A film was constructed by placing a drop of formvar E-ethylene dichloride solution on the surface of a dish of water. The drop spread out on the water and formed a fairly even layer. After the ethylene dichloride had evaporated, the formvar E-film was picked up from below onto a piece of Lectromish, a commercial square grid with a transparency of about 30%. The film can just as easily be picked up onto a large ring. The weight of such a formvar E film was found to be roughly 5 micrograms/cm^2. A curium salt was then vacuum evaporated onto the side of the formvar away from the collimator. It is worth noting that not only is it possible to make large thin films by this technique, but in addition a small amount of copper or gold can be evaporated onto the film to make it conducting.

The U^{235} samples were made by evaporating uranium in the metallic state onto a platinum plate. The plate was then heated in air to oxidize the uranium.

RESULTS

The three dimensional fragment distribution for the spontaneous fission of curium^{242} is shown in Figs. 4 and 5. The data are presented as a density plot in Fig. 4 and in a summed form in Fig. 5. The summed presentation of the basic data is a form suitable for further calculations. Loci of interest are indicated in Fig. 5. It would be possible to construct a continuous plot from the data available; however, as such a construction would involve an unwarranted and possibly misleading smoothing operation, it has not been made.

The information obtained from channel I should be identical, within the statistics of the experiment, with the information obtained from channel II. In terms of the three dimensional energy plot, the distribution should be symmetrical around the equal fragment energy line. It follows that as the U^{235} calibration run, indicated that the gain of the two channels was identical, Fig. 9, the plot of Fig. 4 should be symmetrical around a 45° line through the origin.

Consider the thin curium sample. The fragments entering channel I have passed through the collimator and lost energy in this region. This is because in the vicinity of the collimator the field is insufficient to prevent the recombination of the electrons and ions formed by the fragment. Therefore, the electrons formed in the collimator region may not be counted. Experimental results reported elsewhere[21] indicate that the curium is absorbed evenly throughout the film, and therefore the small amount of energy lost in the film (less than 1 Mev) is on the average the same for fragments in both sides of the chamber. The fragments entering channel II, except for small film losses, lose all of their energy in the active region of the chamber. It is thus reasonable to assume that the data from channel II are more accurate than the data from channel I. If this assumption is made, it is possible to correct the channel I information and the three dimensional plot.[21] However, for the results of this experiment an excellent match, or good symmetry, is obtained if the origin is shifted slightly. The required shift of 1.5 units, approximately 4.3 Mev, is indicated in Figs. 5 and 6.

Several facts are worth noting with respect to this correction. First, the estimate of film loss discussed above is based upon the data of Segrè and Wiegand[25] and is believed to be conservative. Second, let us assume that all of the electrons in the region of the collimator are lost. West[26] has made

extensive measurements of the initial ionization of fission fragments in nitrogen at low pressure and extrapolated the results to standard conditions. He estimates that ionization causes the initial energy loss of fission fragments in nitrogen at standard conditions to be 6.5 Mev per mm of path length. The energy loss in the 4-mil collimator is thus expected to be roughly 6 Mev. It should be mentioned that previous experiments[21] with a much thicker collimator emphasize the importance of collimation losses and also indicate that they are larger than expected.

These observations indicate that the differences in the channel I and channel II data are probably due to collimation losses. For this reason, channel I was corrected to agree with channel II. There is no adequate explanation for the magnitude of the correction needed.

The single fragment energy distribution curves for channel I and channel II can be constructed from the three dimensional plot of Fig. 5. Fig. 6 shows the sum of events in a row plotted against the deflection or energy corresponding to that row; this is the information as seen from channel II. The channel I information is found by summing the columns and is indicated, after correction, by the small circles.

The lines of constant total deflection, or total energy, are shown in Fig. 5. The sum of events along each of these lines has been taken and the result is plotted in Fig. 7.

The constant mass ratio (or mass) lines are the radial lines drawn through the origin of Fig. 5. The segments shown were distorted so that each square of the plot was completely in one segment. The sum of the number of events in each distorted segment was taken; the resulting mass yield curve is shown in Fig. 8. A high degree of accuracy is obviously not to be expected from such a plot. Nevertheless, it is

interesting to note that as for slow neutron fission, the heavy mass peak is close to 139. Mayer[27] and Present[6] have suggested the possible importance of the so-called magic numbers in such a division.

Calibration and Errors

The basic energy calibration of the experiment was the energy distribution of the fragments from slow neutron fission of U^{235}. The U^{235} was evaporated onto two platinum plates and these were run back to back in the chamber. The samples contained roughly 100 and 200 micrograms of electromagnetically separated U^{235}, respectfully. Except for the sample itself and the Po-Be neutron source, the conditions were identical with those existing when the curium data were taken. The chamber was not designed for high neutron geometry with the result that the amount of paraffin that could be used was insufficient to slow down many of the neutrons. Fig. 9 indicates the result of the calibration run. The value of 92.7 Mev is from the paper of Burton and Hanna[14] and has not been corrected for self absorption and collimation losses. It is assumed that the absolute energy calibration of their experiment was correct. It is worth noting, however, that as many of the results of the present experiment can be compared directly with previous data on the slow neutron fission of uranium, the absolute energy calibration is not too important.

The film and collimation losses in the curium sample have been discussed previously. The uranium samples used in the experiment were less than 50 micrograms/cm^2. Using the value of Segrè and Wiegand[25] for the stopping power of uranium, the U^{235} high energy peak shift has been estimated as about 0.7 Mev.[21]

There is a chance that an alpha-particle will be emitted by one nucleus coincidental with the fissioning of another nucleus with the result that the recorded energy will be too large. Coincidental events are defined as events occurring within the resolving time of the equipment. The probability of such an occurrence can be estimated from Poisson's law. This calculation has been made and less than one out of ten fissions should have an alpha-particle superimposed on it. Less than one fragment out of two hundred will be coincidental with two alpha-particles. The shift in the high energy peak as a result of these coincidental events has been estimated as less than 0.6 Mev.[21]

It is possible that if a sufficient number of alpha pulses occur within the resolution time of the chamber, the result will be interpreted as a fission pulse. The probability that this will occur simultaneously in both chambers is insignificantly small.

The gain of the equipment was frequently checked by means of a pulse generator. It has already been mentioned that the pulse generator was connected to the sample plate of the ionization chamber and thus provided an over-all equipment check. A drift of more than 3 Mev would have been detectable, and it is expected that the error due to drift is within this limit. The possible film reading errors are of the same order of magnitude.

After the data presented here were taken, the curium sample was again placed in the chamber. A short run indicated that no detectable charge had taken place since the original run. The criteria for comparison purposes was the location of the single fragment high energy peak. The U^{235} sample was then placed in the chamber. Again, a short test run indicated that no charge had taken place.

The possibility that coupling existed between the two channels was investigated when the equipment was assembled but none was observed. Later checks, including short curium runs with only one channel operating, verified the results of this investigation. It is apparent that during the curium data taking runs, fission fragments simultaneously occurred in both channels; whereas during the U^{235} calibration runs, they did not. It follows that if any coupling existed, it would seriously affect the results. The results of every experiment to detect coupling were negative and indicated that no detectable coupling between channels existed.

All factors considered, it is expected that the absolute values of the errors in the results presented here are less than 5 Mev.

DISCUSSION

The double fragment energy distribution data of this report can be compared to the previous results from slow neutron fission. Burton and Hanna[14] have done the most recent work with uranium, while Burton and Thompson[15] have reported the latest experiments on plutonium. Their papers give a summary of the previous work.

Since the work described in the present paper was first undertaken, three other groups have reported work on the fragment energy distribution of spontaneous fission. Wiegand and Segrè[19] investigated Pu^{240}; Hanna and his co-workers[28] at Chalk River have reported some preliminary results with Cm^{242}; and Whitehouse and Galbreith[20] have studied natural uranium. All of these investigations were concerned with only one of the two fission fragments of a binary fission.

Wiegand and Segrè electroplated 17 micrograms of separated Pu^{240} onto a platinum plate.[19] The single sided fragment energy distribution was observed and compared with the results from the slow neutron fission of

the Pu^{239} present in the same sample. The energy was measured by photographing the amplified pulses from the ionization chamber. No detectable difference between the spontaneous fission of Pu^{240} and slow neutron fission of Pu^{239} was observed.

Hanna and his co-workers[28] used a sample of Cm^{242} with 4×10^7 alpha-counts per minute. A collimator of 1/12 transmission was placed over the sample. The fragment energy was detected in an ionization chamber and recorded by means of a ten pen recorder. They reported high and low energy peaks at 95 and 65 Mev, respectively. They also report a valley more shallow than for Pu^{239}, but attribute this to instrumentation errors. Their results are to be considered very preliminary.[29]

Whitehouse and Galbreith utilized a large cylindrical ionization chamber with 57 milligrams of natural uranium in a 100 microgram/cm^2 layer. No collimator was used, but a self-absorption correction was made. They compared their results with the slow neutron fission of the same sample, and no difference between spontaneous and slow neutron fission was reported.

The information on slow neutron and spontaneous fission is summarized in Fig. 10. The results for uranium and plutonium have been linearly extrapolated to curium and are given in the table. In the liquid drop model of the nucleus[2] the value of Z^2/A is an indication of the stability of a heavy nuclei, and for this reason it has been included in the table.

Burton and Hanna[14] and Burton and Thompson[15] have constructed three dimensional energy-probability plots for fission fragments resulting from the slow neutron fission of uranium and plutonium, respectively. Their results are given in the form of contour plots where the contour lines represent constant probability. Their source of neutrons was the Chalk River Pile. The data were taken on a 30-channel pulse analyzer. The copious source of neutrons and pulse analyzer resulted in data with good

statistics and in a form suitable for presentation as a contour plot. The resulting contour plots can be compared with Figs. 4 and 5 in the present work.

It is apparent that the topological features of the curium plot are the same as those for the uranium and plutonium plots. By this is meant, the general shape and characteristics are the same. From Fig. 5 it is quite clear that the maximum energy release does not correspond to a symmetric fission.

The single fragment energy distribution derived from Fig. 5 is shown in Fig. 6. The depth of the valley between the high and low energy peaks has often been taken incorrectly as an indication of the degree of symmetry of fission. It is known that most instrumentation errors spread out the two probability peaks of Fig. 4 without placing counts on the equal fragment energy line. However, when viewed from one of the energy coordinate directions, the resulting peaks overlap. This end view is in effect a single fragment energy plot. The depth of the valley is thus seen to be very sensitive to instrumentation errors and is not, from a practical standpoint, a good indication of the symmetry of fission. The ratio of the high to low energy peaks remains a good measure of the symmetry of fission. The allowed deviations from the most probable division are indicated by the sharpness of peaks in three dimensional plot and to some extent by the single fragment valley shape. Both of these properties are subject to instrumentation errors.

Consider the comparison table of Fig. 10. It should be remembered that spontaneous fission is believed to be the fissioning of a nucleus in the ground state, while in slow neutron fission the nucleus has an excitation energy equal to the binding energy of the added neutron plus the neutron kinetic energy. It was mentioned in the introduction that for particle induced fission, an increase in the atomic number of the fissioning nucleus or the kinetic energy of the

impinging particle results in more symmetrical fission. It might therefore be expected that spontaneous fission, as it is the splitting of a nucleus in the ground state, would be less symmetrical than slow neutron fission. The U^{238} and Pu^{240} results indicate that the lack of excitation energy in spontaneous fission is not an important factor in determining the mode of fission. The topological features of the Cm^{242} plot verify this indication. It might be mentioned that in view of the small differences existing between slow and fast neutron fission[18] this conclusion is not surprising. The energetic causes determining the fission division probably correspond to energies larger than 10 Mev. In light of the above, it would seem logical to attribute the differences between uranium slow neutron fission and curium spontaneous fission to the higher atomic number and greater mass of curium. Let us consider what these differences are. The table of Fig. 10 is a convenient basis for comparisons.

The positions of the high and low energy peaks reported in the present work are higher than expected from the extrapolation of Fig. 10 and are also higher than the Chalk River results. The ratio between the high and low energy peaks reported here is near the expected value and the Chalk River value high. It should be remembered that the Chalk River figures are of a preliminary nature.[29] The ratio between the high and low energy peaks is an indication of the most probable mass division in fission. The extrapolated value and the value reported here are consistent with the viewpoint that the heavy fragment mass is constant. It may be recalled that this is experimentally true for slow neutron fission, and has been associated with the magic neutron and proton numbers.[6] Hanna[29] has indicated that the Chalk River value is in error but the magnitude of this error is not known to the author.

The surprisingly high energy reported here combined with the reasonable value of peak ratio raises the question as to how valid the energy calibration is. The calibration method, checks, and errors have been discussed previously. Only the self-absorption, film absorption, and alpha background errors are different from the uranium and curium runs, and the sum of these differences should be less than two Mev. If there is a large error in the estimates of the initial energy loss of fission fragments, the difference may be larger. It is felt that the Chalk River results are probably low and the values reported here high. Support is given to this feeling by the recent report[29] that self-absorption and collimation corrections should be made to the preliminary Chalk River figures. The size of these corrections is not known.

There is no experimental evidence to support the feeling that the results of the present experiments are high, and, therefore, the calibration has been left unchanged. It is expected that the measurements are correct with plus or minus 5 Mev, or roughly 5 percent. The disagreement with the Chalk River results is not explained.

It is clear that if the results of the present work are correct, the kinetic energy released in the spontaneous fission of curium^{242} is considerably greater than that liberated in the slow neutron fission of U^{235}. We have seen that this difference is probably a property of the elements involved and not a difference between spontaneous and slow neutron fission. It is interesting to consider the possible reasons for the increase in the kinetic energy released.

Assume first that the mode of fission in going from uranium to curium remains constant. The binding energy of the curium nucleus is known to be greater than that of uranium. A crude estimate of this difference

can be obtained by adding the alpha-decay energy[30] of Cm^{242} to that of Pu^{238}; the result is roughly 11.6 Mev. Seaborg has suggested that if the results of this experiment are assumed to be 5 percent high, the increased binding energy of curium may account for most of the additional fission kinetic energy. Because the basic calibration of this experiment was with uranium, the comparison between uranium and curium is given in preference to that between curium and plutonium.

Second, Bohr has pointed out[2] that for a given nucleus, as fission becomes more symmetrical, the total energy released should increase. Obviously, the end products of the decay chain should be different. The chemical mass yield curve for curium fission is not known, but the present ionization chamber results indicate the fission is probably more symmetrical and at least the initial division is more symmetrical.

Third, we can consider the total energy released constant. It is known that the total energy released in the fission of U^{235} is greater than 200 Mev.[32] The difference between the total energy and the sum of the fragment kinetic energies is accounted for by the prompt neutrons, prompt gamma-rays, and radioactive fragment decay chains. The kinetic energy of the fragments would be greater if less energy were carried away by prompt neutron and gamma-rays. A decrease in the initial binding energies of the fragments would have the same effect and would change the decay chains.

It is seen that there are three effects which could make the fission fragment energy of curium greater than that of uranium: namely, the greater binding energy of curium; the more symmetrical fission of curium; and, a redistribution of energy lost by prompt neutron, prompt gamma-rays, and fragment decay chains. These effects are undoubtedly not independent. The increased kinetic energy released by the fission of curium and that of uranium can be largely explained by the first two effects. The remaining

energy could be accounted for by small changes of the third type or of the mode of fission. The present experiment does not provide sufficient data to permit an accurate estimate of the relative importance of these three effects.

SUMMARY

The energy distribution of the spontaneous fission fragments of Cm^{242} has been measured. Both fission fragments from a binary fission were measured simultaneously. The topological features of the distribution are the same as for slow neutron fission. The fission is more symmetrical than uranium or plutonium slow neutron fission. The topological and symmetry changes are believed to be differences resulting from the change of elements and not a difference between spontaneous and slow neutron fission. The total kinetic energy released is greater than that released for plutonium or uranium fission.

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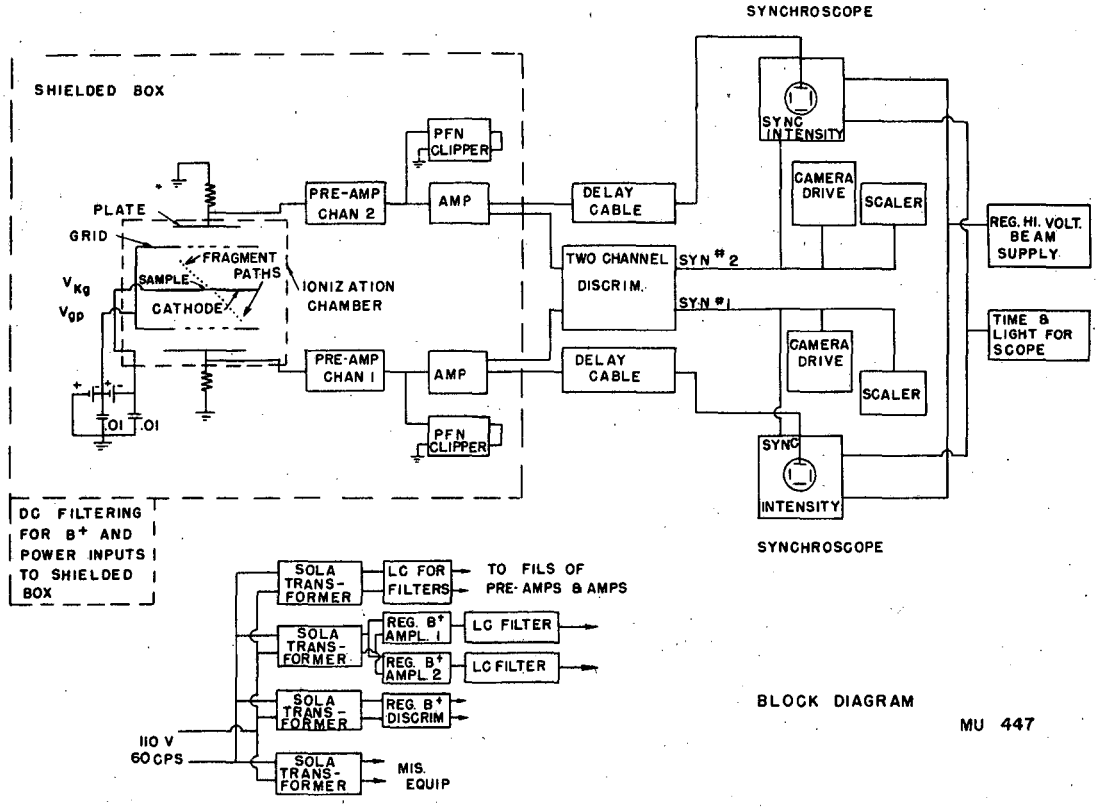


Fig. 1

General Block Diagram of Double Ionization Chamber and Associated Electronics

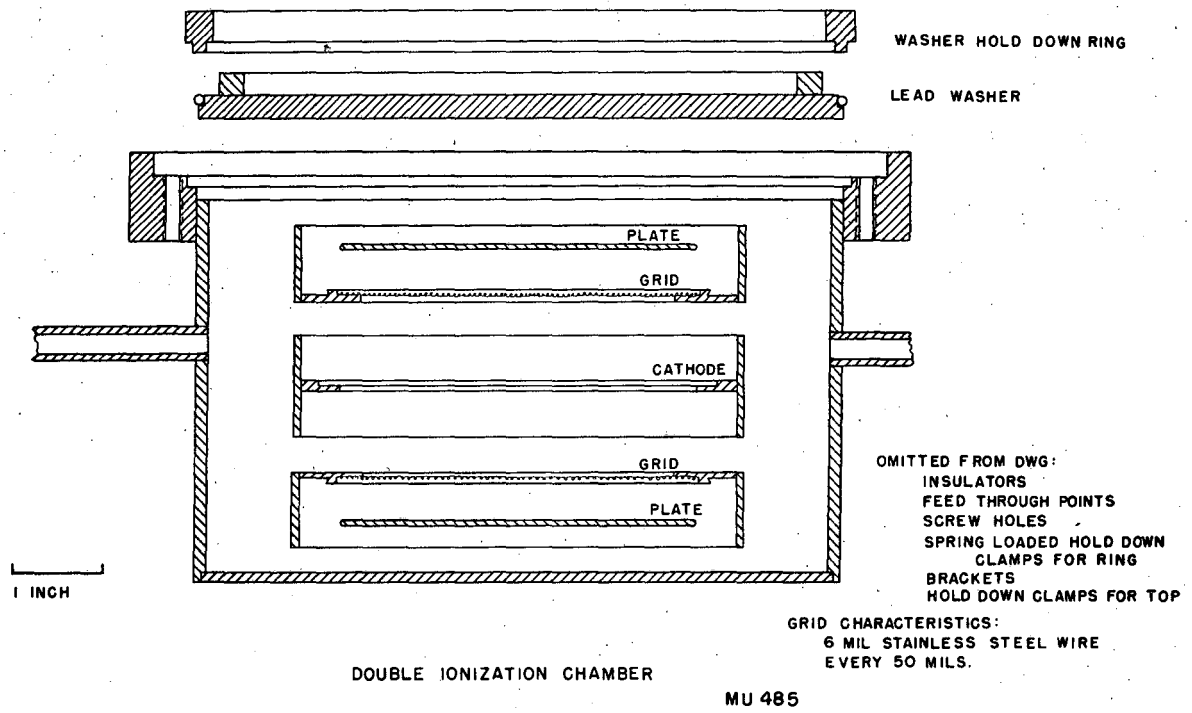
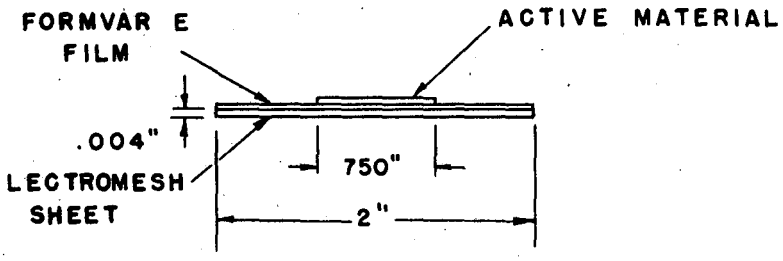


Fig. 2

The drawing shows a section view of the double ionization chamber. It is intended to show dimensions only. Electrical connections are shown in Fig. 1

Cm^{242} Sample



Active material: Cm^{242}

Collimation one side

9.3×10^6 ac/m non-collimated side

Purifier: oxygen absorber, drier and circulating pump

Pressure: 4 lbs/in^2 Gauge

Sample-grid field strength = 1500 volts/in^2

Grid-collector field strength = 3000 volts/in^2

Lectromesh: a commercial square grid about 30% transparent. The collimation removes all particles below 30^o.

Preparation: vacuum evaporation

MU 497

Fig. 3

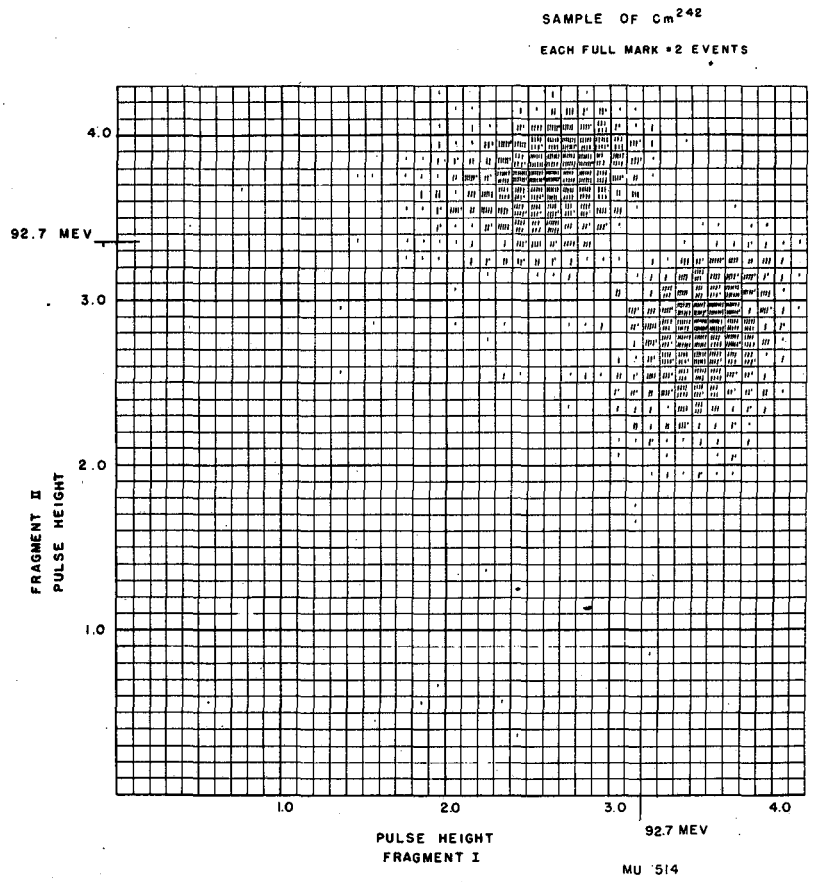
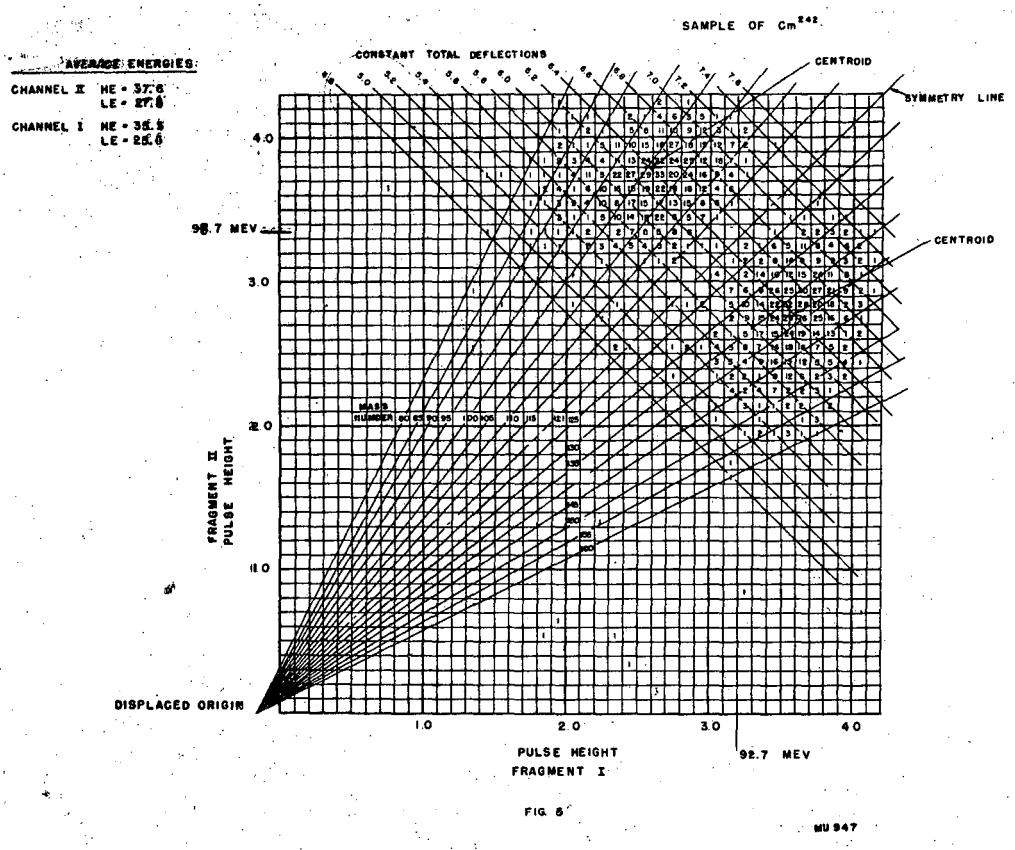


Fig. 4

Three dimensional spontaneous fission fragment energy distribution for curium^{242}



Three dimensional spontaneous fission fragment energy distribution for curium^{242}

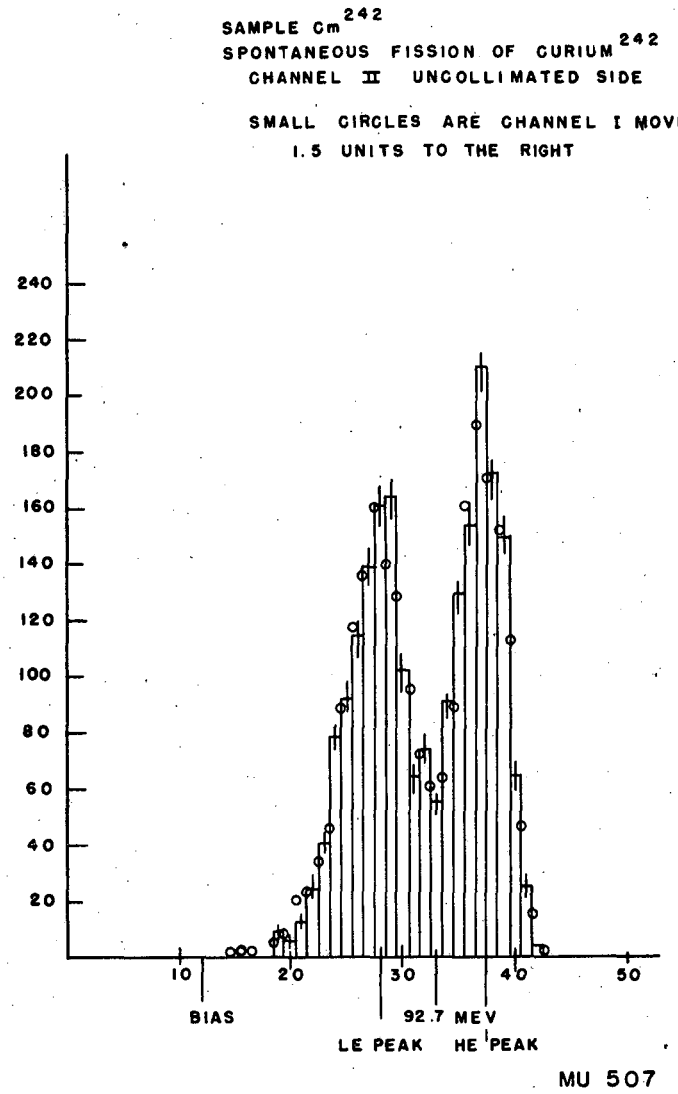

SAMPLE Cm 242
SPONTANEOUS FISSION OF CURIUM 242
CHANNEL II UNCOLLIMATED SIDE
SMALL CIRCLES ARE CHANNEL I MOVED
1.5 UNITS TO THE RIGHT
Number of Events
240
220
200
180
160
140
120
100
80
60
40
20
10
20
30
40
50
BIAS
92.7 MEV
LE PEAK
HE PEAK
MU 507
Pulse Height

Fig. 6

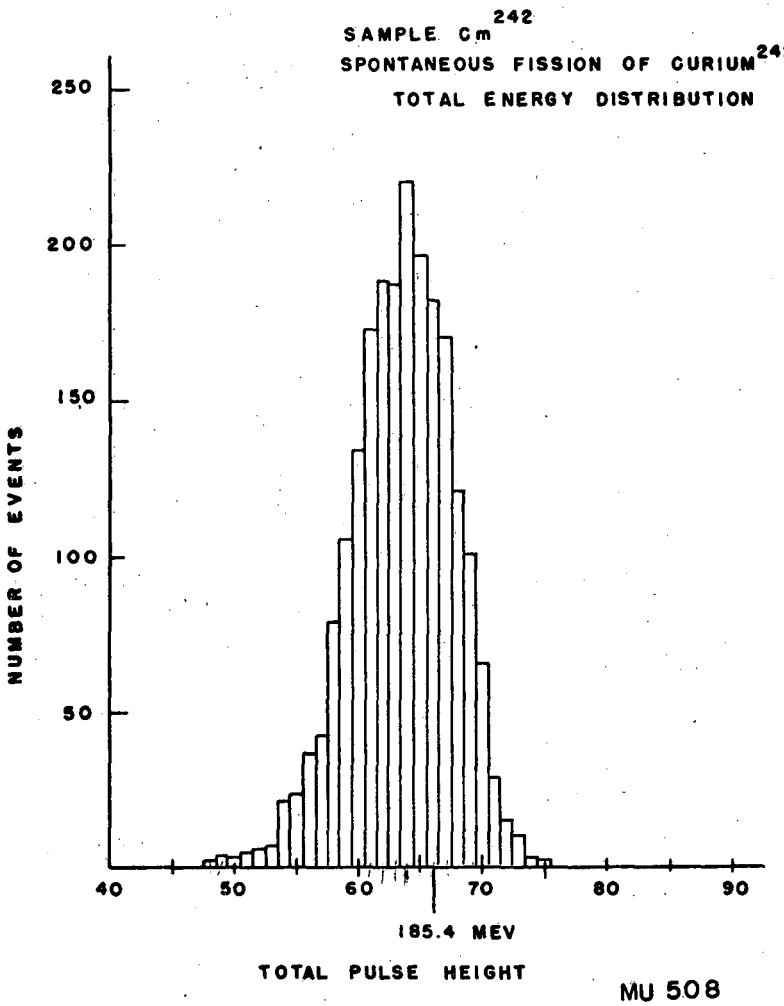
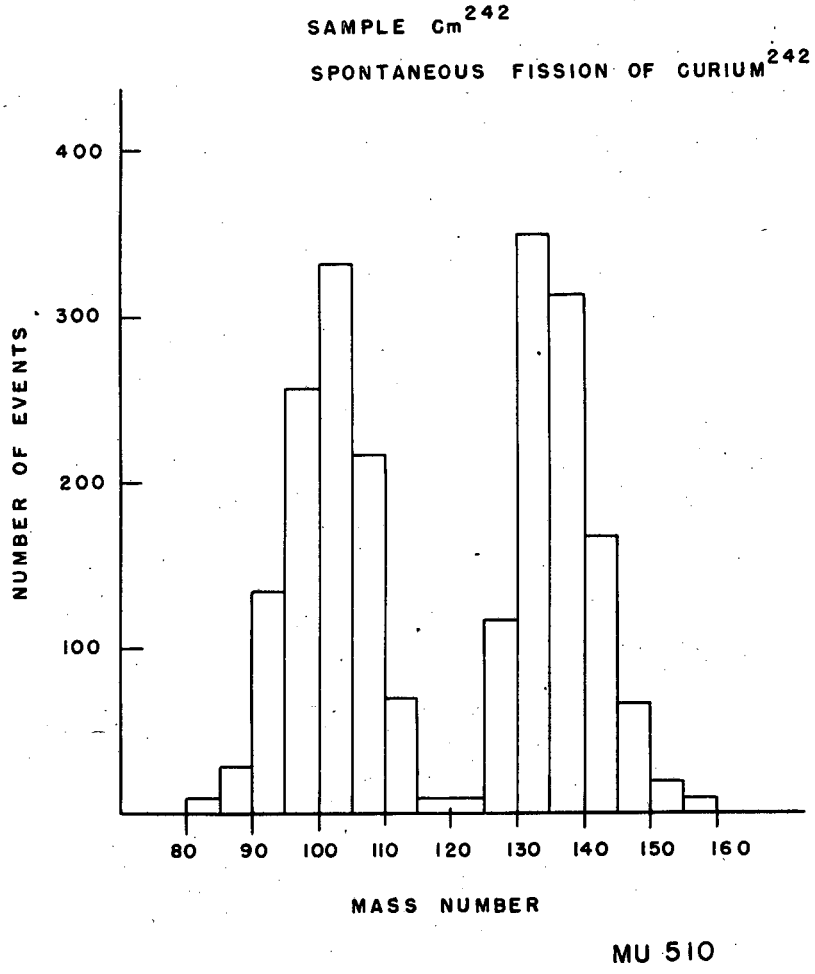

SAMPLE Cm242
SPONTANEOUS FISSION OF CURIUM242
TOTAL ENERGY DISTRIBUTION
NUMBER OF EVENTS
250
200
150
100
50
40
50
60
70
80
90
185.4 MEV
TOTAL PULSE HEIGHT
MU 508

Fig. 7



Mass Yield Curve

Fig. 8

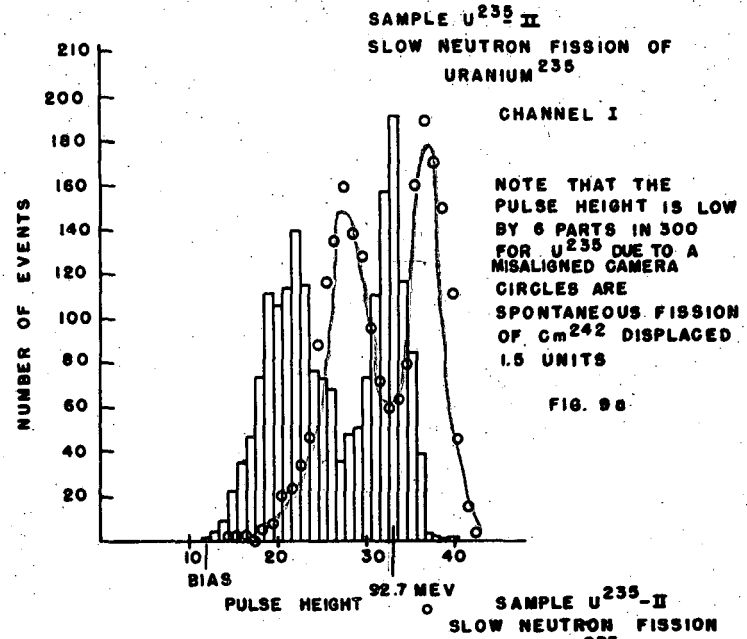


FIG. 9a

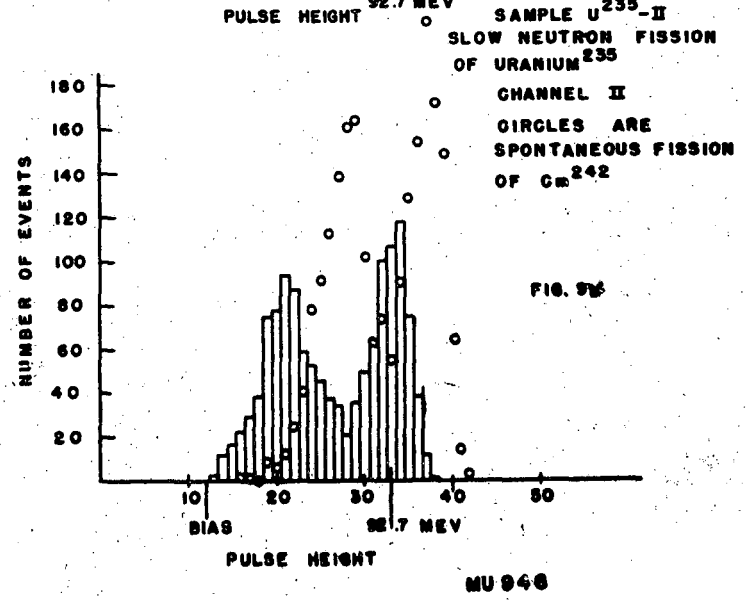


FIG. 9b

MU 946

161871

FIGURE 10

Material	HE Peak	LE Peak	HE/LE	Total E	Z^2/A	E_t/E_tU^{233}	Ref.
*Th^{232}	92.6	58.3	1.58	150.9	34.9	1.02	18
*U^{233}	91.2	55.5	1.64	146.7	34.8	1.00	14
*U^{235}	92.7	59.0	1.57	151.7	36.0	1.03	14
**U^{238}	See note				35.6		20
*Pu^{239}	93.3	63.9	1.47	157.2	37.0	1.07	15
**Pu^{240}	See note				36.8		19
Cm^{242}(Extr)	93.9	68.8	1.37	162.7	38.1	1.11	
Cm^{242}(CR)	95	65	1.46	160	38.1	1.09	28
Cm^{242}(UC)	105	78	1.35	183	38.1	1.25	

*Slow Neutron Fission

**The statistics of these data are not very good. When compared to U^{235} or Pu^{239} no difference is reported outside of the statistical fluctuations.