

#183

UNCLASSIFIED FILE COPY

ORNL-4
PHYSICS-GENERAL

LABORATORY REPORT

ORNL
MASTER COPY

CHEMISTRY DIVISION

DESCRIPTIVE MANUAL OF RADIOISOTOPES PRODUCED BY
NEUTRON BOMBARDMENT IN THE CLINTON PILE

By

R. T. OVERMAN, L. M. FRY, J. W. JONES,
W. D. BALDWIN, E. LAMR, J. E. SAVOLAINEN

OAK RIDGE NATIONAL LABORATORY

DIVISION OF
CARBIDE AND CARBON CHEMICALS CORPORATION
POST OFFICE BOX P
OAK RIDGE, TENNESSEE

UNCLASSIFIED

This document consists 101
pages.
Copy 63 of 153 Series A.

J. B. Whitney

OAK RIDGE NATIONAL LABORATORY
(Contract No. W-7405, eng 26)

* * * * *

Chemistry Division

* * * * *

DESCRIPTIVE MANUAL OF RADIONUCLIDES PRODUCED BY
NEUTRON BOMBARDMENT IN THE CLINTON PILE

R. T. Overman, L. M. Fry, J. W. Jones, E. Lamb,
W. D. Baldwin, J. E. Savelainen

* * * * *

April 5, 1948

Date Received: 6/23/48

Date Issued: AUG 6 1948

ORNL-4
Physics-General

DISTRIBUTION:

1. G. T. Felbeck	62c G. H. Jenks
2. 706-A	63. I. B. Whitney
3. 706-A	64. A. F. Rupp
4. 706-A	65. C. E. Winters
5. 706-B	66. K. Way
6. Biology Library	67. P. Levy
7. Training School	68. M. M. Shapire
8-37. Central Files	69. E. O. Wellan
38-39. Central Files	70. R. T. Overman
40. E. J. Murphy	71. AEC, ORNL
41. E. H. Taylor	72-79. Argonne National Laboratory
42. M. D. Peterson	80. Armed Forces Special Weapons Project
43. A. M. Weinberg	81-82. Atomic Energy Commission, Washington
44. H. Etherington	83. Battelle Memorial Institute
45. J. A. Cox	84-91. Brookhaven National Laboratory
46. W. A. Johnson	92-95. Carbide & Carbon Chemicals Corp. (K-25 Area)
47. J. R. Huffman	96-99. Carbide & Carbon Chemicals Corp. (Y-12 Area)
48. A. Hollaender	-100. Columbia University (Dunning)
49. C. D. Cagle	101-104. General Electric Company
50. S. R. Sapirie	105-109. Hanford Directed Operations
51. H. M. Roth	110. Iowa State College
52. M. E. Ramsey	111-113. Los Alamos
53. C. W. Shepard	114-115. Monsanto Chemical Company, Dayton
54. R. A. Bolomey	116-117. National Bureau of Standards
55. A. D. Conger	118. Naval Radiological Defense Labs.
56. W. A. Arnolds	119. NEPA
57. J. X. Kyha	120-121. New York Directed Operations
58. D. S. Anthony	122. Patent Advisor, Washington
59. M. H. Feldman	123-137. Technical Information Division, ORDO
60. G. E. Boyd	138. UCLA Medical Research Laboratory (Warren)
61. B. H. Ketelle	139-143. University of California, Radiation Labs.

144-145. University of Rochester
 146-153. R. T. Overman

REFERENCES

The following references have been published since the last report was issued. This information includes the following:
1. A detailed description of the successful application of the
X-ray diffractometer, the automation design and the function of the
object in a flow sheet of a purification process, the extent of purity
found in the material, absorption and density of the radioactive
source, the yield in $\mu\text{c}/\text{kg}/\text{K}$ day containment at 50% maximum flux, the cross
sections and the Q's and a discussion of the non-routine errors in the
determination. The foregoing data are given for S, P, Ca, Sc, Ti, Fe, Cr,
Mn, Sr, Ag, In, Cd, Sn, Li, Ta, V, Os, Ib, Si. It is hoped that this
list will be extended and the manual amplified.

TABLE OF CONTENTS

	Page
A. Introduction	5
B. Purpose	5
C. Procedures	7
D. Measurement of Activity	9
E. Errors	11
F. Summary	12
G. Discussion of Individual Radioisotopes	17 - 100
1. Sulfur	17
2. Monobasic Potassium Phosphate	26
3. Calcium	29
4. Scandium	32
5. Titanium	37
6. Iron	40
7. Cobalt	46
8. Nickel	50
9. Selenium	55
10. Silver	59
11. Indium	63
12. Cadmium	68
13. Antimony	74
14. Europium	77
15. Tantalum	80
16. Tungsten	83
17. Osmium	87
18. Thallium	94
19. Bismuth	97

Index to Figures

Figure	Target Material	Type of Curve			
		Decay	Al Absorption	Pb Absorption	Other Absorption
1	S	X			
2	SSS	X			
3	"	X			
4	"	X			
5	"	X			
6	KH ₂ PO ₄	X	X		
7	"	X	X		
8	Ca CO ₃	X	X		
9	"	X	X		
10	Sc ₂ O ₃	X	X		
11	"	X	X		
12	"	X	X		
13	Ti O ₂	X	X		X
14	Fe	X	X		X
15	"	X	X		X
16	"	X	X		X
17	"	X	X		X
18	Co ₃ O ₄	X	X		X
19	"	X	X		X
20	"	X	X		X
21	Ni	X	X		X
22	"	X	X		X
23	Se	X	X		X
24	"	X	X		X
25	AgI ₃	X	X		X
26	"	X	X		X
27	In(NO ₃) ₃	X	X		X
28	"	X	X		X
29	Cd	X	X		X
30	"	X	X		X
31	"	X	X		X
32	"	X	X		X
33	Sb	X	X		X
34	"	X	X		X
35	Eu ₂ (C ₂ O ₄) ₃	X	X		X
36	"	X	X		X
37	Ta O ₂	X	X		X
38	"	X	X		X
39	WO ₃	X	X		X
40	Os	X	X		X
41	"	X	X		X
42	"	X	X		X
43	"	X	X		X
44	"	X	X		X
45	Tl(NO ₃) ₃	X	X		X
46	Bi	X	X		X
47	"	X	X		X
48					

The Physics and Operating Departments set up a joint program to identify and measure the radioisotopes produced in the pile. This program was originally to cover all of the long-lived isotopes produced in the pile and then to be extended to as many isotopes as possible. With the departure of the two scientists involved it has not been possible to cover more than 19 radioisotopes. It is hoped that this work will continue.

B. Purpose

The previous work of Seren¹ and his group at Chicago was a rapid

1. Seren, L., Friedlander, H. N., and Turkel, S. H., CP-2576 (1944)

survey or cross sections. Many of these measurements were made in the thermal column of the Chicago pile but some were made in the pile itself. Their procedure was to activate the target material and sprinkle some of the powder on scotch tape and count it in a beta counter. They obtained the flux by one of several types of monitors. The accuracy of the cross sections which they measured was limited to 10-20% in most cases according to their report, but in their discussion of the errors in their determinations they listed the following limits for the various components in their measurements:

Conversion coefficients	up to 15%
Extrapolation to zero absorber	15%
Counting of gamma rays	3%
Geometry of beta counters	4%
Geiger counter plateaus	2%
Ra-Be standard pile calibrations	15%

Monitors	15%
Weighing samples	10%
Half life	5%

These factors, coupled with the unsatisfactory knowledge of the flux of the Clinton pile and particularly with the variation of flux from one position to another made it seem desirable to look into the matter here at Oak Ridge National Laboratory in some detail. This was particularly important in that the Isotope Distribution program was in vital need of more precise data on the materials that were being shipped out by the Atomic Energy Commission. It was felt that, with the revised techniques that have been worked out in cooperation with other members of the group of Radiochemical Measurements and Standardization, many of the errors could be materially reduced.

It was hoped, as a result of this study, that:

-
- (1) The yield values in the isotope catalog² could be revised
-
- (2) AEC Catalog and Price List No. 2 Radisotopes, Revised September 1947.
-

with more accurate information;

- (2) Gross impurities of the target materials could be identified and measured;

- (3) Decay and absorption graphs of pure activities could be prepared for reference purposes;

- (4) A practical method for measuring the total neutron exposure of samples could be developed;

- (5) The radiation hazard in handling isotopes being removed from the pile could be measured. This objective was to be carried out by the Operating Department;

6) Chemical separation processes could be developed by which the isotope purchasers could purify the material.

C. Procedures

The general procedure in the preparation of the sample was as follows: The target material was obtained from H. E. Bedell of the Operating Division. Duplicate samples of each target material were weighed into two aluminum stringer cans and a monitor clip attached to each by the Chemistry Division. The samples were returned to the Operating Division for irradiation in the pile.

After a period of time, approximately the irradiation time listed in the catalog, the samples were removed. One of the duplicates was brought to the Chemistry Division for chemical separations and measurements; the other was kept by the Operating Department for measuring gross decay and for determining radiation hazards. The radiations from the monitor clips were measured in order to study the total neutron exposure. This last-named work will be described briefly here; a more detailed and separate report is planned later.

If a known weight of a monitor material whose activation and decay characteristics are known is exposed in the pile with the sample, subsequent measurement of the monitor permits calculation of the total neutron exposure.

For this work aluminum alloy clips have been prepared containing 0.53% cobalt and 0.21% manganese. A clip can be attached to a stringer can or placed in the rabbit during irradiation. The activity induced in the clip is measured in an ion chamber³ calibrated for detecting gamma radiation, and the average

(3) Jones, J. W. and Overman, R. T., Mon C-399 (1945)

flux or neutron density for the exposure is calculated from the cross-section, time of exposure, and decay before measurement. Manganese (half-life of 2.59 hours) is used to monitor short exposures, that is, up to 18 hours. Cobalt

Na $t_{1/2}$ of 5.3 years) is used to monitor longer exposures from 16 hours to 1000 minutes.

The alloying was performed by C. Smith of the Metallurgical Section of the Technical Division, and the clips were prepared by H. B. Hawkins of the Research Shops. The clips can be easily removed from the cans after irradiation, without damage to the can, and measured separately.

In the first alloy prepared, some sodium was inadvertently introduced in the alloy from the flux. In order to measure the pure cobalt radiation, at least five days must be allowed for the sodium to die out. It is hoped in the future to prepare the alloy free of sodium.

The total sample brought to the Chemistry Division was dissolved and decay measurements on a small portion of this gross sample were begun as soon as possible after removal from the pile in order to find short-lived activities. In some cases the large amount of long-lived target material activity produced by long bombardment obscured the small amounts of activities due to impurities. A short bombardment was then made to measure the short-lived activities which predominated over the long-lived ones.

Gross chemical separations and purifications were performed when necessary. Decay and absorption data were taken on all fractions.

Disintegration rates and activities were determined by measuring aliquots of the fractions on calibrated Geiger-Muller mica window counters, and, where the radioisotope was a gamma emitter with a known disintegration scheme, by measuring aliquots on the previously-mentioned calibrated ion chamber⁴.

D. Measurement of Activity

A sample for accurate beta counting was mounted on a polystyrene film 2.5 mg/cm^2 in thickness and fixed over a $35/16"$ hole in an aluminum card by means of rubber cement. The procedure that was used followed closely the methods outlined by Zumwalt⁵. An aliquot of radioactive solution was placed in the center

(5) Zumwalt, L. R., Ken C-397 (1948)

of the hole on the film and evaporated to dryness under a drying lamp. A sample for ordinary beta counting was sometimes mounted as above, sometimes evaporated to dryness in a small porcelain dish 4.2 cm in diameter and about 400 mg/cm^2 in thickness.

The β absorption curves were taken by placing a sample in the center (with respect to both vertical and horizontal positions) of a shelf of our standard counting apparatus, and placing aluminum absorbers on top of the first shelf.

The γ absorption curves were taken with the sample in the center of the third or fourth shelf, and the lead absorbers on top of the second shelf.

When the ion chamber was used to determine activities, a solution of a gamma-emitting radioisotope in a sealed glass ampoule was put into the glass thimble, inserted in and attached rigidly to the chamber to retain the filling gas (argon at twenty atmospheres). Within the chamber and surrounding the thimble was the negative collecting electrode. The chamber was the other electrode. The entire assembly was shielded with eight inches of lead to obtain low backgrounds.

The ion chamber is calibrated in terms of Co^{60} which decays with two γ 's (average energy = 1.2 Mev, per disintegration). When the decay scheme of any other γ -emitter is known, its activity may be measured and then calculated

from its counting efficiency with respect to Co . For example, if a radionisotope with $\bar{\nu}$'s average energy = 0.9 Mev, per disintegration, its efficiency in the ion chamber is 75% of that of Co . The flux measurements were made using the pressure ion chamber method outlined above. The chamber and the monitors were calibrated and the flux was determined by the methods given by Clark, Jones and Overman⁶.

(6) Clark, H. M., Jones, J. W., and Overman, R. T., Mon C-398 (1948)

Actually, in the case of Seren's measurements as well as ours, the quantity determined that was significant was the product σv . Since the flux was determined by a gold monitor essentially and the cross section of gold is 96 barns at 2000 meters/sec, the σv for gold is 2.2×10^7 bcs (barn centimeters/sec). Since the activations were made at some unknown velocity of neutrons, the product determined, for example, for Ca^{44} is 2.9×10^3 bcs. Since this is the constant for the isotope one must only multiply this by n or the neutron density for the pile at the given point to obtain the yield per nucleus of the $nv\sigma$ for a given irradiation. The value determined by Clark et. al., for n was 4.5×10^6 n/cm³ at the center of the Clinton Pile at operating power level.

Since most of the measurements of these quantities made by physicists are reported in terms of thermal velocities, it is helpful for comparison to make an assumption about the way in which the cross section behaves as a function of energy. If one assumes that the cross section follows a $1/v$ law then one may divide the σv by the thermal velocity and obtain the cross section corresponding to this energy of neutron. This has been given for all of the activities but it is recommended that the product of the cross section times velocity be considered the important nuclear constant for these pile reactions. It is particularly important to note that where resonance levels occur in the thermal region

one may not make this calculation to arrive at a cross section for thermal neutrons.

The use of the σ_v also has another advantage for those reactions which are brought about by fast neutrons. There has always been considerable question as to how to report yield values for fast neutron reactions. This is occasioned by the fact that cross sections should correctly be reported for the energy of the neutron. We do not know the energy distribution of fast neutrons, in general, in the pile since this will be a function of the amount of moderator between the slug and the sample. This would change the fast spectrum quite markedly in a short distance. It does not seem quite proper to report the fast neutron yields on the basis of the slow neutron flux by the use of an "effective" cross section in which one uses the slow flux and weight of target isotope. The σ_v , however, is a function of this reaction, too, so the results may be expressed in the bcs. units. This implies that, if one knew the n or density of neutrons above a given threshold for the reaction, one could determine the cross section. This cannot usually be determined.

On the basis of the flux report mentioned above, it seems probable that the flux may be known to an accuracy of about 10%.

E. Errors

The statistical counting error in beta counting was less than 2%. The error in determining counter geometries was about 3%. The error in assay was about 1% except when otherwise stated in the detailed discussion of each individual target material. As mentioned above it is probable that the errors in the flux measurement are of the order of 10%. This gives an overall accuracy which might be expected for the yields of the order of 11%. The error in value for the cross sections would be higher in the case of those elements having resonance peaks. No cadmium differences were taken except those mentioned in the report Mon C-398.

F. Summary

The following table shows the experimental data obtained. It might be noted that these materials were procured by the Operating Department in quantities that were estimated to last a year. It is possible to get samples from there of any of the target materials discussed below.

It should be understood that it was not a purpose of this study to confirm or replace existing literature values for half-lives or radiation energies. The values shown on the graphs on the following pages are experimental and merely confirm the identities of the radioisotopes. The usefulness of the graphs is in showing the kind of data obtained in measuring activities of radioisotopes produced at Oak Ridge National Laboratories.

After the tabular summary, the target materials are discussed in detail. The following information is listed for each material: Target material, source, weight of sample, spectrographic impurities, time of irradiation, the average flux for the time of irradiation, the separations procedure that was used to purify the activity and the percentage recovery in the various steps, the radioactivities found reported both in the percentage of total activity and calculated to parts per million of stable impurity in the target material, the yield in mc/g/30 day bombardment at 50% maximum flux, the σv in barns cm/sec., the cross section per atom of normal element and per atom of isotope assuming a i/v law, and a statement of non-routine errors.

Acknowledgement

We would like to acknowledge the assistance given us by many members of the Operating Department, particularly C. D. Cagle, H. E. Bedell. We would also like to thank Edna Hennessee and Georgia Gibson for doing most of the tremendous job of counting the samples.

Table I

Summary of Experimental Radioisotope Data

Target Material	Nuclide	Half-Life Expt'l Literature	Radiation Expt'l Literature	Yield		UV in bcs	Isotopic Cross-Sections (in barns)	Effective Cross-Sections per Atom Normal Element	Remarks
				mc/gm element /mc at 50% maximum flux	mc/gm element /mc at 50% maximum flux				
S	S ³⁵	87d	87..1d	0..17β No γ	0..17β No γ	0..279	1..15x10 ⁻³	0..124	0..26±20%
	P ³²	14..3d	14..7d	1..7β No γ	1..7β No γ	0..304	3..68x10 ⁻²	0..0017 (thermal neutrons)	0..0016 (fast neutrons)
KH ₂ PO ₄	P ³²	14..5d	14..7d	1..7β No γ	1..7β No γ	49..6	5..52x10 ⁻⁴	0..251	0..23±20%
	K ⁴²	12..8h	12..4h	--	3..58β (75%) 2..07β (25%)	38..6	4..09x10 ⁻⁴	2..81	1..0±20%
CaCO ₃	Ca ⁴⁵	154d	180d	0..21β No γ	0..21β No γ	0..291	2..90x10 ⁻³	0..62	0..63±20%
Sc2O ₃	Sc ⁴⁶	84d	85d	0..37β 1..0γ	0..36β K? 1..12γ 0..9γ	838	3..17x10 ⁻⁶	14..4	22±20%
TiO ₂	Ti ⁵¹	--	72d	0..5β 0..9β	0..36β 1..0γ	1..133x10 ⁻²	0..01	0..039±20%	5..15x10 ⁻⁴

Target Material	Nuclide	Half-Life Expt'1 Literature	Radiation Expt'1 Literature	Yield $\text{m}^2/\text{fm}^2 \text{ sec}$ at 50% maximum flux	$\bar{\sigma}_V$ in barns	Isotopic Cross Sections (in barns)	"Effective" literature	"Effective" Cross Sections per atom percent	Remarks	
Fe	Fe59	47.5d	1.6.3d	0.14 β 1.2 γ	0.26 β 0.46 β 1.10 γ 1.30 γ	0.144	6.03x10 ⁻²	0.23	0.79	2.00 γ
	Fe55		X-ray		K, e ⁻ 0.007 γ					
Co	Co60	~5.3yr	5.3yr	0.3 β Hard δ	0.3 β 1.10 γ 1.30 γ	42.5	6.51x10 ⁻⁶	29.6	21.7 \pm 20%	29.6
Co304										
Ni	Ni65	3hr	2.6h	1.9 β	1.9 β 0.28 γ 0.65 γ 0.93 γ	2.11	3.37x10 ⁻³	1.32	1.4 \pm 20%	0.0153
	Ni59	---	12yr	—	0.05 β				0.5450%	
Se	Se75	~124d	115d	0.16 e ⁻ K, e ⁻ X-ray γ present 0.18 γ	9.92	1.29x10 ⁻⁵	67.4	22.4 \pm 0%	0.586	X-ray and δ -rays present make Se75 a suitable tracer, but absolute measurement is extremely difficult
AgNO ₃	Ag110	231d	225d	0.4 β 0.7 β γ present	1.3 β 0.6 β 1.40 γ 0.93 γ	2.38	7.96x10 ⁻⁴	0.74	2.3420%	0.36

Target Material	Nuclide	Half-Life	Expt'l Literature	Radiation	Yield mc/gm element /mc at 50% maximum flux	σ_V in bcs	Isotopic Cross-Sections (in barns)		Effective Cross-Sections per atom normal element	Remarks
							Expt'l	Literature	Effective	
In(No3) ₃	In114	50d	48d	e^- 0.7 γ 2.2 β	I.T. 0.19 β 1.98 β	20.4	1.80x10 ⁵	19.4	56 \pm 10%	0.82 0.19 γ is apparently 100% converted
Cd	Cd115	2.4d	2.33d	0.5 β 1.3 β 0.65 γ	0.55 β 1.25 β 0.65 γ	12.8	3.92x10 ⁴	0.63	1.1 \pm 20%	0.18
		54d	43d	1.8 β	1.85 β ~0.5 γ	0.456	3.96x10 ³	0.064	0.14 \pm 20%	0.018
Sb	Sb124	60d	60d	2.6 β 0.6 β γ present	2.4 β (50%) 0.7 β (50%) 1.7 γ (50%) 0.6 γ	54.9	4.0x10 ⁵	4.26	2.54 \pm 20%	1.82
Eu ₂ (C ₂₀₄) ₃	Eu154	~6.3yr	5-8yr.	0.17 β 0.6 β 2.0 β γ present	0.34 β 0.82 β K 1.1 γ	268	1.13x10 ⁸	1010	768 \pm 20%	514
Ta02	Ta182	--	117d	e^- 1.0 γ	0.55 β 0.53 β 1.22 γ (57%) 1.13 γ (37%) 0.22 γ (4%) C.15 γ (2%)	31.9	3.54x10 ⁶	16.1	214 \pm 20%	16.1

Target Material	Nuclide	Half-Life Expt. I Literature	Radiation Expt. I Literature	Yield mc/gm element /mo et 50% maximum flux	σ_V in bcs	Isotopic Cross-Sections (in barns) Effective Literature	Effective Cross-Sections per atom normal Element	Remarks
WO ₃	W185	76d	74d	0.45 β No γ	0.6 β No γ	7.55 1.54x10 ⁵	2.28 2.1420%	0.7
	W187	--	24.1h	--	1.35 β 0.6 β 6% between 0.18 & 0.77 Mev	Didn't look for --	34 \pm 20%	
Os	Os185	60d	95d and ~30h	0.8 β 0.7 δ (?)	1.1 β , 1.5 β Y	0.290 7.34x10 ⁻³	6x10 ³ 31.6 5.45x10 ⁻⁴	0.0273 1.44x10 ⁻⁴ See remarks under Osmium
	Os191	--	32h	1.0 β	0.95 β 1.17 β			
	Os193	17.4d.	17d	0.16 β 0.7 δ (?)	0.35 β Y	7.11 4.14x10 ⁻⁴	0.58 5.34x10 ⁻⁴	0.188
Tl(No ₃) ₃	Tl204	--	3.5yr	0.88 β No γ	0.87 β No γ	1.96 6.71x10 ⁵	10.3 7.5	3.05
Bi	Bi210	5d	5d	1.2 β	1.17 β No γ	0.70 3,960	0.018 0.015420%	0.018
	Po210	--	140d	α	4.8 α			

SulfurTarget Material: Sulfur, U.S.P., MerckWeight: 23.72 gmSpectrographic Impurities:

Ag	FT	Fe	T
Ca	FT	Mg	FT
Cu	FT	Si	T

Irradiation: 31 days at $\text{nv} = 4.64 \times 10^6 \text{ n/cm}^2/\text{sec}$ Separations: See diagram

Activities Found At T_0 in Bombardment	% Total Activity	Activity per gm. Sulfur	ppm Impurities
S^{35} (87d)	47.8	0.266 mc.	
P^{32} (14.7d)	51.3	0.286	
Si^{31} (170 m)	0.5	0.003	87
Unidentified (17m)	0.4	0.002	

Yields:

0.279 mc S/gm S/30 day bombardment at 50% maximum flux
 0.304 mc P/gm S/ " " " " "

Cross sections for sulfur:

$$\begin{aligned}\sigma v &= 1.15 \times 10^3 \text{ barns cm/sec} \\ \sigma &= 0.0052 \text{ per atom normal element} \\ \sigma &= 0.124 \text{ per atom isotope}\end{aligned}$$

Cross sections for phosphorus:

$$\begin{aligned}\sigma v &= 3.7 \times 10^2 \text{ barns cm/sec} \\ *(\sigma &= 0.0016 \text{ barns per atom normal element}) \\ *(\sigma &= 0.0017 \text{ " " " " isotope})\end{aligned}$$

* Of questionable value since it is based on slow nv.

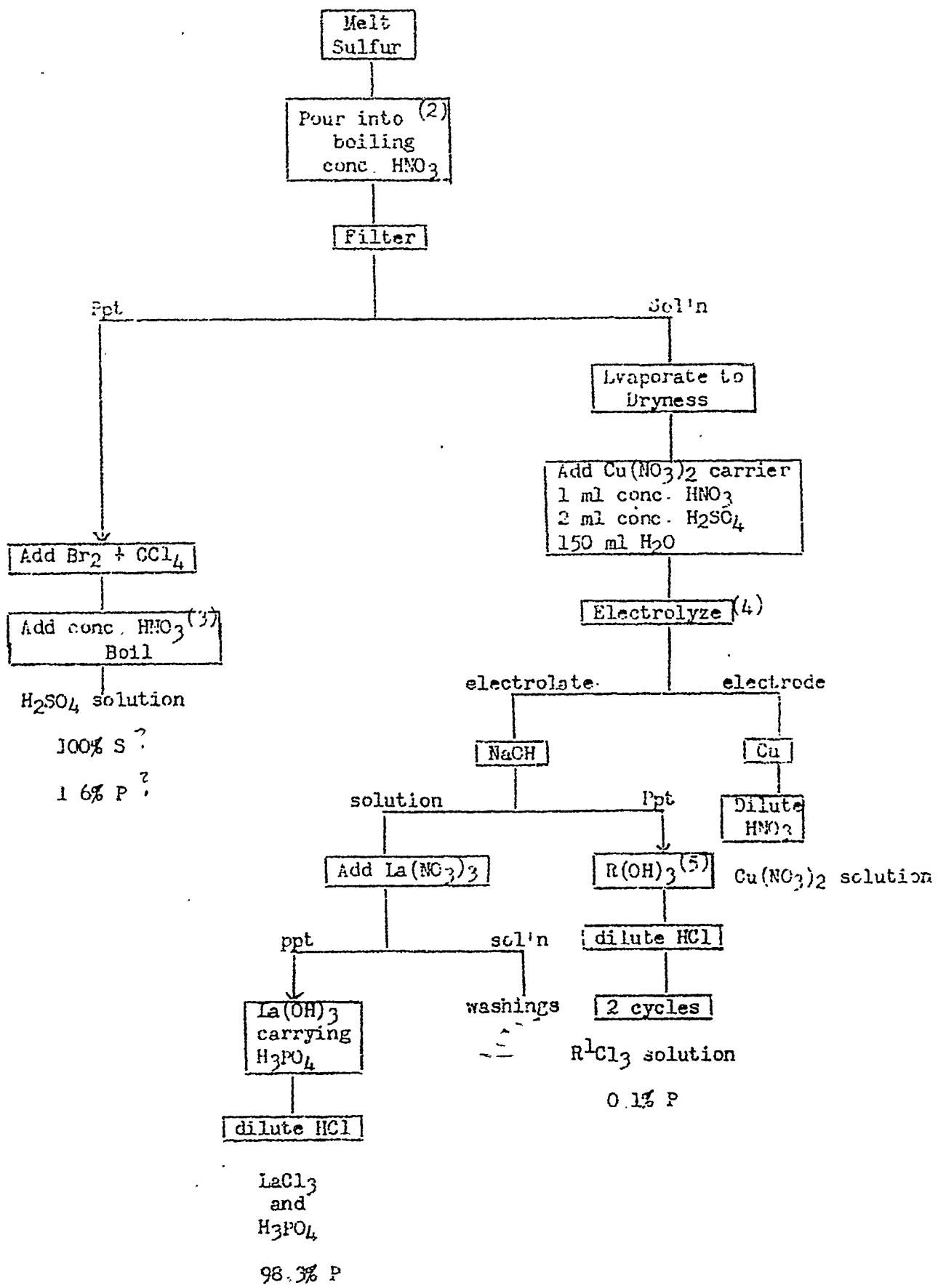
Non-routine Errors: None

Remarks

In measuring absorption of S^{32} beta radiation, absorbers of low Z material were used. Some of the absorbers were made of Formvar plastic material which is a polyvinyl acetal resin. The others were made of aluminum. Formvar and aluminum seem to have approximately the same absorption coefficient.

Sulfur (1)

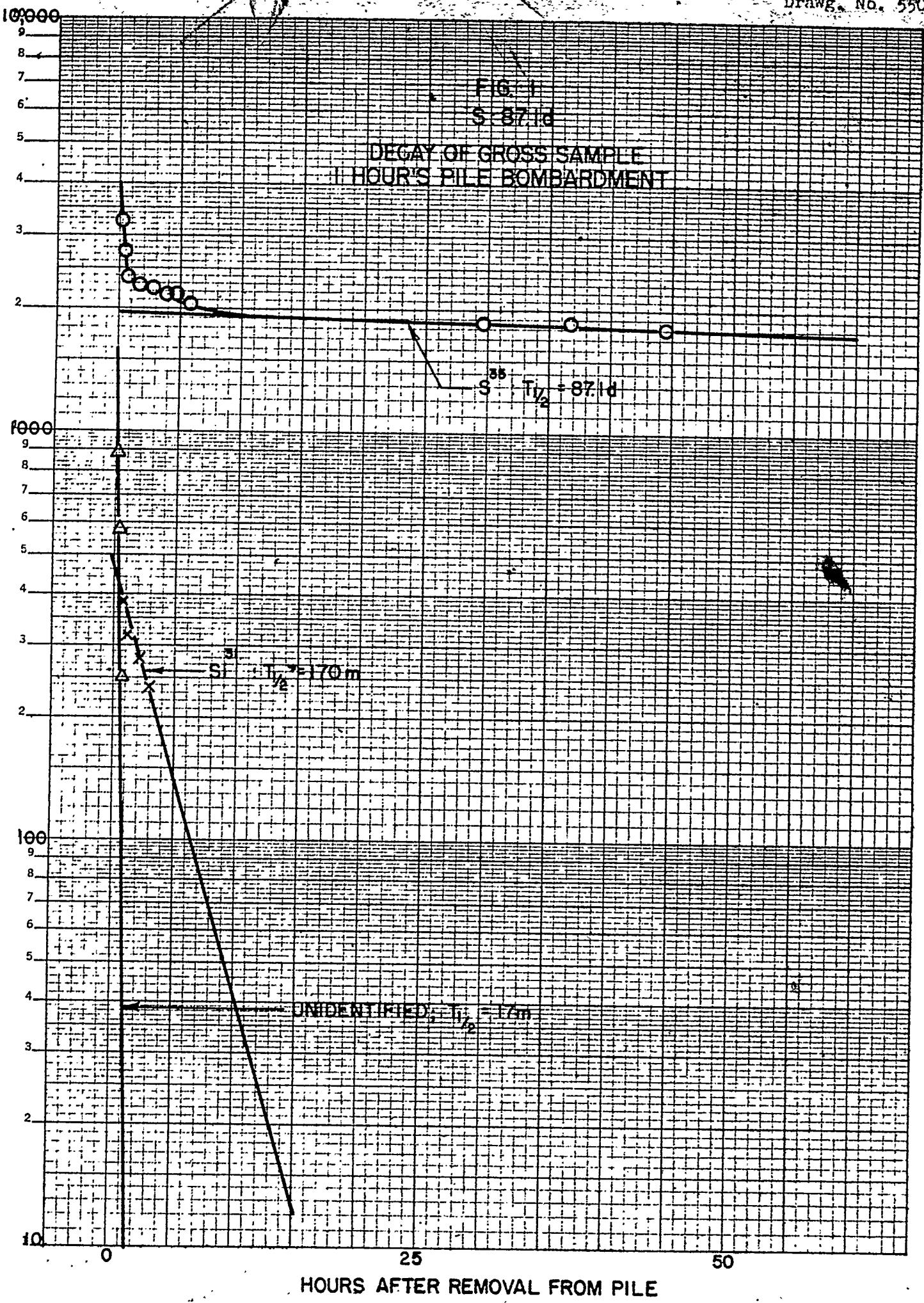
19.



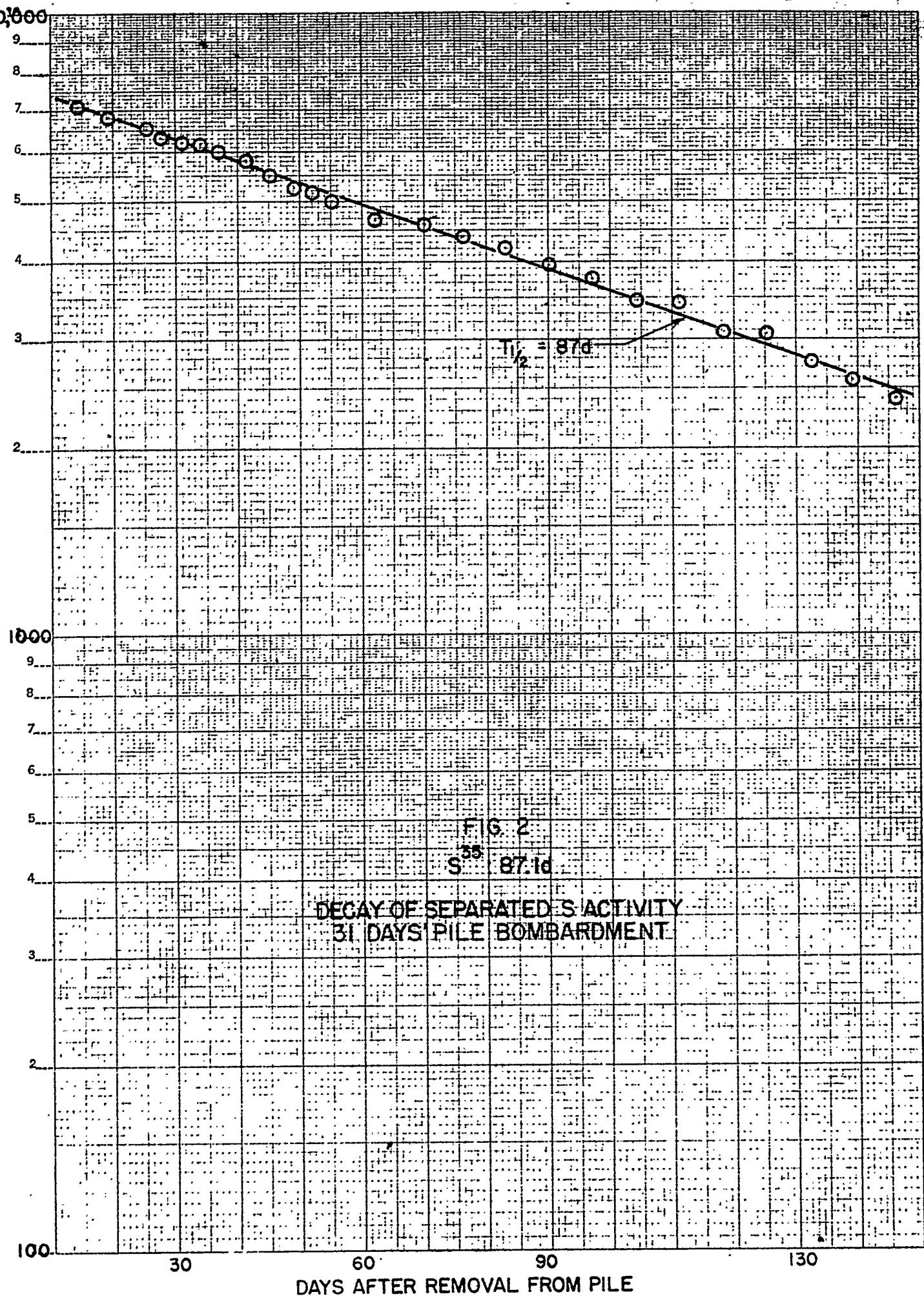
- (1) MDDC-518, W. E. Cohn, Separation of Carrier-Free P^{32} from Sulfur.
- (2) Boiling fuming concentrated HNO_3 will oxidize more P to H_3PO_4 than will the non-fuming acid.
- (3) Ten to thirty seconds after the HNO_3 is poured into the $Br-CCl_4-S$ mixture, the reaction becomes violent. A large beaker should be used to prevent losses from overflow and spattering.
- (4) Kolthoff and Sandell, Textbook of Quantitative Inorganic Analysis, pp 423-425.
- (5) The hydroxide precipitate should be dissolved and reprecipitated to minimize the amount of P carried on it

FIG. I

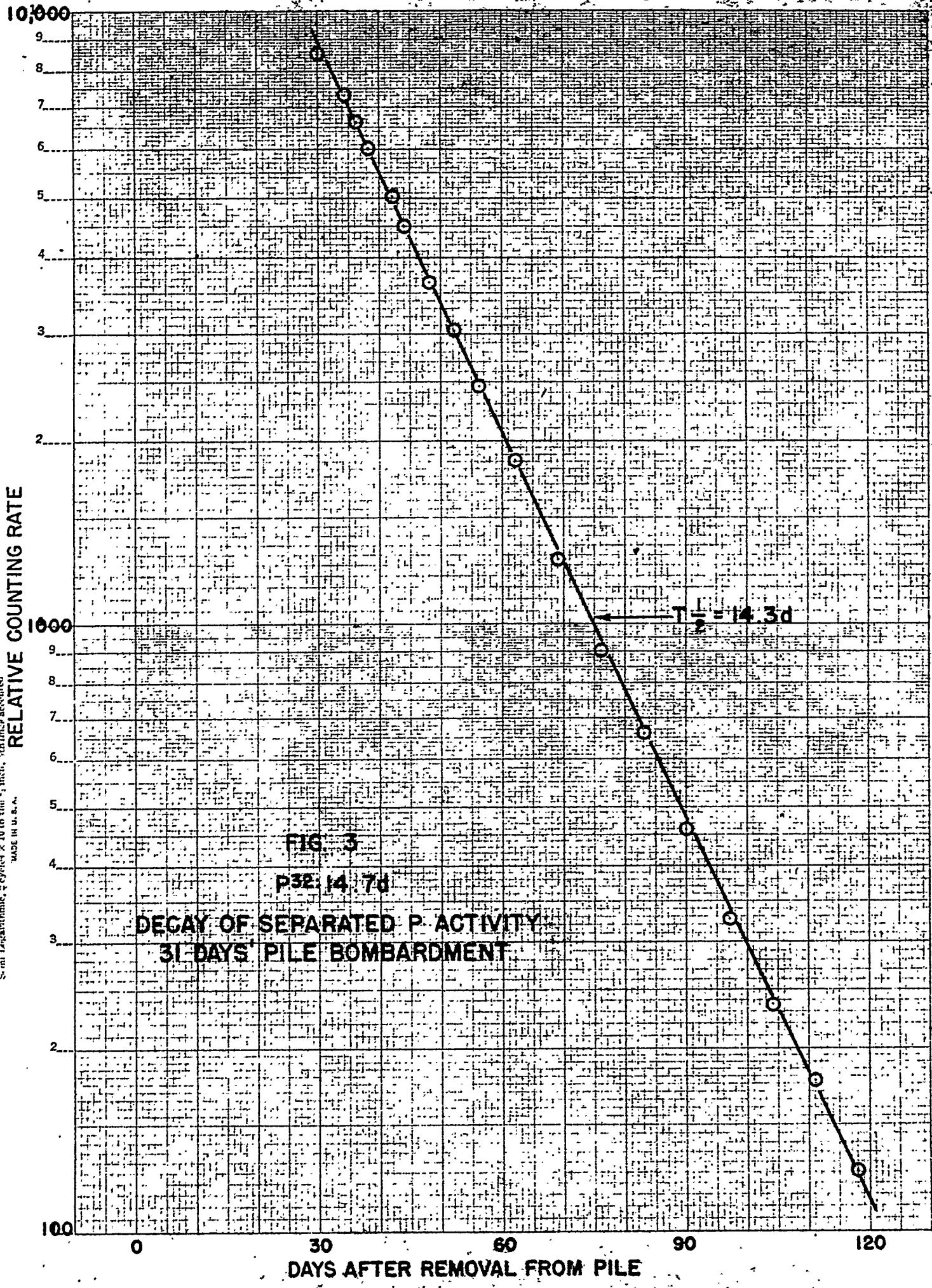
S-87 Id

DECAY OF GROSS SAMPLE
1 HOUR'S PILE BOMBARDMENT

KRÜFFEL & ESSER CO., N. Y. NO. 359-63
Semi-Logarithmic, 2 cycles X 10 to the $\frac{1}{2}$ inch, 5th lines accurate.
MADE IN U.S.A. REI A



KEFFEL & ESSER CO., N.Y. NO. 306-03
Semi Logarithmic, 4 cycles X 10 to the $\frac{1}{3}$ incl., "Uline" acetated
MADE IN U.S.A.



10,000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE
Neuffer & Eber Co., N.Y. No. 380-63
Semi-Logarithmic, 2 cycles X 10 to the 4th, 5th lines recorded.
MADE IN U.S.A.

FIG. 4

S-3718

ABSORPTION OF RADIATION IN LOW Z MATERIAL

COMPONENT 0.17 Mev

 $\log \frac{C}{C_0} = -2.186$
 $(-0.17/3)$

1000

9

8

7

6

5

4

3

2

1

0

100

9

8

7

6

5

4

3

2

1

100

0

2

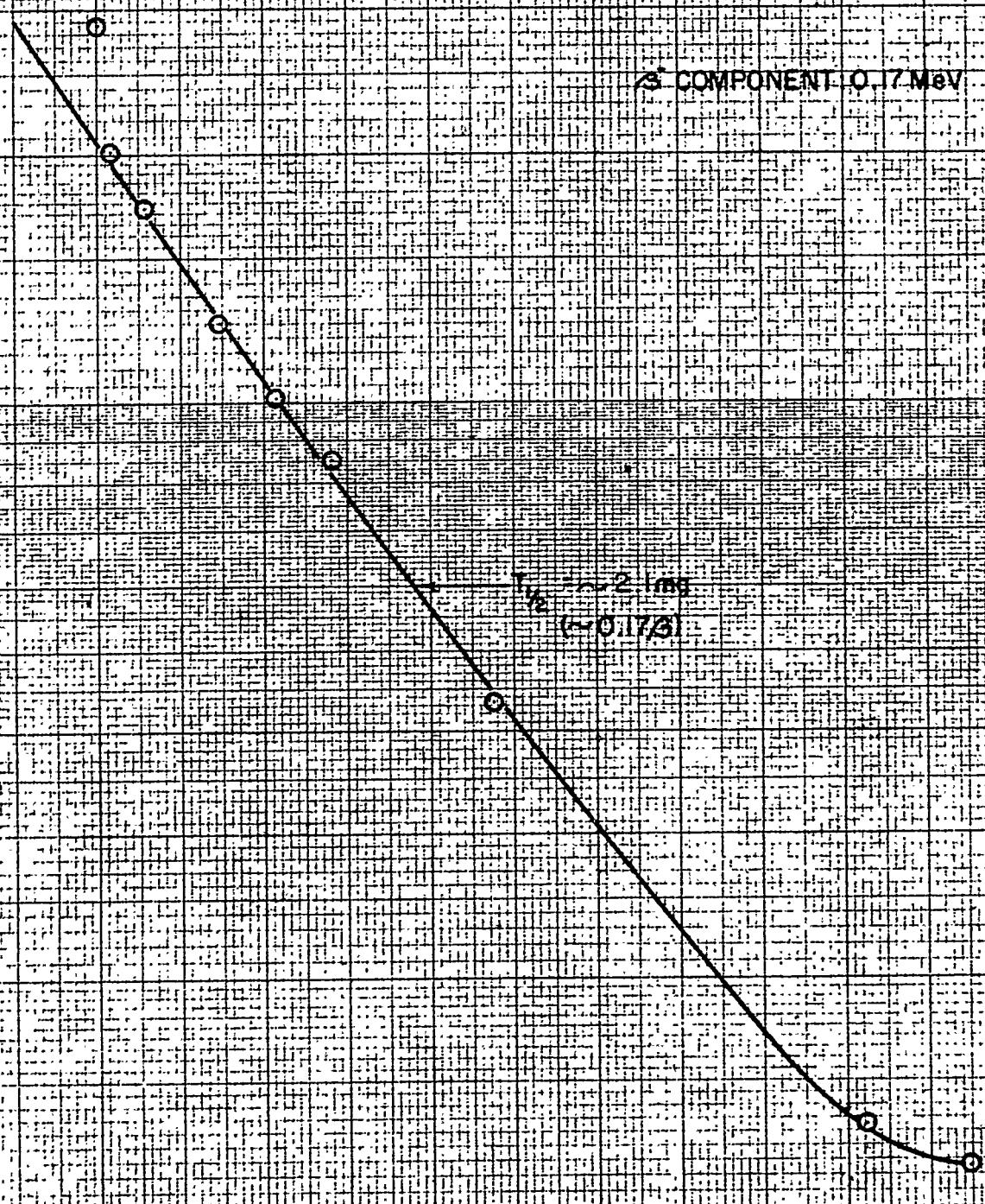
4

6

8

10

12

TOTAL ABSORBER: mg/cm²

10,000

6

3

2

1000

8

6

4

2

0

RELATIVE COUNTING RATE

ABSORBING LAYER EXPRESSIONS AND UNITS

C COMPONENT - 7.0 MV

CENTIFUGAL FIELD
OF MOTION

14.71 G's

TOTAL ABSORBED DOSE

0 100 200 300 400 500 600

KH₂PO₄

Target Material: Monobasic Potassium Phosphate, Anhydrous, Reagent, Merck

Weight: 30.96 gm.

Spectrographic Analysis:

Al	FT	Fe	VFT
Ca	FT	Mg	FT

Irradiation: 56 days at $\bar{n}v = 3.54 \times 10^6$ n/cm²/sec

Separations: The sample was dissolved in water, made up to 250 ml, and aliquots taken. Chemical separations were unnecessary because the difference in half-lives of K⁴² and P³² made it possible to calculate their activities separately.

Activities Found at T₀ in Bombardment:

	% Total Activity	Activity per gm.
K ⁴² (12.4 hr)	43.8%	27.3 mc/gm K
P ³² (14.7 d)	56.2	35.15 mc/gm P

Yields:

38.6 mc K⁴²/gm K/30 day bombardment at 50% maximum flux
49.6 mc P³²/gm P/30 day

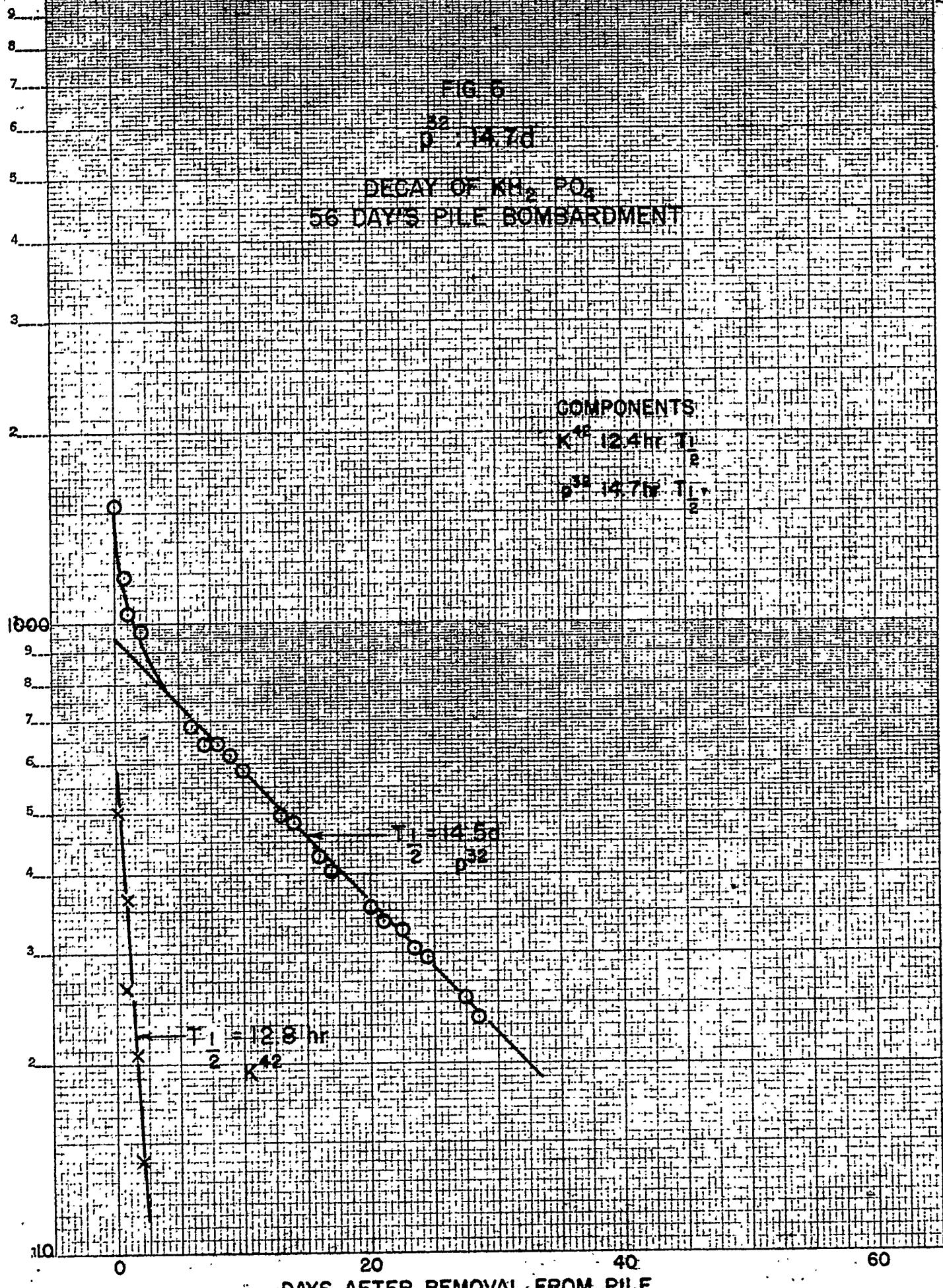
Cross Sections:

K⁴²: $\sigma v = 4.09 \times 10^4$ barns cm/sec
 $\sigma = 0.186$ barns per atom normal element
 $\sigma = 2.81$ barns per atom isotope

P³²: $\sigma v = 5.52 \times 10^4$ barns cm/sec
 $\sigma = 0.251$ barns per atom normal element
 $\sigma = 0.251$ " " " "

Non-Routine Errors: None

10,000



ABSORPTION OF RADIATION IN ALUMINUM

FIG. 7

52-14-7d

 γ^3 COMPONENT 1.7 Mev

FEATHER RANGE ~ 4850 mg.

(1.7 Mev) 52-14-7d 632

KUFFEL & ESSER CO., NEW YORK, NO. 359-63
 Semi-Logarithmic, 2 cycles x 10 to the $\frac{1}{2}$ inch, 50 mm
 MADE IN U.S.A.

10,000

9

8

7

6

5

4

3

2

1

0

1000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

100

0

100

200

300

TOTAL ABSORBER: mg/cm²

CalciumTarget Material Calcium Carbonate, Powder, C.P., Baker'sWeight 24.15 gmSpectrographic Impurities:

Al	PT	Mg	PT
Tu	PT	Sr	PT
Fe	PT		

Irradiation 32 days at $\text{nv} = 4.81 \times 10^6 \text{ n/cm}^2/\text{sec}$ Separations The CaCO_3 was dissolved in dilute HCl, made up to 100 ml., and an aliquot taken to work with.Activities Found at T_0 in Bombardment:

	% Total Activity	Activity per gm. Ca	ppm Impurities
$\text{Ca}^{45}/\text{Ca}^{40}$	77.6%	0.298 mc	
P^{32} (14.7 d)	22.4	0.065	1,920 P

Yields.

0.291 mc/gm Ca/30 day bombardment at 50% maximum lux

Cross Sections:

$$\sigma v = 2.9 \times 10^3 \text{ barn cm/sec}$$

$$\sigma = 0.013 \text{ barns per atom normal element}$$

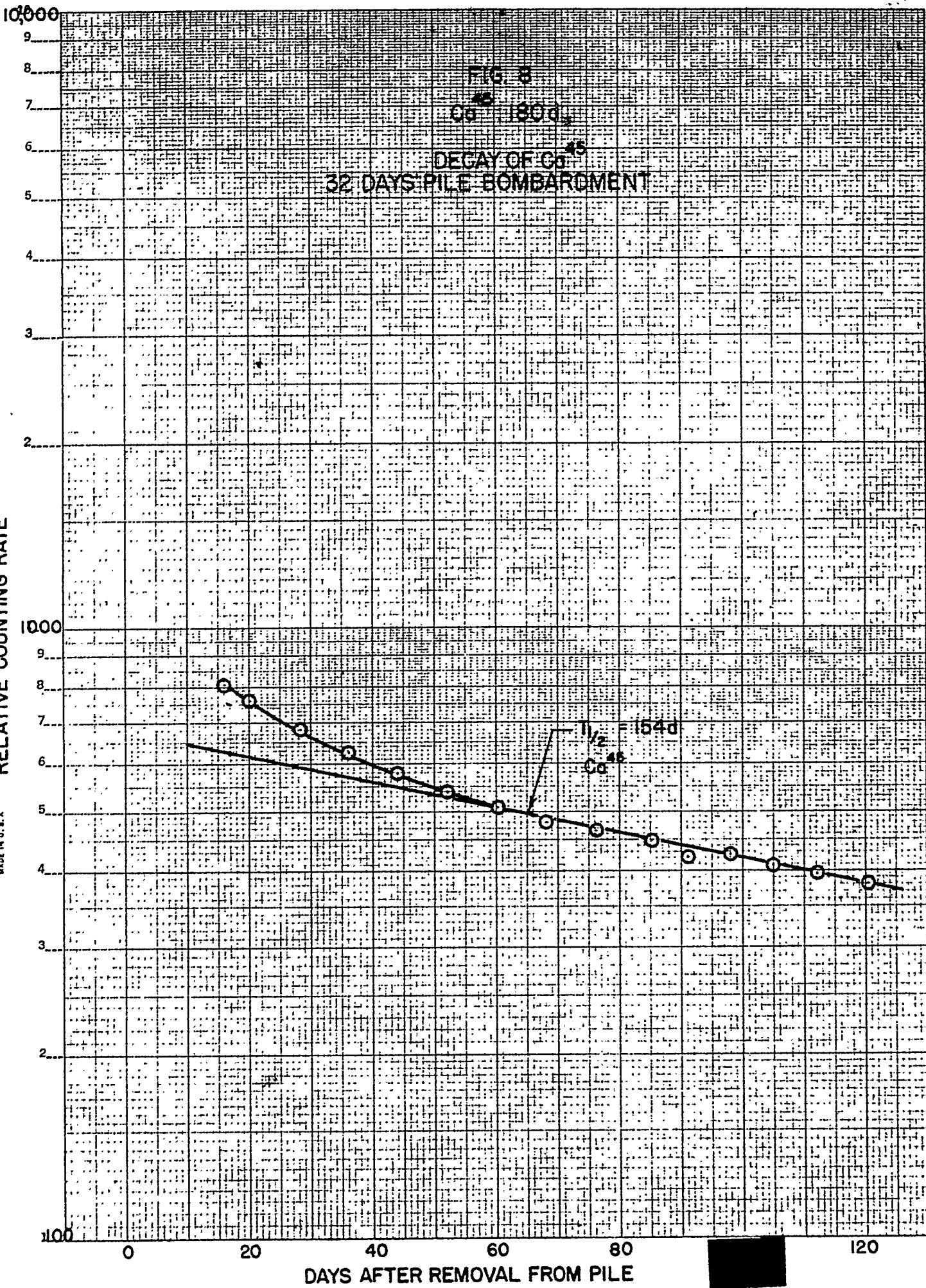
$$\sigma = 0.62 \text{ barns per atom isotope}$$

Non-Routine Errors: Lost <0.5% during assay. A large self-absorption factor introduces an error of +2%.Remarks: By comparing the two absorption curves shown in Fig. 9, one taken two months later than the other, one can see that the 1.7 MeV β component is decaying much more rapidly than the 0.21 MeV β component. The 1.7 MeV β component is P^{32} , and allowance must be made for its contribution to the total activity of a CaCO_3 sample bombarded in the Oak Ridge pile.

卷之三

卷之三

DECAY OF C₆₀
32 DAYS PILE BOMBARDMENT



10000

8

6

4

2

1

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

.

ABSORPTION OF RADIATION IN ALUMINUM

FIG. 9

 Ca^{45}

COMPONENT: 0.21 MeV

(DATA TAKEN 14 DAYS AFTER REMOVAL
FROM FILE)FEATHER RANGE ~ 850 mg
(1.7 MeV) 4.7d b_{32} (DATA TAKEN 72 DAYS AFTER
REMOVAL FROM FILE)FEATHER RANGE ~ 45 mg
80d Ca^{45} (0.21/3)

0

100

200

300

TOTAL ABSORBER: mg/cm^2

Scandium

Target Material: Scandium Oxide, from Adam Hilger, Ltd., London

Weight: 2 mg

Spectrographic Impurities:

Ca	FT	Mg	FT
----	----	----	----

Irradiation: 68 days at $\text{nv} = 3.8 \times 10^{11} \text{ n/cm}^2/\text{sec}$

Separations: See diagram.

Activity Found at T_0 in Bombardment: Activity per gm Scandium

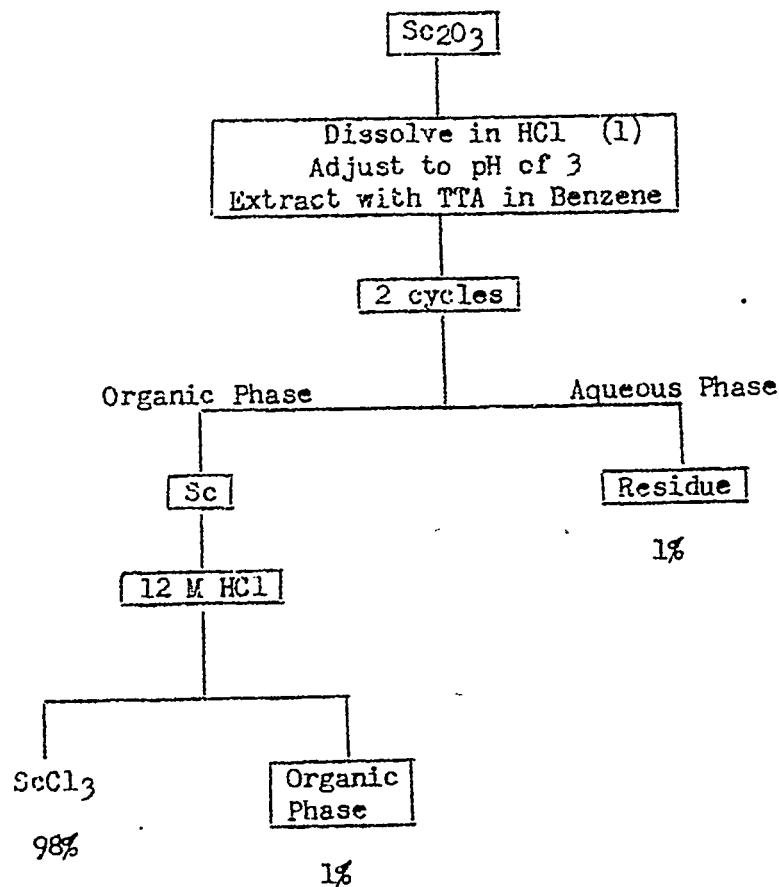
Sc ⁴⁶ (85d)	838 mc
------------------------	--------

Yield: 563 mc/gm Sc/30 day bombardment at 50% maximum flux

Cross Sections:

$$\begin{aligned}v &\approx 3.17 \times 10^6 \text{ barns cm/sec} \\&= 14.4 \text{ barns per atom normal element} \\&= 14.4 \text{ barns per atom isotope}\end{aligned}$$

Non-Routine Errors: None



(1) A. Broido, MonC-350, Purification of Scandium and Preparation of Ca^{45}

10,000

9
8
7
6
5
4
3
2
1
1000
100
10
1
100
0

RELATIVE COUNTING RATE

KUFFEL & CRAYER CO., N.Y. NO. 355-63
Scale-Logarithmic, 2 cycles x 10 to the $\frac{1}{2}$ inch, 5th line ascended
MADE IN U.S.A.

FIG. 10
 Sc^{46} - 850
 DECAY OF Sc^{46}
 68 DAYS PILE BOMBARDMENT

 $T_{1/2} = 840$ Sc^{46}

DAYS AFTER REMOVAL FROM PILE

Days After Removal	Relative Counting Rate (approx.)
0	10,000
10	1,500
20	1,000
30	1,200
40	1,000
50	1,100
60	1,000
70	1,000
80	1,000
90	1,000
100	1,000
110	1,000
120	1,000
130	1,000

100000

9

8

7

6

5

4

3

2

1

0

10000

9

8

7

6

5

4

3

2

1

RELATIVE COUNTING RATE

1000

9

8

7

6

5

4

3

2

1

0

100

9

8

7

6

5

4

3

2

1

0

1000

0

100

200

300

TOTAL ABSORBER: mg /cm²

FIG. 1
Sc 85d

ABSORPTION OF RADIATION IN ALUMINUM

3 COMPONENTS

0.36 MeV

K(?)

FEATHER RANGE ~ 110 mg
(0.37 MeV) 85d Sc 85

BKG.

X

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

O

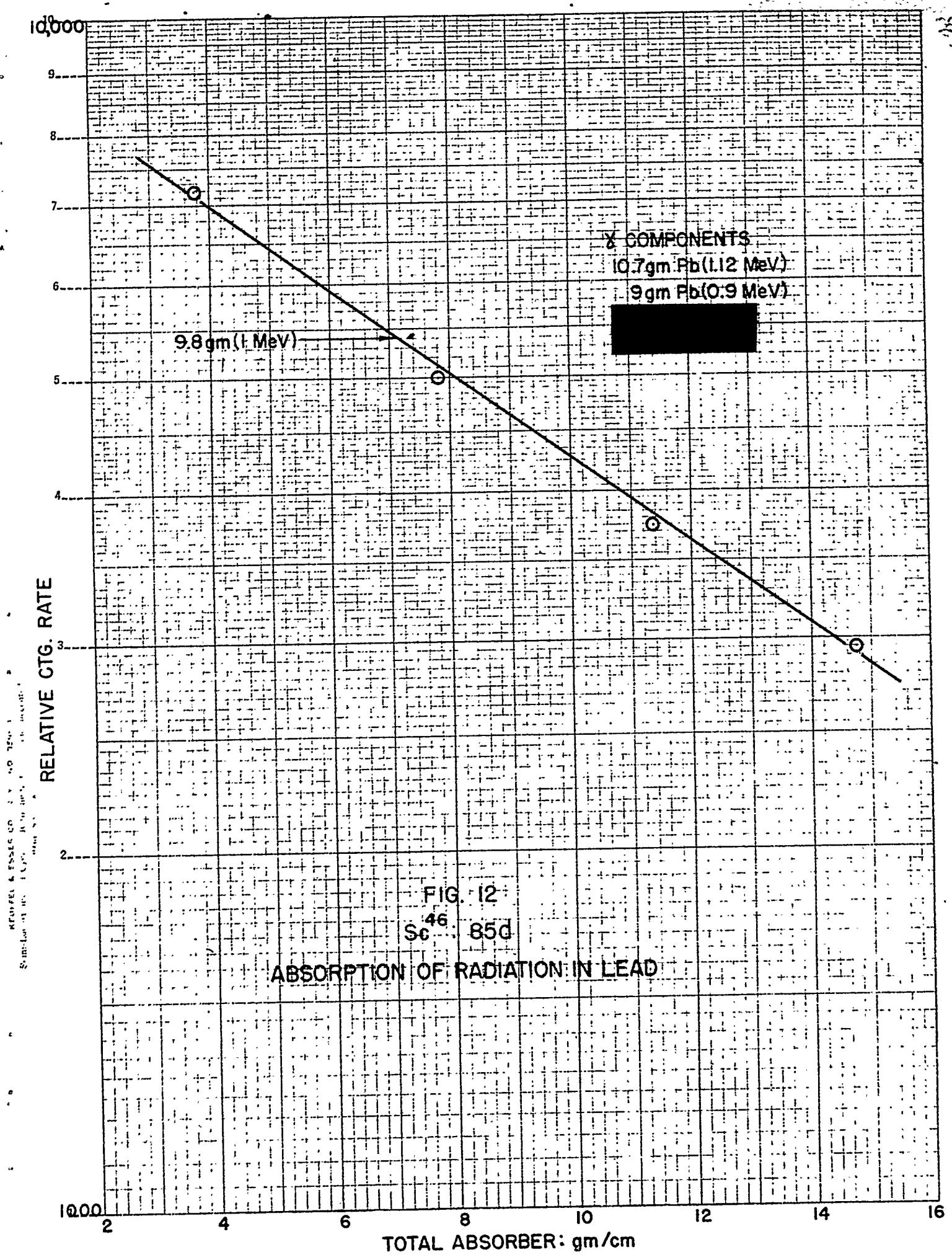
O

O

O

O

O



Titanium

Target Material: Titanium oxide, Pure, Amend Drug & Chemical Corp.

Weight: 18.73 g

Spectrographic Impurities:

Al	FT	Fe	T
Ca	FT	Mg	FT
Li	FT	Si	T
Cu	FT		

Irradiation: 69 days at $\bar{n}v = 3.2 \times 10^6 n/cm^2/\text{sec}$

Separations: See diagram

<u>Activities at T_0 in bombardment:</u>	<u>% Total Activity</u>	<u>Activity per Gram</u>	<u>ppm Impurities</u>
Ti51(72 d)	52%	0.027 mc	
P32 (14.7d)	48	0.025	1600 S32

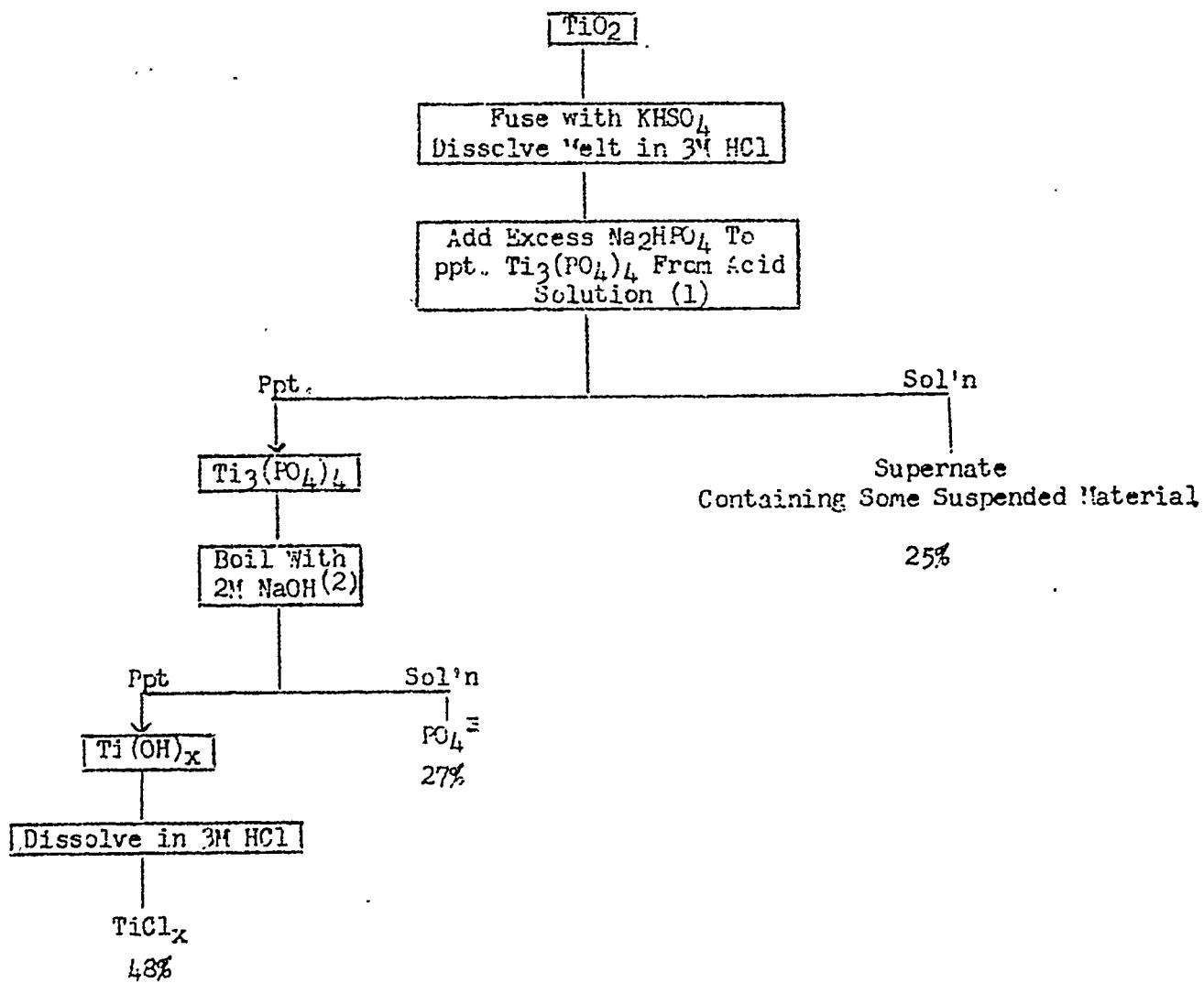
Yield: 0.022 mc/gm Ti/30 day bombardment at 50% maximum flux

Cross Section:

$$\begin{aligned}\sigma^- v &= 1.13 \times 10^2 \text{ barns cm/sec} \\ \sigma^- &= 5.15 \times 10^{-4} \text{ barns per atom normal element} \\ \sigma^- &= 0.0097 \text{ barns per atom isotope}\end{aligned}$$

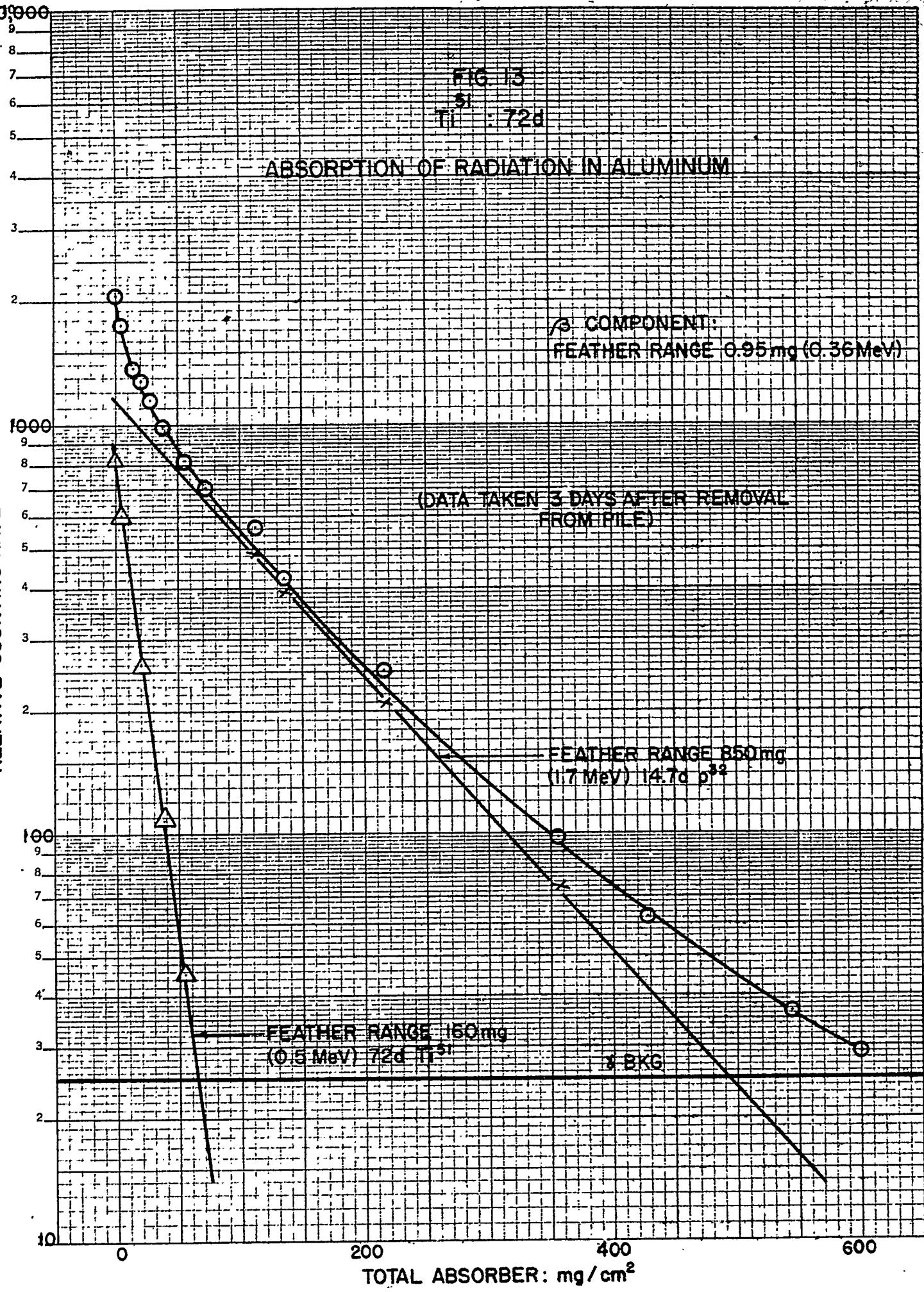
Non-Routine Errors: None

Remarks: The 1.7 Mev β radiation shown in Fig. 13 may be attributed to P32 activity originally present in the TiO_2 sample probably as SO_4^{2-} .



(1) Noyes and Bray, Qualitative Analysis for the Rare Elements, p. 83

(2) Ibid, p. 78.



Iron

Target Material: Carbonyl Iron Powder, A. D Mackay

Weight: 17.73 gm

Spectrographic Impurities:

Cu	FT	Ni	T
----	----	----	---

Irradiation: 32 days at $\text{nv} = 4.76 \times 10^6 \text{ n/cm}^2/\text{sec}$

Separations: See diagram.

<u>Activities Found at T_0 in Bombardment:</u>	<u>Activity per gm Fe</u>	<u>% Total</u>	<u>ppm</u>	<u>Purities</u>
Fe ⁵⁹ (46.3d)	0.144 mc	~99.8%		
Fe ⁵⁵ (~ 4 yr)	Identified but not calculated			
P ³² (14.8d)	1.1×10^{-4} mc	0.08%	1 ppm	
* (2.5 hr)	2.2×10^{-4}	0.15%	4	

* Mn or Ni probably

Yield: 0.144 mc Fe⁵⁹/ gm Fe/30 day bombardment at 50% maximum flux

Cross Sections:

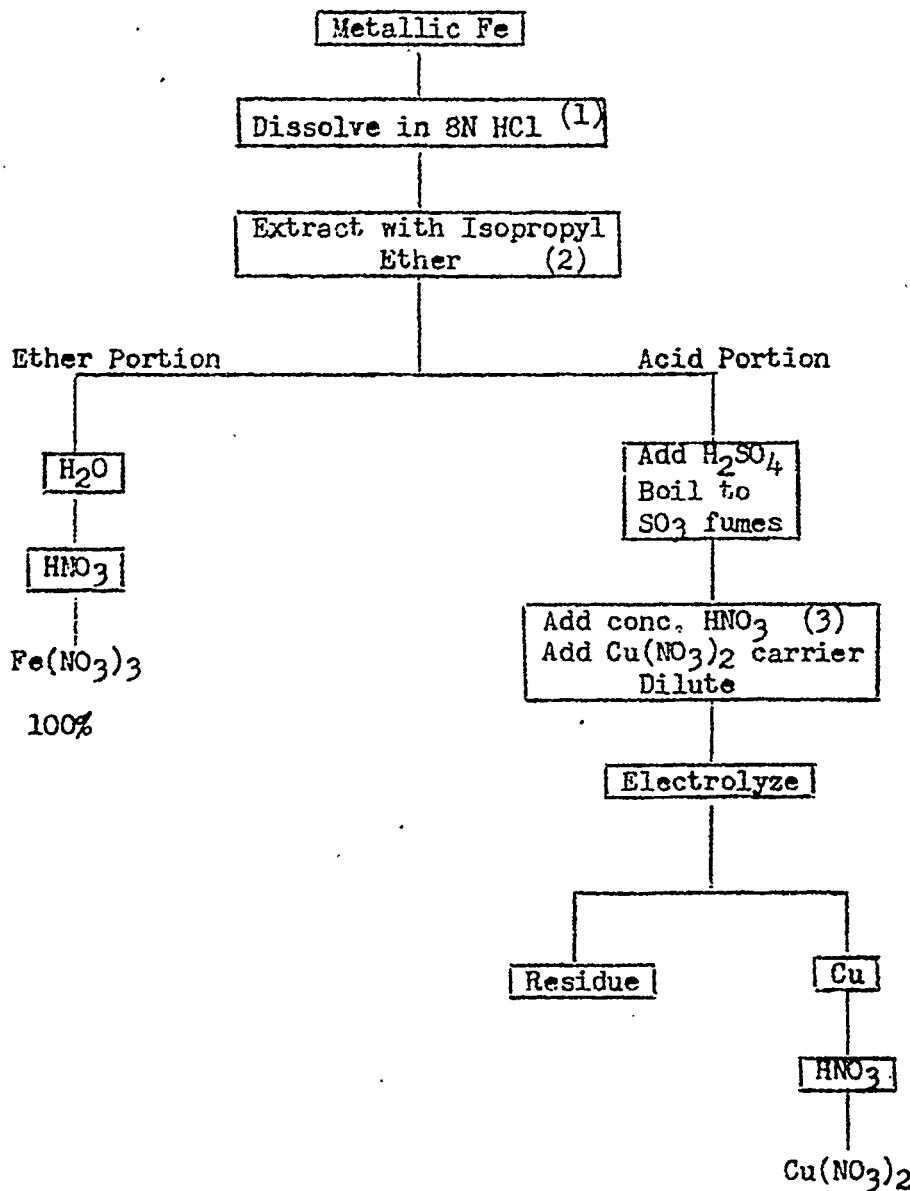
$$\sigma - v = 639 \text{ cm/sec}$$

$$\sigma = 2.9 \times 10^{-3} \text{ barns per atom normal element}$$

$$\sigma = 0.878 \quad " \quad " \quad " \text{ isotope}$$

Non-Routine Errors: None

Remarks: The slight amount of very soft component in the Fe absorption curves is due to the ~ 7 KeV x-rays of Fe⁵⁵. This will vary with the bombardment time and the flux. If it is desired to analyze for it one might use Be or C absorbers to enhance its absorption coefficient.



- (1) Great care should be taken to subject pile-bombarded iron to as little oxidizing action as possible; "passive" oxidized iron is easily formed, and can be dissolved only with extreme difficulty.
- (2) Scott's Standard Methods of Chemical Analysis, pp. 465-466.
- (3) Kolthoff and Sandell, Textbook of Quantitative Inorganic Analysis, pp. 423-425.

10000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

KEUFFEL & SHERE CO., N.Y. NO. 365-69
 Semi-Logarithmic, 2 cycles X 10 to the 1/2 inch, 5th lines spaced.
 MADE IN U.S.A.

FIG. 12

 Fe^{65} AND P^{32} DECAY OF Fe^{65}

1 HOURS PILE BOMBARDMENT

1000

9

8

7

6

5

4

3

2

1

0

0

10

20

30

HOURS AFTER REMOVAL FROM PILE

 $\frac{1}{2}$
 $T_{1/2} = 2.6 \text{ hr}$
 $\text{Mn}^{65} \text{ OR } \text{Ni}^{63}$
 Fe^{65} AND P^{32} EKG

10,000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

MEUFFEL & EASER CO., N. Y. NO. 359-63
 Semi-Logarithmic, 2 cycles X 10 to the 4th, 10th lines omitted
 MADE IN U.S.A.

FIG. 15

 Fe^{59} DECAY OF Fe^{59}

32 DAYS PILE BOMBARDMENT

 $T_{1/2} = 47.5\text{d}$ Fe^{59}

1000

9

8

7

6

5

4

3

2

1

0

100

0

DAYS AFTER REMOVAL FROM PILE

140

120

100

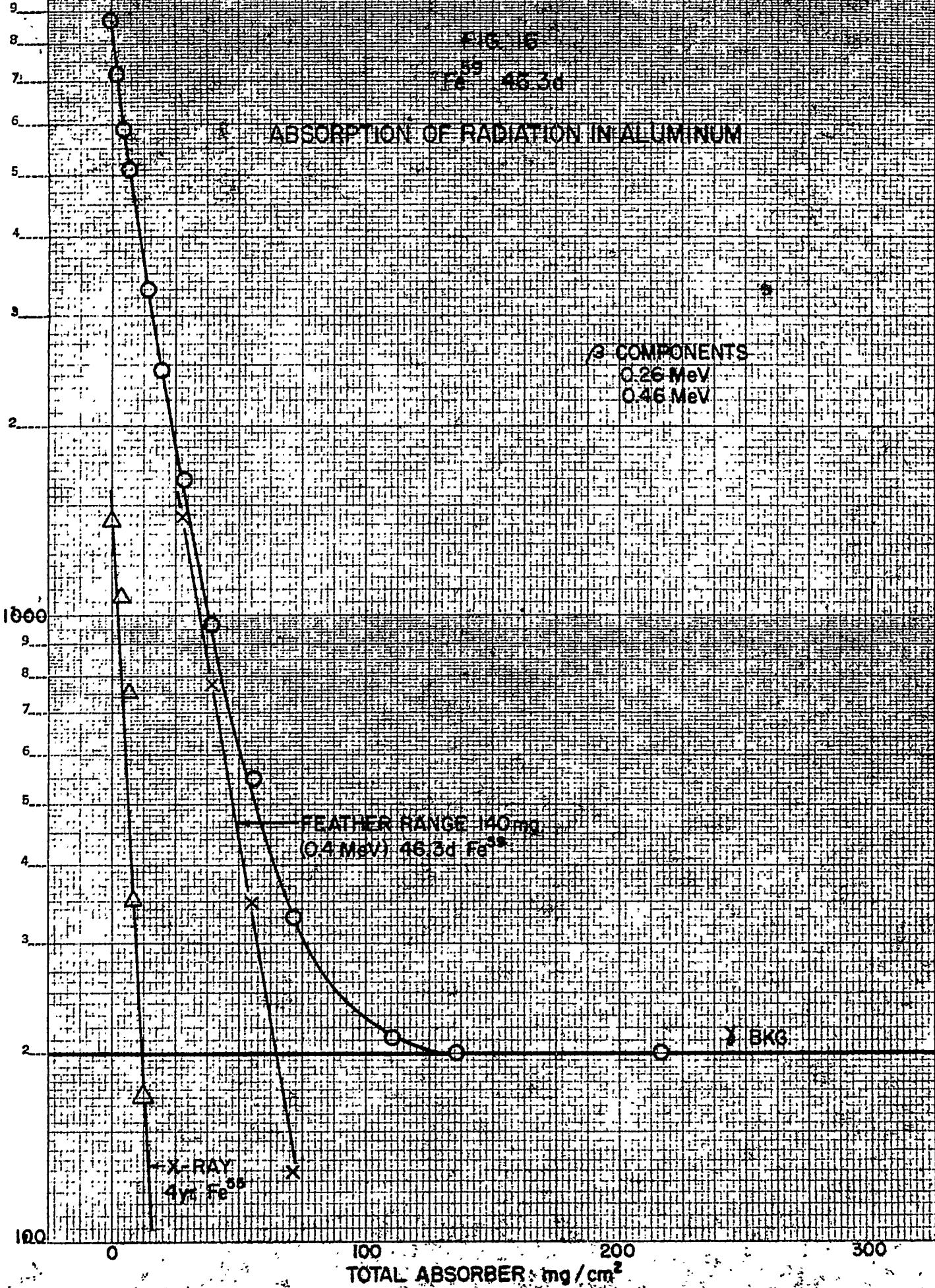
80

60

40

20

10,000



10,000

FIG. 17

58

F₀ : 46.3d

ABSORPTION OF RADIATION IN LEAD

* COMPONENTS

1.1 MeV

1.3 MeV

11.4 gm Pb (1.2 MeV)

46.3d F₀

RELATIVE COUNTING RATE

1000

0

2

4

6

8

10

12

TOTAL ABSORBER: gm/cm²

Cobalt

Target Material: Cobalt (ic) Oxide, C.P., Baker's

Weight: 1.03 gm

Spectrographic Impurities:

Ca	FT	Mg	VFT
Cu	FT	Hi	FT
Fe	FT		

Irradiation: 32 days at 4.34×10^9 n/cm²/sec

Separations: Dissolved the sample in 12N H₂SO₄ made it up to 100 ml., and took an aliquot with which to work.

<u>Activities Found at T₀ in Bombardment:</u>	<u>Activity per gm Co</u>
Co ⁶⁰ (5 3 yr)	36.8 mc

Yield: 42.5 mc/gm Co/30 day bombardment at 50% maximum flux

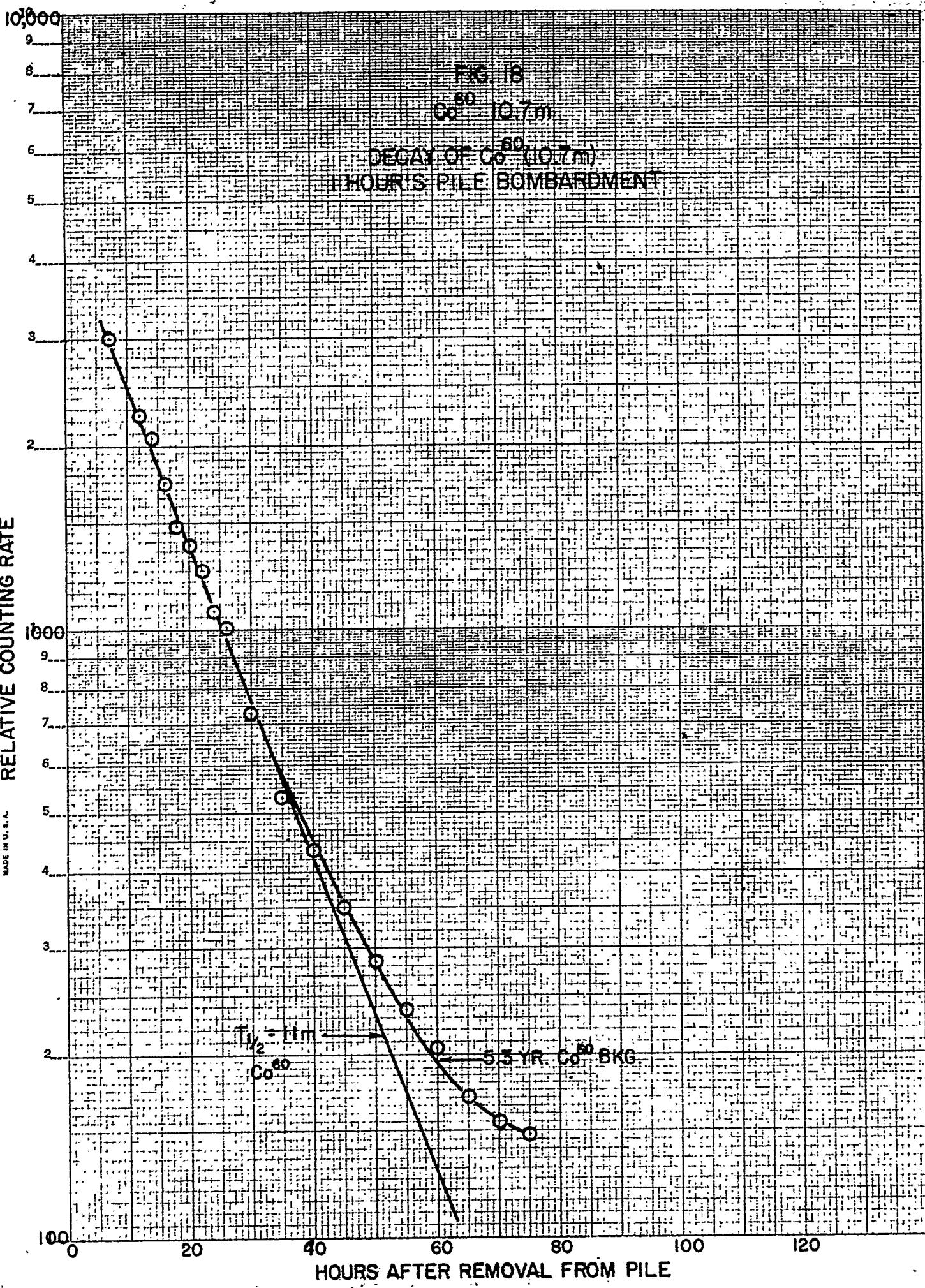
Cross-Sections:

$$\sigma \nu = 6.51 \times 10^6 \text{ barns cm/sec}$$

$\sigma = 29.6$ barns per atom normal element

$\sigma = 29.6$ barns per atom isotope

Non-Routine Errors: None



10,000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

KEUFFEL & SALTER CO., N. Y. NO. 369-03
 Serial Logarithmic, 2 cycles X 10 to the 4th, fifth place recorded
 MADE IN U. S. A.

FG 19

 Co^{60} 5.3yDECAY OF Co^{60}
32 DAYS' PILE BOMBARDMENT

1000

9

8

7

6

5

4

3

2

1

0

100

20

40

60

80

100

120

DAYS AFTER REMOVAL FROM PILE

0

20

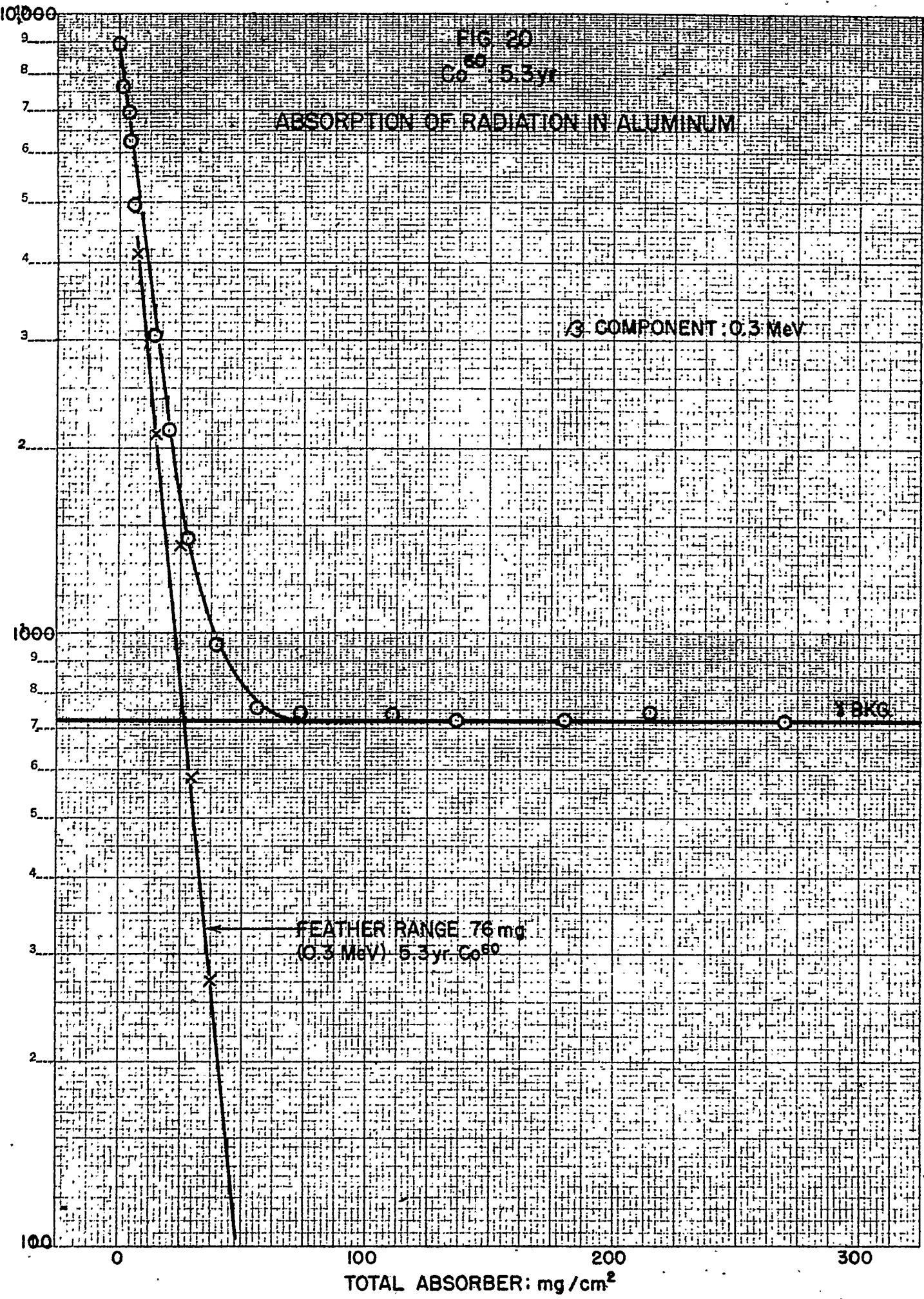
40

60

80

100

120



NickelTarget Material: Nickel Powder, Belmont Smelting & Refining WorksWeight: 10.05 g.Spectrographic Impurities:

Ca	T	Fe	W
Co	T	Mg	FT
Cu	M	Si	T

Irradiation: 63 days at $\bar{n}v = 4.6 \times 10^9 n/cm^2/sec$ Separations: See diagram.

Activities Found at T_0 in Bombardment	% Total Activity	Activity per gm. Ni	ppm Impurities
Ni ⁶⁵ (2.6 hr)	92.5%	1.94 mc	
Co ⁶⁰ (5.3 yr)	2.5	0.053	1,300
Fe ⁵⁹ (46.3 d)	--	<0.0014	8,000
Cu ⁶⁴ (12.8 hr)	5.0	0.13	350
Unidentified	--	0.001	

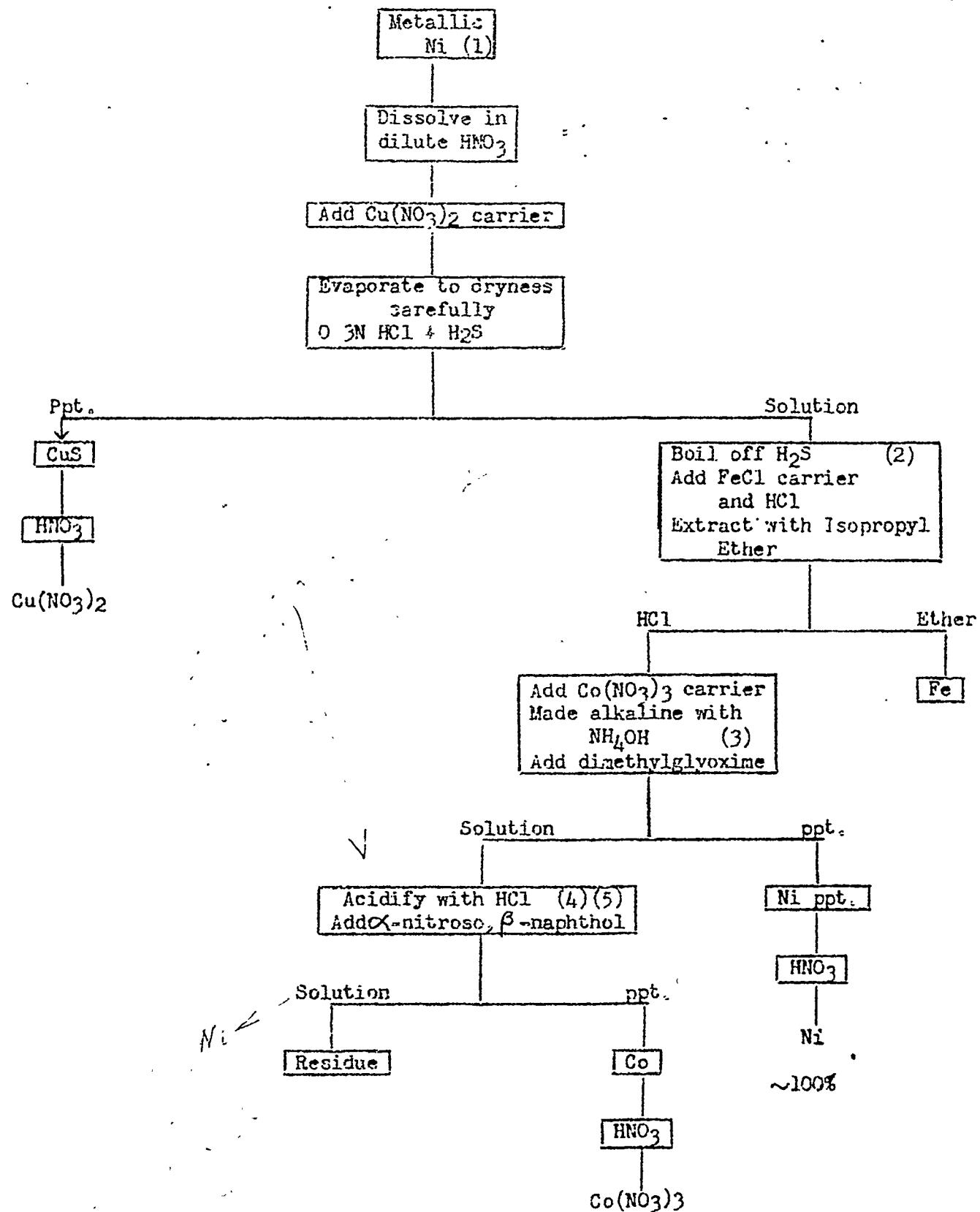
Yield: 2.11 mc/gm Ni/30 day bombardment at 50% maximum fluxCross-Sections:

$$\sigma - \sigma = 3.37 \times 10^3 \text{ barns cm/sec}$$

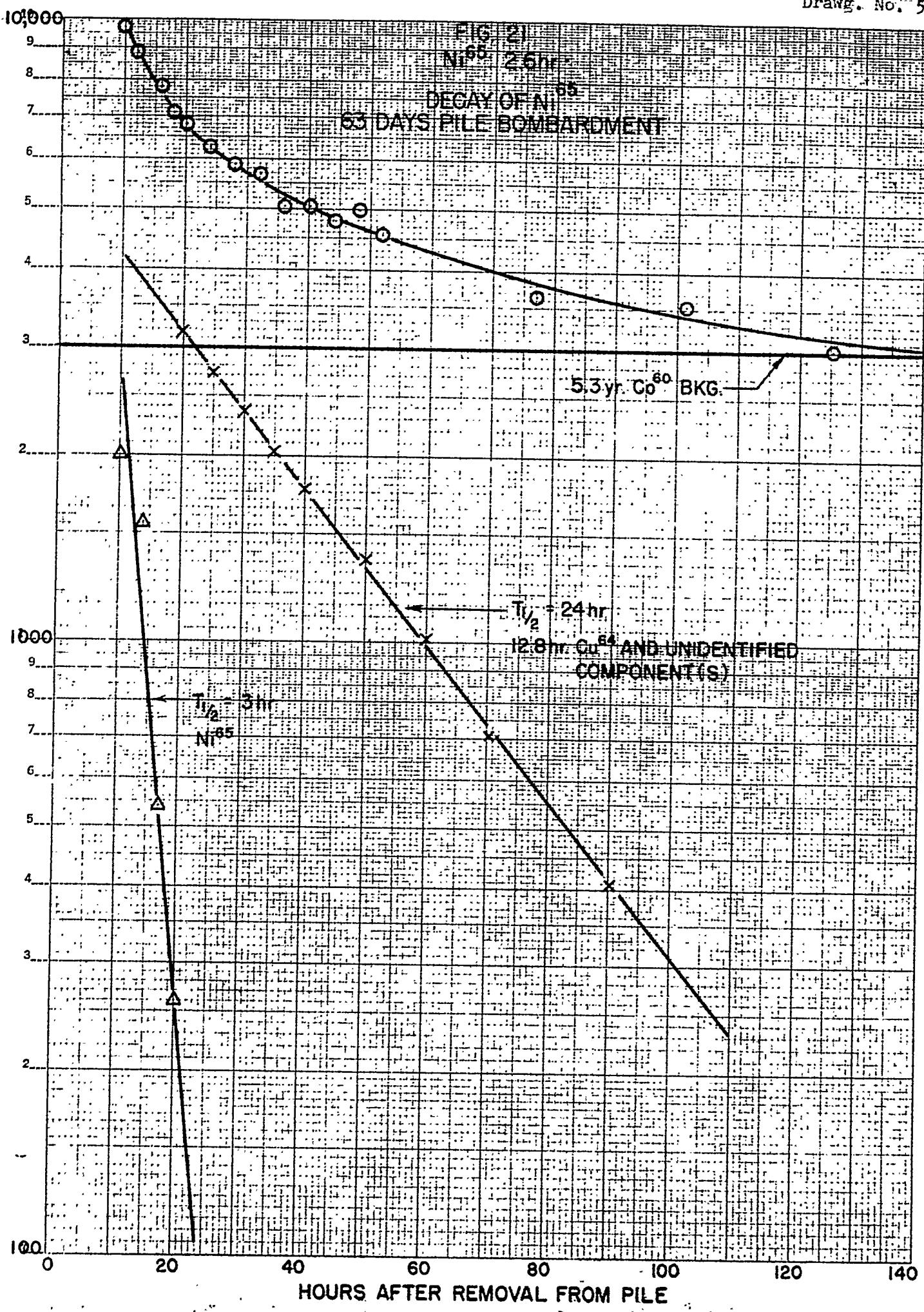
σ = 0.0153 barns per atom normal element

σ = 1.32 barns per atom isotope

Non-Routine Errors: NoneRemarks: % chemical recovery figures were not available.



- (1) The Ni. bombarded contains 0.8% Fe which will become "passive" if subjected to strong oxidizing action. The Ni should therefore be dissolved in cold dilute acid, and evaporated to dryness carefully.
- (2) Scott's Standard Methods of Chemical Analysis, pp. 465-466.
- (3) Dimethylglyoxine precipitates iron as well as nickel.
- (4) α -nitroso, β -naphthol precipitates iron as well as cobalt.
- (5) Ibid , p. 314



10⁹000

8

7

6

5

4

3

2

1

0

FIG. 22

NI⁶⁵ 2.6 HR

ABSORPTION OF RADIATION IN ALUMINUM

 β COMPONENT: 19 MevFEATHER RANGE 870 mg
(19 Mev) 2.6 HR NI⁶⁵

RELATIVE COUNTING RATE

1000

9

8

7

6

5

4

3

2

1

0

100

9

8

7

6

5

4

3

2

1

0

0

100

200

300

TOTAL ABSORBER: mg/cm²

Selenium

Target Material: Selenium powder, General Chemical Co.

Weight: 20.13 g

Spectrographic Impurities:

Al	FT	Mg	T
Ca	T	Si	T

Irradiation: 98 days at $\text{nv} = 3.1 \times 10^7 \text{ n/cm}^2/\text{sec}$

Separations: See diagram.

Activities Found* at T₀ in Bombardment: Activity per gm. Se

Se ⁷⁵ (115d)	15.74 mc
-------------------------	----------

*The above figure was obtained from gamma measurements on the ion chamber; the gamma efficiency was calculated by assuming one 0.335 Mev γ per disintegration. X-rays and δ -rays present make Se⁷⁵ a suitable tracer, but absolute measurement is extremely difficult.

Yields: 9.92 mc/gm Se/30 day bombardment at 50% maximum flux

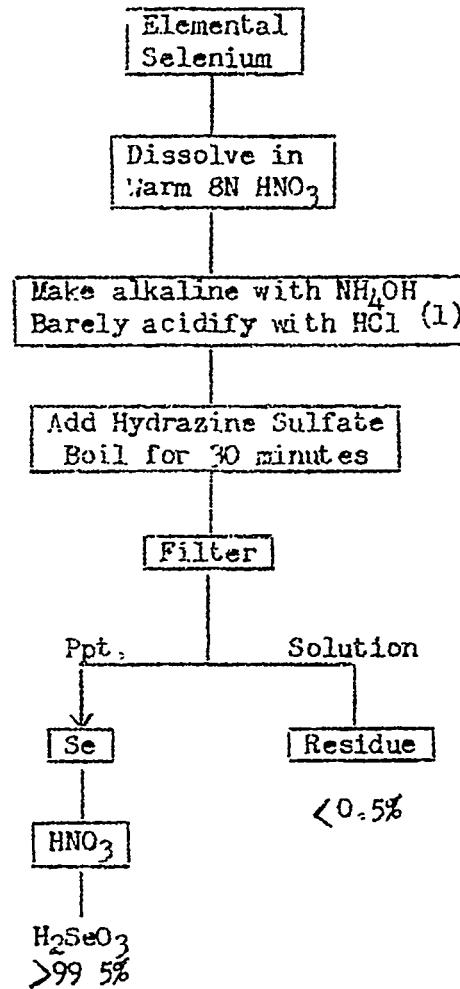
Cross-Sections:

$$\sigma v = 1.29 \times 10^5 \text{ barns cm/sec}$$

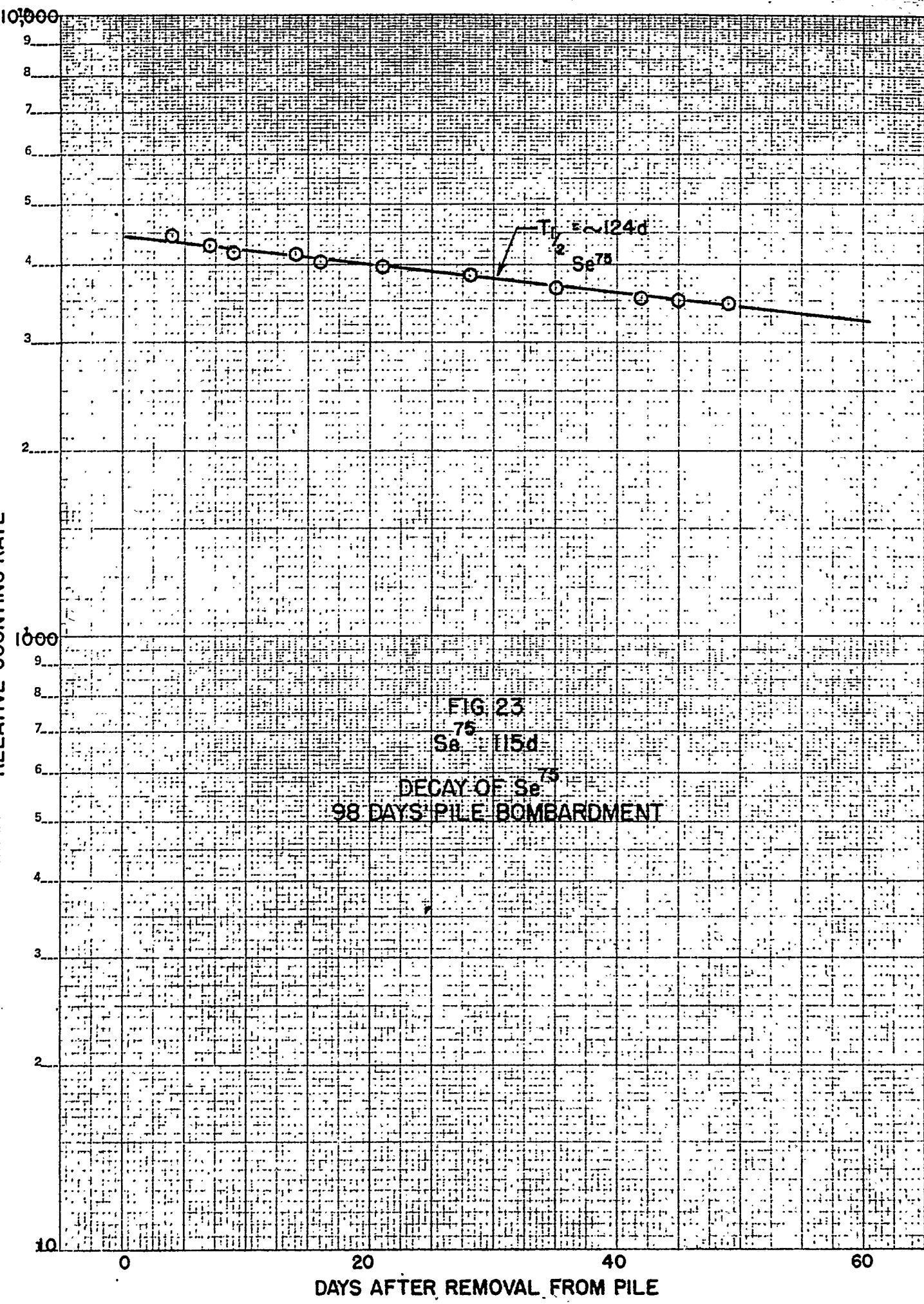
$$\sigma = 0.586 \text{ barns per atom normal element}$$

$$\sigma = 67.4 \text{ barns per atom isotope}$$

Non-Routine Errors: None

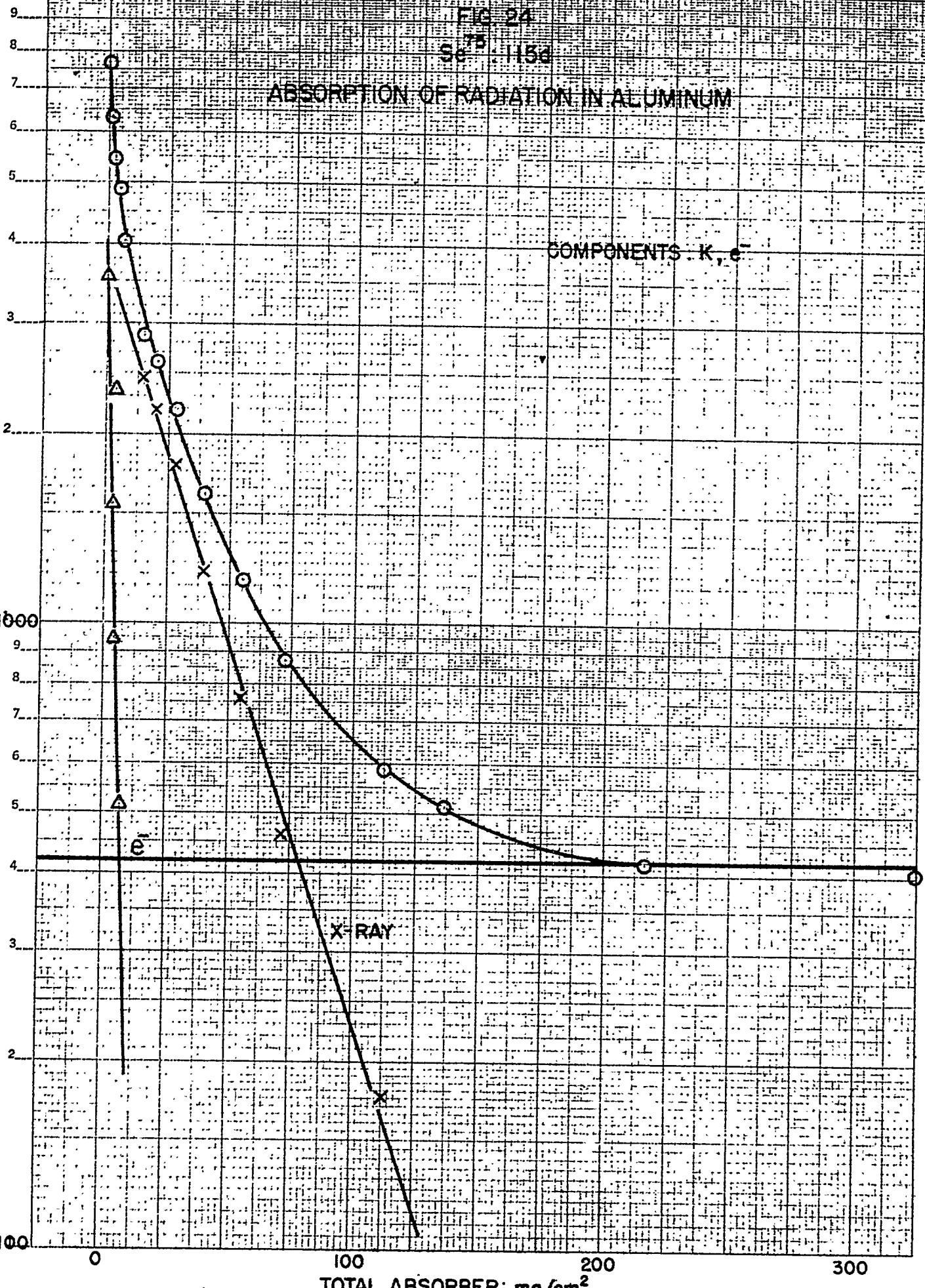


(1) Treadwell & Hall, Analytical Chemistry, Vol. II, p. 107.



KEUFFEL & ESSER CO., N. Y. NO. 255-63
Serial Logarithms. 2 cycles X 1¹/₂ to the 4 inch, 5th Line
MADE IN U. S. A. PEI

10,000



Silver

Target Material: Silver nitrate, crystal, Reagent, General Chemical Co.

Weight: 7.09 gm

Spectrographic Impurities:

Al	FT	Fe	FT
Ca	FP	Mg	T
Cu	T	Si	T

Irradiation: 35 days at $\bar{n}v = 6 \times 10^6$ n/cm²/sec

Separation: See diagram.

<u>Activity Found at T₀ in Bombardment:</u>	<u>Activity per gm. Ag</u>
--	----------------------------

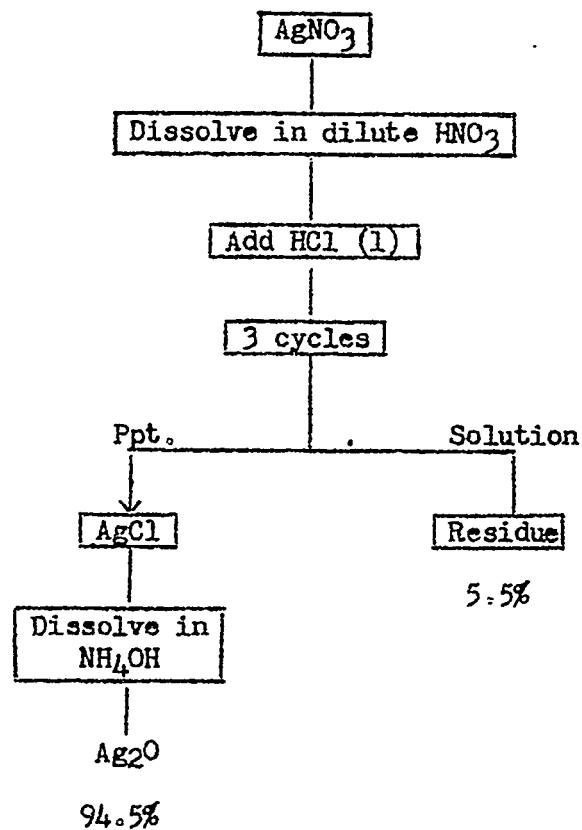
Ag ¹¹⁰ (225 d)	3.3 mc
---------------------------	--------

<u>Yield:</u>	2.38 mc/gm Ag/30 day bombardment at 50% maximum flux
---------------	--

Cross-Sections:

$$\begin{aligned}\sigma v &= 7.96 \times 10^4 \text{ barn cm/sec} \\ \sigma &\approx 0.36 \text{ barns per atom normal element} \\ \sigma &\approx 0.74 \text{ barns per atom isotope}\end{aligned}$$

Non-Routine Errors: None



(1) Scott's Standard Methods of Chemical Analysis, p. 818.

FIG 25

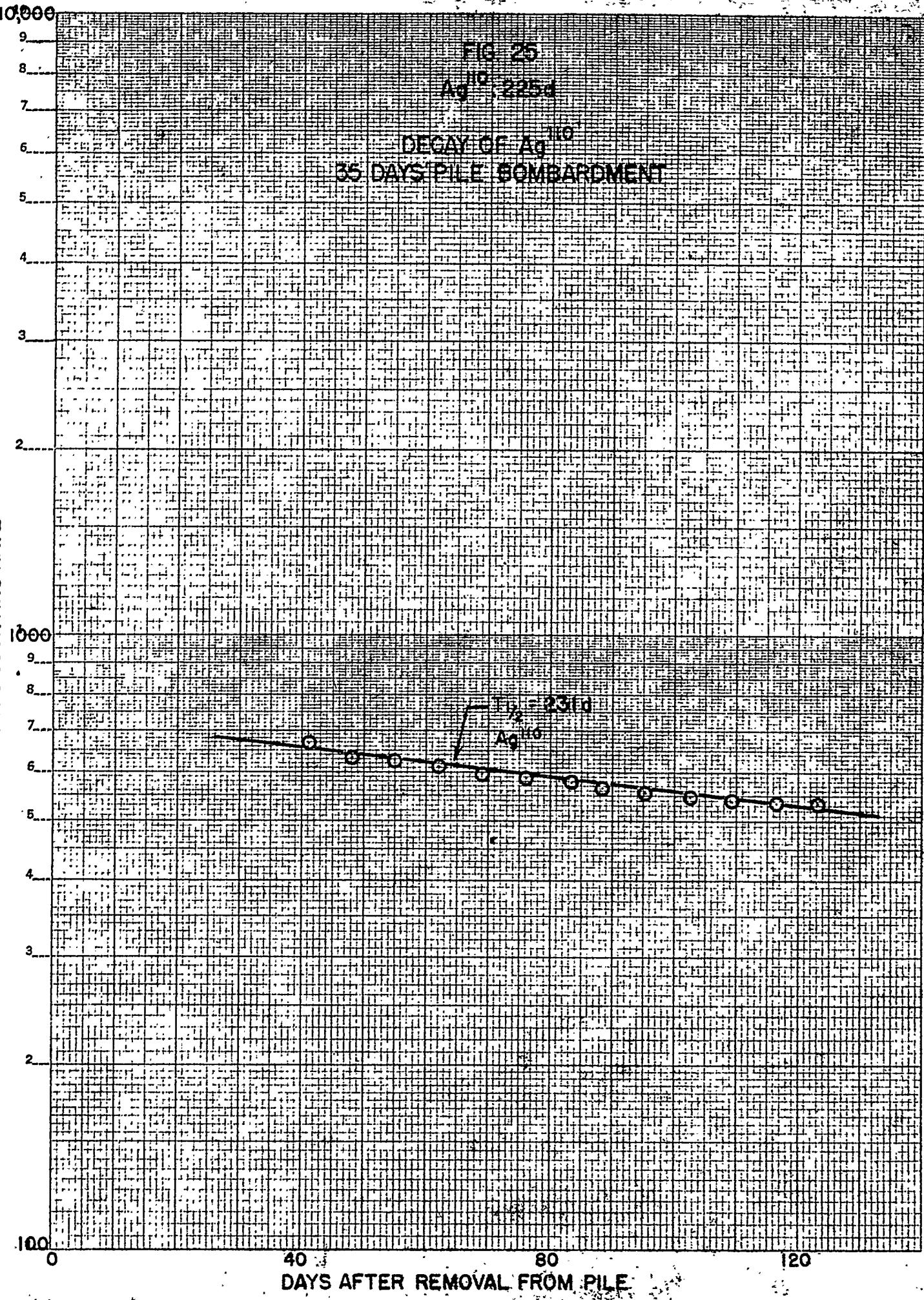
Ag-225

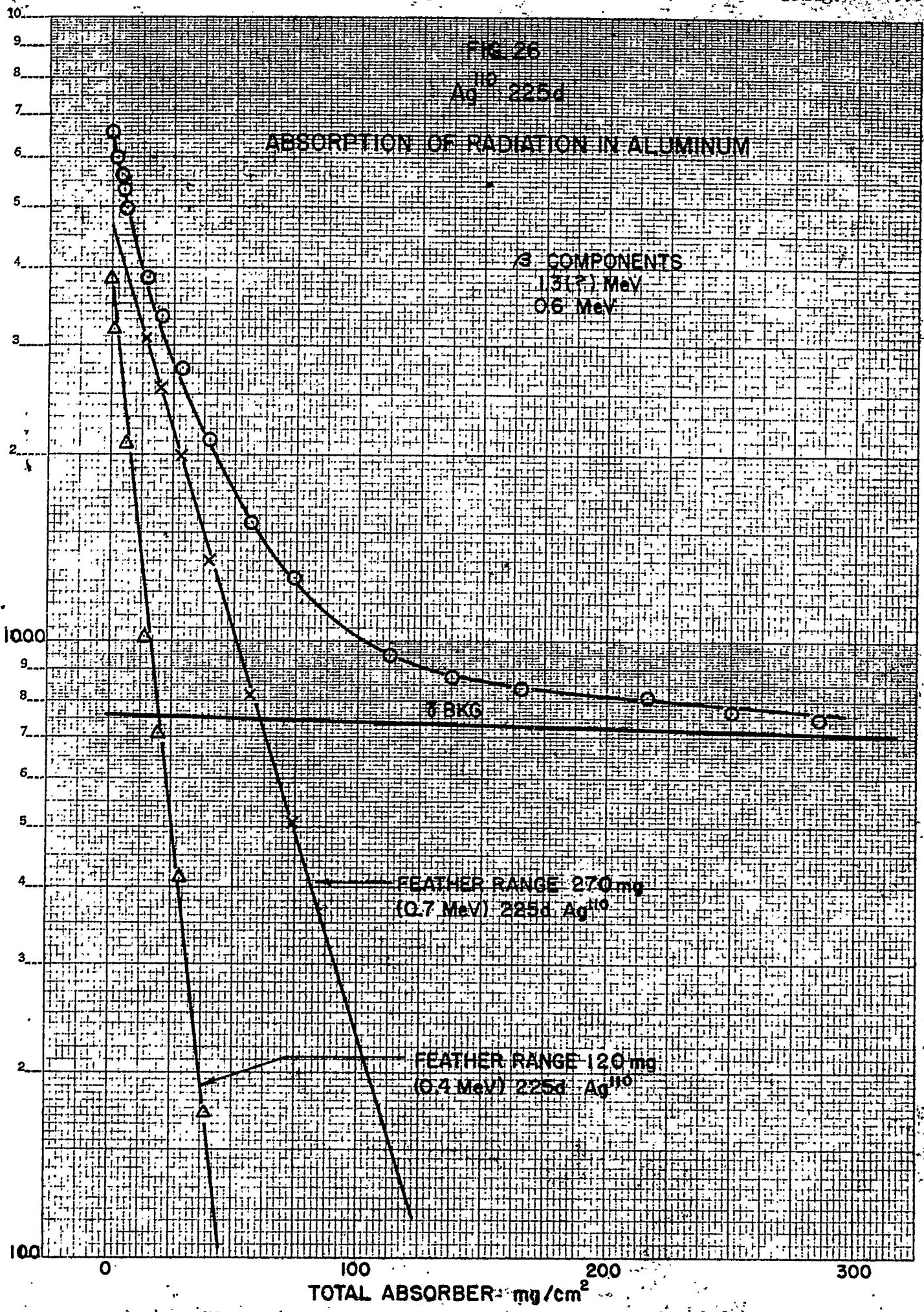
DECAY OF Ag¹⁰

35 DAYS PILE BOMBARDMENT

RELATIVE COUNTING RATE

KUEFFEL & ESSER CO., N.Y. NO. 388-63
 Semi-Logarithmic, 2 cycles X 10 to the 1/2 Inch, Sub Scales Accented,
 MADE IN U.S.A.





IndiumTarget Material: Indium Nitrate, C.P., A.D. MackayWeight: 0.38 gmSpectrographic Impurities:

Ag	FT	Cu	FT	Ni	FT
Al	FT	Fe	VW	Pb	FT
Be	FT	Mg	T	Si	FT
		Na	FT		

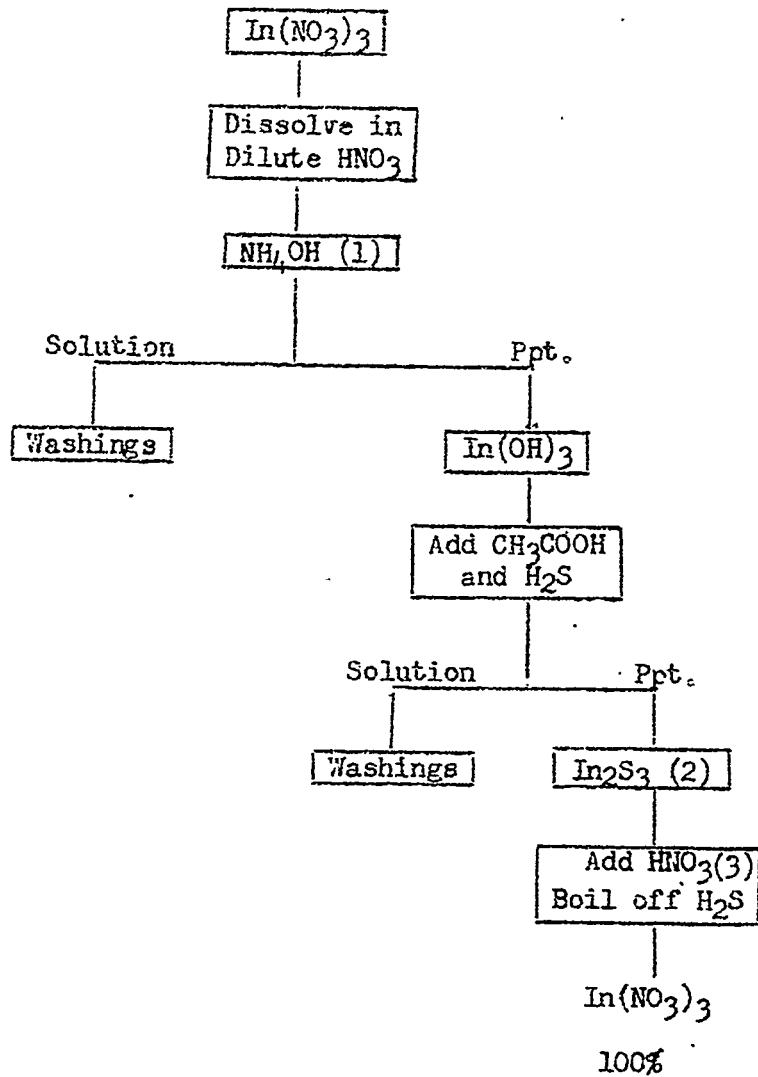
Irradiation: 27 days at $\text{nv} = 5.2 \times 10^9 \text{ n/cm}^2/\text{sec}$ Separations: See diagramActivity Found at T₀ in Bombardment: Activity per gm. InIn¹¹⁴ (48 d)* 19.4 mcUnidentified impurity with 0.7 Mev γ is present in small quantities* 0.19 γ is apparently 100% convertedYield: 20.4 mc/gm In/30 day bombardment at 50% maximum fluxCross-Sections:

$$\sigma \cdot v = 1.80 \times 10^5 \text{ barns cm/sec}$$

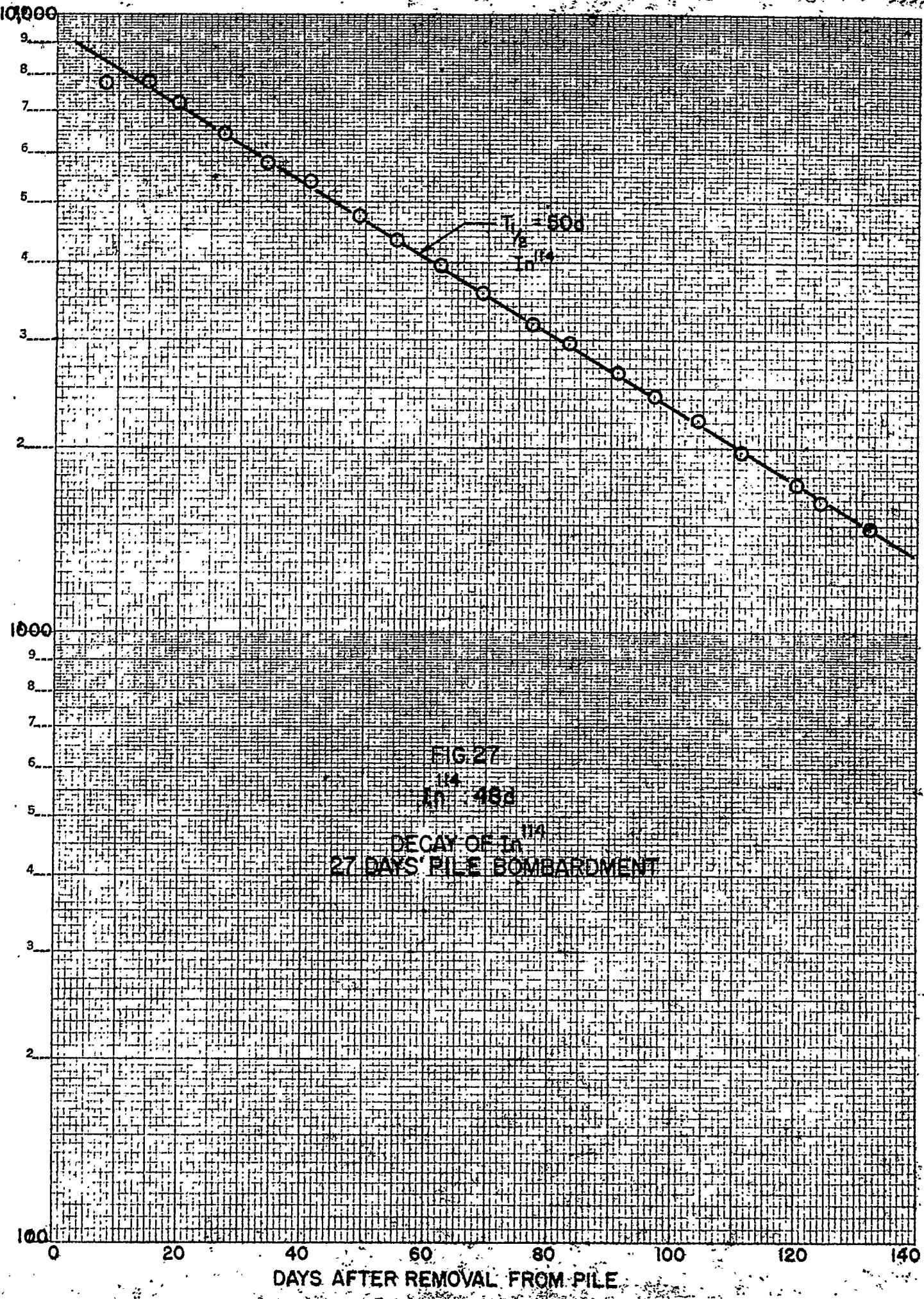
$$\sigma = 0.82 \text{ barns per atom normal element}$$

$$\sigma = 19.4 \text{ barns per atom isotope}$$

Non-Routine Errors: None



- (1) Noyes and Bray, Qualitative Analysis for the Rare Elements, p. 193
- (2) In_2S_3 precipitates rapidly and finely from a 6N acetic acid solution, more slowly and flocculently from a more dilute solution.
- (3) InCl_3 is somewhat volatile, so HNO_3 is to be preferred to HCl for dissolving the In_2S_3 .



KEUFFEL & ESSER CO., N.Y. NO. 388-83
Semi-Logarithmic, 5 cycles X 10 to the 14 both, Schenectady,
MADE IN U.S.A.

10000

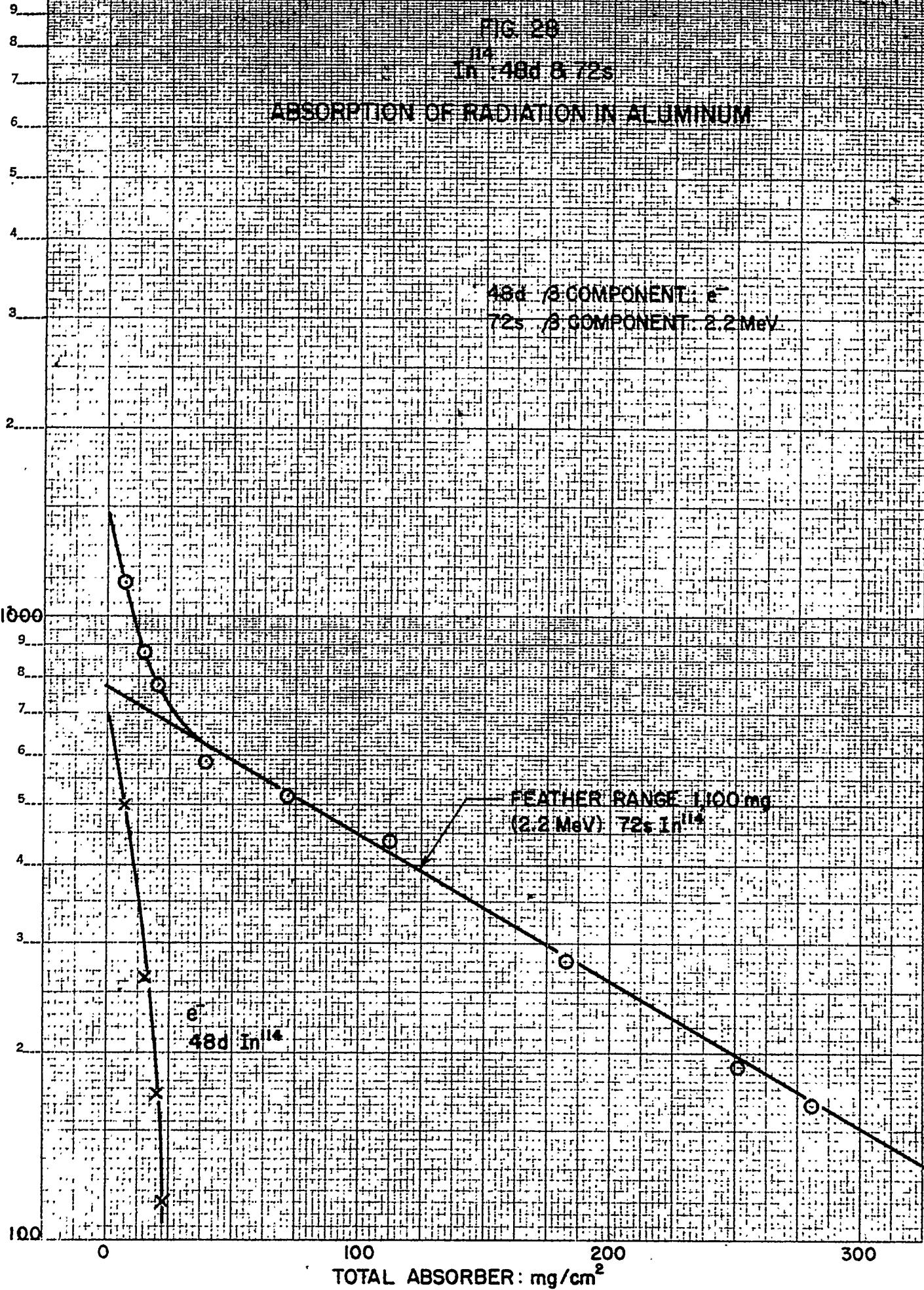


FIG 29

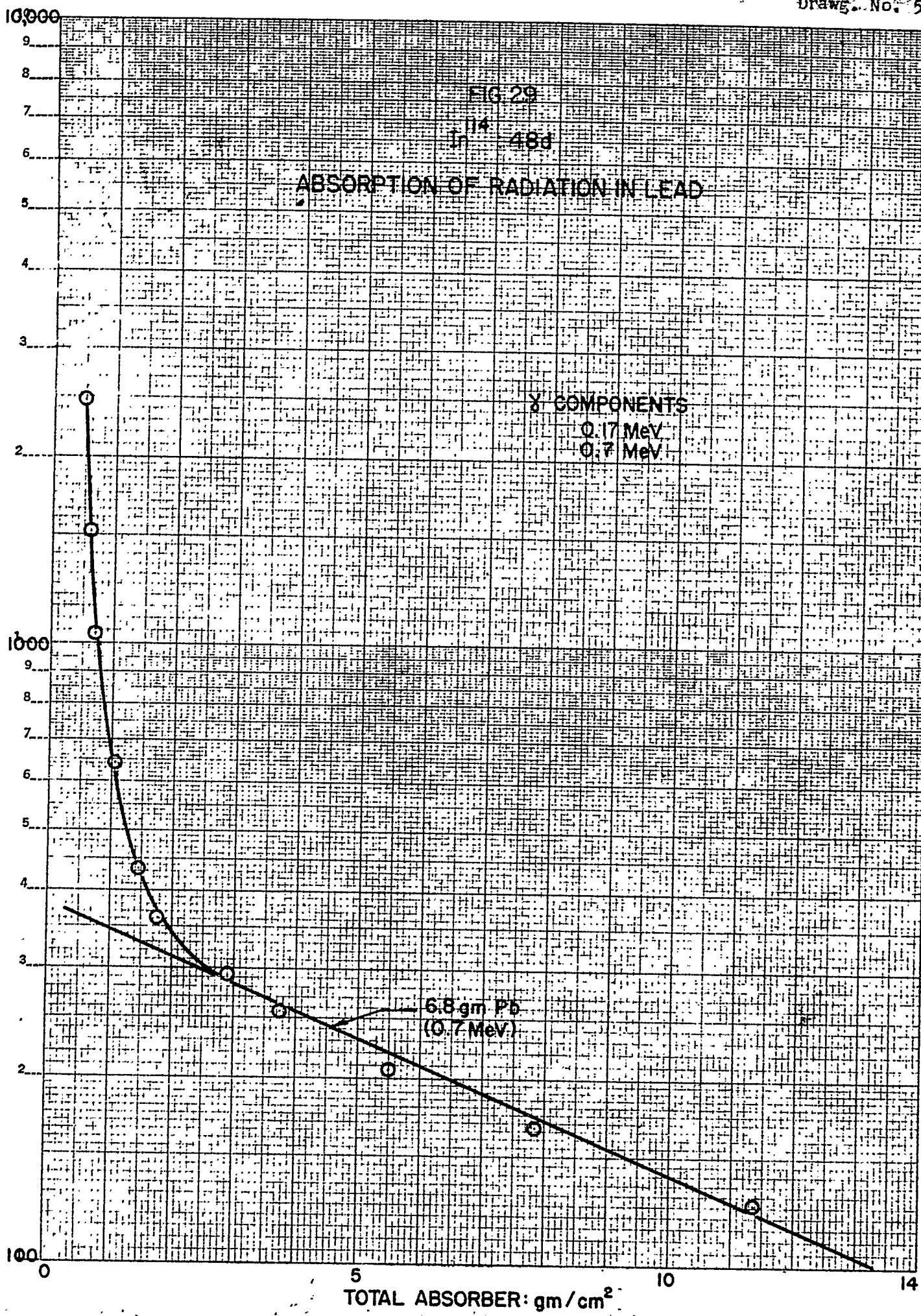
In 48d

ABSORPTION OF RADIATION IN LEAD

X COMPONENTS

0.17 MeV
0.7 MeV

MEUFFEL & REED CO., N.Y. NO. 389-63
 Semi-Logarithmic 2 cycle $\times 10$ to the $\frac{1}{2}$ inch 5th line accepted
 MADE IN U.S.A.



Cadmium

Target Material: Mosay cadmium metal, General Chemical Company

Weight: 1.03 gm

Spectrographic Impurities:

Ag	VFT	Fe	VFT
Ca	PP	Mg	T
Cu	T	Pb	T
Si	VFT		

Irradiation: 27 days at $\text{nv} = 4.51 \times 10^9 \text{ n/cm}^2/\text{sec}$

Separations: See diagram.

<u>Activities Found at T_0 in Bombardment</u>	<u>% Total Activity</u>	<u>Activity per gm. Cd</u>	<u>ppm Impurities</u>
Cd ¹¹⁵ (2.3 d)	96.6%	11.54 mc	
Cd ¹¹⁵ (43 d)	3.4	0.41	
Cu ⁶⁴ (12.8 hr)	< 0.02	< .002	< 3 ppm

Yields:

Cd¹¹⁵ (2.3 d) 12.80 mc/gm Cd/30 day bombardment at 50% maximum flux
 Cd¹¹⁵ (43 d) 0.456 mc/ " " " " "

Cross-Sections:

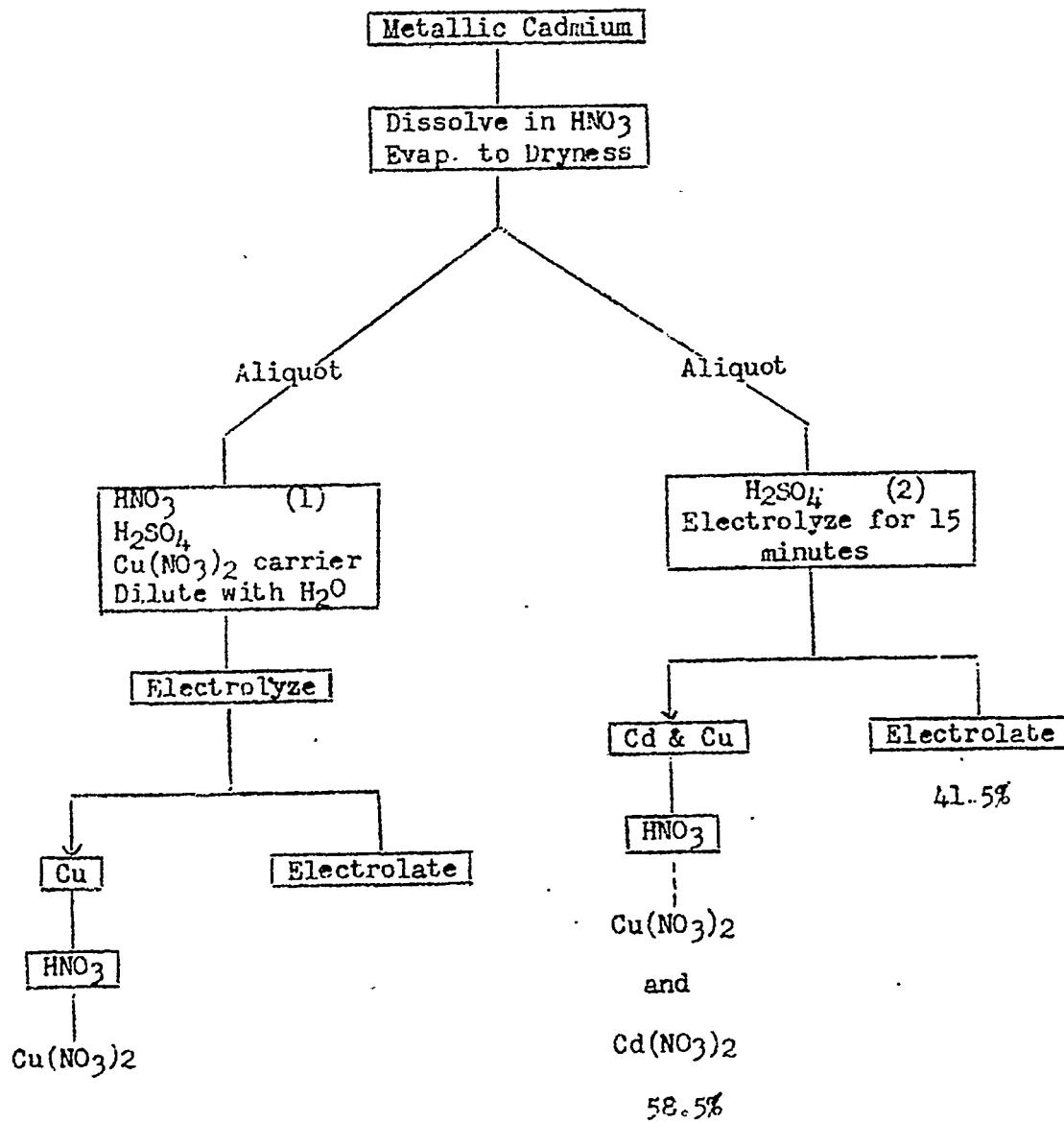
43 d Cd¹¹⁵:

$\sigma_v = 3.96 \times 10^3 \text{ barns cm/sec}$
 $\sigma = 0.018 \text{ barns per atom normal element}$
 $\sigma = 0.064 \text{ barns per atom isotope}$

2.3 d Cd¹¹⁵:

$\sigma_v = 3.92 \times 10^4 \text{ barns cm/sec}$
 $\sigma = 0.178 \text{ barns per atom normal element}$
 $\sigma = 0.634 \text{ barns per atom isotope}$

Non-Routine Errors: None



- (1) Kolthoff and Sandell, Textbook of Quantitative Inorganic Analysis,
pp. 423-425
- (2) Scott's Standard Methods of Chemical Analysis, p. 202

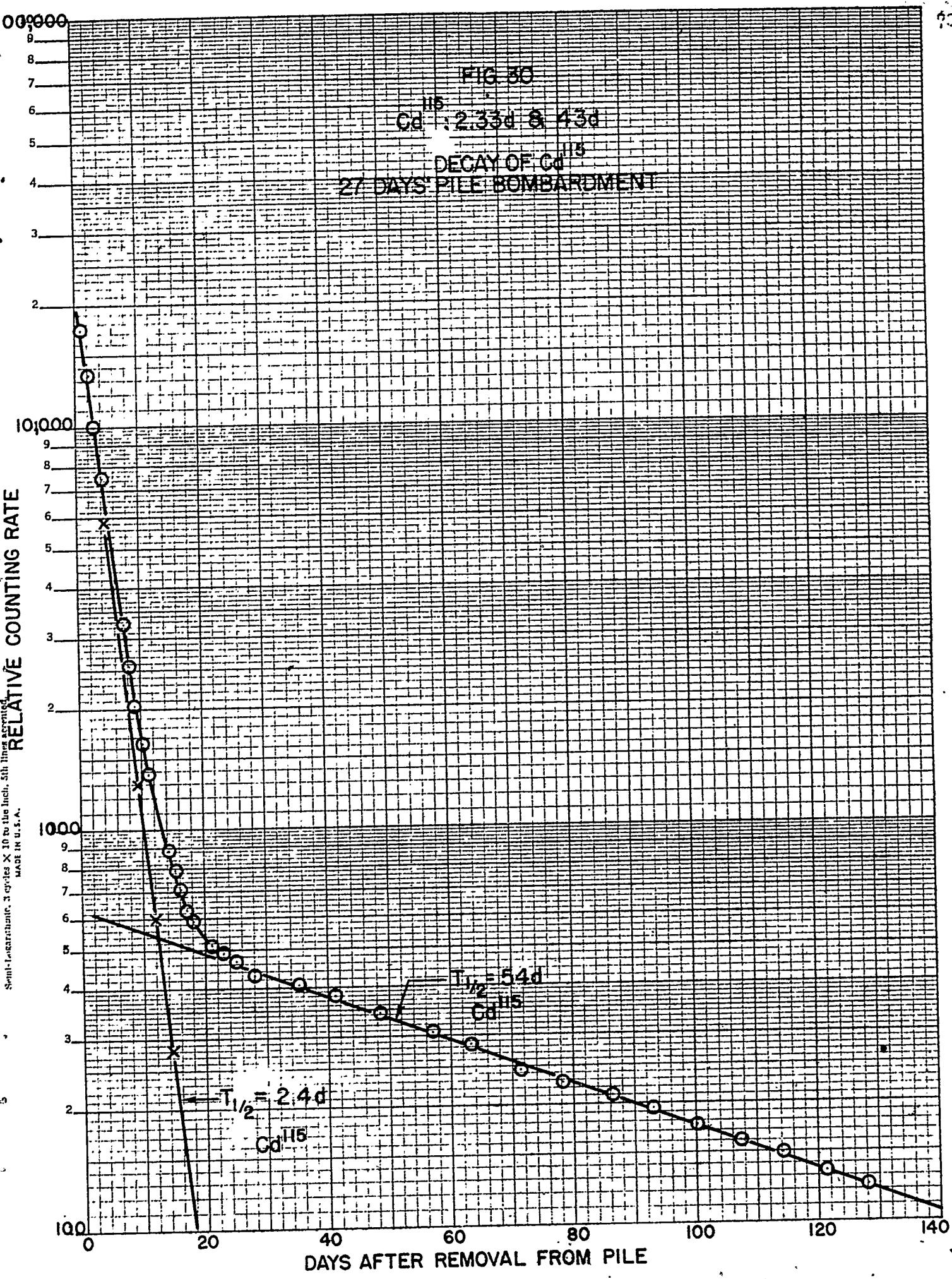


FIG. 31

 Cd^{113} 2.33d & 4.3d

ABSORPTION OF RADIATION IN ALUMINUM

2.33d /3 COMPONENTS

0.5 MeV

1.3 MeV

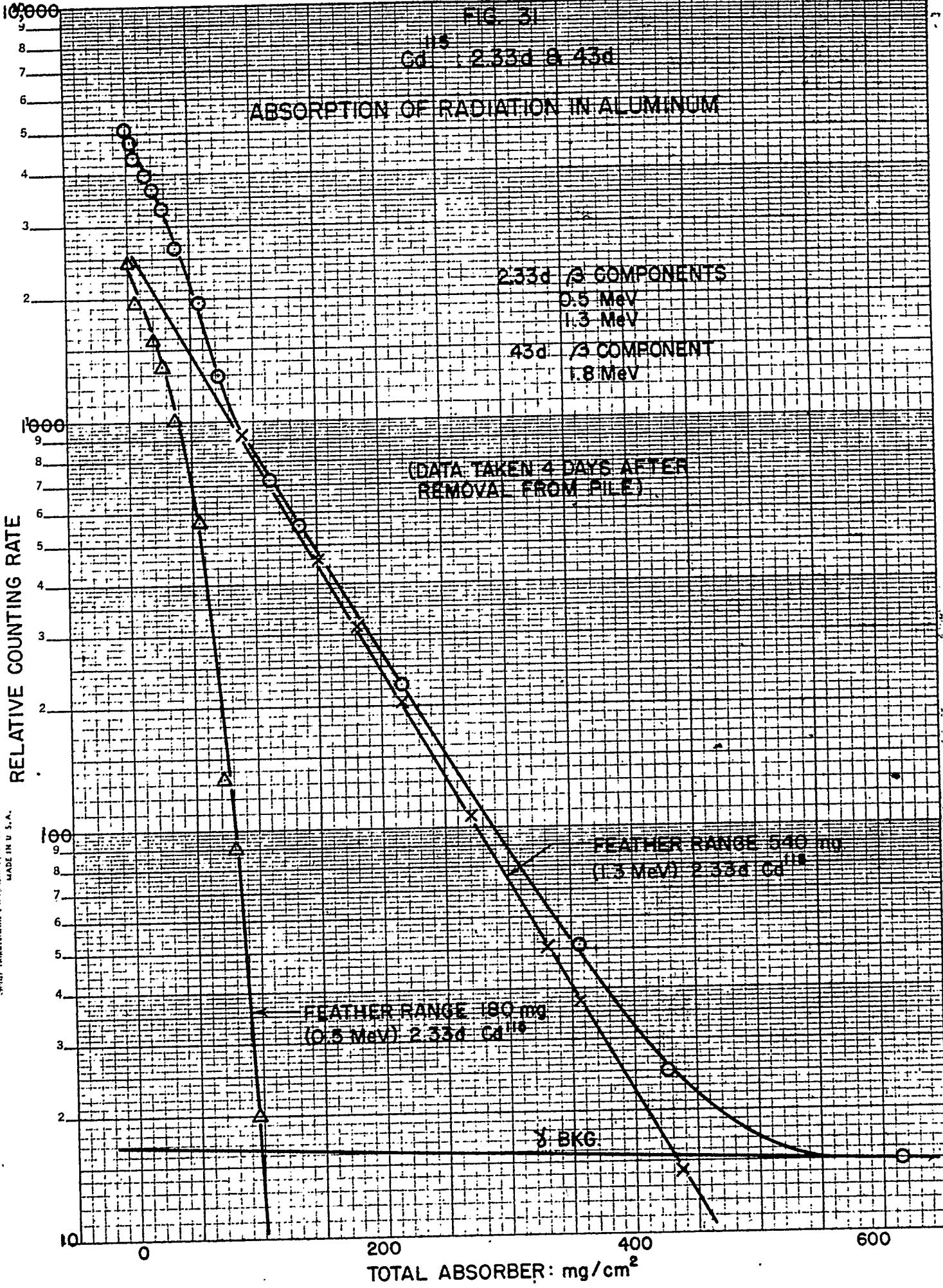
4.3d /3 COMPONENT

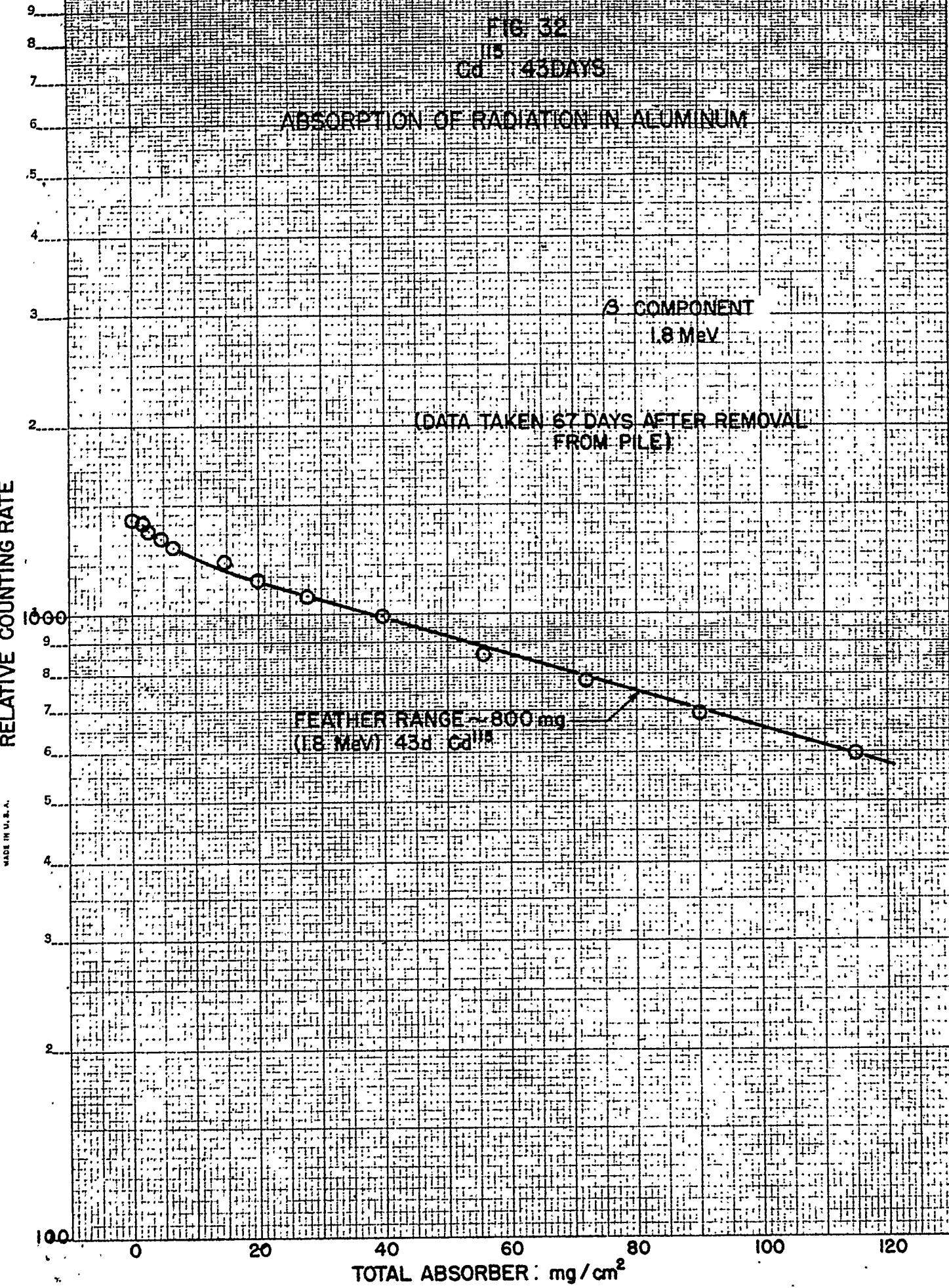
1.8 MeV

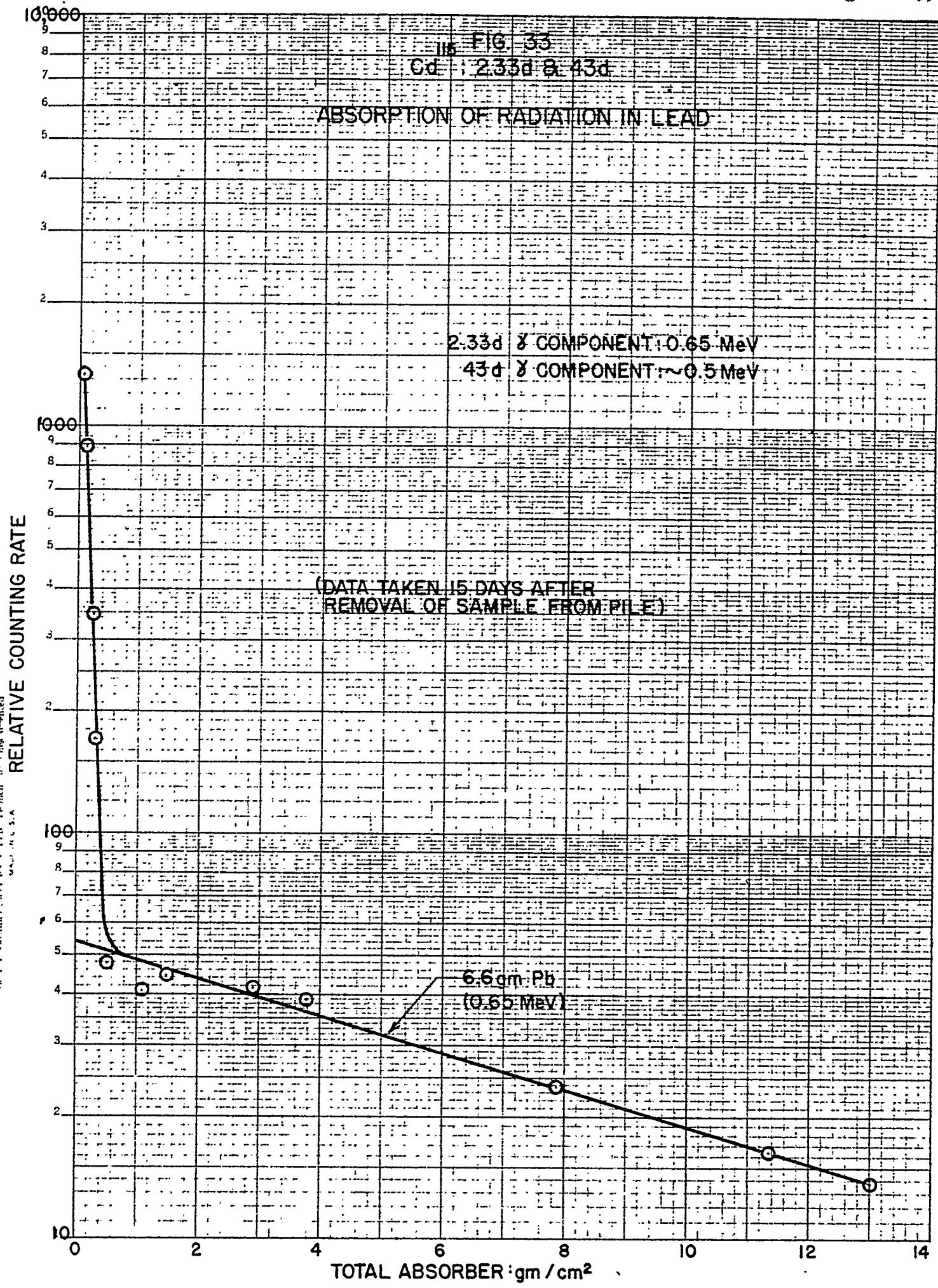
(DATA TAKEN 4 DAYS AFTER
REMOVAL FROM FILE)

MCUFFEE & ECKER CO., N.Y. NO. 358-71
 Serial logarithmic - 2 cm. x 10 to the tenth. 5th linear section.
 MADE IN U.S.A.

RELATIVE COUNTING RATE



10¹⁰⁰⁰



Antimony

Target Material: Antimony metal, Lump, C. P. Baker's

Weight: 0.206 g

Spectrographic Impurities:

Ag	T+	Ni	T
Cu	T	Pb	VW
Fe	T	Si	FT
Mg	FT		

Irradiation: 28 days at $\text{nv} = 8.34 \times 10^6 \text{ n/cm}^2/\text{sec}$

Separations: The antimony was dissolved in aqua regia, made up to 25 ml., and aliquots were taken.

Activities Found at T₀ in BombardmentActivity per gm Antimony

Sb¹²⁴ (60 day)

54.9 mc

Yield: 34.8 mc/gm Sb/30 day bombardment at 50% maximum flux

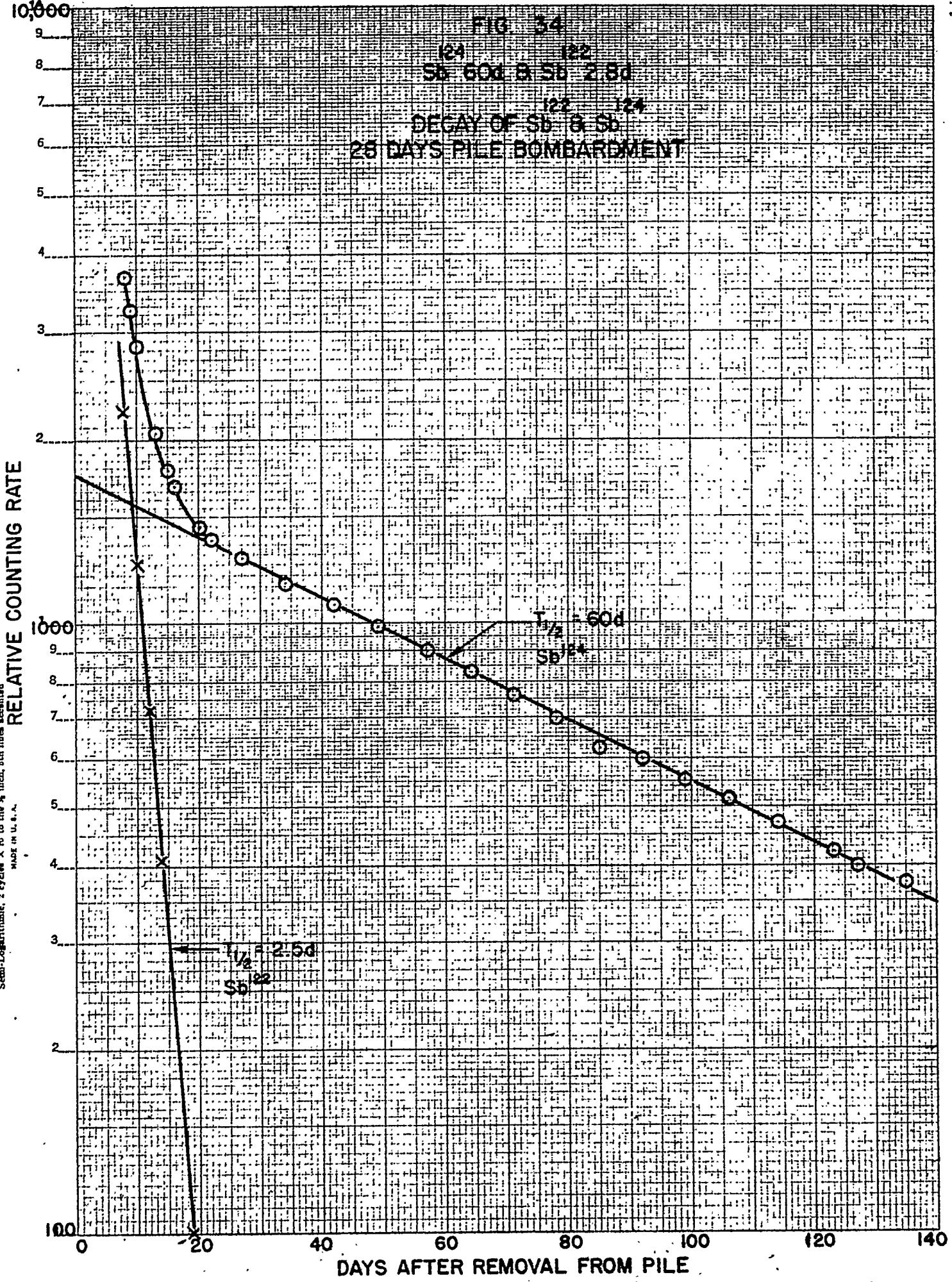
Cross Sections:

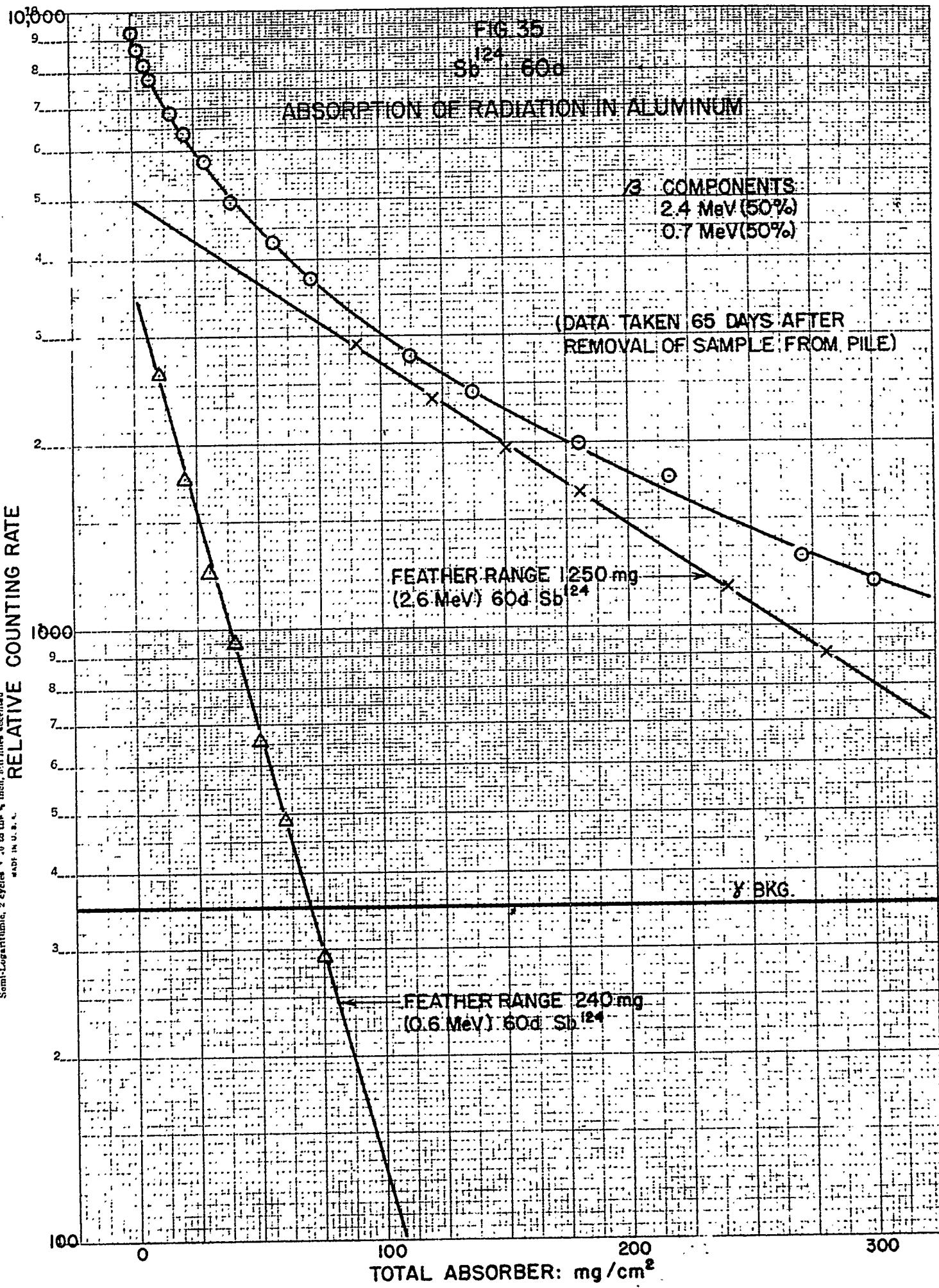
$$\sigma^- v = 4.0 \times 10^5 \text{ barns cm/sec}$$

$$\sigma^- = 1.82 \text{ barns per atom element}$$

$$\sigma^- = 4.26 \text{ barns per atom isotope}$$

Non-Routine Errors: None





EuropiumTarget Material: Europium OxalateWeight: 0.0112 gSpectrographic Impurities:

Ca	T	Cd	T	Mg	T
----	---	----	---	----	---

Irradiation: 31 days at 3.17×10^6 n/cm²/secSeparations: Dissolved the sample in 10N HNO₃, made it up to 10 ml, and took an aliquot with which to work.Activities Found at T₀ in Bombardment: Activity per gm Eu

Eu ¹⁵⁴ (6.3 y)	170 mc
---------------------------	--------

Yield: 268 mc/g/30d bombardment at 50% maximum fluxCross-Sections:

$$\sigma' v = 1.13 \times 10^8 \text{ barns cm/sec}$$

σ' = 514 barns per atom normal element

σ' = 1010 barns per atom isotope

Non-Routine Errors: NoneRemarks: The 2.0 MeV β radiation shown in Fig. 27 indicates presence of 9.2 hr Eu¹⁵².

KLEFFEL & FISCHER CO., NO. Y. NO. 363-2
Semi-logarithmic, 2 cycles $\times 10$ to the $\frac{1}{2}$ inch, with lines spaced
MADE IN U. S. A.

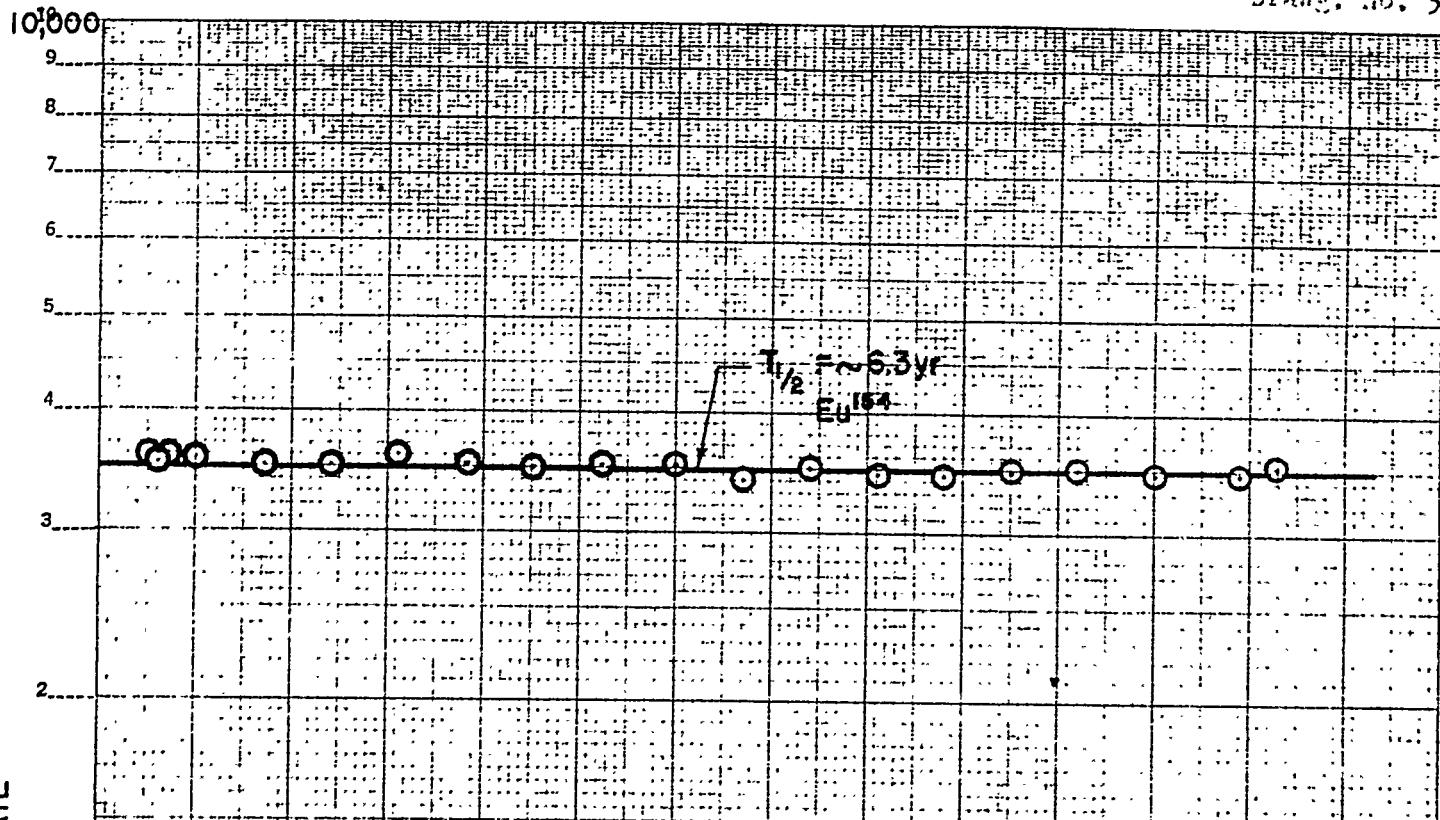


FIG. 36
 ^{154}Eu : $\sim 6.3\text{ yr}$
 DECAY OF ^{154}Eu
 31 DAYS PILE BOMBARDMENT

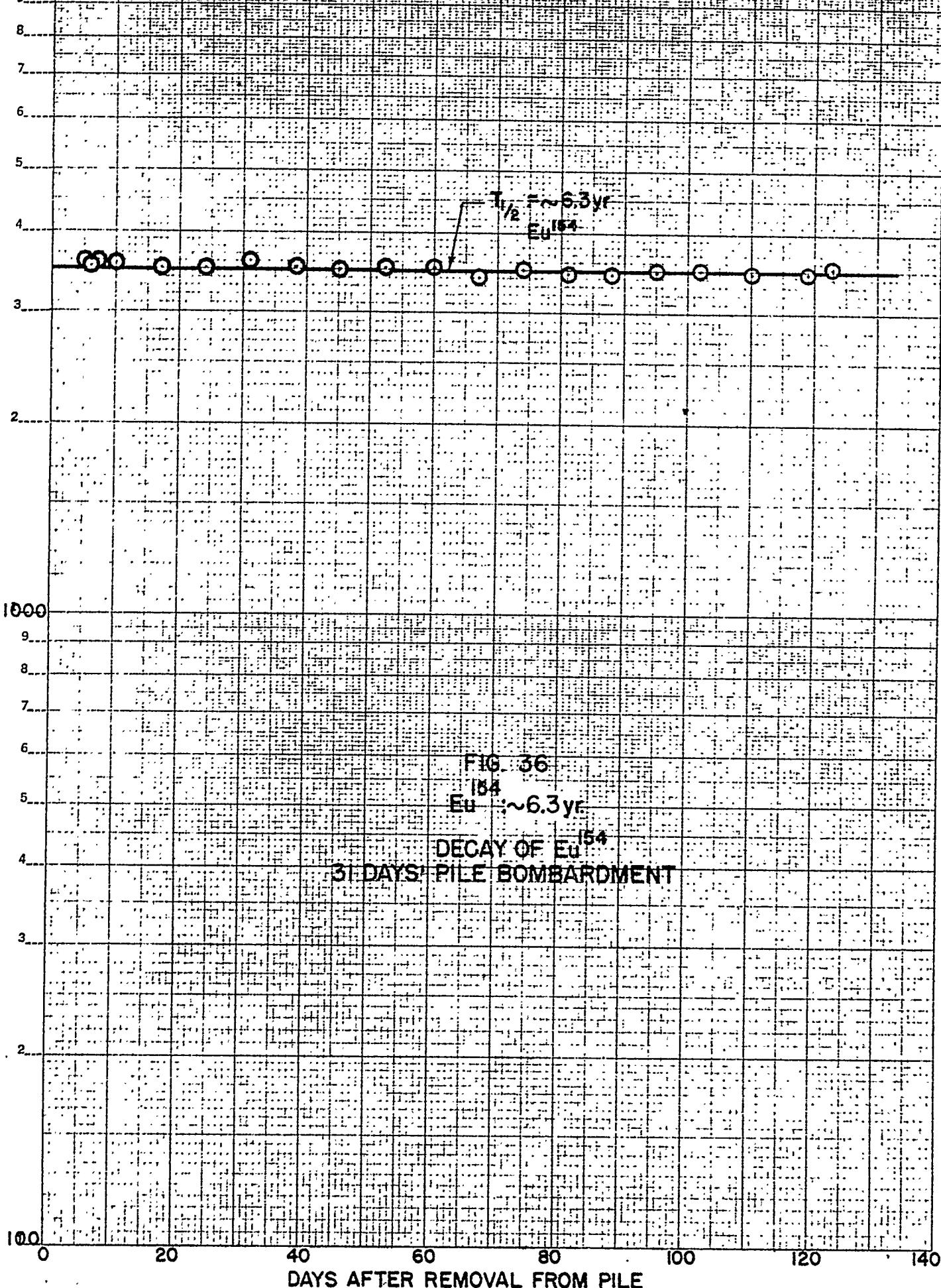
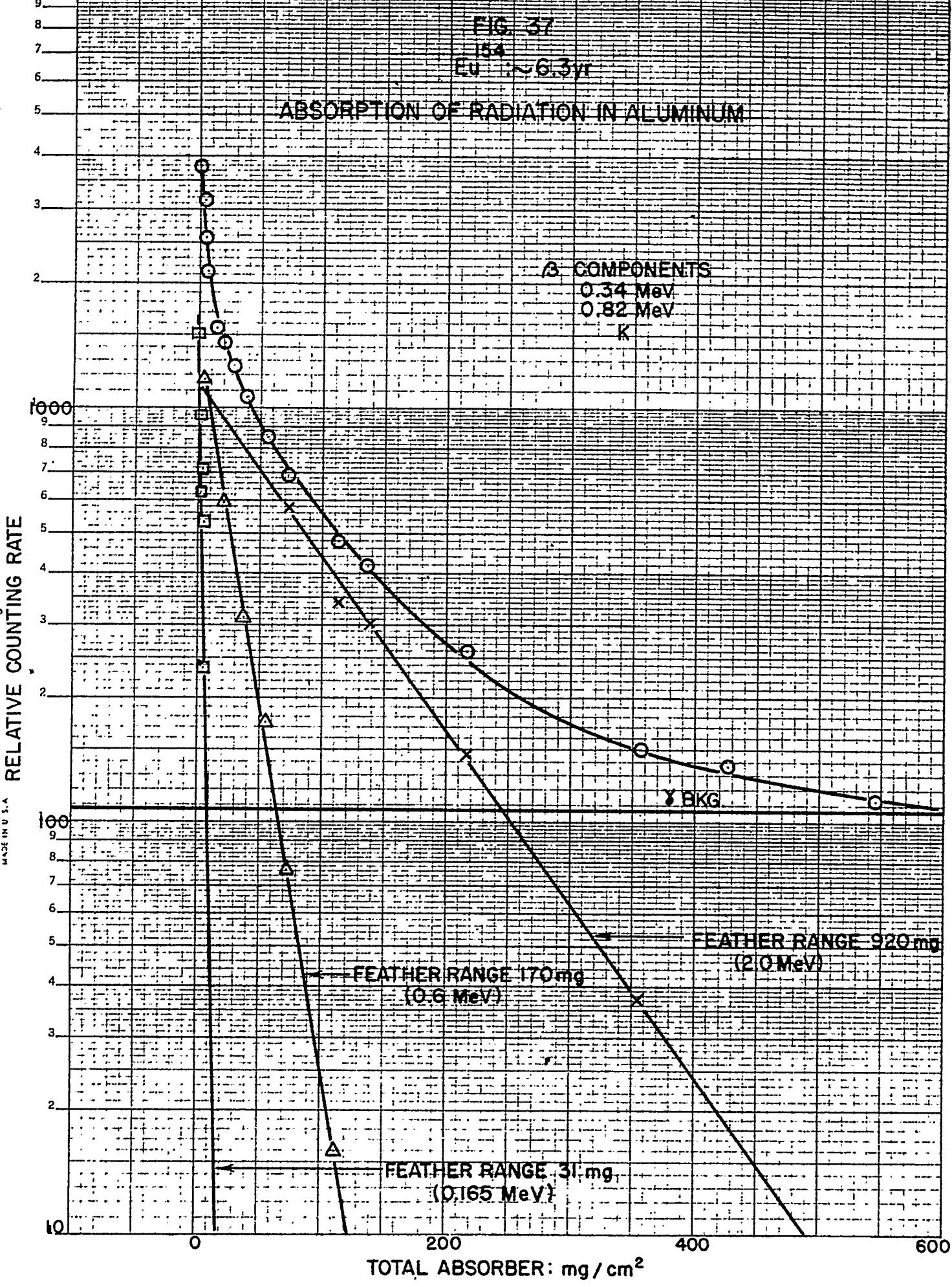


FIG. 37
154
 $E_\gamma \sim 6.3 \text{ MeV}$

ABSORPTION OF RADIATION IN ALUMINUM



Tantalum

Target Material: Tantalum tetraoxide, C.P., City Chemical Corp.

Weight: 0.22 gm

Spectrographic Impurities:

Al	FT	Mg	T
Ca	FT	Mo	T
Cu	FT	Si	T
Fe	FT	Ti	W

Irradiation: 83 days at $\text{nv} = 5.7 \times 10^9 \text{ n/cm}^2/\text{sec}$

Separations: The sample was dissolved by two successive fusions with KOH in a nickel crucible. This flux dissolved the sample far more readily than did KHSO_4 . The melt was dissolved in H_2O , made up to volume, and an aliquot taken⁽¹⁾.

(1) A Textbook of Inorganic Chemistry, Vol. 6, pt. 3, p. 125

Activity Found at T₀ in BombardmentActivity per gm Ta

Ti^{51} (72 d)

319 mc*

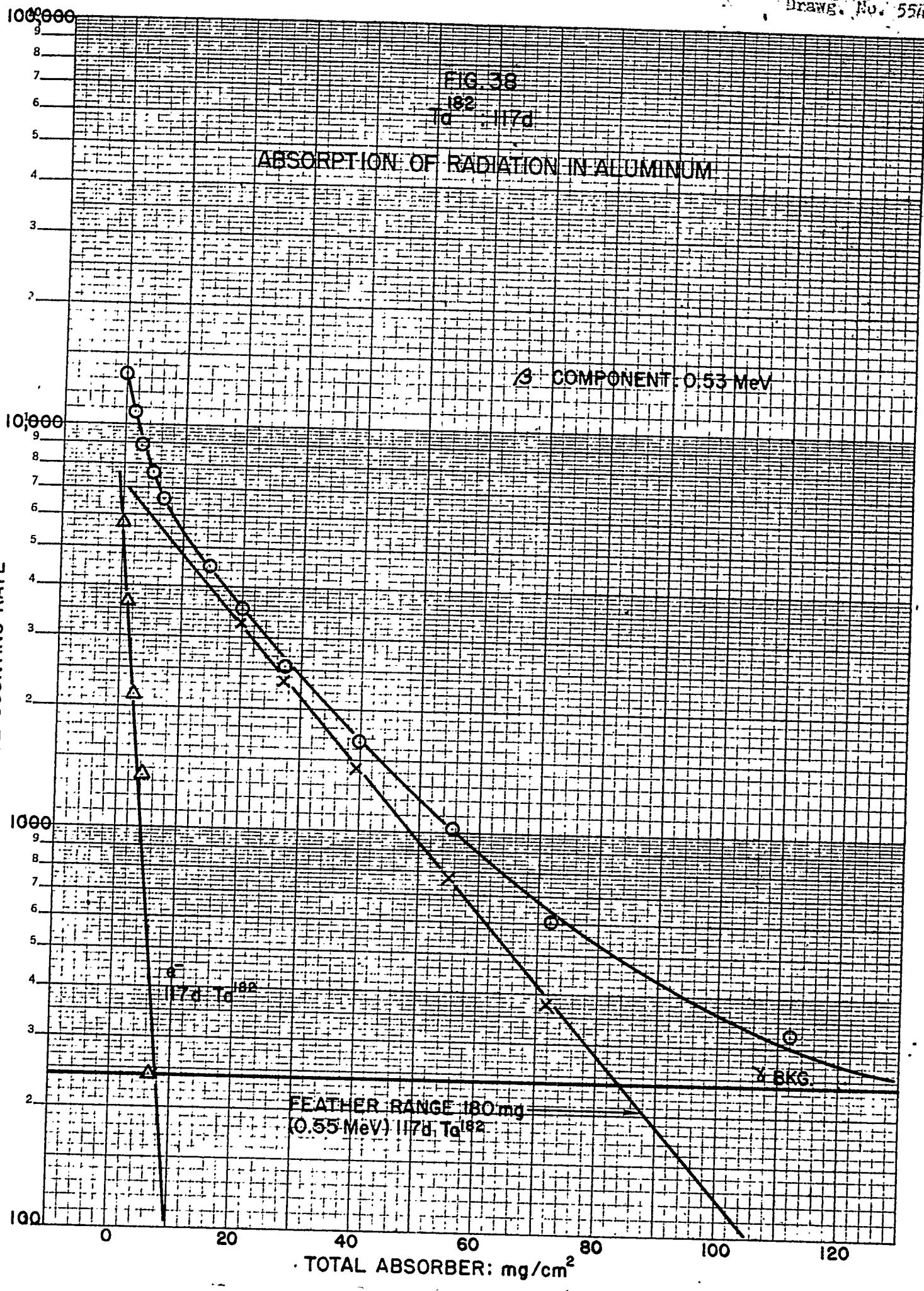
* based on 0.53 Mev β .

Yield: 121.0 mc/gm Ta/30 day bombardment at 50% maximum flux

Cross-Sections:

$$\begin{aligned}\sigma^- v &= 3.54 \times 10^6 \text{ barns cm/sec} \\ \sigma^- &= 16.1 \text{ barns per atom normal element} \\ \sigma^- &= 1.1 \text{ barns per atom isotope}\end{aligned}$$

Non-Routine Errors: None



10000

9

8

7

6

5

4

3

2

1

0

1000

9

8

7

6

5

4

3

2

1

0

100

9

8

7

6

5

4

3

2

1

0

100

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

KURELL & ESSER CO., N.Y. NO. 350-93
 Scale-Logarithmic, 2 cycles X 10 to the $\frac{1}{2}$ inch, 6th U.S.A.
 MADE IN U.S.A.

ABSORPTION OF RADIATION IN LEAD

FIG. 29

1951-172

5 COMPONENTS

1.22 Mev (57%)

1.13 Mev (37%)

0.22 Mev (4%)

0.15 Mev (2%)

9.8 gm Pb (1.0 Mev)

100

0

2

4

6

8

10

12

TOTAL ABSORBER: gm / cm²

Tungsten

Target Material: Tungsten trioxide, C. P., Fisher Scientific Company

Weight: 1.80 gm

Spectrographic Impurities:

Ca	FT	Mo	T
Fe	VFT	Si	W

Irradiation: 69 days at $\bar{n}v = 3.2 \times 10^{11}$ n/cm²/sec

Separations: See diagram.

<u>Activities Found at T₀ in Bombardment</u>	<u>Activity per gm W</u>
---	--------------------------

W ¹⁸⁵ (74 d)	9.3 mc
-------------------------	--------

Yield: 7.55 mc/gm W/30 day bombardment at 50% maximum flux

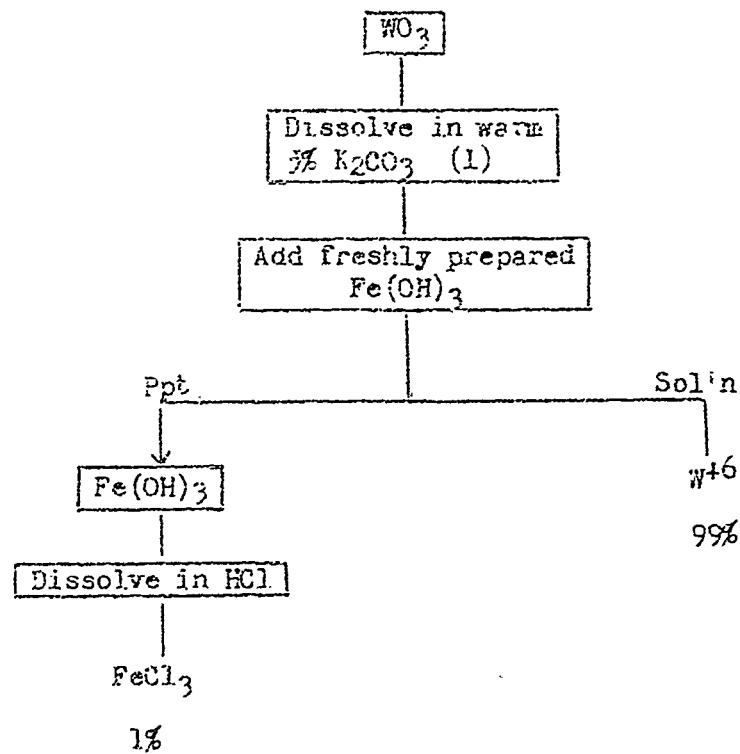
Cross-Sections:

$$\sigma_V = 1.54 \times 10^5 \text{ barns cm/sec}$$

$$\sigma = 0.7 \text{ barns per atom normal element}$$

$$\sigma = 2.28 \text{ barns per atom isotope}$$

Non-Routine Errors: None



(1) Scott's Standard Methods of Chemical Analysis, p. 1002

10,000

9

8

7

6

5

4

3

2

1

0

FIG. 140

185

W

140

DECAY OF ^{185}W

69 DAYS PILE BOMBARDMENT

RELATIVE COUNTING RATE

Keuffel & Esser Co., N.Y. NO. 365-03
 Semi-Logarithmic, 3 cycles X 10 to the 14 inch, 6th line selected
 MADE IN U.S.A.

1000

9

8

7

6

5

4

3

2

1

0

100

0

20

40

60

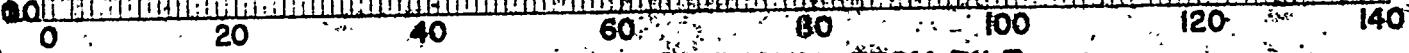
80

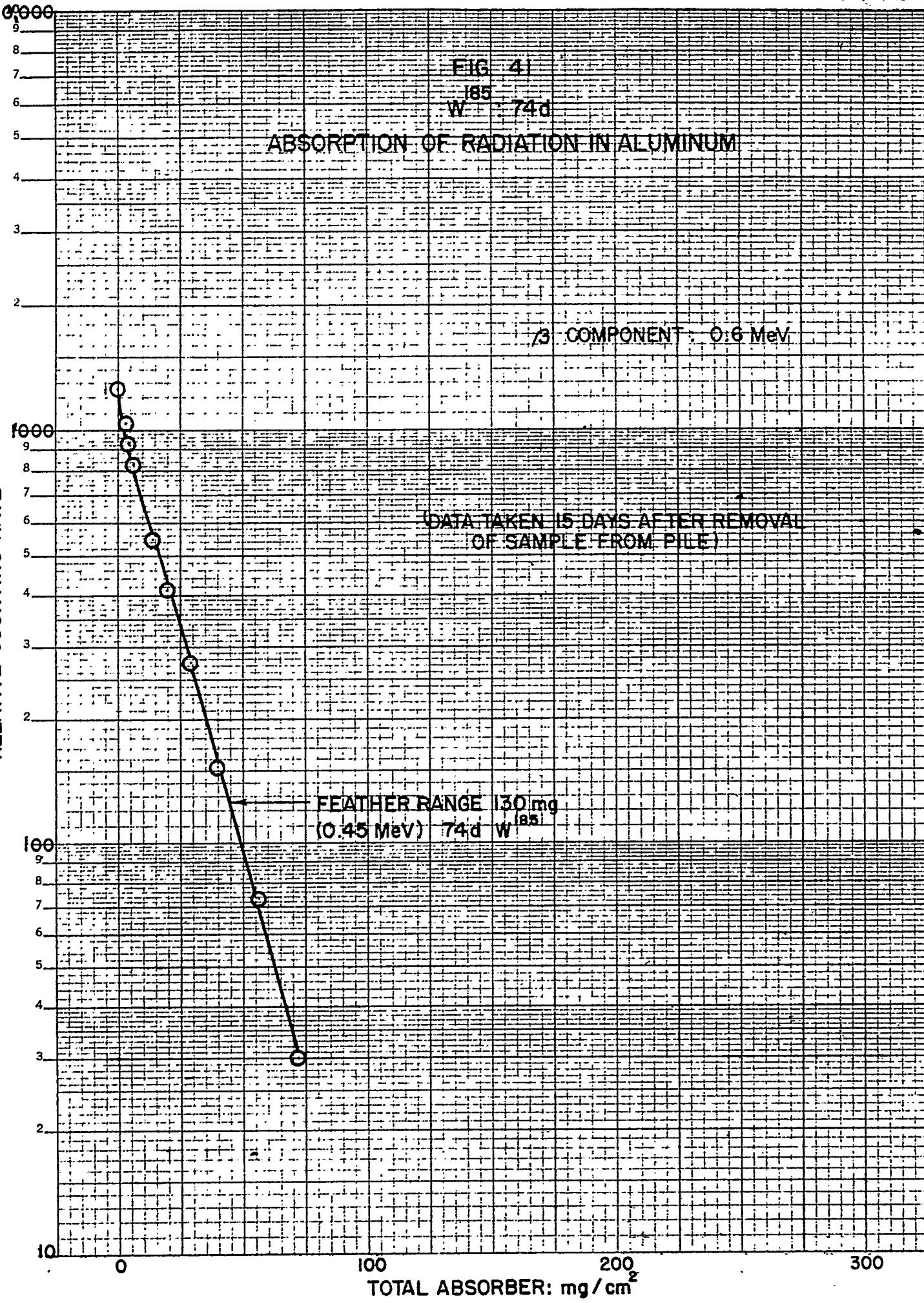
100

120

140

DAYS AFTER REMOVAL FROM PILE





Osmium

Target Material: Osmium Powder, American Platinum Works

Weight: 0.546 gm

Spectrographic Impurities:

Ag	FT	Fe	FT
CA	T	Mg	FT
Cu	T	Mn	FT
Si	T		

Irradiation: 35 days at $nV \approx 6 \times 10^9 n/cm^2/\text{sec}$

Separations: See diagram.

Activities Found at T_0 in Bombardment:

Os^{185} (95 d & 30 hr)	0.314 mc
Os^{191} (32 hr)	1.8×10^{-3} mc
Os^{193} (17 d)	9.19 mc

Yield:

Os^{185} (95 d & 30 hr) 0.230 mc/gm Os/30 day bombardment at 50% maximum flux
 Os^{191} (32 hr) 7.34×10^{-3} mc/gm Os/30 day bombardment at 50% maximum flux
 Os^{193} (17 d) 7.11 mc/gm Os/30 day bombardment at 50% maximum flux

Cross-Sections:

Os^{185} : $\sigma v = 6 \times 10^3$ barns cm/sec
 $\sigma = 0.0273$ barns per atom normal element
 $\sigma = 152$ barns per atom isotope

Os^{191} : $\sigma v = 31.6$ barns cm/sec
 $\sigma = 1.44 \times 10^{-4}$ barns per atom element
 $\sigma = 5.45 \times 10^{-4}$ per atom isotope

Os^{193} : $\sigma v = 4.14 \times 10^4$ barns cm/sec
 $\sigma = 0.188$ barns per atom normal element
 $\sigma = 0.575$ barns per atom isotope

Non-Routine Errors: Yield figures should be revised upwards because of a loss during assay of an estimated $< 8\%$.

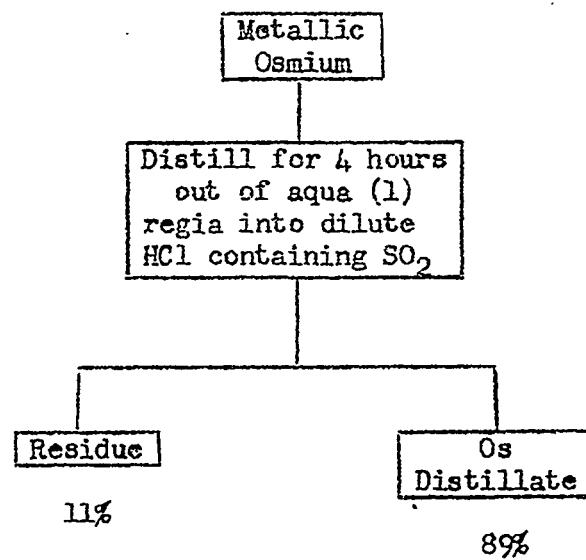
- Remarks:
- (A) From Fig. 43 it may be seen that some of the component emitting strong β radiation is present 90 days after the sample was removed from the pile.
 - (B) Evidence points to the existence of four activities as characterized as follows:

<u>Probable Mass</u>	<u>Radiation</u>		<u>Yield</u>
	<u>Experimental</u>	<u>Literature</u>	
^{185}Os (95 d)	**0.7 γ (?)	I.T., γ	*0.314 mc/gm Os
^{185}Os (~30 hr)	0.8 β	1.5 β	0.314 mc/gm Os
^{191}Os (32 hr)	1.3 β , γ (?)	0.95 β , 1.17 γ	8.8×10^{-3} mc/gm Os
^{193}Os (17 d)	0.3 β , 0.7 γ (?)	0.35 β , γ	7.11 mc/gm Os

* Measuring 30 hr daughter and assuming equilibrium.

** γ measured at three months out of pile, so it may be composite of 95 d I.T. and 17 d gammas.

No great accuracy is claimed for 95 d and shortlived activities. 17 d should be quite satisfactory.



(1) Treadwell and Hall, Analytical Chemistry, Vol. 2, pp. 142-143

10000

9

8

7

6

5

4

3

2

1

0

RELATIVE COUNTING RATE

KUFFEL & ESSER CO., N. Y. NO. 350-3
Semi-Logarithmic, 2 cycles X 10 to the $\frac{1}{2}$ inch, 5th line assembled
MADE IN U.S.A.

FIG. 42
1944
OS-171
DECAY OF OS-¹⁹³
35 DAYS PILE BOMBARDMENT

1000

9

8

7

6

5

4

3

2

1

0

1/2
OS-171

100

0

20

40

60

80

100

120

140

DAYS AFTER REMOVAL FROM PILE

100,000

8

7

6

5

4

3

2

10,000

9

8

7

6

5

4

3

2

1000

9

8

7

6

5

4

3

2

1

RELATIVE COUNTING RATE

KEUFFEL & ESSER CO., N.Y. NO. 359-71
 S/N. Length 1/2 in. Width 1/2 in. Thickness 1/16 in.
 MADE IN U.S.A.

FIG. 43

 ^{191}Os : 32 hr
 ^{193}Os : 17 d

ABSORPTION OF RADIATION IN ALUMINUM

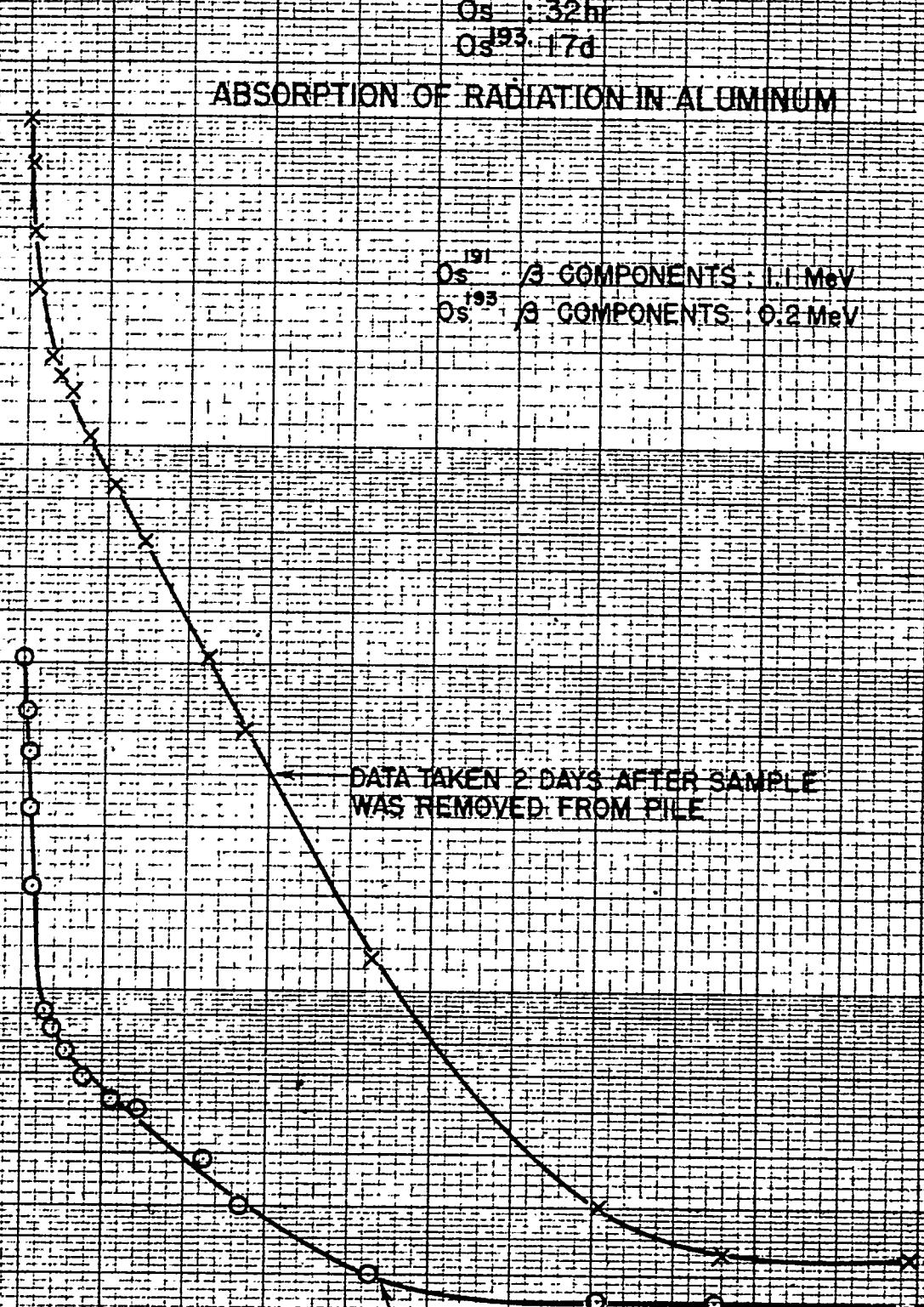
 ^{191}Os /3 COMPONENTS : 1.1 Mev
 ^{193}Os /3 COMPONENTS : 0.2 Mev
DATA TAKEN 2 DAYS AFTER SAMPLE
WAS REMOVED FROM PILEDATA TAKEN 90 DAYS AFTER SAMPLE
WAS REMOVED FROM PILE

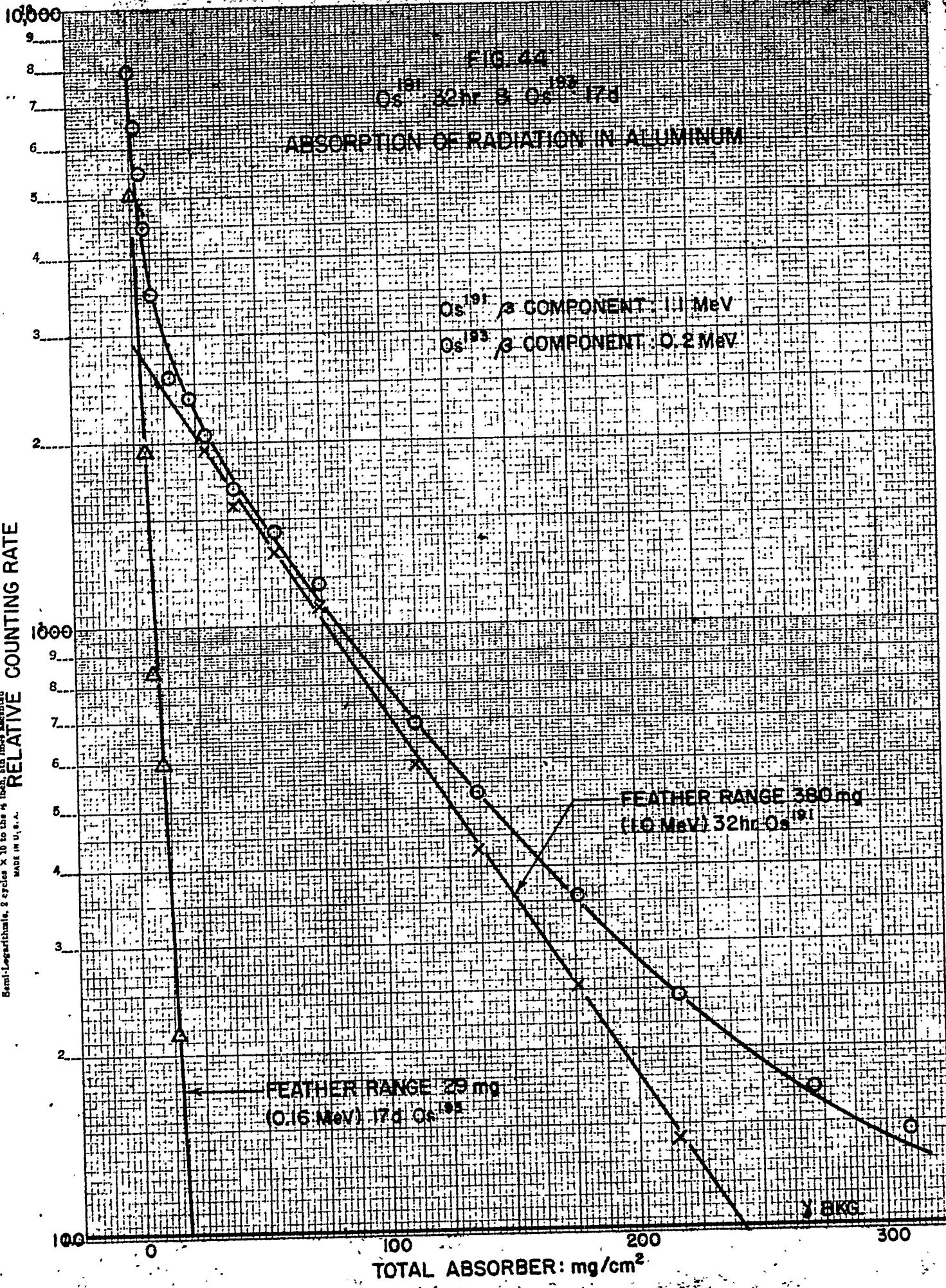
0

200

400

600

TOTAL ABSORBER: mg/cm²



10,000

9

8

7

6

5

4

3

2

1

0

1000

9

8

7

6

5

4

3

2

1

0

ABSORPTION OF RADIATION IN LEAD

FIG. 45
 Os^{191} γ component Os^{185}
 Os^{191} γ component Os^{176}

Os^{191} γ component: 1.17 Mev
 Os^{191} γ component: ?

7.0 gm Pb (0.7 Mev)

(DATA TAKEN 114 DAYS AFTER
REMOVAL OF SAMPLE FROM PILE)

0

2

4

6

8

TOTAL ABSORBER: gm/cm²

Thallium

Target Material: Thallium (ic) Nitrate, C.P., Fordomes Trading Company

Weight: 9.98 gm

Spectrographic Impurities:

Ag	FT	Mg	VFT
Al	VFT	Ma	VFT
Ca	FT	Pb	FT
Fe	FT	Si	VFT

Irradiation: 68 days at $\bar{n}v = 4.0 \times 10^6$ n/cm²/sec

Separations: See diagram.

Activities Found at T₀ in bombardment:Activity per gm Tl

Tl ²⁰⁴ (3.5 yr)	3.70 mc
----------------------------	---------

Yield: 1.96 mc/gm Tl/30 day bombardment

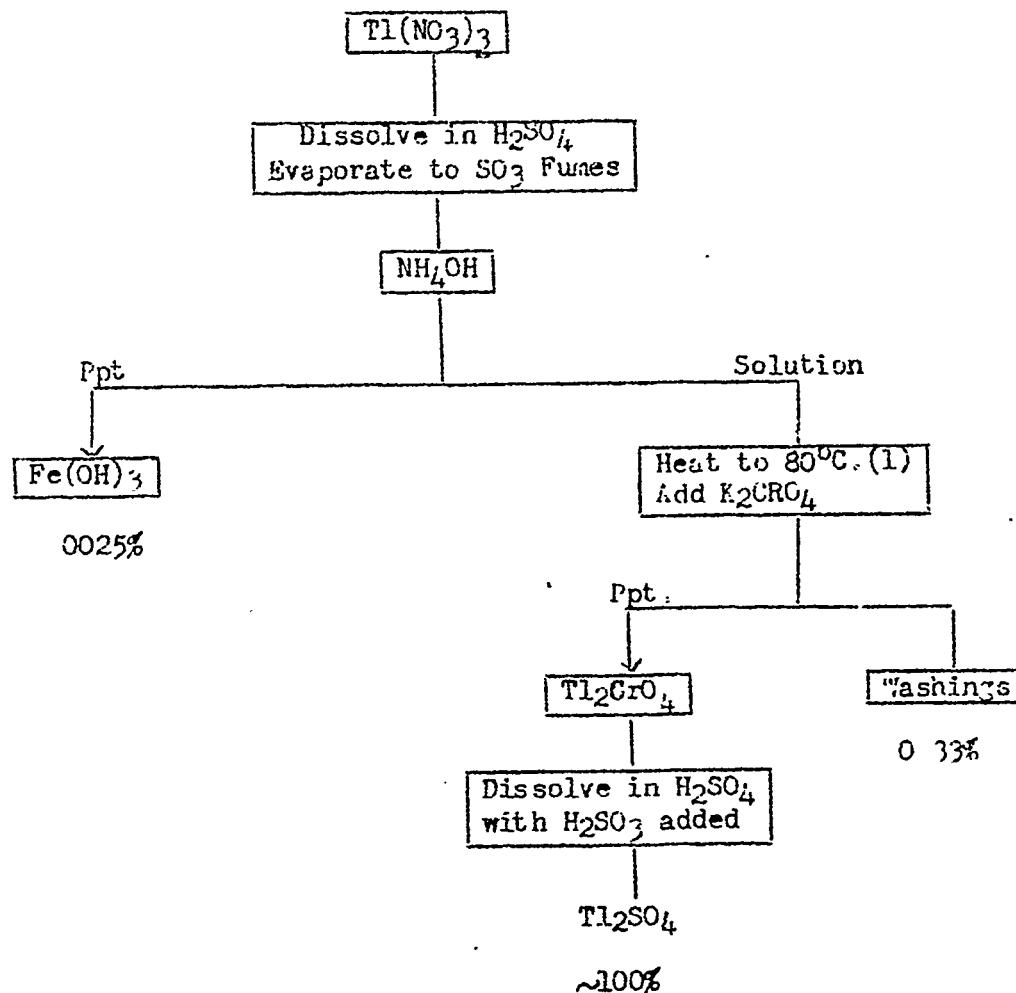
Cross-Sections:

$$\sigma^- v = 6.71 \times 10^5 \text{ barns cm/sec}$$

$$\sigma^- = 3.05 \text{ barns per atom normal element}$$

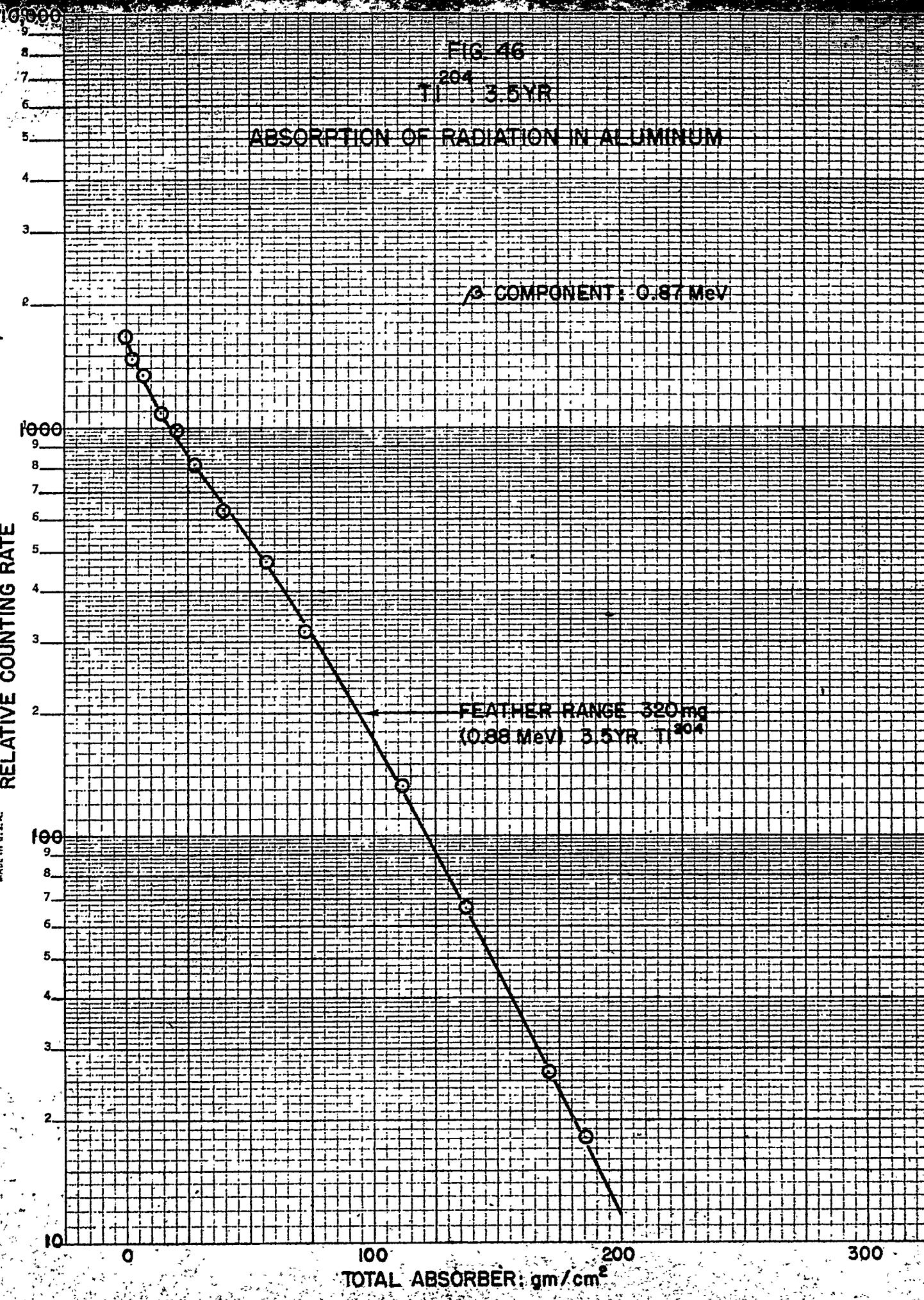
$$\sigma^- = 10.3 \text{ barns per atom isotope}$$

Non-Routine Errors: None



(1) Browning and Hutchins, Am. J. Sci., 8, 460 (1899)

RELATIVE COUNTING RATE



Bismuth

Target Material: 99.8% Bismuth metal, C.P., Baker's

Weight: 24.58 gm

Spectroscopic Impurities:

Ag	T	Fe	VW	Ni	FT
Al	T	Mg	W	Pb	T
Ca	T	Mo	FT	Si	T
Cu	W			Sn	W

Irradiation: 28 days at $\text{nv} = 3.56 \times 10^6 \text{ n/cm}^2/\text{sec}$

Separations: See diagram

Activities Found at T₀ in Bombardment: Activity per gm Bi

Bi²¹⁰ (5 d) 0.498 mc

Yield: 0.704 mc/gm Bi/30 day bombardment at 50% maximum flux.

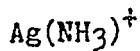
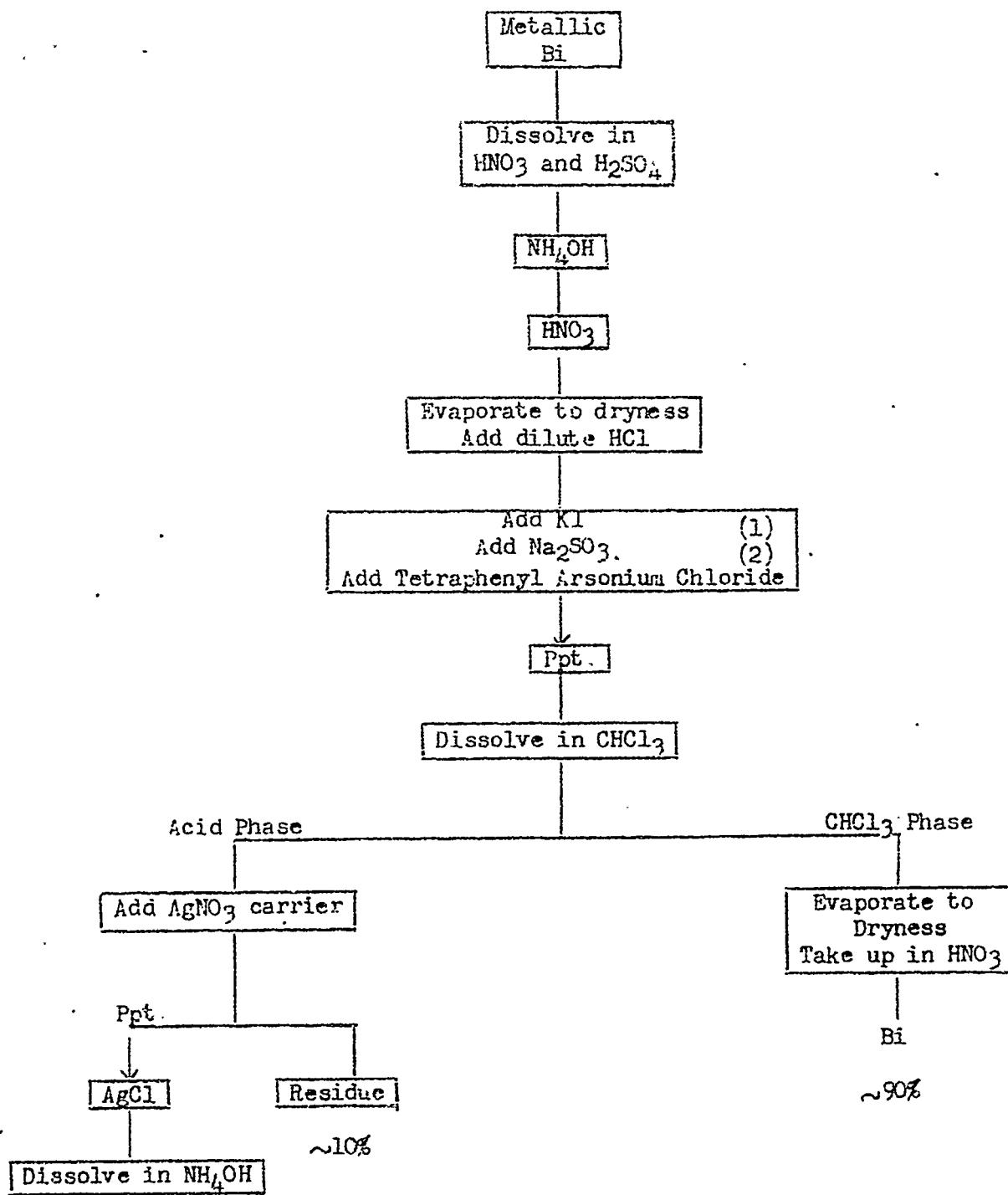
Cross-Sections:

$$\sigma^- v = 3.96 \times 10^3 \text{ barns cm/sec}$$

$$\sigma^- = 0.018 \text{ barns per atom normal element}$$

$$\sigma^- = 0.018 \text{ barns per atom isotope}$$

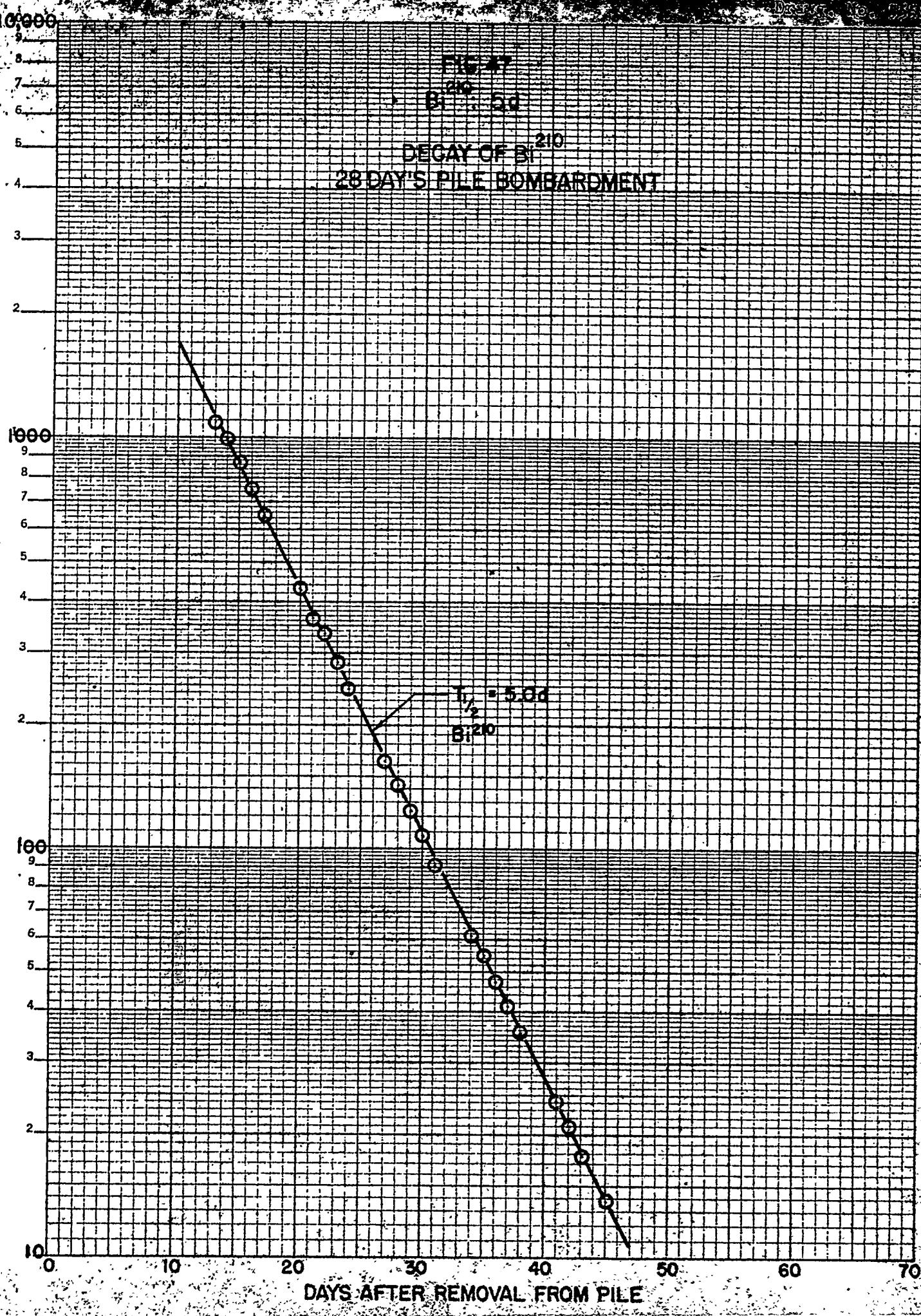
Non-Routine Errors: A large amount of solids in one of the sources made it difficult to determine the disintegration rate more accurately than $\pm 10\%$ for the entire sample.



(1) Boyd, et al. in CC-934

(2) If present, Cu, Pb, Sb, Cd, Hg, and Ag will also precipitate

REUFFEL & CO., N. Y. NO. 329 71
Serial-Indexer Unit. 2 cycles X 11 to the inch. 5th lines accentuated.
MADE IN U. S. A. REU ATC



ABSORPTION OF RADIATION IN ALUMINUM

FIG. 48
216
Bi - 5d

(S COMPONENT Li7 MeV)

FEATHER RANGE 480 mg
(1.2 MeV) Bi²¹⁰

KRUPP & ESSER CO., NEW YORK NO. 338-71

Hand Logarithmic, 3 cycles X 10 to the Inch, 5th lines screened.
MADE IN U.S.A.

RELATIVE COUNTING RATE

0

100

200

300

TOTAL ABSORBER mg/cm²

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

10⁰
10¹
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹