Soft 15–800 kev Radiation Accompanying the Thermal Neutron Fission of Uranium

V. K. VOITOVETSKII, B. A. LEVIN, AND E. V. MARCHENKO
Institute of Atomic Energy, Academy of Sciences, USSR
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A scintillation spectrometer investigation of the γ-rays coincident with fission has established the presence of a series of lines. It has been shown that γ-quanta having energies of 101, 119, 142, 207, 295, 360, 490, and 590 kev are emitted in fission. It is suggested that these γ-quanta are emitted by excited fragments following neutron emission. Intense radiation having a maximum at 27 kev apparently consists of the K x-rays of heavy fragments.

INTRODUCTION

THE γ-rays accompanying the thermal neutron fission of U^{235} have been the subject of a series of investigations[1–3] These studies have yielded a value for the total energy emitted in the form of γ-rays; the average number of γ-rays per fission has been determined and likewise the general character of the spectrum.

Kinsey, Hannah, and Van Patter[1] have shown that γ-rays are emitted within a time $T \leq 0.7$ microsecond following fission, and that the total γ-ray energy is 4.6 ± 1 mev. The method used in this work was not one that could give a correct result concerning the spectral distribution of the radiation and in fact contradicts later results.[2–3] The work of Rose and Wilson[2] concerned the angular distribution of the γ-rays. The experimental results suggest that at least some of the γ-quanta are emitted by the fragments. Analyzing the composition of the radiations, the authors concluded that, on the average, 6 quanta are emitted in fission with a wide energy distribution (up to 2.5 mev) and that the total energy is 5.2 ± 0.5 mev.

The data of Gambla and Francis[3] show that the radiation intensity falls exponentially with the energy. The average number per fission is less than 7.5, the total energy is less than 7.5 mev and the upper limit of the energy is approximately equal to 7 mev.

A study of the soft component (15–250 kev) of the γ-ray spectrum accompanying the thermal neutron fission of U^{235} established a presence of a series of lines.[4] The present work extends the energy region investigated up to 800 kev. It is shown that in the energy region 15–800 kev there are 8 monochromatic lines and an intense radiation having a maximum at 27 kev.

EXPERIMENTAL ARRANGEMENT

An ionization chamber with U^{235} registering fission fragments is placed in a beam of thermal neutrons (Fig. 1). The γ-rays emitted in fission are detected in a scintillation counter γ-spectrometer. A coincidence circuit and gate circuit (Fig. 2) select for amplitude analysis the pulses from the scintillation counter that are coincident with the fission fragment pulses.*

The beam of neutrons is collimated by a channel in the pile (Fig. 1). This figure also shows the distribution of the neutron flux over the chamber. The chamber is made out of thin walled aluminum. The five lower foils of the chamber carry films of uranium oxide (approximately 3 mg/cm^2). The chamber is filled with one atmosphere of argon; the working voltage is a thousand volts. The rise time of the amplified pulses from fission was ≤ 0.3 μ sec. After discrimination the shaped pulses were put into the coincidence circuit and simultaneously registered by a scalar (multiplication factor 10^4).

The spectrometer was made from a type C photo multiplier and a NaI–Tl crystal ($\phi = 29$ mm, $h = 12$ mm) with magnesium oxide reflectors. The scintillator was protected from the slow neutrons and γ-rays by a boron and lead shield. The amplified pulse from the photo multiplier was sent through the gate circuit into a 20 channel pulse height analyzer.[5] The same pulse after discrimination and shaping was sent into the coincidence circuit governing the gates. The analyzer was constructed on the principle of converting an amplitude into a delay and makes possible a pulse height analysis into 80 channels with subsequent use of 20 of them.

In order to get the characteristics and calibrate the spectrometer there were obtained pulse height analyses from γ-rays of several isotopes. The resolving power of the spectrometer for the Cs^{137}

*The resolving time of the coincident circuit was $2\tau = 0.4$ μsec. Increasing this by a factor of 1.5 increased the number of coincidences only by 5–6%.

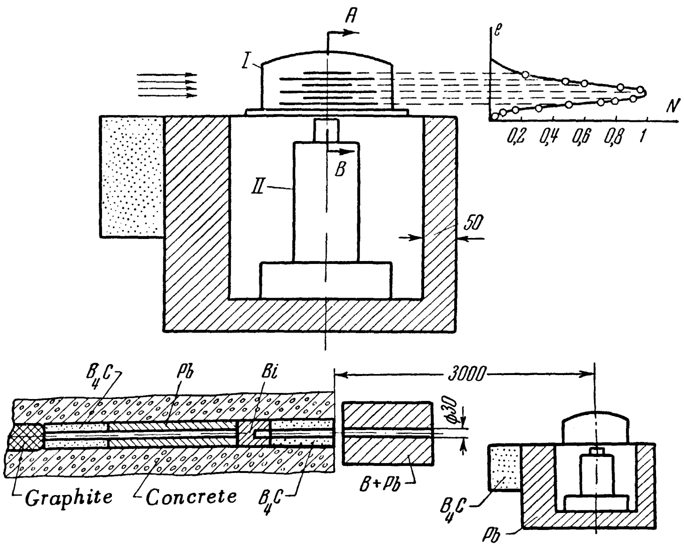

FIG. 1. I — Multifoil ionization chamber; II— Scintillation counter. Above on the right is given the distribution of neutron flux across the cut AB. The arrows on the left indicate the neutron direction of motion.

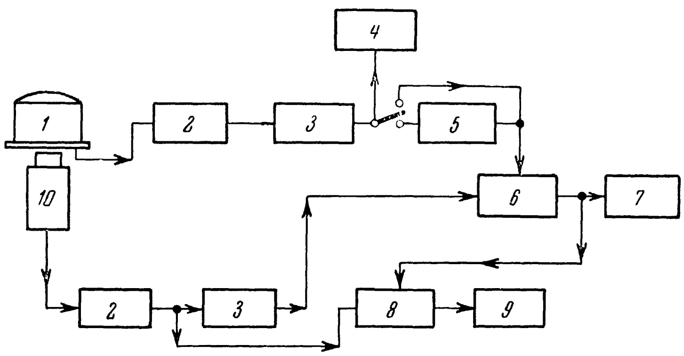

FIG. 2. Block Diagram of Electronics. 1—Ionization chamber, 2—Amplifier, 3—Discriminator, 4—Scalar ($\times 10^4$), 5—Delayline, 6—Coincidence circuit, 7—Scalar ($\times$ 64). 8—Gate circuit, 9—20 channel analyzer. 10—Scintillation counter.

line (662 kev) was 8%; for the Ce^{141} line (145 kev) it was 16%. In this energy region the position of the photo-peaks is a linear function of the γ-ray energy. The stability of the spectrometer was controlled with known photo-peaks. The displacement of these photo-peaks during long measurements (8–12 hours) did not exceed 1%.

In order to check the operation of the spectrometer together with the gate circuits, the radiations coming from the uranium in the chamber were analyzed. The spectrum obtained with the chamber registering α-particles and the gate circuits governed by $\alpha-\gamma$ coincidences (Fig. 3) had the same appearance as a spectrum of γ-rays from uranium taken without coincidences.

RESULTS OF THE MEASUREMENTS

The measurements were carried out in the following fashion. Simultaneously with the amplitude analysis of the pulses from the γ-rays, the number of fissions and the number of coincidences were recorded; this allowed a normalization from one part of the work to another. The number of fissions registered per second was about 5×10^3; the number of coincidences was about 200. In order to

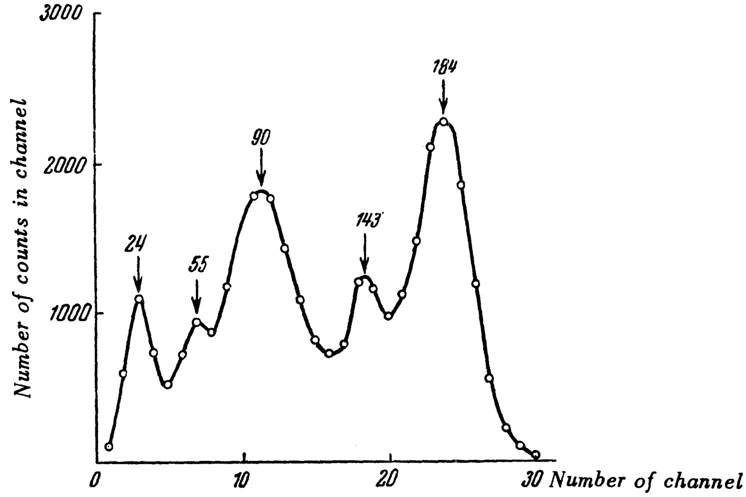

FIG. 3. The numbers on the peaks are given in kev.

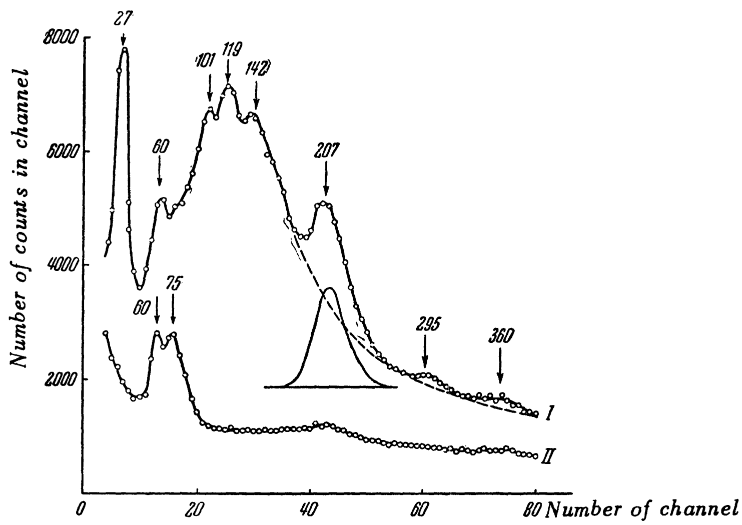

FIG. 4. The numbers on the peaks are given in kev.

determine the background of accidental coincidences the fission pulses were delayed by 0.9 μ sec. This background of accidental coincidences did not exceed 3% in any channel of the analyzer. The experimental results were completely reproducible upon numerous repetitions of the measurements.

Fig. 4 (curve 1) shows the pulse height distribution from γ-rays coincident with fission pulses and having energies between 15 and 400 kev. (5 kev per channel). The numbers have all been normalized to 10^7 fissions. The statistical errors of the measurements are 0.5 –1.5%. The photopeaks correspond to energies of 27, 60, 101, 119, 142, 207, 295 and 360 kev. The calibration points used for this region were obtained from the radiations of Hg^{203} , (279 and 71 kev) and Ce^{141} (145 and 35 kev). Some of the lines in the spectrum (60, 207 kev) may have arisen from the inelastic scattering of fission neutrons in iodine.[6]

Measurements carried out with a 5 mm sheet of lead between the chamber and the crystal made it possible to evaluate the contribution of this inelastic scattering. The spectrum obtained with the lead (Fig. 4, curve 2) does not have lines at 27, 101, 119, 142, and 295 kev and has the 360 kev line strongly absorbed. The line at 60 kev is not affected and there is present weak radiation at 207 kev. The pulse height distribution also

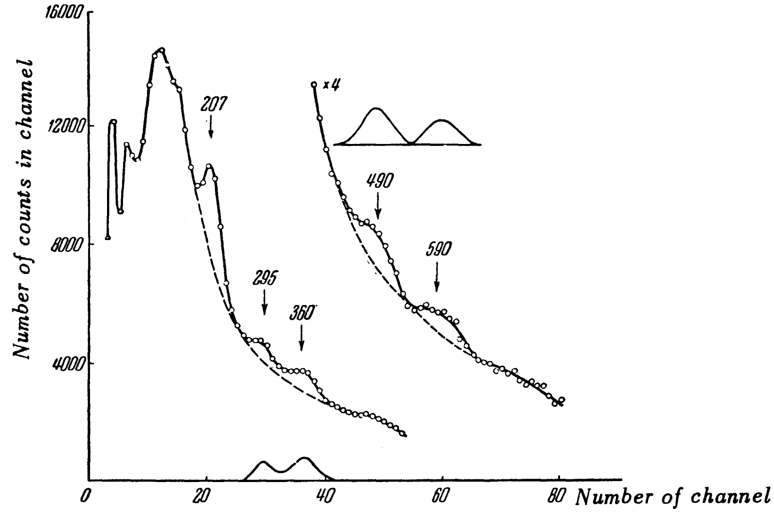

FIG. 5. The numbers on the peaks are given in kev.

shows a photo-peak from the x-rays of lead (75 kev).

The results of the experiment with the lead absorber allow us to conclude that the lines at 27, 101, 119, 142, 207, 295, and 360 kev correspond to γ-rays accompanying fission but that the lines at 60 kev and a small part of the 207 kev line are due to inelastic scattering of fission neutrons by the iodine of the crystal. A quantitative estimate of the probability of inelastic scattering agrees well with the experimental results.

The pulse height distribution in the energy region between 20 and 800 kev (10 kev per channel) shows additional photo-peaks from γ-rays having energies of 490 and 590 kev (Fig. 5; the curves are likewise normalized to 10^7 fissions). Here the calibration was made using the radiations from Cs^{137}, Hg^{203}, and Ce^{141}. Absorption measurements using 5 mm of lead (Fig. 6) (20 kev per channel) ruled out the possibility that the 490 and 590 kev peaks are due to inelastic scattering of fission neutrons by iodine (490 kev) or lead (590 kev).[6]

The data on the energies and intensities for the γ-ray lines accompanying fission are presented in the table.

The possibility of intense radiation of soft γ-rays by uranium nuclei during fission does not appear likely. The intensity of the lines in the soft part of the spectrum is comparable to the yield of fragments. It would appear that these radiations are emitted by excited fragments after neutron emission. This conclusion is supported by the results in work in Ref. 7. The energies of these soft γ-rays are characteristic of rotational levels. It may be that the residual excitation of the fragments is connected with collective motion of the nucleons. The x-rays from the heavy fragments of fission

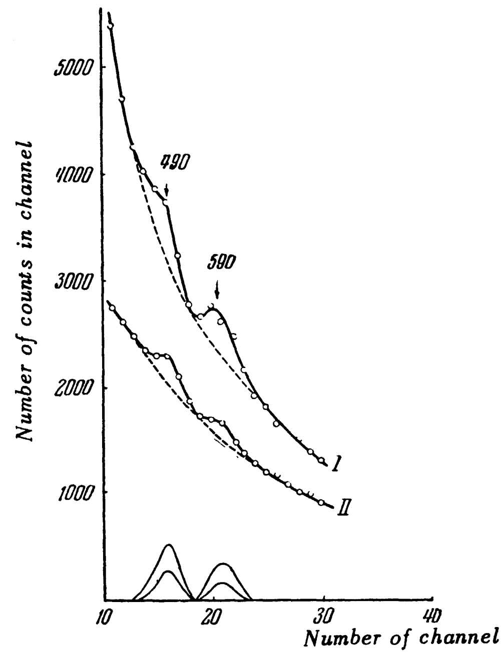

FIG. 6. I-without lead; II—with lead

lie in the region 25–30 kev. It may be assumed that the intense radiation having an energy of 27 kev is not monochromatic, but consists of the characteristic x-rays of these heavy fission fragments.

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Energy	Intensity (quanta per fission)
27±3	0.45±0.15
101±3	—
119±3	—
142±5	—
207±5	0.107±0.052
295±5	0.026±0.020
360±10	0.085±0.050
490±10	0.071±0.037
590±15	0.101±0.047

and to G. N. Sofiev who helped in the construction of the pulse height analyzer.

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Investigation of Slow Electron Emission Induced by High Energy Protons

E. S. MIRONOV AND L. M. NEMENOV
Institute of Atomic Energy, Academy of Sciences, USSR

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An investigation has been carried out of the electron emission produced by high energy protons. The method is described. Values of the emission coefficients, γ_1 and γ_2 for aluminum and nickel in the energy range from 2 to 7.3 mev are presented.

INTRODUCTION

THE question of the interaction of positive ions with a metallic surface is not a new one. Most of the published work devoted to the dependence of the coefficient of emission γ on the energy of the impinging ions has involved relatively low energy ions. Thus for hydrogen and helium, the energy has not exceeded 400 kev[1]. Only in one investigation [2] has electron emission been observed using mercury ions having an energy of the order of 2.2 mev.

The present authors posed themselves the problem of studying the emission of electrons from thin foils both in the direction of the motion of protons (coefficient γ_1) and in the opposite direction (coefficient γ_2) At the same time it was proposed to determine the dependence of the coefficients γ_1 and γ_2 on the impinging proton energy in the interval from 2 to 7.3 mev. Aluminum and nickel were chosen to be the substances to be studied.

The source of the protons was a 1½ meter cyclotron having an external focused beam. The proton beam was obtained from hydrogen molecule ion acceleration up to approximately 14.7 mev with subsequent break-up of the molecule upon going through a thin aluminum foil. The beam of charged particles was taken to a distance of 12 m from the shielding wall of the cyclotron.

Work on measuring the beam strength of protons of the order of 7 mev showed that electron emission from the usual conducting materials amounted to 20–30% of the proton beam current. Calculations evaluating the expected magnitude of γ indicated values of the order of 30–40%. These facts determined to a certain extent the method used in the investigation.

1. METHOD OF MEASUREMENT

Fig. 1 shows the six principal methods used in measuring all the required quantities.

Method 1 is used to measure the total current,