# Energy Spectrum of Spontaneous Fission Fragments*

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The energy spectrum of spontaneous fission fragments of $Pu^{240}$ is compared with the same spectrum for slow-neutron fission of $Pu^{239}$. No significant difference was found, and the interpretation of this result is discussed.

THE energy spectrum of fission fragments for fission induced in $Pu^{239}$ by slow neutrons has been investigated recently by Deutsch,[1] who measured the ionization produced by the fission fragments. There is also detailed information of the yield of the various chains based upon chemical evidence.

It is of considerable interest to compare the energy spectrum of spontaneous fission of $Pu^{240}$ with that of the slow-neutron-induced fission of $Pu^{239}$. The nucleus undergoing fission is in both cases $Pu^{240}$, the only difference being that in the case of spontaneous fission it is in the fundamental state, whereas in the case of slow-neutron-induced fission it has an excitation of about 5 Mev. This excitation reduces the "half-life" for fission from $1.25\times10^{11}$ years to an estimated $10^{-15}$ second, i.e., by a factor $10^{34}$. Now one could think that in the case of spontaneous fission, only a very special type of nuclear motion may be conductive to fission and that only one or very few types of fragments would be emitted. If this were true, the energy spectrum would contain one pair or very few pairs of lines (pairs because there are always one line due to the heavy fragment and one line due to the light fragment).

It can be remarked, however, that even if only one type of motion ends in spontaneous fission, the two fragments, *after* having passed the potential barrier so that their destiny of coming apart is fixed, may interchange nuclear matter and hence change their relative mass and energy.

In order to settle these problems experimentally, we have investigated the energy spectrum of spontaneous fission of $Pu^{240}$ and compared it with that of slow-neutron fission of $Pu^{239}$. The results of the investigation do not show any very great difference between the two spectra, a fact which could be interpreted by the assumption that several types of motion lead to spontaneous fission—in other words, that there are several passes through which the potential barrier can be crossed by the fragments. Another possible interpretation would be a reshuffling of nuclear matter after the crossing of the barrier as mentioned above.

It must be pointed out, however, that the experiments are not completely conclusive because the resolution of the apparatus used has turned out to be relatively poor, as one can see by comparing, e.g., the spectrum of the slow-neutron fission fragments of $Pu^{239}$ measured by Deutsch with ours. It does not appear to us that it would be expedient to try to improve our technique by a large margin, and we would rather suggest a chemical approach to the problem, namely, observation of the yields of the various chains in spontaneous fission. This procedure seems feasible if one operates with about 50 grams of Pu containing about 2 percent $Pu^{240}$. Special precautions should, of course, be taken to prevent the multiplication effects from playing an important part in determining the rate of fission in the material. This can be obtained, e.g., by working with very small batches or by using some protective substance, such as boron or cadmium, in the solutions.

In our experiment the ionization produced by the spontaneous fission fragments emerging from a thin layer of Pu was measured with a linear pulse amplifier and recorded photographically. With the same apparatus and samples, we recorded also the ionization produced by slow-neutron fission fragments.

The chamber used contained purified argon and operated on electron collection. The collecting electrode had a screen grid shield in order to make the pulse size independent of the place at which the ions originated.

The data from a resolution test using alpha particles from natural uranium showed the two groups resolved and their energies in the correct ratio.

The sample used in the fission-fragment energy experiment was a deposit of plutonium one cm in diameter electroplated on 0.005-inch thick platinum. The sample weighed about $17\times10^{-6}$ gram, the measurement being made by counting the alpha activity (7 percent of the Pu was $Pu^{240}$). The sample gave 1.91 spontaneous fissions per hour. Seven hundred and fifty spontaneous and 839 slow-neutron-induced fissions were used in our histograms.

The linear amplifier used had a time of rise of 0.2 microsecond. The time of collection of the electrons in the chamber was about one microsecond and the decay time of the amplifier was 5 microseconds. This resistance-capacitance decay time resulted in considerable loss of pulse height but was necessary because of the fluctuating background of the alpha-particle ionization when the apparatus was adjusted to record

* This paper is, with minor literary changes, a report dated December 19, 1949, of work done at the Los Alamos Scientific Laboratory and at the Radiation Laboratory of the University of California. It has recently been declassified.
[1] M. Deutsch and M. Ramsey, U. S. Atomic Energy Commission Report MDDC-945 (unpublished).

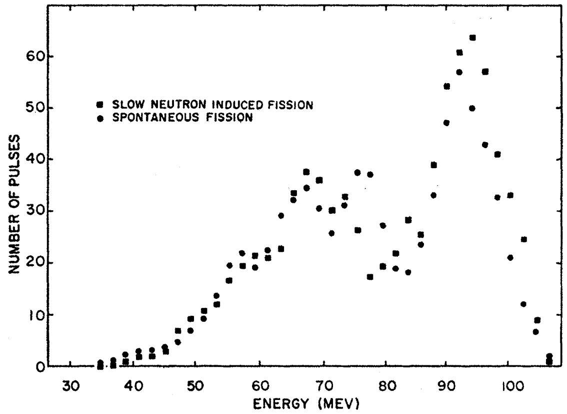


FIG. 1. Histograms of the ionization produced by spontaneous fission pulses of $Pu^{240}$ and by slow-neutron fission pulses of $Pu^{239}$.

fission pulses. However, an absolute determination of the energy of the fission fragments was not needed since a comparison was made with fragments produced by slow neutrons. The recording was done by feeding the output of the amplifier to an oscilloscope and photographing the screen.

In order that drifts in gain of the amplifying equipment could be detected and corrected for, a series of pulses from a standard pulse generator was impressed on the film at the beginning and end of each run. For this calibration the pulse generator was connected directly to the screen electrode of the chamber and, by capacitance coupling to the collecting electrode, the pulse was fed through the entire apparatus.

Figure 1 presents a histogram of the spontaneous-fission pulses recorded. For comparison the pulse-height distribution of slow-neutron-induced fissions is shown on the same graph. The induced-fission curve was obtained with the same apparatus and sample. The slow neutrons were obtained from a radium-plus-beryllium source with water as the slowing-down medium.

The abscissa scale is a scale of deflections of the oscilloscope, in arbitrary units. We assume that the energy of the fragment is proportional to the organization produced. Under this assumption we have calibrated the abscissa scale in such a way that the energy corresponding to the light fragment peak is 93 Mev as measured by Deutsch.[1] In the ordinates we have the number of pulses giving an ionization between definite limits.

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# Spontaneous Fission Systematics

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Previous correlations of spontaneous fission half-lives *vs* $Z^2/A$ predict that the half-lives of even-even isotopes increase with $A$. A deviation from the above correlation is discussed, and it is shown that the spontaneous fission half-lives of the even-even isotopes go through a maximum with increasing $A$. The shorter spontaneous fission half-lives beyond the maximum may be a result of the greater deformations of the larger-$A$ nuclides. Some comments are made on fission thresholds.

THE most successful correlations of spontaneous fission half-lives to date are those of Seaborg[1] and Whitehouse and Galbraith.[2] These authors plotted the logarithm of the spontaneous fission half-lives of several nuclides as a function of the parameter $Z^2/A$, and observed that the logarithm of the spontaneous fission half-lives of even-even nuclides decrease with increasing $Z^2/A$ values in a linear manner. Whitehouse and Galbraith point out that the exception of $U^{234}$ is so striking that the question of experimental error cannot be dismissed.[2] Ghiorso *et al.*[3] remeasured the spontaneous fission half-life of $U^{234}$ and confirmed the earlier results.

The purpose of this note is to call attention to a consistent deviation from the $Z^2/A$ relationship suggested by the above authors,[1,2] and in addition to point out a new relation, namely, that each group of even-even isotopes exhibits a maximum stability toward spontaneous fission. The latter phenomenon suggests the possibility of obtaining information on nuclear deformation and nuclear configuration from spontaneous fission half-lives.

At constant $Z$, the $Z^2/A$ parameter predicts that the spontaneous fission half-lives of even-even nuclides increase with increasing values of $A$. For example, at constant $Z$ an increase of two mass units in the heavy region of the periodic table should produce a tenfold increase in spontaneous fission half-life. This can be readily calculated using the slope of the spontaneous

[1] G. T. Seaborg, Phys. Rev. **85**, 157 (1952).
[2] W. J. Whitehouse and W. Galbraith, Nature **169**, 494 (1952).
[3] Ghiorso, Higgins, Larsh, Seaborg, and Thompson, Phys. Rev. **87**, 163 (1952).