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ABSTRACT

Bombardments of europium oxide with alpha particles of energies from 38 Mev to 75 Mev inclusive were made and various studies on the terbium nuclides produced were carried out. No distinctive new activities were observed in Geiger counter decay curve resolution. A probable mass assignment of 151 for the nineteen hour Tb alpha emitter was made on the basis of bombardment energy threshold observations and a slightly lower half-life value of 17.2 hours determined. Attempts at mass spectrographic mass assignment of this alpha emitter were unsuccessful. Lower limits on the alpha to electron capture branching ratios for Tb^{149} and Tb^{151} were determined experimentally. The terbium chemical fraction from a 38 Mev alpha bombardment of europium oxide was examined in a high resolution beta spectrometer. The results are given in summary form.

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*This work was performed under the auspices of the AEC.

†Research associate from the Politecnico Di Milano, Milan, Italy.

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I. INTRODUCTION

In previous papers the following terbium isotopes were reported and classified.

Mass	Radiation	Half-life	Nucl. reaction	Energy of alphas (Mev)	References
Tb^{156}	K, β^+	5.00 h.	Eu^{153} - α, n	19 to 38	1
Tb^{155}	K, $\bar{e}$, γ	188. d.	Eu^{153} - α,2n	All 19 to 38	1
Tb^{154}	K, $\bar{e}$, β^+, γ	17.2 h.	Eu^{151} - α, n	19 to 38	1
			Eu^{153} - α,3n	All 19 to 38	1
Tb^{153}	K, $\bar{e}$, γ	5.1 d.	Eu^{151} - α,2n	19 to 38	1
Tb^{151} or 150	α (3.95 Mev)	19. h.	Eu^{151} - α,4n	60, 90, 120	2
Tb^{149}	α (3.44 Mev)	4.0 h.	Eu^{151} - α,6n	60, 90, 120	2
			Eu^{153} - α,8n	60, 90, 120	

II. SEARCH FOR NEW NEUTRON-DEFICIENT TERBIUM ACTIVITIES

One object of this research was a search for the radioactive terbium isotopes between mass numbers 149 and 153. Bombardments of europium oxide with alpha particles of 38, 45, 55, 65, and 75 Mev

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[1]G. Wilkinson and H. Hicks, Phys. Rev. 79, 815 (1950), and Phys. Rev. 74, 1733 (1948).

[2]Rasmussen, Thompson, and Ghiorso, U. C. Radiation Laboratory Reports, 1473 and 1875. Phys. Rev. (in press).

were made and alpha decay and GM counter decay followed. No new active isotope has been found, the picture of neutron deficient terbium nuclides thus remaining like the one described above. Tb^{152} and Tb^{150} are either quite short-lived, very long-lived, or have half-lives near other Tb activities. The half-life of the longer-lived alpha activity was determined as 17.2 hours rather than the 19 hour value reported previously.[2]

III. MASS ASSIGNMENT OF 17 HOUR TERBIUM ALPHA EMITTER

Alpha threshold energies for production of terbium alpha emitters by europium bombardment were determined as follows:

Alpha Activity	Threshold
4 hour Tb^{149}	$55 < E_{t1} < 65$
17 hour $Tb^{150 \text{ or } 151}$	$38 < E_{t2} < 45$

From these experimental limits on the threshold for production of seventeen hour terbium by the

$$Eu^{151}\ (\alpha, xn)\ Tb^{155-x}$$

reaction, we can say the following about the difference of the two threshold energies:

$$10 \text{ Mev} < E_{t1} - E_{t2} < 27 \text{ Mev}.$$

From these limits it would appear most probable that the mass number of the seventeen hour Tb alpha emitter is greater by two or three than the four hour Tb mass number of 149, hence that the seventeen hour Tb alpha emitter is mass 151 or 152. However, if the mass number were 152, the activity surely would have been seen prominently in the 38 Mev alpha bombardment, since the $(\alpha,3n)$ reaction threshold should be in the neighborhood of 30 Mev in this region. Therefore, the most probable mass number is 151. Two bombardments were made to attempt a confirmatory mass spectrographic mass assignment to the seventeen-hour alpha-emitter, using the procedure described by Rasmussen et al.[3] Both attempts were unsuccessful, the low yield of the cyclotron bombardment of Eu_2O_3 (alpha particles of 55 Mev energy) being responsible in the first case. In spite of the use of a large amount of oxide (180 mg) and of a very successful column separation following five amalgam reductions, the nitrate solution of the active terbium isotopes was not active enough to give a detectable number of alpha tracks on the mass spectrographic transfer plates. The ionization efficiency for terbium from a thermal filament is extremely low, $\sim 10^{-5}$. This failure suggested turning to a cyclotron reaction utilizing the proton beam of the 184-inch cyclotron, this beam being more intense than the alpha beam. The second bombardment was made with 75 Mev protons on Gd_2O_3, using 100 mg of Gadolinium oxide. This method of production leads to a larger mixture of terbium activities because there are five fairly abundant Gd stable nuclides: Gd^{160} (21.8%); Gd^{158} (24.8%); Gd^{157} (15.7%); Gd^{156} (20.6%); and Gd^{155} (14.8%). The material obtained had an alpha-activity of about 3.10^5 alpha counts per minute twenty-four hours after the end of the bombardment, and the terbium isotopes were mixed with very little inactive mass of target gadolinium owing to an excellent separation in a large ion-exchange column. Most of this activity was due to the four hours Tb^{149} and little to the seventeen hours terbium. The alpha sensitive plates obtained by the transfer

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[3]Rasmussen, Reynolds, Thompson, and Ghiorso, Phys. Rev. **80**, 475 (1950).

technique from the mass spectrograph platinum strips showed no alpha tracks.

IV. DETERMINATION OF LOWER LIMITS TO THE α/K BRANCHING RATIOS IN Tb^{149} AND Tb^{151}

For Tb^{149} in the sample $75\rho 1$ at 1800, October 15, there were 6.4×10^3 alpha counts per minute, or $(6.4 \times 10^3)/0.52 = 1.23 \times 10^4$ alpha disintegrations per minute. In $75\rho 2$ no four-hour component could be observed in the Geiger counter decay curve. Both these samples were obtained by bombarding Gd_2O_3 with 75 Mev protons and separating the Tb nuclides by ion-exchange column. That is, we can say that at 1800, October 15, there were less than 1×10^4 c/m of four-hour activity on shelf three. The geometry factor of shelf three is about 0.02, and the poorest conceivable counting efficiency for K capture would result if only K x-rays were emitted. Assuming 0.05 for counting efficiency, we calculate the K capture disintegration rate in $75\rho 2$ at 1800 to be less than

$$\text{K capture} < \frac{1 \times 10^4}{0.02 \times 0.05} = 1 \times 10^7 \text{ d/m.}$$

The ratio of activities of $75\rho 1$ to $75\rho 2$ is 16:22, so in $75\rho 1$ at 1800 we have

$$\text{K capture} < \frac{16}{22} \times 10^7 = 7.3 \times 10^6 \text{ d/m.}$$

Therefore, for Tb^{149}

$$\alpha/K > \frac{1.23 \times 10^4}{7.3 \times 10^6} \approx 2 \times 10^{-3}$$

Similarly, for Tb^{150} in sample 55A at 1200, October 9, there were 38 alpha c/m and a seventeen-hour Geiger decay component on shelf three of 2×10^4 c/m. We calculate

$$a/K > \frac{38}{0.52} \cdot \frac{0.02 \times 0.05}{2 \times 10^4} \approx 4 \times 10^{-6}$$

These are only lower limits and may be far from the true branching ratios, as the presence of such large amounts of other K capture nuclides in the samples introduce this uncertainty.

V. BETA RAY SPECTROMETER STUDY OF SEVENTEEN-HOUR Tb^{154}

On the basis of one bombardment (Eu_2O_3 with 38 Mev alpha particles), where the chemically isolated terbium fraction was studied on the "double focusing" beta spectrometer described by O'Kelley,[4] the following tentative results are reported. Further work is indicated before any decay schemes can be proposed. Beta decay energies have been determined from Fermi-Kurie plots using the Fermi factor tables (no screening corrections) computed by the National Bureau of Standards.[5]

Nuclide	Half-life	Radiation	Energy (Mev)	Rel. integrated intensity
Tb^{154}	17 h.	β_1^+	2.75	1
		β_2^+	1.66	1
		* β^-	2.34	1.9

[4] G. D. O'Kelley, Ph. D. Thesis, University of California, (Chemistry) 1948. Issued as UCRL-1243, p. 22.

[5] Tables of the Fermi Function. Computation Laboratory, The National Bureau of Standards, (privately circulated).

*Insufficient decay points were taken to assign the β^- activity with certainty to Tb^{154}. If the β^- activity is indeed due to Tb^{154}, then Dy^{154} is established as beta stable, although it is missing in nature. Its absence in nature could be due to an alpha decay half-life short with respect to the age of the elements.

Nuclide	Half-life	Radiation	Energy (Mev)	Rel. integrated intensity
Tb^{154} (Continued)	17 h.	e^-	0.54_9	
			0.51_7	
			0.37_4	
			0.32_2	
			0.28_1	
			0.23_3	
			0.18_8	
Others	>17 h.	β^+	3.1	
		e^-	0.20_5	
			0.15_3	
			0.12_6	
			0.08_8	
			0.07_6	