# *INVESTIGATION OF GAMMA RAYS EMITTED IN $U^{235}$ FISSION INDUCED BY 2.8 AND 14.7 Mev NEUTRONS*

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Submitted to JETP editor August 30, 1957

J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 331-333 (February, 1958)

Gamma rays coinciding in time with fission fragments were recorded with a scintillation counter. It is shown that the $\gamma$-ray spectrum is the same for $U^{235}$ fission induced by 2.8 and 14.7 Mev neutrons as for fission induced by thermal neutrons. It is concluded that the total quantum energy per $U^{235}$ fission event induced by 2.8 and 14.7 Mev neutrons is the same to within 15% as that for thermal fission by neutrons.

SEVERAL recent works[1-4] are devoted to a study of the $\gamma$ rays emitted by fission of heavy nuclei. These works have investigated the spectrum of the $\gamma$ rays and the average total $\gamma$ quantum energy per fission event.

The varied values of the residual fragment energy after emission of "prompt" neutrons, and the large number of the fragments themselves, result in a rather complicated $\gamma$ spectrum, resembling a continuous spectrum whose intensity diminishes rapidly with increasing energy. Individual monochromatic lines have been noted in Refs. 5 and 6, but their intensity is small relative to the background of the main spectrum. It is possible that some of these lines are due to the superposition of $\gamma$ transitions of nearly-equal energy in different nuclear fragments. The total energy of the $\gamma$ rays emitted in $U^{235}$ fission induced by thermal neutrons, in accordance with recent investigations,[2,4] is estimated at approximately 7.5 Mev, with approximately eight $\gamma$ quanta produced per fission.

Leachman[2] calculated the energy emitted by the excited fragments in the form of $\gamma$ rays and obtained values of 3.8 and 4.1 Mev for fission of $U^{235}$ by thermal and 3-Mev neutrons respectively. The value obtained by Leachman, as can be seen from the above, does not agree with experiments on fission of $U^{235}$ by thermal neutrons. No $\gamma$-ray investigation has been made for fission by high-energy neutrons.

In the present work we investigated the emission of $\gamma$ rays in $U^{235}$ fission by 2.8 and 14.7 Mev neutrons. A coincidence circuit was used to measure the spectrum of the $\gamma$ quanta that coincide in time with $U^{235}$ fission induced by both fast and the thermal neutrons. By subsequently comparing the experimental spectra it is possible to draw conclusions concerning the $\gamma$ rays that accompany the fission of $U^{235}$ by fast neutrons.

Figure 1 shows the block diagram of the apparatus employed. The $\gamma$ quanta were recorded with a scintillation counter with a NaI (T1) crystal and a FEU-S spectrometric photomultiplier. Two pulses were picked off simultaneously from the photomultiplier, one fed through a linear amplifier to a multi-channel amplitude analyzer, and the second to the coincidence circuit. The operation of the scintillation counter was checked against a $Cs^{137}$ compound with a single-channel analyzer.

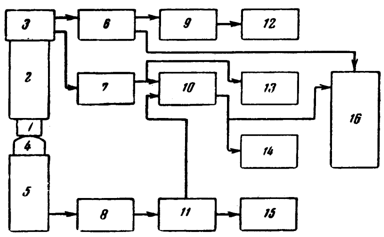


FIG. 1. Block diagram of the apparatus. 1 – NaI(T1) crystal, 2 – photomultiplier, 3 – cathode follower; 4 – ionization chamber; 5 – preamplifier; 6, 7, 8 – linear amplifiers; 9 – single-channel amplitude analyzer; 10 – coincidence circuit; 11 – pulse-delay regulating network; 12, 13, 14, 15 – counting devices; 16 – multi-channel amplitude analyzer.

The fission fragments were recorded with a multi-layer ionization chamber, filled with a mixture of argon (95%) and carbon dioxide (5%) at a pressure of 760 mm Hg. The layers of the uranium oxide, containing 97.8% $U^{225}$, were coated on the electrodes of the chamber by electrolysis, to a mean density of 1 mg/cm$^2$. The total weight of the uranium oxide coated on the electrodes was 100 mg. The chamber pulses were fed through a linear amplifier to the coincidence circuit.

Upon simultaneous receipt of pulses from the scintillation counter and from the fission chamber, the coincidence circuit triggered the multi-channel amplitude analyzer, which photographed the pulses from the cathode ray tube on a moving photofilm. To compensate for the time shifts of the pulses arriving at the coincidence circuit, a network was used to regulate the delay of the pulses from the ionization chamber. The resolving time of the coincidence circuit was $2 \times 10^{-7}$ sec.

Neutrons of energy 2.8 and 14.7 Mev were produced through $D(d, n)He^3$ and $T(d, n)He^4$ reactions by bombardment with 180-kev deuterons. The fission chamber was placed 10 cm from the neutron source. This made it possible to obtain uniform neutron-flux density on the chamber layers. When operating with fast neutrons, the chamber was covered with a layer of cadmium. The thermal neutrons were obtained by moderating the fast neutrons with lead (10 cm) and paraffin (25 cm). In all measurements, the relative placement of the fission chamber and the crystal with photomultiplier was maintained strictly constant.

The amplitude distributions of the pulses, obtained as a result of the measurements, are shown in Fig. 2 (which shows also the amplitude distribution obtained with $\gamma$ rays from $Cs^{137}$). It is seen from the diagram that in all cases the spectra have the same form within the measured range of amplitudes. For fission of $U^{235}$ by thermal

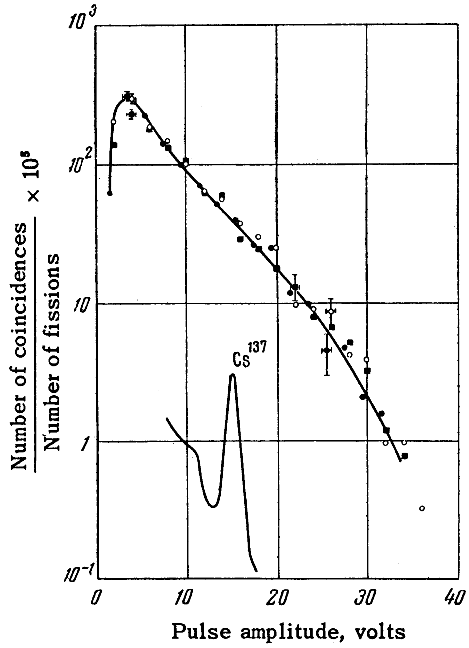


FIG. 2. Amplitude distribution of scintillation-counter pulses accompanying the fission of $U^{235}$: ● – by thermal neutrons, ○ – by 2.8 Mev neutrons, ■ – by 14.7 Mev neutrons.

neutrons, the amplitude range, fixing the photopeaks up to 1600 kev and the Compton peaks up to 2,000 kev, covers approximately 90% of the total number and 65 — 70% of the total energy of the "prompt" quanta. Considering that the spectrum of the harder $\gamma$ rays, produced upon fission of $U^{235}$ by fast neutrons, is also similar to the $\gamma$-ray spectrum due to fission by thermal neutrons, (as occurs in the case of $\gamma$ quanta of energy less than 2,000 kev), we can conclude that the total energy of the $\gamma$ quanta emitted by fission is proportional to their average number per fission.

After eliminating the background, the ratio of the number of coincidences between the $\gamma$ quanta and the fragments for $U^{235}$ fission by 2.8 and 14.7 Mev neutrons to the number of coincidences for fission by thermal neutrons is found to be $1.10 \pm 0.05$ and $1.05 \pm 0.05$ respectively. It must be noted, that extrapolation of the spectrum introduces a certain indeterminacy in the final results, and that it would be desirable to carry out the measurements for a larger energy interval. However, an estimate of the indeterminacy shows that the error due to extrapolation cannot exceed 10 — 15% of the total $\gamma$-ray energy. Taking this indeterminacy into account one can assume that, within the experimental accuracy (on the order of 15%), the total energy of the $\gamma$ quanta accompanying the fission of $U^{235}$ by 2.8 and 14.7 Mev is the same as obtained in fission by thermal neutrons. This result is not unexpected, considering that the prompt $\gamma$ rays are emitted essentially by excited fragments after the emission of the neutrons.

The authors thank Iu. M. Artem' ev for great help in the preparation for this investigation.

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Translated by J. G. Adashko
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