New Terbium Isotope, Tb^{152}†

KENNETH S. TOTH,* KENNETH T. FALER, AND JOHN O. RASMUSSEN
Radiation Laboratory and Department of Chemistry, University of California, Berkeley, California
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A careful examination of photon and electron spectra from cyclotron-produced mixtures of light terbium isotopes has led to the identification of a new isotope, Tb^{152}, with an 18.5-hr half-life. The 344.1-kev transition from first excited state to ground in daughter Gd^{152} has been identified and shown to be identical in energy to a transition associated with the beta decay of 9.3-hr Eu^{152m} to the same daughter nucleus. Gamma transitions of 180 and 265 kev are also assigned to the decay of Tb^{152}.

TERBIUM-152 has not been previously reported despite the fact that Tb^{151}, Tb^{153}, and Tb^{154} have been known for some time. In this study Tb^{152} has been produced and given a mass assignment in a series of bombardments using alpha particles accelerated in the Berkeley 60-inch cyclotron. The half-life has been found to be 18.5 ± 0.5 hr. The similarity of the half-lives of two neighboring isotopes, Tb^{151} (19 hr) and Tb^{154} (17 hr), makes it clear why this isotope has been previously overlooked.

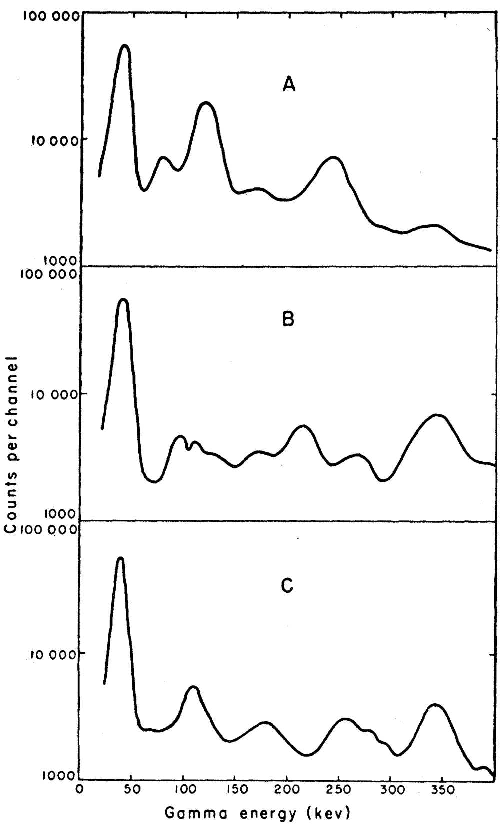

FIG. 1. Gamma spectra of terbium isotopes by alpha-particle bombardment of enriched europium isotopes. (*A*) 37-Mev alphas on Eu^{153}, 3×3-inch NaI(Tl) detector; (*B*) 37-Mev alphas on Eu^{151}, 3×3-inch detector; and (*C*) 48-Mev alphas on Eu^{151}, 1.5×1-inch detector.

A series of bombardments was undertaken using the enriched isotopes, Eu^{151} (91.9% Eu^{151}, 8.1% Eu^{153}) and Eu^{153} (5.0% Eu^{151}, 95.0% Eu^{153}), with bombarding energies of 48 Mev and 37 Mev. At the higher energy the most probable reaction is $(\alpha,4n)$, while the lower energy is below the threshold for this reaction and produced mostly $(\alpha,3n)$.

After bombardment the elements were chemically separated by means of a cation-exchange method described elsewhere.[1] Gamma rays emitted by the terbium isotopes were studied using 3×3-inch and $1\times1\frac{1}{2}$-inch NaI(Tl) crystal scintillation counters in conjunction with a 100-channel pulse-height analyzer. Accurate gamma-ray energies were obtained from conversion electron spectra taken in 180-degree-focusing permanent-magnet electron spectrographs described by Smith and Hollander.[2]

In Fig. 1, curve *A* shows the gamma spectrum of the chemically separated terbium isotopes following 37-Mev alpha-particle bombardment of Eu^{153}. This sample should consist mostly of Tb^{154} with smaller amounts of Tb^{155} and very little Tb^{153} and Tb^{152}. The three peaks have energies (determined precisely by conversion electron measurements) of 123.2, 248.1, and 347.1 kev and have previously been ascribed to Tb^{154} decay.[3,4]

Curve *B* of Fig. 1 shows the gamma spectrum following 37-Mev alpha-particle bombardment of Eu^{151}. Here the majority of product should be Tb^{152} with smaller amounts of Tb^{153} and Tb^{154}. Again a peak is seen at 340 kev and its rate of decay as obtained from a series of spectra taken at various times after bombardment indicates a half-life nearly the same as that of Tb^{154}. That it is not, in fact, the same gamma as the 347.1 kev one of Tb^{154} is readily seen when its intensity is compared with the intensities of the other peaks seen in the Tb^{154} spectrum in curve *A*. In curve *B* the relative intensities of the 120- and 240-kev gammas are greatly reduced. This evidence indicates the presence of a new

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* Present address: University Institute for Theoretical Physics Copenhagen, Denmark.

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[2] W. G. Smith and J. M. Hollander, Phys. Rev. **101**, 746 (1956).
[3] Mihelich, Harmatz, and Handley, Phys. Rev. **108**, 989 (1957).
[4] K. S. Toth and J. O. Rasmussen, preceding paper [Phys. Rev. **115**, 150 (1959)].

isotope whose decay includes a prominent 340-kev gamma. Since Tb^{153} is known to have a half-life of 60 hr,[3,5] the isotope must be Tb^{152} or perhaps Tb^{151} which also has nearly the same half-life. Since this bombardment was at an energy below the threshold for production of Tb^{151} it is most probable that the gamma belongs to Tb^{152}, and additional evidence is obtained by comparison with curve C of Fig. 1. This is the spectrum of gamma rays following a 48-Mev bombardment of Eu^{151} which produced an abundance of Tb^{151}. This spectrum was obtained with a $1\times 1\frac{1}{2}$-inch scintillation crystal and thus in a visual intensity comparison with the upper curves, the different counting efficiencies must be borne in mind. It is possible, however, to obtain relative intensities of gamma rays and correct these for differences in counting efficiencies in order to make comparisons between curves B and C. This having been done, the corrected intensity ratio of the 340-kev gamma to the 110-kev gamma (assuming all of the 110-kev peaks in curves B and C to be due to Tb^{151}) is 9.5 to 1 in curve B and 5.8 to 1 in curve C. This variation strongly supports assignment of the 340-kev gamma to Tb^{152}.

The spectrum shown in curve B was obtained after an elapsed time of 32 hours following bombardment and thus some of the peaks shown are due to gamma rays of longer-lived nuclides. The peak at 212.2 kev is the prominent gamma seen in the decay of 62-hr Tb^{153}. The peaks near 100 kev are complex, consisting of the 97.3- and 103.1-kev gammas from the decay of Gd^{153} and several weak gammas from Tb^{153} decay. It is also possible that there is a gamma of about 90 kev in Tb^{152}. No gammas are seen which can be assigned to Tb^{151} or Tb^{154}.

[5] K. S. Toth and J. O. Rasmussen (unpublished data).

The rate of decay of the peaks at 180 and 265 kev indicate that these also belong to the decay of Tb^{152}. A spectrum taken at higher energies shows a large number of low-intensity gammas which could not be resolved and assigned with certainty. From the high-energy side of the 340-kev peak may be resolved a gamma of 415-kev energy with an intensity about 20% that of the 340. This is doubtless the 413-kev gamma seen in the decay of Eu^{152} to the same daughter nuclide.

Several permanent-magnet spectrograph sources were made from the terbium fraction of the sample obtained in the 48-Mev alpha particle bombardment of Eu^{151}. Conversion electron energies were compared with energies observed in the decay of Eu^{152} on the same instrument and corresponded exactly to those of the 344.1-kev gamma seen here and elsewhere.

In addition to the two gamma rays discussed above, there are peaks at 180 and 265 kev in spectrum B which decayed with about the correct half-life to indicate that they belonged to Tb^{152} decay, and there was some indication that a gamma around 90 kev also had a 19-hour half-life but this was less certain. An additional gamma was seen at 125 kev which decayed very rapidly and whose identity or half-life was not determined.

Finally, alpha particles from Tb^{152} decay were sought in the sample obtained from the 37-Mev bombardment of Eu^{151}. No alpha counts were detected, and estimating the disintegration rate of Tb^{152} from the K x-ray peak together with the statistical uncertainty in the alpha counter background allowed an alpha-to-electron capture branching ratio to be set at a limit of $<10^{-7}$. This number is to be compared with the branching ratio of 3×10^{-6} for Tb^{151} which has been recently determined experimentally by Toth and Rasmussen.[5]