Radioactive Decay of Tb^{157} and Tb^{158}

M. R. BHAT* AND M. L. POOL
Department of Physics and Astronomy, Ohio State University, Columbus, Ohio
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Dysprosium, enriched to 13.8% in the mass number 156 and to 0.9% in the mass number 158, was irradiated with neutrons and a terbium chemical fraction was obtained. The mass number of 158 was assigned to the gamma activity in the chemical fraction. The assignment was confirmed by a comparison of the scintillation spectrum of the terbium chemical fraction with that obtained from gadolinium enriched in the mass numbers 157 and 158, respectively, when bombarded with 6-MeV protons. Tb^{158} decays mostly by electron capture and partly by beta emission. In the electron capture decay of Tb^{158}, gamma rays of energy 79.7, 182.7, 770 and 950 keV are emitted. A gamma ray of energy 99.3 keV is emitted in the beta decay of Tb^{158}. Coincidence studies were carried out and the relative intensities of the gamma rays determined. A decay scheme consistent with the data obtained is given. The enriched samples of gadolinium bombarded with protons did not show any gamma rays that could be associated with a long-lived activity of Tb^{157}. Experimental results indicate a long-lived activity of Tb^{157} which decays by L and K capture.

I. INTRODUCTION

THE isotope Tb^{158} has a short-lived metastable state with a half-life of 10.5 sec.[1] Recently, the electron-capture decay of a long-lived activity of Tb^{158} emitting gamma rays of energy 79.7, 182.7, and 970 keV has been reported.[2,3] The half-life of this long-lived activity is estimated at 1200 ± 400 yr.[3] The Tb^{158} was obtained by neutron irradiation of enriched oxide samples of Dy^{156}. Chemical and mass spectroscopic analyses were then made. From conversion electron measurements, both the 79.7- and the 182.7-keV gamma rays have been designated as electric quadrupole transitions which are in cascade to the 0+ ground state of Gd^{158}. It has also been suggested[4] that 25% of the Tb^{158} decay is by beta emission with an accompanying 99.3-keV gamma ray from the first excited 2+ to the 0+ ground state of Dy^{158}. Since no coincidence data were available on this isotope, it was thought advisable to carry out coincidence experiments and determine the relative intensities of the different gamma rays.

The available data on the decay of Tb^{157} ascribe a half-life of either less than 30 min or greater than 100 yr.[5] A half-life of about 5 days has also been suggested.[6,7] The transition energy for the decay of Tb^{157} by electron capture has been estimated at 20 keV from experimental data together with the oribtal assignments made based on the collective model of the nucleus.[8] No evidence was obtained for radiations accompanying the decay of Tb^{157} in the work of Lewis *et al.*[3] In the discussion of the experimental observations to be presented below, evidence will be submitted which may be interpreted by ascribing an L and K capture decay to Tb^{157}.

II. EXPERIMENTAL RESULTS

A. Gamma Ray Spectrum

Dysprosium enriched to 13.8% in the mass number 156 and to 0.9% in the mass number 158 was irradiated with an average flux of 5×10^{12} neutrons cm^{-2} sec^{-1} in the Battelle reactor for a period of three weeks beginning in August 1958. A chemical separation of the resulting activity was performed and a terbium fraction obtained. Initially, the gamma spectrum of this chemical fraction showed the Tb^{160} activity with a half-life of 73 days. After an elapse of 27 months, the terbium fraction was found to emit x rays of energy 43 keV and gamma rays of energy 79.7, 182.7, 770, and 950 keV. The scintillation spectrum of this terbium activity, shown in Fig. 1, was obtained by the use of a 3-in. by 3-in. right-cylindrical crystal of NaI(Tl) mounted on a Dumont 6363 photomultiplier tube and connected to a 200-channel differential pulse-height analyzer. The crystal was shielded in a lead cave with 4-in.-thick walls and with inner dimensions of $32\times32\times30$ in. A graded shielding of 30-mil tin and 15-mil copper was on the inside. The source was situated at a distance of 5 cm along the axis of the crystal detector. No gamma rays of an energy higher than 950 keV were observed. Gain checks of the amplifier carried out before and after the experiment for accurately measuring the energy of the 950-keV gamma ray indicated that the gain of the amplifier had remained constant within half a channel on the multichannel analyzer. A straight-line calibration curve obtained in this experiment indicated that one channel corresponded to an energy range of 20 keV. Therefore, the energy of this gamma ray is 950 ± 10 keV.

The gamma spectrum of the terbium chemical fraction was recorded with the 3- by 3-in. flat crystal using a higher gain on the amplifier to detect the 99.3-keV gamma ray reported.[4] The gamma spectrum obtained

* Now at the Atomic Energy of Canada Limited, Chalk River, Ontario.

[1] N. B. Grove, R. W. Henry, L. T. Dillman, and R. A. Becker, Phys. Rev. **112**, 489 (1958).

[2] R. A. Naumann, M. C. Michel, and J. L. Power, Bull. Am. Phys. Soc. **6**, 73 (1961).

[3] H. R. Lewis Jr., R. A. Naumann, and J. L. Power, Bull. Am. Phys. Soc. **6**, 238 (1961).

[4] Results presented along with reference 3 at the 1961 Washington meeting of The American Physical Society.

[5] T. H. Handley and E. L. Olson, Phys. Rev. **90**, 500 (1953).

[6] G. Wilkinson and H. G. Hicks, Phys. Rev. **79**, 815 (1950).

[7] B. S. Dzhelepov, B. K. Preobrazhenskii, I. M. Rogachev, and P. A. Tishkin, Izvest. Akad. Nauk S.S.S.R. Ser. Fiz. **22**, 126 (1958).

[8] B. R. Mottelson and S. G. Nilsson, Kgl. Danske Videnskab. Selskabs. Mat.-fys. Skrifter **1**, No. 8 (1959).

with the same geometry as used in Fig. 1, and four times the gain showed a pulse distribution on the high-energy side of the 79.7-keV photopeak which could be associated with the presence of a 99.3-keV photopeak. Gaussian curves centered at 79.7 and 99.3 keV were fitted to the pulse-height distribution in this region. The total numbers of pulses under these two Gaussian curves were found to be in the ratio 3.4:1, respectively.

The gamma spectrum of the terbium chemical fraction showed photopeaks at energies of 995, 230, and 130 keV when the source was situated inside a well crystal and are attributed to the 43-keV x-ray summing with the 950-, 182.7-, and 79.7-keV gamma rays, respectively. The fact that the 770-keV gamma ray is not seen with this geometry indicates that the gamma ray is in coincidence with a gamma ray (viz., 182.7 keV) whose energy is such that their sum peak falls very nearly on the sum peak of the 950-keV gamma ray and the x ray.

There is no observable positron emission accompanying the electron capture decay. The upper limit on the number of postulated positron emitting transitions is 3% of the 950-keV transitions as estimated from the gamma spectrum of the terbium chemical fraction. The emission of electrons was detected by using an anthracene beta scintillator.

In order to make a mass assignment, a sample of Gd_2O_3 enriched to 92.87% in the mass number 158 and containing 3.15% of mass number 157 was bombarded with 6-MeV protons and the resulting activity examined after an interval of 20 months. In this time, the Tb^{160} activity initially present had essentially died out. Similarly, another sample of gadolinium enriched to 69.68% in the mass number 157 with 19.8% of mass number 158 was bombarded with protons and the resulting activity examined after an interval of 18 months. These two activities will be referred to as $Gd^{158}+p$ and $Gd^{157}+p$, respectively. The scintillation spectra of these two proton bombardments are also shown in Fig. 1. A comparison of these two spectra shows that they are composed of gamma rays of the same energy. As a further check, a comparison of the intensities of the 950- and 182.7-keV gamma rays in the two proton-bombarded samples was carried out. The two enriched samples of gadolinium mentioned above contained, respectively, 2.84% and 1.74% of Gd^{160} which under proton bombardment gives the Tb^{160} activity. A comparison of the Tb^{160} activity in these two samples, corrected for the decay of Tb^{160} and for the differences in the ratios of the isotopic enrichment of Gd^{158} to Gd^{160}, indicates that the activity emitting the 950- and 182.7-keV gamma rays, if due to Tb^{158}, should be 2:7 times stronger in the enriched Gd^{158} sample than in the enriched Gd^{157} sample. If this activity were due to Tb^{157}, the above ratio should be 0.03 instead of 2.7. The observed ratio of the counting rates on the 950- and 182.7-keV photopeaks in these two samples was 3.1 and 3.6, respectively. Therefore, the mass number of 158 is assigned to the activity emitting the observed gamma

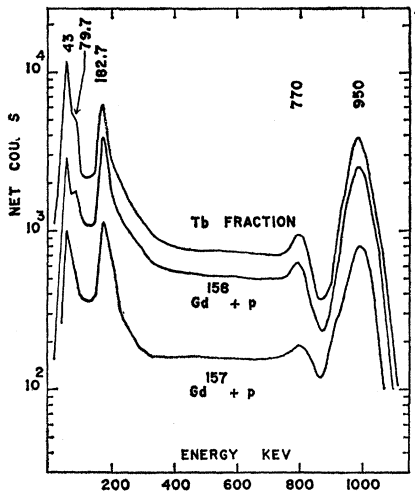

FIG. 1. The gamma spectra of the proton bombarded samples of enriched Gd^{158}, Gd^{157} and of the terbium chemical fraction from $Dy^{156}+n$.

rays. A comparison of the gamma spectra of these two proton-bombarded samples also indicates that there are no gamma rays that could be associated with a long-lived activity of Tb^{157}. The gamma activity in the chemical fraction mentioned above is, therefore, also attributed to Tb^{158}.

The 3- by 3-in. crystal connected to a 200-channel analyzer was used to determine the relative intensities of the gamma rays. The source was situated at a distance of 5 cm along the axis of the crystal to reduce any coincidence summing. A net spectrum was then obtained and unscrambled in the usual manner.[9] After having obtained the total number of counts under the photopeak and the Compton distribution of each of the gamma rays and the x ray, these intensity values were corrected for crystal efficiency. The photopeaks of the 79.7- and 99.3-keV gamma rays were not seen resolved. Hence, the counts under the composite photopeak were divided in the ratio 3.4:1 to obtain the intensity of the 79.7 and the 99.3-keV gamma rays, respectively. The internal conversion coefficients for the $E2$ gamma ray transitions[3,4] 79.7, 99.3, and 182.7 keV were obtained

TABLE I. Internal conversion coefficient data for the $E2$ transitions of 79.7, 99.3, and 182.7 keV in Tb^{158}. The α's are from reference 10. In this Table, N_T/N_γ, N_T/N_K, and N_T/N_L are the ratios of the total number of transitions to the number of gamma rays, the K-converted transitions, and the L-converted transitions, respectively.

E (keV)	$\alpha(K)$	$\alpha(L)$	$\alpha(M)$	N_T/N_γ	N_T/N_K	N_T/N_L
79.7	1.95	2.85	1.28	7.08	3.63	2.48
99.3	1.11	1.23	0.57	3.91	3.52	3.18
182.7	0.21	0.073	0.033	1.32	6.29	18.1

[9] R. L. Heath, Atomic Energy Commission Research and Development Report IDO-16408, 1957 (unpublished).

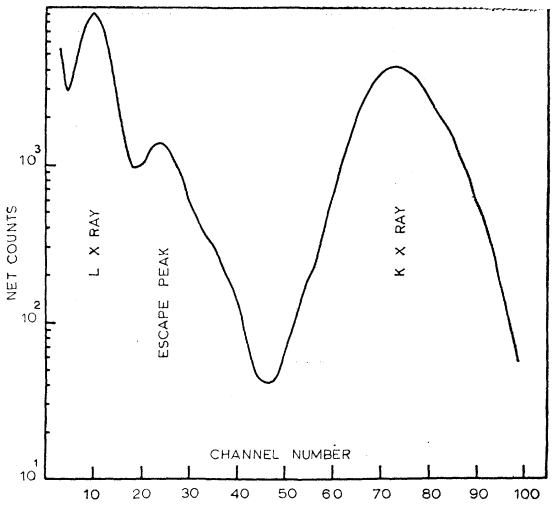

FIG. 2. The L and K x-ray spectrum of the terbium chemical fraction from $Dy^{156}+n$.

from Rose's Tables.[10] These interpolated values are given in Table I. The intensities of these gamma rays were corrected for internal conversion and the contributions of their internal conversion to the total observed K x-ray intensity were subtracted. The reduction in intensity of the 950- and 770-keV gamma rays due to internal conversion is assumed to be negligible. The intensity of the K x ray was checked by recording the gamma spectrum on a larger gain, so that both the iodine escape peak and the K x-ray peak were clearly displayed. Correction was also applied to the intensity values of the different gamma rays for absorption in the crystal housing. The absorption in the source holder was negligible, since the active material was enclosed in only one layer of 1/2-mil thick Mylar. Unscrambling analyses made with the terbium chemical fraction as well as the Tb^{158} activity in the sample of $Gd^{158}+p$, gave essentially the same relative number of transitions of the different gamma rays and the values obtained in these unscrambling analyses are given in Table II. The number of K-capture transitions observed in these two activities, however, are widely different and are respectively 110 and 0.61, when normalized with respect to the corresponding number of the 950-keV transitions.

L and K X-Ray Spectrum

The L and K x rays emitted by the terbium chemical fraction were detected by a 1/4-in.-thick NaI(Tl) crystal mounted on an EMI 6097B photomultiplier tube. The front face of the crystal was covered with a 0.005-in.-thick beryllium foil backed by a 1 μ thick aluminum reflector. The active material itself was mounted between two layers of 1/2-mil Mylar. The spectrum of the terbium chemical fraction obtained with this experimental arrangement is shown in Fig. 2. The

[10] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

TABLE II. Relative number of transitions of the gamma rays in the Tb chemical fraction and in $Gd^{158}+p$ sample.

Sample	L x ray	K x ray	79.9 keV	99.3 keV	182.7 keV	770 keV	950 keV
Tb chemical fraction	291	110	1.27	0.204	0.236	0.212	1.0
$Gd^{158}+p$		0.61	1.37	0.218	0.286		1.0

K x ray emitted by the terbium chemical fraction was identified as that of gadolinium by a comparison with the x rays emitted by radioactive Gd^{153} and Dy^{159}. The K and L x-ray energies were found to be, respectively, 43 and 6 keV. The 6-keV L x ray of gadolinium is clearly seen separated from the noise peak. On the low-energy side of the broad 43-keV K x-ray peak, the iodine escape peak at 15 keV is evident as a hump superposed on the high-energy side of the L x-ray peak. The following method was used to determine the relative intensities of the L and K x rays. The spectrum was recorded with a 130-mg cm^{-2} aluminum absorber between the source and the detector in order to absorb all L x rays. The spectrum thus obtained showed only the K x ray and the escape peak. This pulse-height distribution was then fitted to the pulse-height distribution obtained without the absorber and was subtracted from the pulse-height distribution showing both the K and L x-ray peaks. The efficiency of the x-ray crystal was assumed to be the same for both the K and L x rays. A correction of 1% was applied to the L x-ray intensity for absorption in the one layer of Mylar covering the source. Similar intensity corrections were applied for absorption in the intervening 9/32-in. layer of air between the source and the detector, 0.005-in. beryllium, and 1 μ of aluminum. These corrections applied successively increase the uncorrected value of the L x-ray intensity by 2, 8, and 3%, respectively. These absorption corrections are negligible for the K x rays. The L and K x-ray intensities are divided by 0.2 and 0.92, respectively, to correct for fluorescence yield.[11] After subtracting the contributions of the 79.7-, 99.3-, and 182.7-keV gamma rays to the L and K x-ray intensities, the L to K x-ray intensity ratio for the terbium chemical fraction was found to be 3.49. From this ratio the number of L-shell vacancies produced in filling one K-shell vacancy[12] is subtracted to give the ratio of the L to K-capture transitions as 2.64.

A comparison of the ratio of the intensity of the 43-keV K x ray to the intensity of the 79.7-keV gamma ray in these two proton bombarded samples of gadolinium was carried out. The $Gd^{158}+p$ and the $Gd^{157}+p$ sources were placed on the front face of a 3- by 3-in. NaI(Tl) detector and the gamma spectra of these two samples recorded. It was found that in the $Gd^{158}+p$ sample the

[11] A. H. Wapstra, G. J. Nijgh and R. Van Lieshout, *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

[12] B. L. Robinson and R. W. Fink, Revs. Modern Phys. **27**, 424 (1955).

K x ray was 3.4 times more intense than the 79.7-keV gamma ray, whereas, in $Gd^{157}+p$ sample, the K x ray is 7.9 times more intense than the 79.7-keV gamma ray. Calculations similar to the above indicate that if the excess of K x rays that are observed in the $Gd^{157}+p$ sample are attributed to the Tb^{157} activity, the half-life of Tb^{157} is approximately 2.6 times longer than that of Tb^{158}.

C. Coincidence Experiments

Gamma-gamma coincidence studies were carried out and the results are summarized below. The 950-keV gamma ray is found to be in coincidence with the 79.7-keV gamma ray and not with others. The 79.7-keV gamma ray is in coincidence with the 182.7, 770, and 950-keV gamma rays. The 182.7-keV gamma ray is found to be in coincidence with the 79.7- and 770-keV gamma rays but not with the 950-keV gamma ray. The window of the single channel analyzer of the coincidence circuit kept at 770 keV showed that the 770-keV gamma ray is in coincidence with the 79.7- and 182.7-keV gamma rays but not with the 950-keV gamma ray. Beta-gamma coincidence experiments made by gating with the beta-scintillator pulses in the energy range 200 to 400 keV confirmed the gamma ray at 99.3 keV.

III. DISCUSSION

A. Tb^{158} Activity

The energy-level diagram for the decay of Tb^{158} consistent with the data obtained in the present work is given in Fig. 3. The highest excited state of Gd^{158} nucleus reached as a result of the electron capture decay is at 1030 keV. The 1030-keV level is depopulated by two transitions: one of 950 keV to the 79.7-keV 2+ level and the other to the 262.4-keV 4+ level. By a comparison with the decay scheme of Tb^{160}, a spin-parity assignment of 3+ is made to the 1030-keV level and an assignment of 3− is made to the ground state of the Tb^{158} nucleus. The assignment of 3+ to the 1030-keV level would account for the observed greater intensity of the 950-keV gamma rays as compared to the 770-keV gamma ray. The 2+ and 4+ levels at 79.7 and 262.4 keV, respectively, are in agreement with the data on the energy levels of Gd^{158} obtained from a study of neutron capture gamma rays.[13] In calculating the branching ratios for the different energy levels in Fig. 3, use was made of the mean of the relative number of gamma-ray transitions obtained by the unscrambling of the gamma spectrum of Tb^{158}. Because of the large spin change involved, the probability of direct electron-capture transitions to the 0+ ground state of Gd^{158} from the 3− level of Tb^{158} is considered to be negligible. The relative transition probabilities of the 950- and 770-keV gamma rays as deduced from Table II indicate that 46% of the Tb^{158} decays by L capture to the 1030-keV level. The intensity measurements of the 99.3-keV gamma ray associated[4] with the beta decay of Tb^{158} indicate that 14% of the decay proceeds by beta emission.

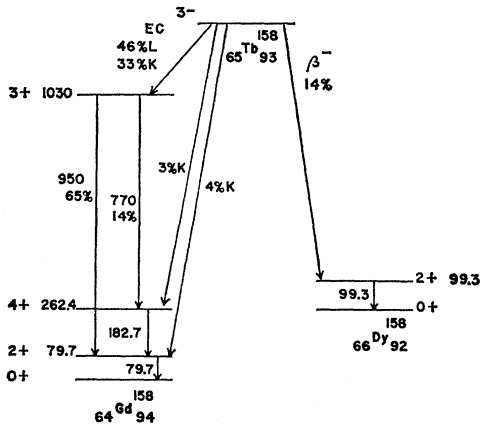

FIG. 3. The proposed decay scheme for Tb^{158}.

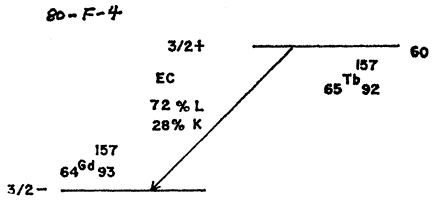

FIG. 4. The proposed decay scheme for Tb^{157}.

B. Tb^{157} Activity

A comparison of the Tb^{158} activity, when produced by proton bombardment of Gd^{158}, with the activity in the terbium chemical fraction indicates that the K x-ray intensity is 180 times greater in the latter case. Intense L x-ray emission is also observed in the latter case. In the sample of enriched dysprosium used for neutron bombardment to produce the terbium activity in the chemical fraction, Dy^{156} by an (n,γ) reaction would decay to Tb^{157}. Therefore, the large amount of L and K x rays that are observed in the chemical fraction are assigned to Tb^{157}. After subtracting the L- and K-capture transitions due to Tb^{158} in the chemical fraction, the remainder of the L- and K-capture transitions are assigned to the electron capture decay of Tb^{157}. The proposed decay scheme for Tb^{157} is reproduced in Fig. 4. The ground state of Gd^{157} has a spin of 3/2 as measured by Speck.[14] A spin of 3/2 has been assigned to the ground state of Tb^{157} by Mihelich *et al.*[15] A negative parity has been assigned[8] to the ground state of Gd^{157} and a positive parity to the ground state of Tb^{157}. Hence, the transition energy for the first-forbidden electron capture

[13] G. A. Bartholomew, J. W. Knowles, and P. J. Campion, Atomic Energy of Canada Limited Report AECL-888, 43, 1959 (unpublished).
[14] D. R. Speck, Phys. Rev. **101**, 1725 (1956).
[15] J. W. Mihelich, B. Harmatz, and T. H. Handley, Phys. Rev. **108**, 989 (1957).

decay of Tb^{157} can be calculated if the L to K-capture ratio is known.[16] This ratio is found to be 2.64 for Tb^{157} from the unscrambling data. The transition energy calculated by using the approximate formula is 60 keV. This value is of the same order of magnitude as the 20 keV estimated from experimental data together with the orbital assignments made based on the collective model of the nucleus.[8]

[16] H. Brysk and M. E. Rose, Revs. Modern Phys. **30**, 1169 (1958). R. Bouchez and P. Depommier, *Reports On Progress in Physics* (The Physical Society, London, 1960), Vol. 23, p. 395, Formula 71.

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Characterization of Ru^{107}, Ru^{108}, Rh^{107}, and Rh^{108}†

WILLIAM R. PIERSON,* HENRY C. GRIFFIN,‡ AND CHARLES D. CORYELL
Department of Chemistry and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

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The mass number of Rh^{107} (21.7±0.4 min) has been confirmed by alpha bombardments of Ru^{104} at selected energies, by fast-neutron bombardment of Pd^{108}, and by chemical identification; and the mass number of Rh^{108} (16.8±0.5 sec) has been established by the nature of its γ radiations. The mass numbers of the two precursors Ru^{107} (4.2±0.3 min) and Ru^{108} (4.5±0.2 min) have thereby also been established. The main radiations associated with these species are as follows (energies in keV): Ru^{107} β groups of 2100±300 and 3150±300, γ rays of 195 (14%, coincident with the 2100 β), 370 (~6%, coincident with the 195 γ), 480 (weak, seen only in coincidence with the 195 γ), 860 (7%, coincident with the 195 γ), 930 (4%), 1030 (4%), and 1290 (4%); Ru^{108} β groups 1150±100 and 1320±100, a γ of 165±3 (28%, coincident with the 1150 β); Rh^{107} β groups 840±40, 940±70, 1140±50, and 1200±50 keV, γ rays of 115 (0.5%), 285 (~3%, seen only in coincidence with the 390 γ), 307 (73%, coincident with the 1200 β), 365 (~2%, coincident with the 307 γ), 390 (11%, coincident with the 1140 and 840 β groups), 470 (1%), 570 (2%, coincident with the 940 β), and 675 (3%, coincident with the 840 β), and γ coincidence-sum lines at 680 (~3%), 880 (very weak), and 1140 (≤0.5%); Rh^{108} β of 4500±600 keV, γ rays of 430 (43%), 510 (10%, partly coincident with the 430 γ), 620 (22%, coincident with the 430 γ), 1520 (5%), and 2000 (≤3%). No 940 γ from the Pd^{108} 940 level could be detected (<3%), and less than one-third of the 510 γ rays follow β transitions to the 940 level. All γ rays above 115 in the four species are in fast coincidence with β rays. There are other γ rays associated with these species, especially for Ru^{107} and/or Rh^{108} above 1500. No evidence was found for isomers of Pd^{107}, Rh^{107}, Pd^{108}, or Rh^{108} from decay of 21.7-min Rh^{107} or 16.8-sec Rh^{108}. No Rh^{107} or Rh^{108} isomers could be isolated. However a γ ray of 21 keV, presumed to be K x rays of rhodium, appears in the short-lived ruthenium spectrum, with an intensity 5 to 8% relative to Ru^{107}; this is attributed to a short-lived (<10 sec) Rh^{107} isomer formed in >8% of the Ru^{107} disintegrations. The following decay paths are proposed: decay of Ru^{107} (Q^β=3200) proceeding to Rh^{107} excited levels of 1290 (4%), 1030 (11%), 930 (4%), 675 or 1530 (<5%), 565 (~6%), and 195 (0 to 5%), and to ground state (74%), with the reservation that it is likely that some of these levels should be referred to the supposed isomeric level rather than to the ground level; decay of Rh^{107} (Q^β=1510) proceeding to Pd^{107} levels of 1140 (~0.2%), 675 (may be more than one level, 7%), 570 (2%), 470 (1%), 390 (8%), and 307 (71%), and to ground state (0 to 17%); decay of Ru^{108} (presumably 0+, Q^β=1320) proceeding to Rh^{108} levels of 165 (0+ or 1+, 28%) and ground state (1+, 72%); decay of Rh^{108} (1+, Q^β=4500) proceeding to Pd^{108} levels of 2000 or higher (≤3%), 1520 or higher (≥5%), 1050 (0+, 22%), 940 (2+, 0 to 5%), and 430 (2+, ~17%), and to ground state (0+, 51%). Interpretations of these schemes are presented.

INTRODUCTION

THE fission of uranium is expected[1,2] to produce ruthenium isotopes from Ru^{101} to beyond Ru^{110}. Beside stable Ru^{101}, Ru^{102}, and Ru^{104}, the β emitters 40-day Ru^{103}, 4.5-h $Ru^{105} \rightarrow$ 45-sec Rh^{105m}+36-h Rh^{105}, and 1.0-yr $Ru^{106} \rightarrow$ 30-sec Rh^{106} are known.[1,3,4] Glendenin showed[5] in 1944 in a study of the chain 4-min Ru → 22-min Rh, discovered by Born and Seelmann-Eggebert,[6] that the yield of 22-min Rh was only about half of that expected from the 4-min Ru, and he proposed that the 4-min activity was a mixture of Ru^{107} and Ru^{108} of almost the same half-period, the latter producing a short-lived Rh^{108} decaying to stable Pd^{108}.

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* Present address: Science Laboratory, Ford Motor Company, Dearborn, Mich.

‡ Present address: Argonne National Laboratory, Argonne, Illinois.

[1] *Radiochemical Studies: The Fission Products*, edited by C. D. Coryell and N. Sugarman, National Nuclear Energy Series, Plutonium Project Record (McGraw-Hill Book Company, New York, 1951), Div. IV, Vol. 9.

[2] C. D. Coryell, M. Kaplan, and R. D. Fink, Can. J. Chem. **39**, 646 (1961).

[3] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).

[4] *Nuclear Data Sheets*, edited by C. L. McGinnis, (National Academy of Sciences—National Research Council, Washington, D. C., 1958).

[5] L. E. Glendenin, reference 1, Paper 115.

[6] J. H. Born and W. Seelmann-Eggebert, Naturwissenschaften **31**, 420 (1943).