Decay of Ruthenium-105

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The decay of Ru^{105} has been studied employing two scintillation spectrometers in coincidence. It is found that Ru^{105} decays to the excited levels of Rh^{105} with the emission of six β groups, with end-point energies of $\sim$ 125, 525, 915, 1080, 1150, and $\sim$1800 kev, the branching ratios being approximately $\sim$0.002, 0.068, 0.11, 0.30, 0.51, and $\sim$0.01, respectively. The subsequent γ rays have the energies of 130, 265, 320, 400, 475, 485, 665, 725, 875, 960, 1350, and 1750 kev. From γ-γ and β-γ coincidence measurements, a level scheme of Rh^{105} has been worked out, showing the excited states at 130, 395, (or 530), 475, 725, 795, 960, 1350, and 1750 kev.

INTRODUCTION

THE decay of 4.5-hr ruthenium-105 has been investigated by a number of workers[1–3] mainly by β-ray spectrometers and Geiger-Müller counters. They have shown that it emits one β group having the end-point energy of 1150 kev followed by a 725-kev γ ray. This γ ray was supposed to terminate at the 45-second isomeric level in Rh^{105} which is 130 kev above its ground state. Only recently Heath and Vegors[4] have observed the γ-ray spectrum of this activity with a scintillation spectrometer. They report the emission of γ rays of energies 265, 315, 400, 480, 670, 720, 870, and 960 kev. Independently of the above unpublished work, we have studied the decay of Ru^{105} by scintillation spectrometers and have established various γ-γ and β-γ sequences.

Natural ruthenium contains seven isotopes. On irradiation with thermal neutrons, four activities of Ru^{97}, Ru^{103}, Ru^{105}, and Rh^{105}, having half-lives of 2.8 days, 42 days, 4.5 hours, and 36 hours, respectively, are produced. In order to suppress the relative strength of Ru^{97}, Ru^{103}, and Rh^{105}, we irradiated our samples of natural ruthenium for periods of 4 to 8 hours in the Apsara reactor. The irradiated samples were further purified by the distillation of RuO_4.

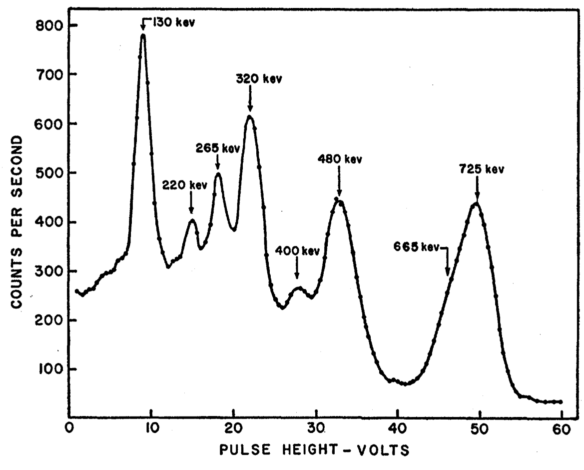

FIG. 1. Pulse-height distribution in NaI(Tl) crystal of the softer γ rays of the 4.5-hr activity of Ru^{105}.

MEASUREMENTS

Two scintillation spectrometers were used in coincidence with a standard fast-slow coincidence technique. The negative pulse output from the collector of a RCA-6810A high-gain photomultiplier tube was inverted and equalized to feed the diode coincidence circuit. The same pulse from the collector was linearly inverted with almost a gain of 1 for pulse-height analysis. The inverter was capable of giving linear positive output up to 80 volts. The resolving time of the coincidence circuit was kept about 0.1 μsec.

The γ-ray spectrum of Ru^{105} up to 800 kev, observed with a 1.5-in. diameter and 2-in. thick NaI(Tl) crystal, is shown in Fig. 1. The spectrum was recorded two hours after the removal of the source from the reactor. The source was placed at a distance of 3 cm from the crystal surface with the intervening absorber of about one g/cm^2 of aluminum and aluminum oxide. The full energy peaks

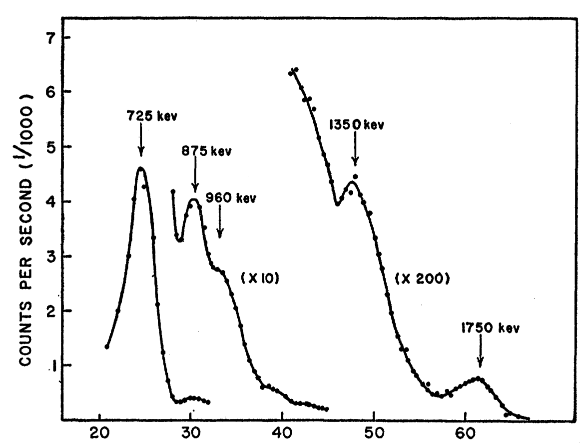

FIG. 2. Pulse-height distribution in NaI(Tl) of the harder γ rays of Ru^{105}.

[1] V. S. Shpinel and G. A. Kuznetsova, J. Exptl. Theoret. Phys. U. S. S. R. **30**, 231 (1956) [translation: Soviet Phys.—JETP **3**, 216 (1956)].
[2] C. L. Scoville, S. C. Fultz, and M. L. Pool, Phys. Rev. **85**, 1046 (1952).
[3] R. B. Duffield and L. M. Langer, Phys. Rev. **81**, 203 (1951).
[4] R. L. Heath and S. H. Vegors (unpublished), as reported in Revs. Modern Phys. **30**, 675 (1958).

TABLE I. Beta spectra and gamma rays of Ru^{105}.

Max. energy of β groups in kev	β transition probability per 100 disintegrations	log ft	Associated γ-ray energies in kev	γ transition probability per 100 disintegrations
125	~ 0.2	~5.6	1750	0.2
525	6.8	5.7	1350	1.0
			875	5.8
915	11	6.5	960	5.3
			485	5.7
1080	30	6.1	665	19
			400	3.5
			320	7.5
1150	51	6.1	725	51
1800	~ 1	~9	...	
			475	19
			265	3.5
			130	5

at 130, 265, 320, 400, 480, and 725 kev were found to be associated with 4.5-hr decay of Ru^{105}. The 220-kev peak appearing in the spectrum, is the most prominent γ ray associated[5] with 2.8-day Ru^{97}. On observing the spectrum after the decay of Ru^{105}, the 495-kev γ ray—which is the strongest in the decay of[6] Ru^{103}—was found to be quite weak. The composite nature of the peak at 725 kev is apparent. On analysis it was found that the peak consisted of two γ rays of energies 665 and 725 kev. By coincidence measurements, to be described later, the peak at 480 kev was also found to be composite in nature, the difference in energy of the two components being less than ~10 kev. These components will henceforth be referred to as 475- and 485-kev γ rays. The γ-ray peak at 320 kev is also complex. A large fraction of this peak is due to 36-hr activity of Rh^{105}, which has

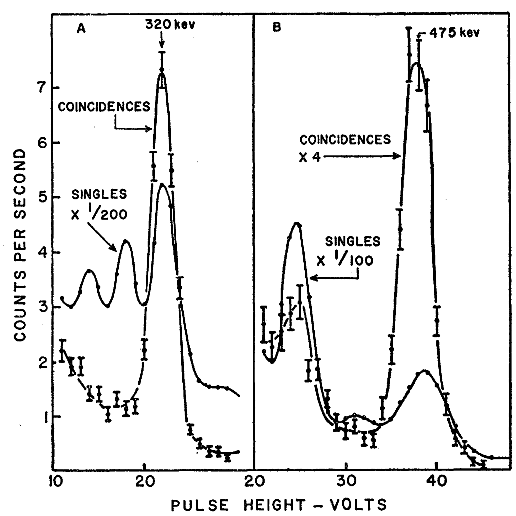

FIG. 3. Part A shows the spectrum in the region of 320 kev, in coincidence with the fixed channel at 475–485 kev. Part B shows a γ-ray peak at 475 kev in coincidence with the fixed channel at 320 kev.

[5] J. M. Cork, M. K. Brice, L. C. Schmid, and R. G. Helmer, Phys. Rev. **100**, 188 (1955).
[6] Babulal Saraf, Phys. Rev. **97**, 715 (1955).

a prominent γ ray of this energy. A careful study indicated that about 20% of this γ ray intensity is due to Ru^{105} activity. The higher energy part of the γ-ray pulse-height spectrum is shown in Fig. 2. The spectrum appears to be complex; the peaks at 875, 960, 1350, and 1750 kev can be identified. These γ-ray peaks were found to decay with the half-life of Ru^{105}. After a period of about 30 hours, the residual spectrum of the γ rays consisted of the well-known lines[5,6] of Ru^{97}, Ru^{103}, and Rh^{105}. The intensities of various γ rays as obtained from Figs. 1 and 2 and also the coincidence measurements are shown along with other information in Table I.

GAMMA-GAMMA COINCIDENCES

In order to establish a level scheme of Rh^{105}, a systematic study of γ-γ coincidences was undertaken. Two detectors were kept in end-on position on either side of the source. Each detector was looking at the source through a hollow Pb cone of half apex angle of ~70°.

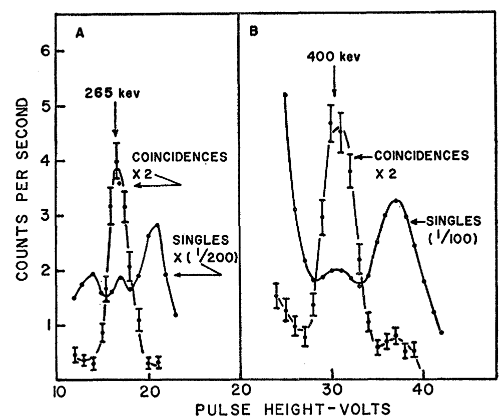

FIG. 4. Part A shows the coincidences in the region of 265-kev γ ray with the fixed channel at 400 kev. Part B shows the spectrum in the region of 400 kev, in coincidence with the fixed channel at 265 kev.

This geometry was very helpful in achieving large coincidence efficiency without involving any unwanted coincidences due to backscattering of high-energy photons. For studying the coincidences between a γ ray and any part of the spectrum, the γ-ray full energy peak was selected in a channel of one of the spectrometers and its position was fixed. The channel of the other spectrometer was then moved across the desired region of the pulse-height spectrum and the coincidence rate was recorded.

Figure 3(A) shows the coincidence counting rate between the 475–485 kev γ-ray peak and the spectrum in the region of 320 kev. Figure 3(B) shows the spectrum in the region of 475–485 kev in coincidence with 320-kev γ-ray peak. It is observed that the coincidence peak is slightly shifted to the lower energy side with respect to the peak in the singles counting rate and hence it is concluded that the 475-kev γ ray is in coincidence with the 320-kev γ ray. Figure 4(A) shows the spectrum in the vicinity of 265 kev, in coincidence with 400-kev γ-ray peak. Figure 4(B) shows the spectrum in the region of 400 kev in coincidence with 265-kev peak. The small coincidence peak below the 480-kev singles peak is due to the detection of 320-kev γ-ray pulses in the channel fixed at the 265-kev peak. Figure 5(A) shows the 475-kev γ ray in coincidence with the 875-kev peak accepted in the fixed channel. Figure 5(B) shows that the 480-kev peak is complex and the two components are in coincidence with each other. It also shows the coincidence peak at 875 kev when the fixed channel was at 475–485 kev.

LEVEL SCHEME

It is known that Rh^{105} has a 45-sec isomeric state of 130-kev excitation energy.[1–3] Coincidence measurements showed that the 320- and 475-kev γ rays are emitted in cascade. The sum of energies of these cascade γ rays,

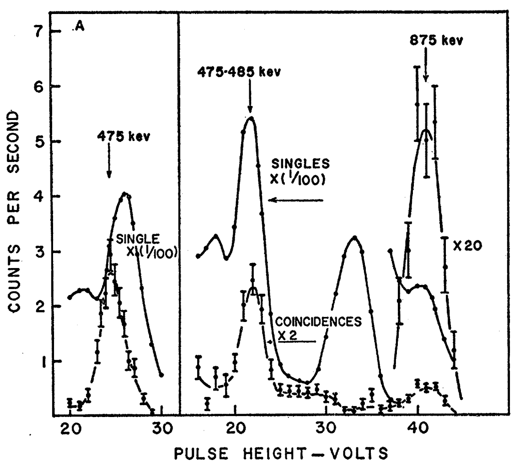

FIG. 5. A γ-ray peak at 475 kev is shown in coincidence with the fixed channel at 875 kev, in part *A*. Part *B* shows the pulse-height distribution above 400 kev, in coincidence with a fixed channel at 475–485 kev peak.

and that of 665 kev—which is not in coincidence with any other γ ray—and 130-kev γ rays are equal, indicating thereby an excited state of Rh^{105} at 795 kev. The sum energy of 265- and 400-kev γ rays, which are shown to be in coincidence in Fig. 4, is the same as that of the 665-kev γ ray, suggesting the latter transition to be a crossover to the 265–400 kev cascade. The level at 795 kev thus decays by the emission of a 320–475 kev cascade to the ground state, and by the emission of a 265–400 kev γ-ray cascade with a 665-kev crossover transition, to the isomeric state. Since the intensity of the 320-kev γ ray is much lower than that of the 475-kev radiation and also because the 475-kev γ rays is in coincidence with the 485- and 875-kev γ rays which are noncoincident with the 320-kev γ ray, the 475-kev transition follows the 320-kev γ ray. Therefore there should be a level in Rh^{105} at 475 kev. From the measurements it is not possible to decide the order of emission

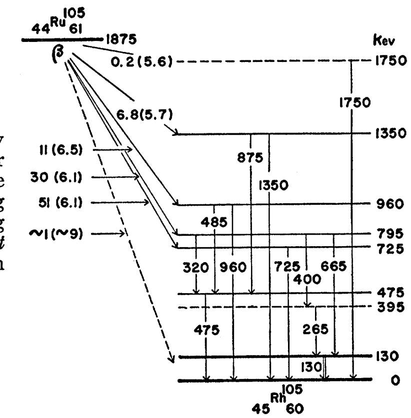

FIG. 6. Decay scheme of 4.5-hr Ru^{105}. All energies are shown in kev. Along with the β-branching ratios, the log ft values are given in the parentheses.

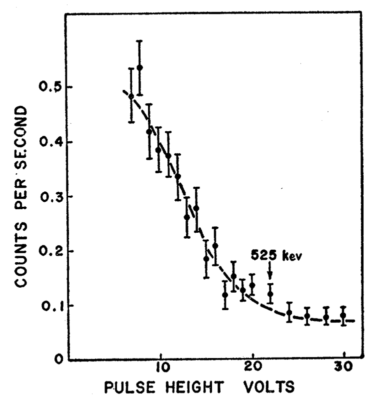

FIG. 7. Pulse-height distribution in anthracene of β particles in coincidence with 875-kev γ ray detected in the fixed channel.

of the 265–400 kev γ rays. Depending upon this order there would be an excited state at 395 or 530 kev. The intensity of the 725-kev γ ray is much larger than that of any other γ ray including the 130-kev transition after taking into consideration its internal conversion.[7] There-

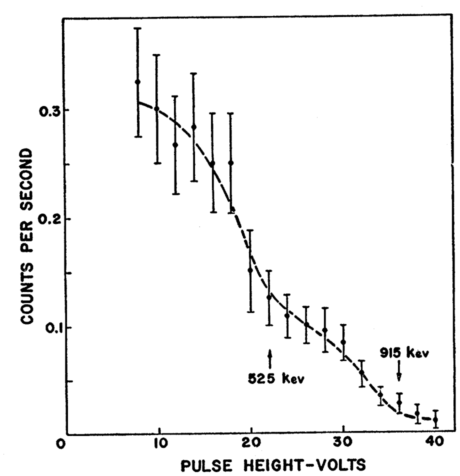

FIG. 8. The β-ray pulse-height spectrum in anthracene, in coincidence with the γ-ray channel fixed at 960 kev. The expected end-point energies of the β groups are also shown.

[7] P. Axel and R. B. Duffield (unpublished), as reported in Revs. Modern Phys. **30**, 678 (1958).

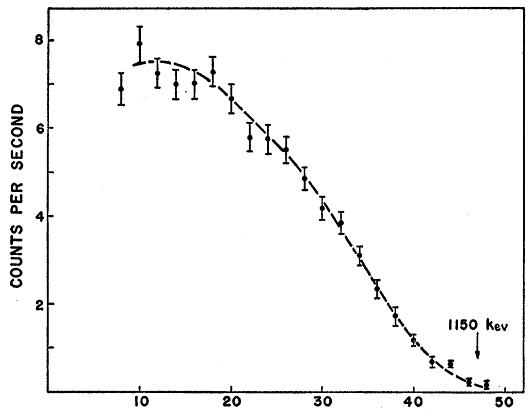

FIG. 9. Pulse-height spectrum of β particles in coincidence with the 725-kev γ ray.

fore it is evident that this γ ray leads to the ground state directly rather than the isomeric state as reported earlier.[1–3] Further, the 725-kev γ ray is found to be noncoincident with any other γ ray, suggesting that the 725-kev excited level is fed by a single β transition. The 960-kev γ ray is not in coincidence with any other γ ray, while the sum energy of the 475–485 kev coincident γ-ray pair is also 960 kev which decays by the emission of a 960-kev γ ray to the ground state or by a 485-kev transition to the level at 475 kev. The 875-kev γ ray is in coincidence with the 475-kev γ ray, suggesting a level at 1350 kev. The 1350-kev γ-ray transition thus appears to be the crossover of the 875-475 kev cascade. The 1750-kev γ ray should represent a transition from the 1750-kev level to the ground state. For if it were to lead to the isomeric level, there would hardly be any energy left over for the β transition to feed the required excited state at 1880 kev. The decay scheme of Ru^{105} as obtained from the above observations is shown in Fig. 6. The end-point energies and the intensities of the various β groups, feeding the levels of Rh^{105}, have been worked out from the intensity measurements of the γ rays and the level scheme as established above. These are shown in column 1 and 2 of Table I.

BETA-GAMMA COINCIDENCES

The decay scheme discussed above is further confirmed by the various β-γ coincidence studies. For these measurements the β particles were detected in an anthracene crystal 1.5 in. in diameter and 0.5 in. thick. Figure 7 shows the β spectrum in coincidence with the 875-kev γ-ray peak in the NaI(Tl) scintillation spectrometer. The expected end-point energy of this spectrum is 525 kev. Figure 7 does show an end-point energy close to this value. The tailing off of the coincidences beyond 525 kev is due to the detection of 960-kev γ-ray pulses—which is in coincidence with a β group of end-point energy 915 kev—in the 875-kev γ ray detection channel. This point is evident in Fig. 8 where it is shown that the β spectrum in coincidence with the 960-kev γ-ray peak extends to 915 kev. The sharp rise in coincidence rate below 525 kev is due to the partial admission of 860-kev γ-ray pulses into the 960-kev γ-ray detection channel. This is unavoidable due to the proximity of the energies of the two γ-rays. Figure 9 shows the β spectrum with an end-point energy of 1150 kev, in coincidence with the 725-kev γ ray. The β-ray pulse-height distribution in coincidence with the 475–485 kev γ-ray peak shown in Fig. 10, is rather complex

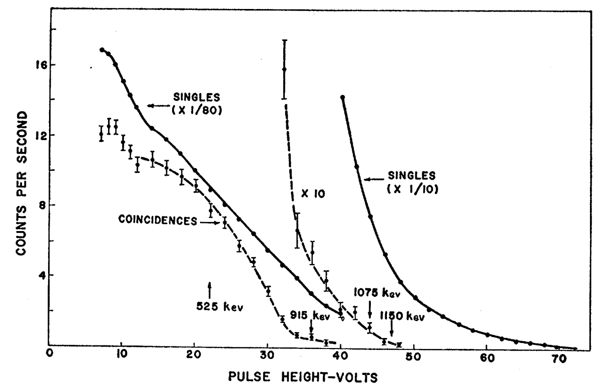

FIG. 10. The continuous curve shows the distribution in anthracene of pulse-height of β rays from Ru^{105}. The broken curve shows the β-ray pulse-height spectrum in coincidence with the γ-ray channel fixed at 475–485 kev peak. The expected end-point energies of various β groups are also indicated.

but not inconsistent with the decay scheme of Fig. 6. The complex nature of the coincidence spectrum arises from the fact that the 475-kev level in Rh^{105} is excited by three β groups of end-point energies 525, 915, and 1080 kev, through various γ transitions; and also the 725-kev γ ray is detected in the fixed channel at the 475–485 kev peak, through Compton scattering absorption. Thus one expects discontinuites in the coincidence spectrum corresponding to the end-point energies of four β groups, at 525, 915, 1080, and 1150 kev. The singles counting rate in β-ray counter is also shown in Fig. 10. Due to the low intensity, the determination of the end-point energy of the highest energy β group is uncertain, making it impossible to determine if it leads to the isomeric level or to the ground state of Rh^{105}.

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