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A.G.Popeko, G.M.Ter-Akopian

MEASUREMENT OF THE ^{238}U SPONTANEOUS-FISSION HALF-LIFE BY DETECTING PROMPT NEUTRONS

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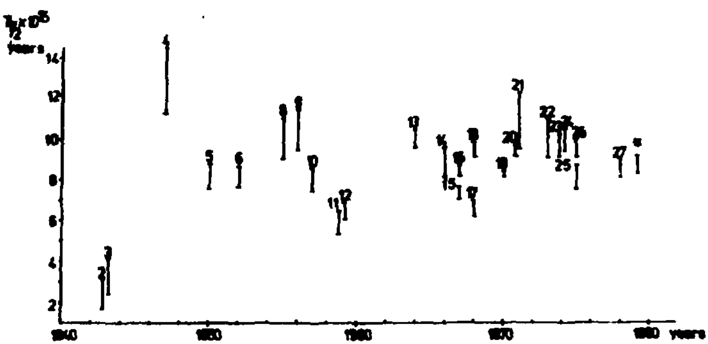
The discovery of the spontaneous fission of uranium by Petrzhak and Flerov [1] was followed by a number of studies in which one of the main characteristics of this phenomenon - half-life - was measured [2-27] (figure). The data published by various authors often differ from each other considerably. For instance, the values of $T_{1/2} = (5.8 \pm 0.5)\cdot 10^{15}$ years and $T_{1/2} = (42 \pm 6)\cdot 10^{15}$ years are given in refs. [11] and [7], respectively. Such a large difference in data seems to be associated not only with difficulties in accumulating sufficient statistics in detection of uranium fission, but also with the implicit systematic errors involved in determination of the absolute values of the efficiency of the decay detection methods.

In the recent years we have observed the explicit tendency of the approach of the measured values of the uranium spontaneous fission constant, and it is conceivable that the accuracy achieved is sufficient for nuclear physics. However, for some applied fields, such as geochronology [30] and the search for spontaneously fissioning superheavy elements in naturally occurring samples [28], it is necessary to have more reliable data on the fission of ^{238}U.



Measured values of the ^{238}U spontaneous-fission half-life.
* - present work.

The experiments to search for elements of $Z > 108$, initiated in 1968, stimulated the development of new sensitive methods of detecting spontaneous fission events [28]. These methods allowed one to return again to the problem of determination of the spontaneous-fission half-life of uranium.

To carry out searches for superheavy elements of $Z > 108$, we have developed neutron multiplicity detectors [28]. The use of such detectors for recording the rare events of fission is based on the fact that in nuclear fission the probability of the emission of more than one neutron is high. For instance, in the fission of ^{238}U, two and more neutrons are emitted in more than 65% of spontaneous fission events [29]. The use of the detector with sufficiently high efficiency for single neutrons, ϵ, makes it possible to record with high probability the multiple coincidences of neutrons and thus identify spontaneous fission events in a massive sample.

The detector had the form of a cylindrical paraffin unit, into which were placed 28 proportional counters filled with ^{3}He at a pressure of 7 atm. The counters were 500 mm in length and 32 mm in diameter. Each counter had an autonomous amplification channel. The resolving time for pulses arriving in one channel was equal to 1.5 μsec, and it was 0.03 μsec for pulses arriving in different channels. An uranium sample was placed in the centre of the detector. The average neutron lifetime in the detector, τ, appeared to be equal to 40 μsec. All measurements were done at the fixed value of the time resolution of the coincidence circuit, $T = 5\tau = 200$ μsec. The singles detection efficiency in the central part of the sensitive volume of the detector was $\epsilon = 0.38$.

To determine the counting rate for multiple neutron coincidences, measurements were carried out with a thin plate of metallic uranium. The plate was made of uranium depleted of the isotope ^{235}U. The ^{238}U content was $P = (945.0 \pm 0.3)$ g. The counting rate for coincidences of neutrons with multiplicity $n \geq 2$ was $N_n = (0.972 \pm 0.003)$ per sec. To determine the counting rate of spontaneous fission events, one should determine the detection efficiency F_n for neutron multiple coindidences. The F_n value can be calculated from the data on the probability $P(\nu)$ of emission of different numbers of neutrons in the spontaneous fission of ^{238}U (ref. [29]) and the value of ϵ, the singles detection efficiency. However, more precise results can be obtained by a direct calibration of the detector using the method of detecting the coincidences of fission fragments and fission neutrons. For this purpose an ionization chamber was placed in the sensitive volume of the detector. On the electrodes of the chamber had been deposited a uranium layer. After being shaped, the pulses due to spontaneous fission fragments arrived to trigger the neutron detection system. In measurements lasting about three months, 42682 fission fragments and 6951 coincidences of a fragment with two and more neutrons have been recorded. These measurements allow one to estimate the value of $F_n = 0.163 \pm 0.002$. The measurements performed also permit estimation of the number of spontaneous fission events per second in one gram of uranium:

$$N = \frac{N_n}{F_n P} = (6.31 \pm 0.25) \times 10^{-3}\ \text{sec}^{-1}\ \text{g}^{-1}\ .$$

ERRORS OF RESULTS

The error of the half-life determination using the mentioned method depends mainly on the accuracy of determining the efficiency of detection of multiple neutron coincidences. The determination of the absolute values of detection efficiencies for fission fragments and neutrons is unnecessary. It is only important that the singles detection efficiency be constant both in the measurements of the counting rate for multiple neutron coincidences and during the calibration of the detector.

The time constancy of detection efficiency for single neutrons, ϵ, was recurrently checked by a reference neutron source. The relative instability of the ϵ value did not exceed 0.2%. Particularly we compared the efficiencies of neutron detection in measurements with the ionization chamber and uranium samples. The difference between the efficiencies can be connected with the angle discrimination of the neutrons recorded in coincidence with fragments. Control measurements were done using a ^{242}Pu sample, which was deposited into one of the electrodes of the ionization chamber. In the measurement of the counting rate of multiple coincidences of neutrons emitted by ^{242}Pu, the ratio of the double to-triple neutron coincidences was $N_2/N_3 = 4.91 \pm 0.09$, whereas during the detection of fission fragment and neutron coincidences it was $N_2/N_3 = 4.93 \pm 0.07$. From comparing these values we can conclude that the possible relative difference in the neutron detection efficiencies does not exceed 1.5%.

To decrease the neutron multiplication effect we carried out measurements using uranium samples having the form of thin plates with a low ^{235}U content. The plate weight varied from

0.9 to 3.2 kg. The measured results and direct calculations show that the increase in the counting rate does not exceed 0.5% for multiple neutron coincidences due to (n,f) reactions.

In order to take into account the cosmic-ray induced fission of uranium, we compared counting rates for neutron multiple coincidences in measurements in the laboratory and in a salt mine at a depth of 430 m underground. It has been established that the probability of induced fission is negligibly small. Within the indicated errors, the following value has been obtained for the spontaneous fission half-life of ^{238}U :

$$T_{1/2} = (8.8 \pm 0.4)\times 10^{15} \text{ years.}$$

This value (see figure) agrees with the data of a number of authors. The method we used to determine the half-life of uranium can also be employed to study the isotopes whose spontaneous fission is difficult to detect because of a small absolute value of fission probability or as a result of α-decay predominance.

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