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RADIOACTIVE ISOTOPES OF THE RARE EARTHS

III. Terbium Isotopes

Geoffrey Wilkinson and Harry G. Hicks

August 18, 1949

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III. Terbium Isotopes

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ABSTRACT

A study has been made of neutron deficient radioactive isotopes of terbium produced by α-particle bombardment of europium and by proton bombardment of gadolinium using the 60-inch Crocker Laboratory cyclotron. Five new isotopes have been characterized.

RADIOACTIVE ISOTOPES OF THE RARE EARTHS

III Terbium Isotopes

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I. Introduction

The experimental techniques used in bombardments, chemical separations and radioactivity measurements have been previously described.(1) In the study of terbium activities, europium was bombarded with α-particles of energy 38, 31 and 19 Mev, while gadolinium was bombarded with 10 Mev protons; the radioactivities observed were shown to be associated with terbium by chemical separation using an ion exchange column.

(1) G. Wilkinson, H. G. Hicks, Phys. Rev. 75, 1370 (1949).

II. Terbium Isotopes

Table I. Production and Characteristics of Terbium Isotopes

Isotope	Type of Radiation	Half-Life	Energy of Radiation in Mev: Particles	γ-rays	Produced by
Tb^{153}	K, e^-, γ	5.1±0.1 days	0.15 ~0.3	L,K x-rays 0.23,1.2	Eu^{151}-α-2n
Tb^{154}	K, e^-, γ β^+ (~0.5%)	17.2±0.2 hours	0.13~0.8(e^-) 2.6(β^+)	L,K x-rays 1.3	Gd-p-n Eu^{151}-α-n Eu^{153}-α-3n
Tb^{155}	K, e^-, γ	190 ± 5 days	0.1(e^-)	L,K x-rays 1.4	Eu^{153}-α-2n
Tb^{156}	K, β^+(<25%)	5.0±0.1 hours	~1.3	L,K x-rays	Eu^{153}-α-n Gd-p-n
Tb^{157}	K, e^-, γ	4.7±0.1 days	0.09, 0.2	L,K x-rays 1.4	Gd-p-n

The production and properties of the terbium isotopes are given in Table I. In the bombardment of europium with α-particles, four activities of half-lives 5.1 days, 17 hours, 190 days and 5.0 hours were observed; from the yields in bombardments using α-particles of energies 38, 31 and 19 Mev, allocation was made to masses 153, 154, 155 and 156 respectively. In the bombardment of gadolinium with 10 Mev protons, the 17 hour, 190 day and 5.0 hour activities were again observed, together with a new activity of half-life 4.7 days which can be allocated to mass 157 or 158, and the well known[(2)] 3.9 hour and 73.5 day Tb^{160} activities . No evidence has, as yet been observed for an additional

(2) G. T. Seaborg, I. Perlman, Revs. Mod. Phys. 20, 585 (1948).

isotope of mass 157 or 158 which should be formed in proton bombardment of gadolinium; this isotope is undoubtedly of long life and the presence of the long-lived Tb^{155} and Tb^{160} activities makes the recognition of a further long lived activity by simple measurements a difficult task.

5.1 ± 0.1 day Tb^{153}

The decay of this activity, which was found in high yields in 38 and 31 Mev α-particle bombardments of europium was followed through ten half-lives (Fig. I) to give a value of 5.1 ± 0.1 days for the half-life. Resolution of aluminum, beryllium and lead absorption data (Figs. II, III) show the radiations to consist of electrons, total ranges in aluminum 32 mg/cm^2 (0.15 Mev), and $\sim$90 mg/cm^2($\sim$0.3 Mev), and electromagnetic radiations of half thickness 7 mg/cm^2 aluminum (6.3 Kev), 60 mg/cm^2 lead (46 Kev), 570 mg/cm^2 lead (0.23 Mev) and 11.6 g/cm^2 lead (1.2 Mev). The two soft components of the electromagnetic radiation correspond to L and K x-radiation of gadolinium. The ratios of the various radiations corrected for counting efficiencies[(1)], etc. are:

0.17 Mev e^- :	$\sim$0.3 Mev e^- :	L x-rays :	K x-rays :	0.23 Mev γ ray :	1.2 Mev γ ray
= 0.02 :	0.001 :	0.2 :	1 :	0.1 :	0.02

The soft electron most likely results from conversion of the 0.22 Mev γ ray in the K shell of the daughter nucleus following decay by orbital electron capture. No positrons were observed on a simple beta ray spectrometer. In the calculation of yields of the 5.1 day activity, one K x-ray quantum has been assumed to represent one disintegration.

17.2 ± 0.2 hour Tb^{154}

In all bombardments of europium with α-particles a 17 hour positron emitting activity was observed; this was also found in low yields in the proton bombardments of gadolinium. The decay of the positive electrons was followed through 8.4 periods on a simple beta ray spectrograph, to give a half-life of 17.2 ± 0.2 hours; the decay of gross and electromagnetic radiations of terbium samples give a similar value (Fig. IV). Resolution of decay and aluminum absorption data (Fig. V) shows electrons of ranges 28 mg/cm^2 (0.13 Mev) and ~300 mg/cm^2 (0.8 Mev), soft electromagnetic radiation of half thickness 7 mg/cm^2 (6.3 Kev) and hard electromagnetic radiation. A positive electron of maximum energy ~ 2.6 Mev was found on the beta ray spectrograph, as well as two groups of negative electrons corresponding to those measured in aluminum absorptions; the ratio of negative to positive electrons was obtained by integrating the distribution curves on the beta ray spectrograph. Lead absorption measurements (Fig. VI) shows components of half thicknesses 60 mg/cm^2 (46 Kev) and 12.2 g/cm^2 (1.3 Mev); the positrons are in such low abundance that no annihilation radiation would be observed in absorption measurements. From the various measurements the following ratios were obtained:

0.13 Mev e^-	:	0.8 Mev e^-	:	2.6 Mev β^+	:	L x-rays	:	K x-rays	:	γ rays
0.1	:	0.02	:	0.004	:	0.3	:	1	:	0.03

It seems reasonable to conclude that the isotope decays at least 98% by orbital electron capture to two or more metastable or excited states of the daughter nucleus.

As has been pointed out(3), it is possible that the hard negative electron may

(3) G. Wilkinson, UCRL-289, Feb. 14, 1949.

be a negative beta particle, indicating decay to an unreported beta stable isotope Dy^{154}. For estimation of yields of the 17 hour activity in various bombardments, 0.9 K x-ray quanta have been assumed to represent one disintegration by orbital electron capture.

190 day Tb^{155}

After decay of the 5.1 day activity in Eu + α bombardments, a long lived activity

(Fig. I) was observed; the best value for the half life at present is 190 ± 5 days. Aluminum and beryllium absorption data (Fig. VI) showed electrons of total range 14 mg/cm^2 (0.1 Mev), and electromagnetic radiation half thickness 7 mg/cm^2 (6.3 Kev); lead absorption measurements (Fig. VI) showed two components of half thicknesses 60 mg/cm^2 (46 Kev) and 12.7 g/cm^2 (1.4 Mev). The two soft quantum radiations correspond to gadolinium L and K x-radiation. The ratios of the radiations obtained were:

0.1 Mev e^-	L x-rays	K x-rays	1.4 Mev γ-ray
0.4	0.2	1	0.3

<u>5.0 ± 0.1 hour Tb^{156}</u>

In bombardments of europium with 19 Mev α-particles, an activity of half-life 5.0 ± 0.1 hours measured through nine half-lives, was observed in high yield.

The aluminum absorption (Fig. VII) showed only a hard electron range ~600 mg/cm^2 (~1.3 Mev) soft electromagnetic radiation 7 mg/cm^2 half thickness (6.3 Kev) and hard quantum radiation background. On a simple beta ray spectrograph, no negative electrons were observed, but only positrons of maximum energy ~1.4 Mev, which decayed with the 5.0 hour half-life. Insufficient activity was obtained for measurement of a lead absorption curve of gamma rays. Assuming 0.5% average counting efficiency for gamma radiation, the ratios of the radiations obtained from aluminum absorptions gives:

1.3 Mev β^+	L x-rays	K x-ray and γ-ray radiation
~0.2	~0.1	1

The isotope thus appears to decay mainly by orbital electron capture with less than 25% positron branching.

<u>4.7 ± 0.1 day $Tb^{157,8}$</u>

In the decay of the chemically separated terbium fraction from 10 Mev proton bombardments of gadolinium, an activity of half-life 4.7 ± 0.1 days measured through seven half lives has been observed.(Fig. VIII) The radiation characteristics obtained by resolution of aluminum and lead absorption curves (Fig. IX) are quite different from those of the 5.1 day activity described above. The latter has been allocated to Tb^{153}

on the basis of yields in the α-particle bombardment of europium, and hence would not be present in the terbium fraction from proton bombarded gadolinium. The aluminum absorption data shows electrons total range ~11 mg/cm^2 (~0.09 Mev), 40 mg/cm^2 (0.217 Mev) and quantum radiation half thickness 7.5 mg/cm^2. Lead absorption data shows components of half thicknesses ~60 mg/cm^2 (~46 Kev) and ~12.7 g/cm^2 (1.4 Mev); the soft component was in very low abundance and may be a mixture of K x-radiation and unconverted gamma radiation. The ratio of the various radiations obtained were

0.09 Mev e^-	:	0.2 Mev e^-	:	L x-rays	:	K x-rays	:	1.4 Mev γ ray
~0.2	:	0.1	:	0.4	:	1	:	0.3

III. Discussion

The mass allocations of the four activities observed in the α-particle bombardment of europium have been made on the basis of yields at bombarding energies of 38, 31 and 19 Mev; this procedure has been used previously for thulium[1], rhenium and tantalum[4] activities. No evidence has been obtained for Tb152 which would be formed

(4) G. Wilkinson, H. G. Hicks (to be published).

by α,3n reaction on Eu^{151}, and an upper limit of about 20 minutes can be placed for the half-life. While the 86 day Gd^{153} activity has been observed in the column separated gadolinium fractions from Eu + α bombardments, the formation of this isotope from the 5.1 day terbium allocated to mass 153 has not been confirmed since sufficient activity was not available. In proton bombardments of gadolinium, the 17 hour activity was observed only in very low yield, agreeing with its allocation to Tb^{154}; the 5.0 hour positron emitting activity, the 4.7 day activity and the beta particle emitting 3.9 hour and 73.5 day activities were observed in high yields as would be expected from the abundances of the gadolinium isotopes. Since the present work on the 4.7 day activity allocated to mass 157 or mass 158 was completed, Butement[5] has reported a 5.9 day activity

(5) D. S. Butement, Phys. Rev. 75, 1276 (1949).

produced in the proton bombardment of gadolinium, and has allocated this to masses 156-7 or 8. The radiation characteristics agree with those reported here for the 4.7 day activity.

As has been pointed out above, the existence of at least one further long lived isotope of terbium at mass 157 or 158 is possible; also, since the half-life of the 5.0 hour Tb^{156} seems rather short, a long lived orbital electron capture isomer may exist, but no difference in the decays of the long lived activities from the various Eu + α bombardments has been noted yet and all are decaying with the 190 day activity allocated to mass 155 on the basis of reaction yields.

Acknowledgements

We wish to thank Dr. J. G. Hamilton, Mr. B. Rossi, Mr. T. Putnam and the crew of the 60 inch Crocker Laboratory cyclotron for their cooperation and assistance in bombardments; we are also much indebted to Professors G. T. Seaborg and I. Perlman for their interest and advice.

This work was done under the auspices of the Atomic Energy Commission.

LEGENDS FOR FIGURES

Fig. I — Decay of 5.1 day Tb^{153} (B) and 190 day Tb^{155} activities from Eu + 38 Mev α bombardment.

Fig. II — Aluminum absorption of 5.1 day Tb^{153} activity from Eu + 38 Mev α bombardment. K x-ray and γ-rays (A), ~0.3 Mev electron (B), 0.15 Mev electron (C), L x-rays (D).

Fig. III — Lead absorption of 5.1 day Tb^{153} activity. 1.2 Mev γ-ray (A), 0.23 Mev γ-ray (B), K x-rays (C).

Fig. IV — Decay of electromagnetic radiations of 5.0 hour Tb^{156} (C), 17.2 hour Tb^{154} (B) and 5.1 day Tb^{153}(A) activities from Eu + 38 Mev α bombardment.

Fig. V — Aluminum and lead absorptions of 17.2 hour Tb^{154} activity.

Aluminum absorption: K x-ray and γ-rays (A), 0.8 Mev electrons (B), 0.13 Mev electrons (C), L x-rays (D).

Lead absorption: 1.3 Mev γ-ray (A), K x-rays (B).

Fig. VI — Aluminum and lead absorptions of 190 day Tb^{155} activity.

Aluminum absorption: K x-ray and γ-ray background (A), 0.1 Mev electron (B), L x-rays (C).

Lead absorption: 1.4 Mev γ-ray (A), K x-rays (B).

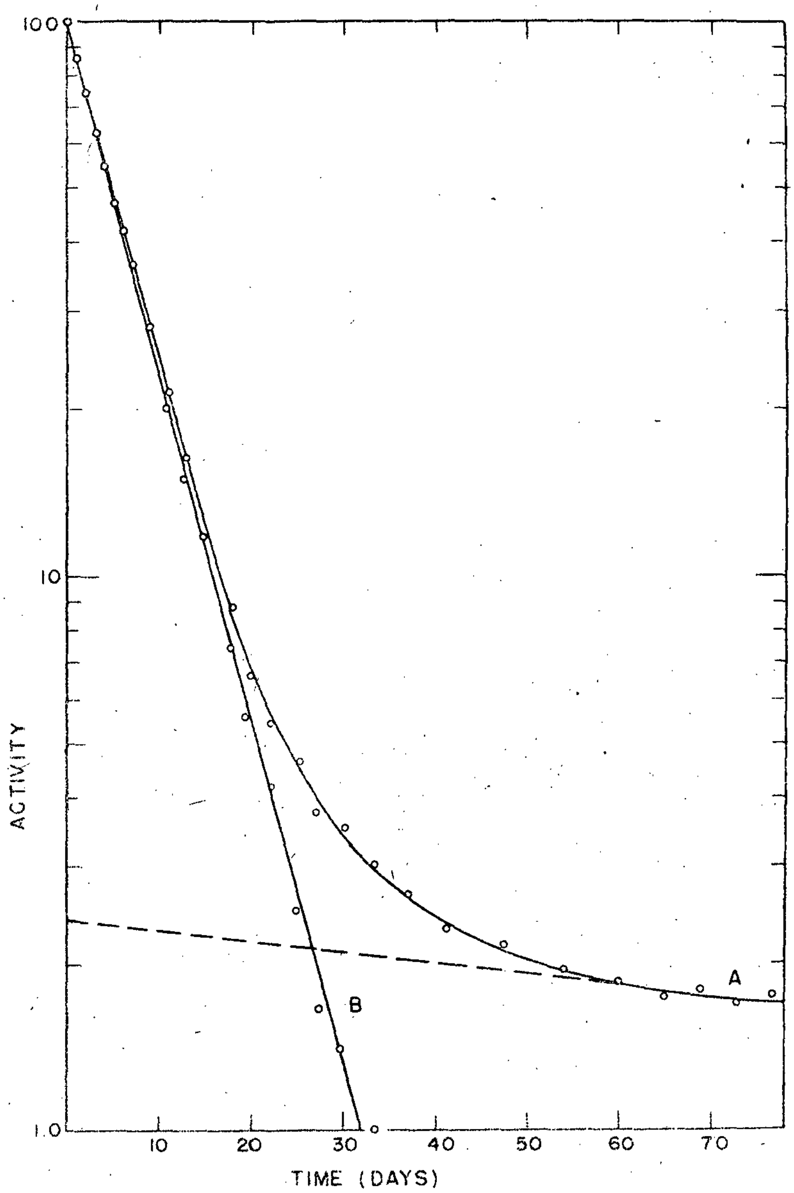
Fig. VII — Aluminum absorption of 5.0 hour Tb^{156} activity from Eu + 19 Mev α bombardment. K x-ray and γ-ray background (A), 1.3 Mev positron (B), L x-rays (C).

Fig. VIII — Decay of 4.7 day $Tb^{157,8}$ (B) and 73.5 day Tb^{160} (A) activities from Gd + β bombardment.

Fig. IX — Aluminum and lead absorptions of 4.7 day Tb activity.

Aluminum absorption: K x-ray and γ-ray background (A), 0.2 Mev electron (B), 0.09 Mev electron (C), L x-rays (D)

Lead absorption: 1.4 Mev γ-ray (A), K x-rays (B).



13439-1

FIG. 1

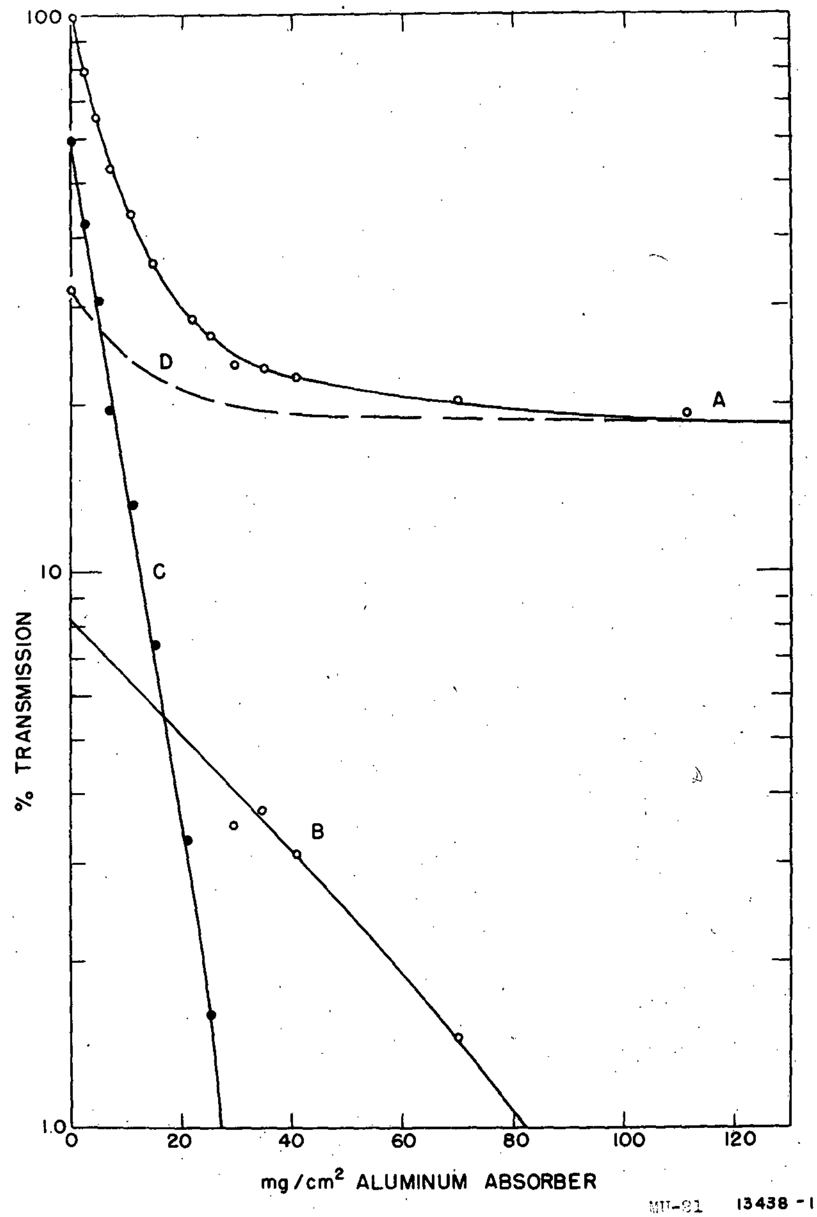
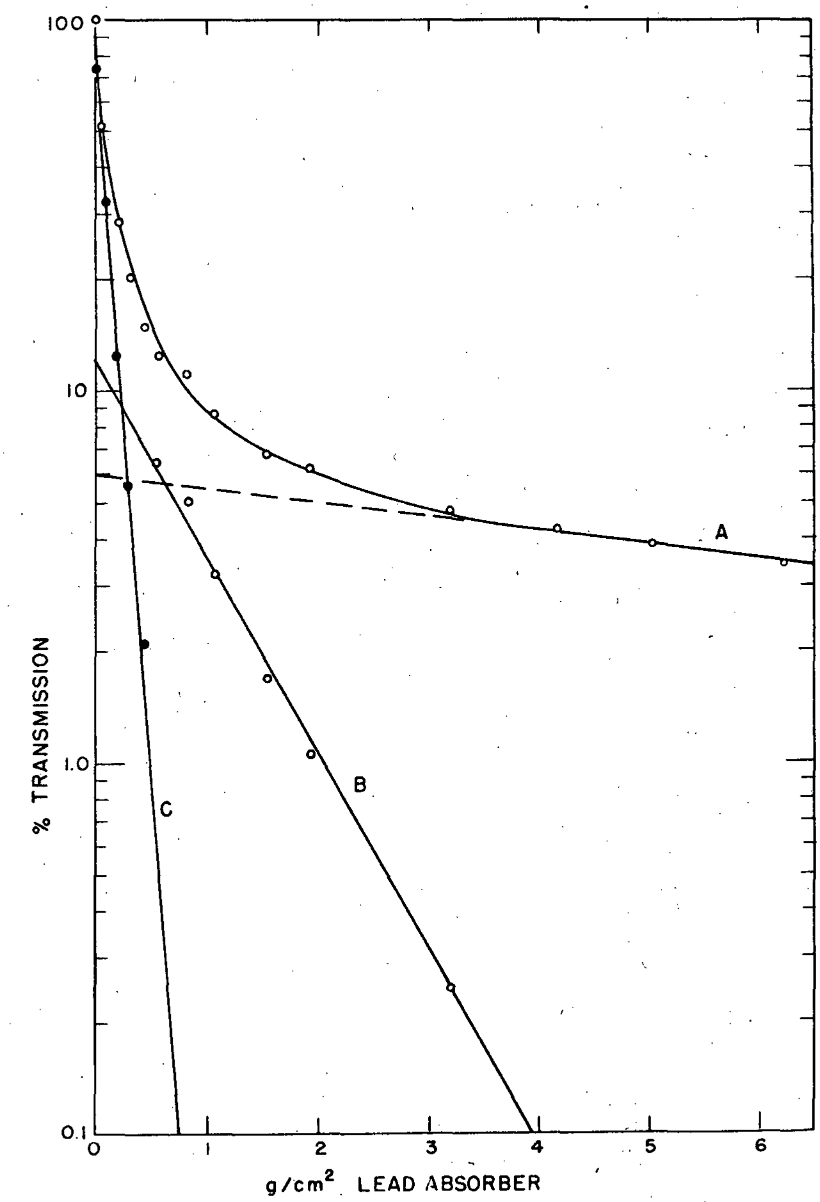

100
10
1.0
0
20
40
60
80
100
120
% TRANSMISSION
mg/cm² ALUMINUM ABSORBER
A
B
C
D
MU-21 13438-1

FIG. 11



13437-1

FIG. 111

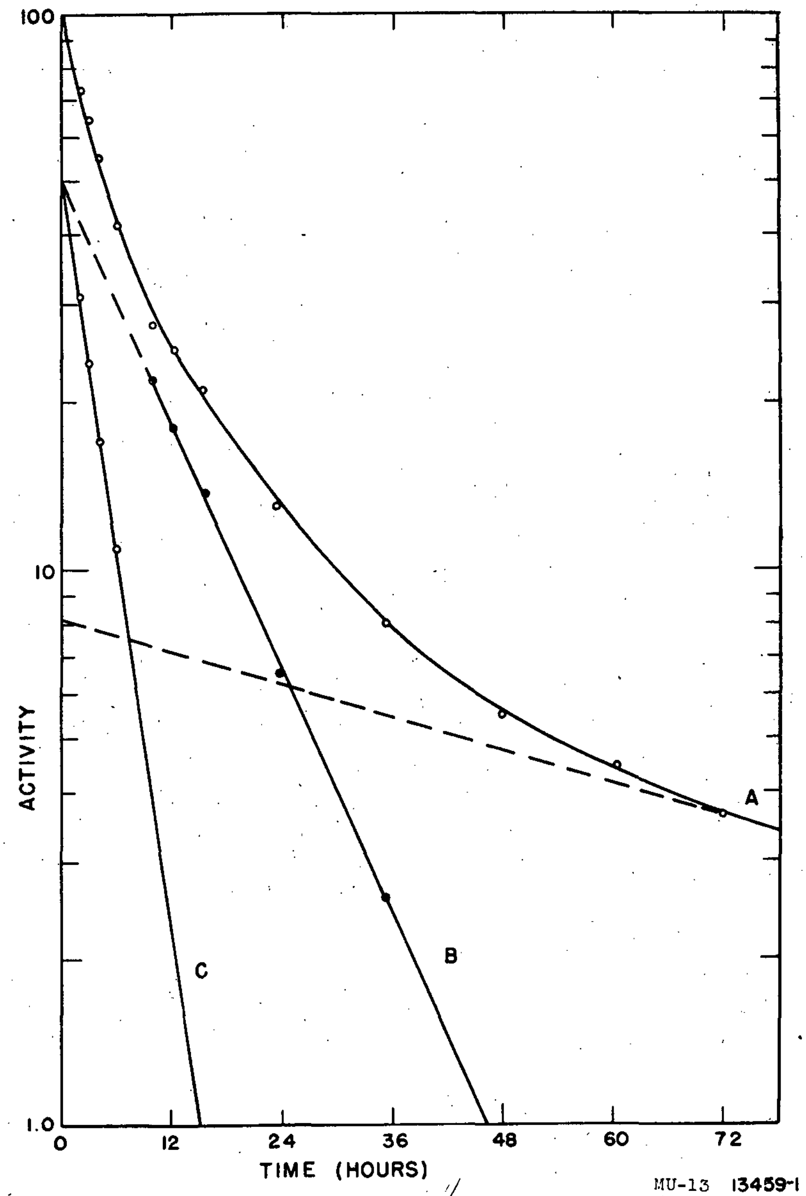
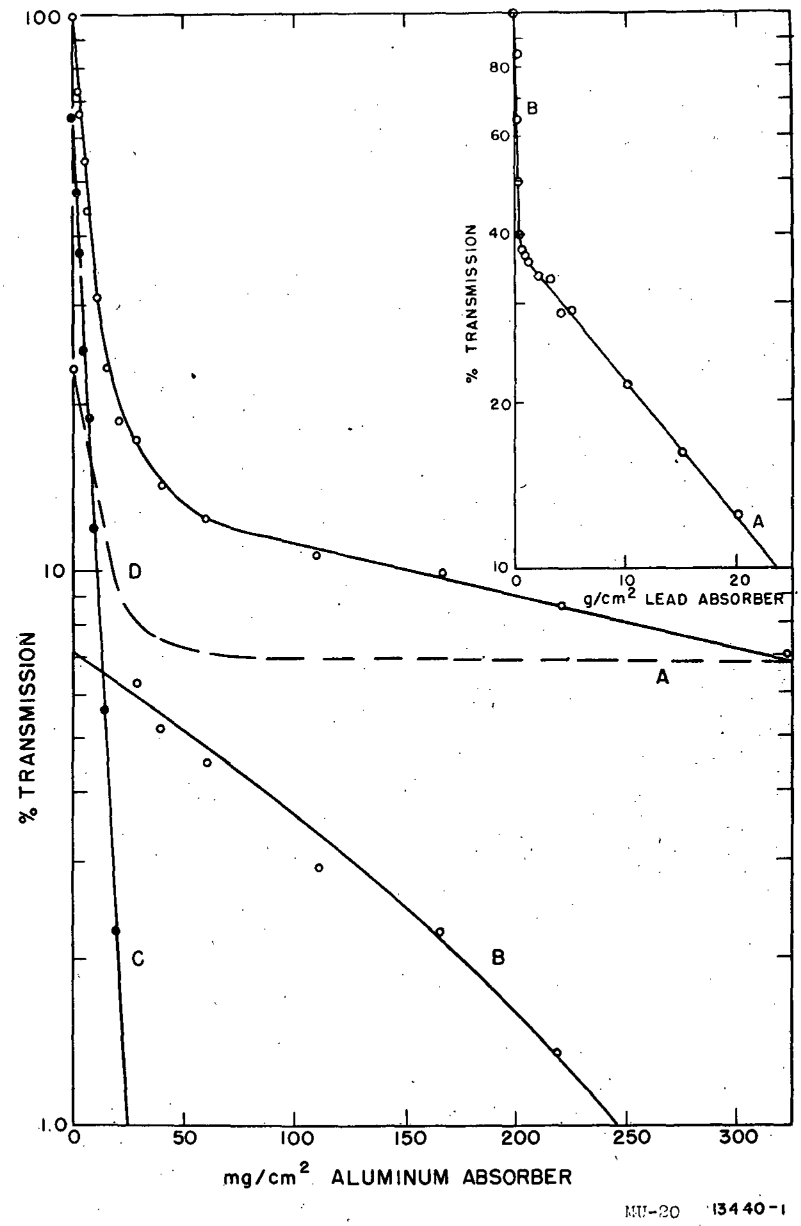

100
10
1.0
ACTIVITY
0
12
24
36
48
60
72
TIME (HOURS)
A
B
C
MU-13 13459-1

FIG. IV



MU-20 13440-1

FIG. V

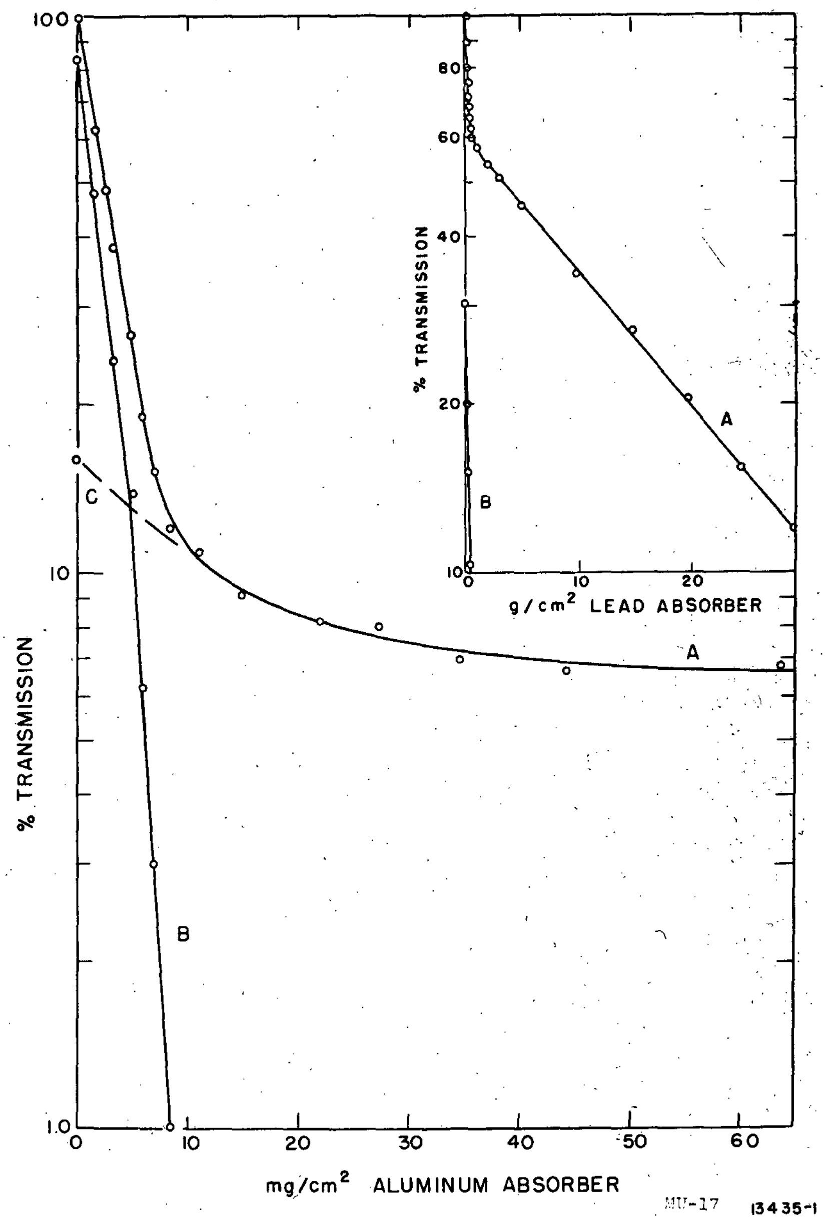

% TRANSMISSION
100
10
1.0
0
10
20
30
40
50
60
mg/cm² ALUMINUM ABSORBER
A
B
C
% TRANSMISSION
80
60
40
20
10
0
10
20
g/cm² LEAD ABSORBER
A
B
MU-17
13435-1

FIG. VI

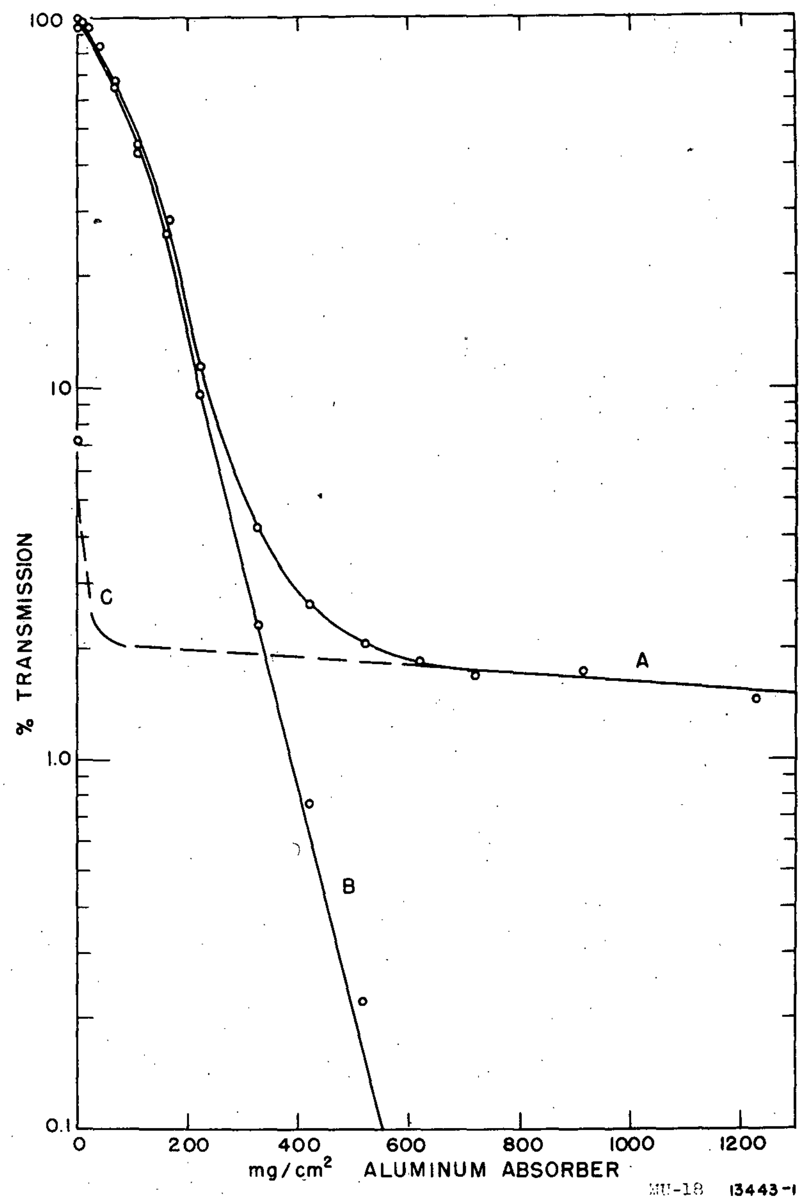
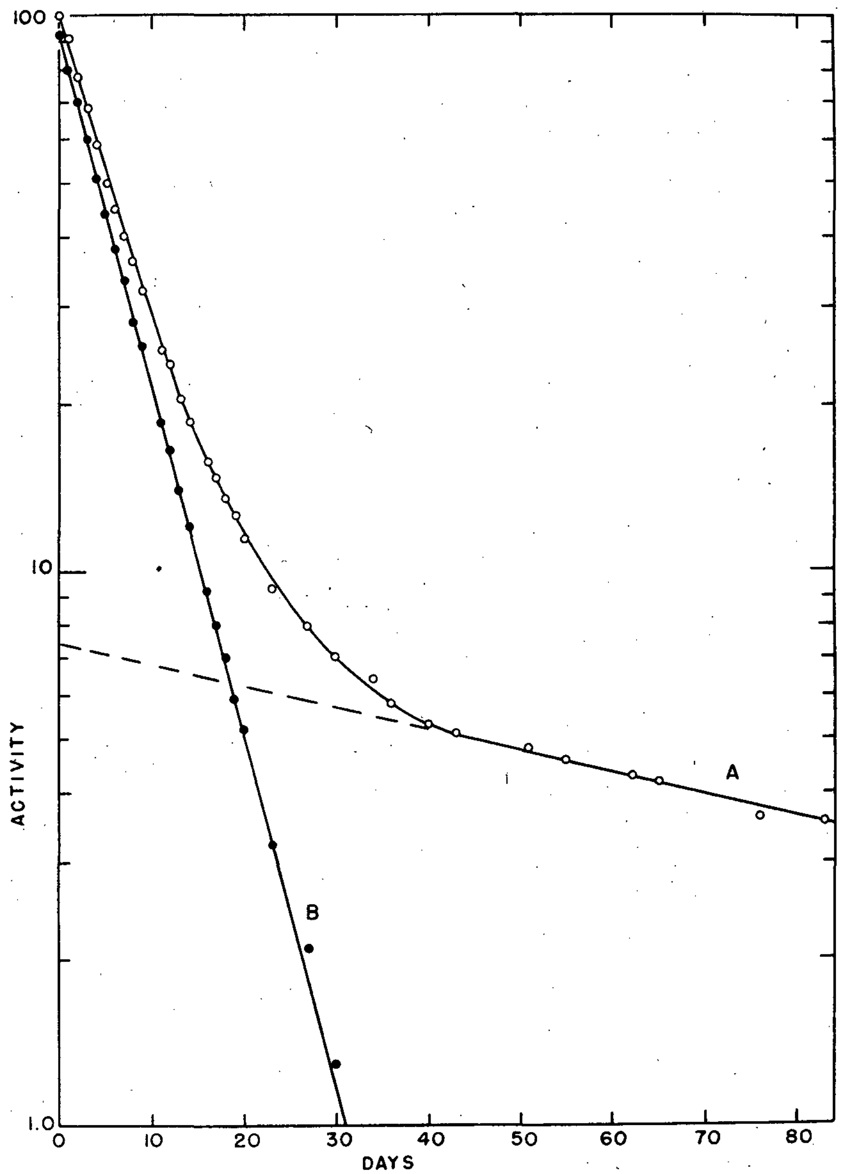
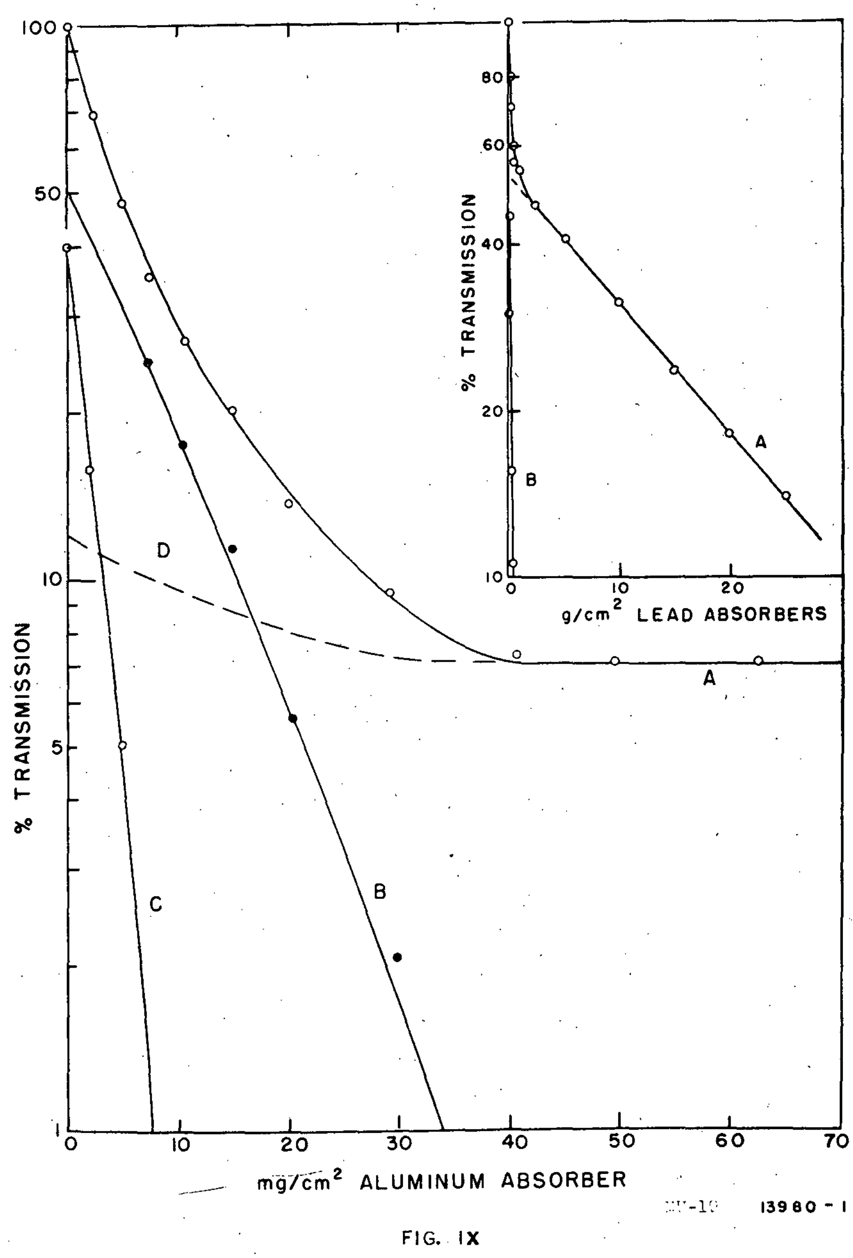

100
10
1.0
0.1
% TRANSMISSION
0
200
400
600
800
1000
1200
mg/cm2 ALUMINUM ABSORBER
A
B
C
MU-18 13443-1

FIG. VII



13979-1

FIG. VIII



100
50
10
5
1
% TRANSMISSION
0
10
20
30
40
50
60
70
mg/cm² ALUMINUM ABSORBER
A
B
C
D
80
60
40
20
10
% TRANSMISSION
0
10
20
g/cm² LEAD ABSORBERS
A
B
13980 - 1

FIG. IX