AN INVESTIGATION OF GAMMA RAYS FROM Cs^{140}

E. A. ZHEREBIN, A. I. KRYLOV, V. I. POLIKARPOV, and N. N. YUZVUK

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The method and results of an investigation of γ rays from the short-lived fission fragment Cs^{140} ($T_{1/2}$ = 66 sec) are described. A "gas loop" at the reactor was used to transport Xe and Kr to the measurement site and to enrich the mixture of decay products with the investigated fragment. Rapid chemical extraction of cesium was employed to investigate Cs^{140}, of which the following γ lines were observed: 0.59 ± 0.01, 0.88, 1.14, 1.62, 1.85, 2.06, 2.32, 2.72, and 3.15 MeV.

PROCEDURE

A stainless steel foil bearing an electrolytic layer of uranium was introduced into the core 3 (Fig. 1) of an atomic reactor by an electromagnetic mechanism. A stream of gas from the tank 1 carried fission fragments to the purifying filter 4, through which only Kr and Xe isotopes passed, to the accumulating tank 5, and to the measuring filter 6. The products of Kr and Xe decay in the tank 5 were stopped by the measuring filter 6. The gas moved in 5 seconds from the reactor core to the accumulating tank, through which it passed in 6 sec. In some runs the time required for the transport of gases and the accumulation of their decay products was increased, the rate of flow being reduced to one-half.

The optimum time of fragment motion from the reactor core to the measuring filter was calculated subject to the requirement of a maximum ratio of the Cs^{140} activity to the Cs^{139} activity (which caused the most interference) while retaining sufficient Cs^{140} activity for measurement in the measuring filter. The calculation was confirmed experimentally.

After accumulating Kr and Xe decay products for two minutes the measuring filter was placed in hot acetic acid containing Ba, Sr, Cs, and Rb carriers. After 30 sec a solution of bismuth potassium iodide was added. The $Cs_3Bi_2I_9$ precipitate was separated in a centrifuge and was washed with acetic acid. The entire chemical separation of Cs required 3—3.5 min.

A test tube containing the $Cs_3Bi_2I_9$ precipitate was placed on the crystal of a NaI(Tl) scintillation γ spectrometer (of 40-mm diameter and 40-mm height) used in conjunction with a FÉU-13 photomultiplier and an AI-100 (100-channel) analyzer. An aluminum plate 0.5 cm thick was placed between the test tube and the crystal to absorb β particles from the cesium. The time required to measure the spectrum was not longer than 30 sec.

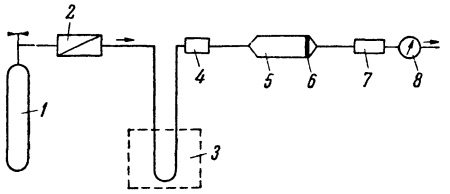

FIG. 1. Schematic drawing of "gas loop." 1 – CO_2 tank, 2 – reducer, 3 – reactor core, 4 – purifying filter, 5 – accumulating tank, 6 – measuring filter, 7 – exit filter, 8 – flow meter.

In order to discriminate other Cs isotopes according to their half-lives we also recorded a few spectra in the shortest possible time intervals (4—5 min) required to accumulate pulses and obtain information from the analyzer. Whenever necessary, an analyzer having a single broad channel was used simultaneously to record a decay curve for a particular region of the γ spectrum.

RESULTS

Figure 2 shows the pulse distribution of the γ spectrum up to 1.5 MeV. In this and the following figures T denotes the time from the conclusion of gas flow to the recording of the spectrum; t_m denotes the time required to record the spectrum; the precipitating time was 2 min.

Curve 1 has a distinct peak at 0.59 MeV, which is greatly reduced after 5 min 34 sec (the time elapsing between the first and second measurements). In order to identify this line a narrow segment of the spectrum in this region was recorded with shorter time intervals between the measurements. The measurements showed that the 0.59-MeV peak contains a contribution of a longer-lived component than Cs^{140} (66 sec). A

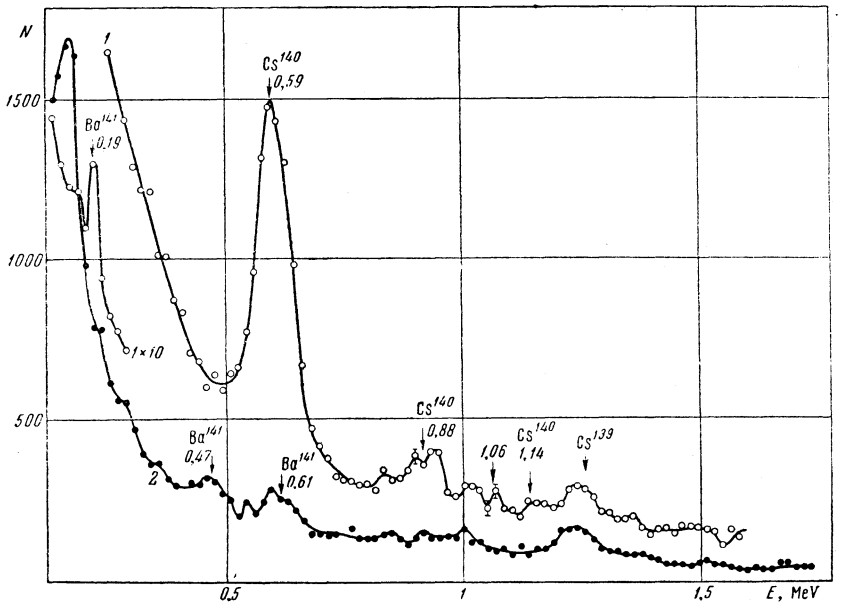

FIG. 2. Spectrograms of softer Cs γ rays (1.5 MeV). 1 – T = 4 min 49 sec, t_m = 20 sec; 2 – T = 10 min 23 sec, t_m = 23 sec. N is the number of pulses in a single analyzer channel; T is the time from the conclusion of gas flow to the recording of the spectrum; t_m is the time required to record the spectrum.

differential analyzer was used to determine the half-life of the latter component. Intensity measurements about the 0.59-MeV peak required 10 sec each and were separated by a 20-sec interval. Figure 3 shows one of the decay curves of the components forming the 0.59-MeV peak. The Cs^{140} activity (exhibiting a 63-sec half-life) was accompanied by Cs^{139} activity (with 9.48-min half-life). The 0.59-MeV peak is thus seen to consist mainly of Cs^{140} γ rays. The Cs^{139} activity in the given energy interval is associated with Compton electrons from Cs^{139} γ rays of higher-energy and with the existence of the corresponding γ line.in this region.

Figure 2 also reveals a 0.88-MeV peak. In all runs (> 10) the shape of this peak indicates its complex composition; Cs^{139} γ radiation is evidently present. From the character of its decay the 0.88-MeV γ line can be assigned to Cs^{140}.

In all measurements a rapidly disappearing peak was noted at 1.14 MeV. This peak was not identified by a thorough analysis, but a comparison with the decay of the 0.59-MeV peak indicates that it can be assigned to Cs^{140} γ radiation.

In some runs the rate of gas flow was reduced one-half. Figure 4 shows one of the spectra recorded when the time of gas transport was doubled. A comparison of the spectra recorded for different fragment transport times is an additional means of identifying the γ lines in these spectra. This comparison performed in the region up to 1.5 MeV confirms all Cs^{140} γ lines observed in this region and also indicates that Cs^{140} has a 1.2-MeV and possibly a 1.06-MeV γ line. The peaks of these lines were observed in all runs and the character of their decay is similar to that of the precisely determined Cs^{140} lines. These peaks can result from pair production by harder Cs^{140} rays; the cross sections for pair production and the photoelectric effect in a NaI(Tl) crystal are approximately equal at ~ 2 MeV, and corresponding high-energy peaks are observed in the harder spectra.

Figures 5 and 6 show the distributions of pulses for the harder γ-ray region. The diminishing efficiency of the γ spectrometer with increasing energy and the occurrence of pair production make it very difficult to identify γ lines in this region.

From an examination of the experimental curves (keeping in mind the possibility of the photoelectric effect and pair production and taking the intensities of the peaks into account) we obtain the result that the hard Cs^{140} spectrum contains γ lines at 1.62, 1.85, 2.06, 2.32, 2.72, and 3.15 MeV. The soft γ lines at 0.59 and 1.14 MeV were determined within ±0.01 MeV.

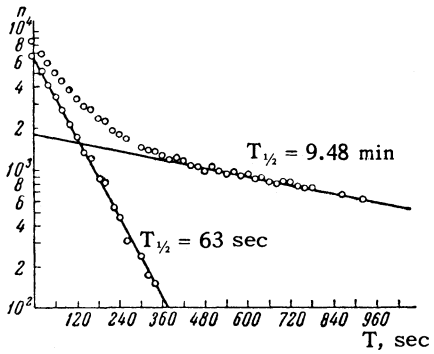

FIG. 3. Cs decay curve recorded with a single-channel analyzer for the 0.5–0.7-MeV region; n is the channel count during 10 sec.

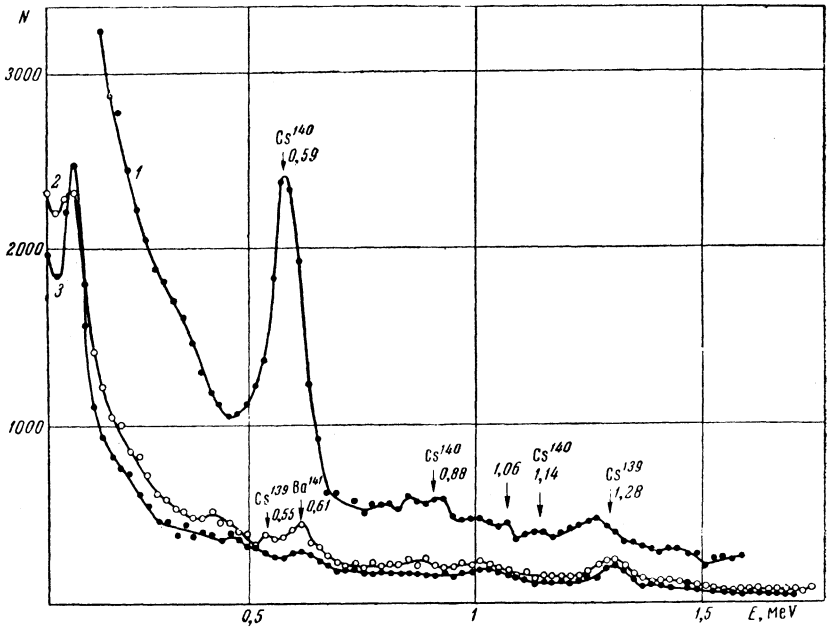

FIG. 4. Spectrograms of softer Cs γ rays recorded when the time of fragment transport was doubled. 1 – T = 4 min 35 sec; 2 – T = 10 min; 3 – T = 13 min 55 sec. In all cases t_m = 21.5 sec. The notation is the same as in Fig. 2.

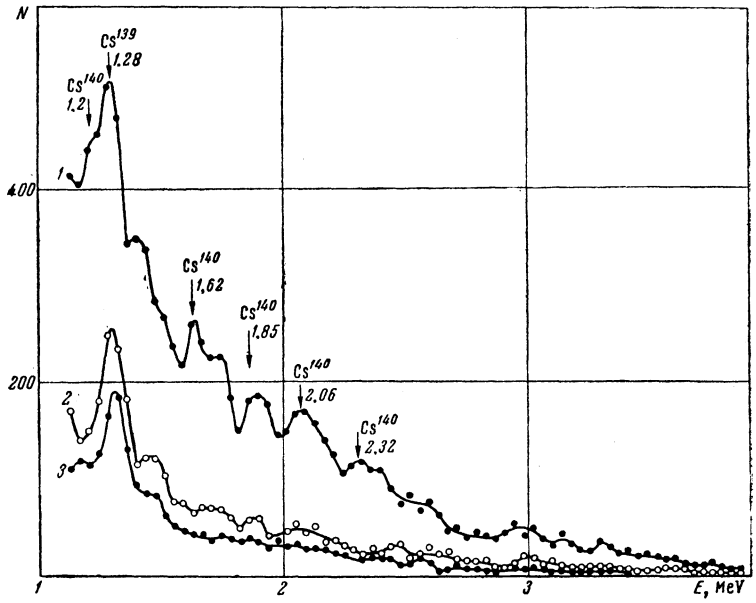

FIG. 5. Spectrograms of harder Cs^{140} γ rays (to 2.5 MeV). 1 – T = 4 min 36 sec; 2 – T = 8 min 24 sec; 3 – T = 11 min 40 sec. In all cases t_m = 20 sec.

Since almost all Cs^{140} γ lines contain a considerable admixture of Cs^{139} lines whose relative intensities are unknown, and since we at present lack sufficient statistics for the hard region, it is still too difficult to determine the relative intensities of Cs^{140} lines reliably.

DISCUSSION OF RESULTS

Beta decay transforms the $_{55}Cs^{140}$ nucleus into $_{56}Ba^{140}$. G. Scharff-Goldhaber[1] studied the dependence of the low excited levels of even-even nuclei on the number of neutrons. Here graphs show that, as a rule, as the number of neutrons or protons departs increasingly from the nearest magic number the energy of the first excited level decreases; a minimum appears for nuclei in which the numbers of neutrons and protons are halfway between two successive magic numbers. The value obtained by us in the present work for the first excited state of $_{56}Ba^{140}$ agrees very well with a graph in [1], where the first excited level of this nucleus at 0.59 MeV lies exactly on the curve for 84 neutrons. This agreement indicates that the first Ba^{140} level is located at 0.59 MeV.

An analysis of the spins and parities of the excited levels of even-even nuclei indicates that the first excited levels of these nuclei almost always have spin 2 and positive parity.[2] Therefore the first excited Ba^{140} level should be identified as 2^+.

Extrapolation on a Cameron grid[3] for the total

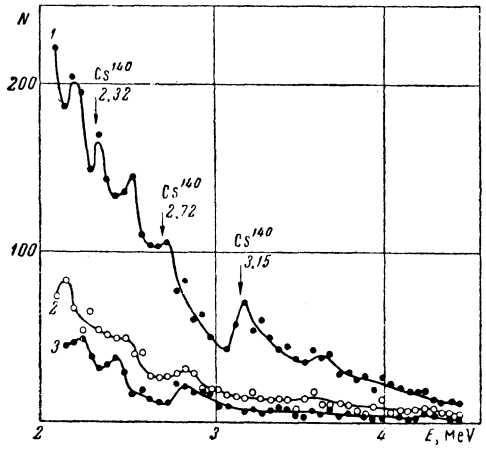

FIG. 6. Spectrograms of harder Cs^{140} rays (to 3.5 MeV). 1 – T = 5 min 15 sec; 2 – T = 9 min 15 sec; 3 – T = 12 min 45 sec. In all cases t_m = 30 sec.

decay energy of even-even nuclei having atomic weights from 128 to 208 indicates that the total decay energy of $_{55}Cs^{140}$ should be at least 5 MeV. By analogy with $_{55}Cs^{138}$ (in which the shell structure is similar to that of Cs^{140}) we should expect intense β decay to 0.59 MeV; therefore the β endpoint energy should be at least 4.4 MeV. In a private communication E. A. Tamanov states that Cs^{140} exhibits β radiation having high energy of this order.

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[1] G. Scharff-Goldhaber, Phys. Rev. 90, 587 (1953).

[2] M. Goeppert-Mayer and J. H. D. Jensen, Elementary Theory of Nuclear Shell Structure, John Wiley and Sons, New York, 1955.

[3] B. S. Dzhelepov and G. F. Dranitsyna, Sistematika energiĭ β raspada (Systematics of β Decay Energies), AN SSSR, 1960.

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