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STUDIES ON THE NUCLEAR CHEMISTRY OF TIN

C. M. NELSON
B. H. KETELLE
G. E. BOYD

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C. M. Nelson D. H. Ketelle
G. E. Boyd

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135-138	Westinghouse Electric Company

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The irradiation of enriched isotopic preparations of all the stable isotopes of tin by intense slow neutron sources has lead to definite mass assignments for all of the previously known periods in tin between the masses 112 and 125, as well as to the discovery and assignment of several new activities. The tin radioactivities produced by either (n,γ) or (n,n) reactions were examined using absorption techniques, and, where possible they were accurately characterized by magnetic lens, proportional and scintillation spectrometer measurements. The following listing summarizes what are believed to be the best values at the present time:

Period	Type of Radiation	Energy of radiation in Mev Particles	γ-rays
9.5 m Sn^{125}	β^-, γ	0.5, 1.17, 2.04	0.326; 1.86
9.4 d Sn^{125}	β^-	2.33	No γ
40 m Sn^{123}	β^-, γ	1.26	0.153; 0.76
126 d Sn^{123}	β^-	1.42	No γ
27.5 h Sn^{121}	β^-	0.383	No γ
>400 d Sn^{121}	β^-	0.42	No γ
245 d Sn^{119m}	I.T., e^-	---	0.069
15 d Sn^{117m}	I.T., e^-	---	0.159; 0.162
~30 m Sn^{113}	β^+, K, γ	~1.2	----
112 d Sn^{113}	K	---	No γ

Introduction

Until quite recently the status of the numerous possible radionuclides of tin has remained unclear despite efforts on the part of several investigators during the past fifteen years. Thus, although a number of periods formed by the action of neutrons, protons, deuterons and alpha particles on tin or on indium, antimony and cadmium respectively have been ascribed to tin, their mass assignments have remained in considerable doubt because of the wide mass range covered by the isotopes of the naturally occurring element[1]. Fortunately, the availability of preparations of enriched stable isotopes of tin[2] produced by the electromagnetic separations process in early 1949 has made new studies possible in which mass assignments could be made with much greater certainty. A series of irradiations of each of these preparations by intense slow neutron sources has lead not only to the discovery of several new periods in tin, but also to the complete isotopic assignments of these and the previously known tin activities. In addition, more accurate characterizations of the emitted radiations of several of the activities were made possible.

Experimental

Enriched stable tin isotopes were irradiated with slow neutrons for lengths of time varying between 10 minutes and 100 days to produce tin activities mainly by an (n,γ) reaction. The isotopic compositions of these preparations are given in Table 1. The spectrochemical analyses given with these

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(1) G. T. Seaborg and I. Perlman, Rev. Mod. Phys., 20, 585 (1948).

(2) On allocation from the Y-12 site, Oak Ridge National Laboratory, operated for the U. S. Atomic Energy Commission by Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee.

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TABLE I
PERCENTAGE COMPOSITION OF PRINCIPAL ISOTOPES

ISOTOPIC COMPOSITION	NATURAL Sn	124	122	120	119	118	117	116	115	114	112
Sn^{112}	0.9	0.1	0.1	1.1	0.6	0.3	1.5	0.9	0.7	3.1	45.5
Sn^{114}	0.6	0.9	0.1	0.2	0.2	0.2	0.3	0.9	2.4	24.1	4.8
Sn^{115}	0.35	0.1	0.1	0.1	0.1	0.1	1.6	4.4	12.1	2.2	0.7
Sn^{116}	14.1	4.4	1.8	0.4	1.8	3.7	6.1	76.3	48.4	19.1	9.1
Sn^{117}	7.5	9.6	6.5	1.1	5.3	7.4	69.8	4.1	8.6	9.9	7.1
Sn^{118}	24.0	7.7	3.7	0.8	5.2	69.3	11.1	3.5	14.1	15.2	9.8
Sn^{119}	8.6	9.8	6.9	1.3	77.1	7.6	1.9	2.8	3.8	7.9	5.9
Sn^{120}	33.0	11.0	10.0	95.4	7.7	8.4	5.2	3.2	7.7	13.1	11.8
Sn^{122}	4.8	4.5	70.7	0.2	1.4	1.8	1.3	1.2	1.1	2.5	2.4
Sn^{124}	6.1	52.0	0.6	0.3	0.8	1.3	1.0	1.1	2.2	3.0	2.9

samples (SnO_2) showed them to be of a high degree of purity. Silver and copper were generally the most abundant contaminants and were present in amounts varying from $<$0.04 to 0.15% and from $<$.04 to 0.63%, respectively. Other elements such as Fe, Pt, Hg, Ti and Si were occasionally observed in much smaller amounts. Accordingly, no chemistry was performed in the study of the short-lived activities. Before conducting measurements on the activities with half-lives of several days or longer, however, the following chemical purification was made: The irradiated SnO_2 was reduced to metallic tin with hydrogen at 550-600° and then dissolved in 6 N HCl. Tellurium and antimony carriers were added and the solution was treated with H_2SO_3 to precipitate elemental tellurium. After separation of the tellurium the supernatant was made 2 N in HCl, heated to boiling and the antimony precipitated with H_2S. Three Sb_2S_3 precipitations were performed before the tin-containing supernatant was adjusted to 0.5 N HCl, the tin precipitated as SnS_2 and then ignited at 900-1000° to form SnO_2.

Sources for decay and absorption measurements using G-M counters were prepared by placing the desired amounts of the finely divided SnO_2 on cellulose tape and covering with a thin film of cellophane (2.8 mg/cm^2). The sources used in the beta ray spectrometer measurements were prepared by placing the SnO_2 on a thin Formvar film (50 μg/cm^2), adding a drop of a benzene solution containing 10 mg of polystyrene per ml, mixing and drying under an infrared lamp. These sources were about 6 mg/cm^2 thick.

In making the mass assignments for the various tin activities it was generally necessary to bombard several of the different enriched isotope preparations to obtain unambiguous results. In one instance, all ten pre-

parations were irradiated at the same time. If only one or two samples are examined for a particular activity an error may occur, since the preparations were not isotopically pure. For example, the radiations of the 112 d Sn^{113} and its 105 m In^{113m} daughter were detected in every source because of the high capture cross section of Sn^{112} even though this isotope was present in relatively very low abundance in some cases. (Cf. Table I.) The variation of the yield of a certain activity among the different enriched preparations was sufficient to permit its definite mass assignment.

No periods in tin falling between 0.5 and 9.5 m were observed in this study. In most of the sources examined there were longer lived components in the decay which had to be subtracted. Generally, however, these contributions were minimized by choosing an irradiation time corresponding to the half-life of the dominant period produced. The maximum energies for some of the beta groups were derived from aluminum absorption curves. When the periods were short (9.5 m, 30 m, 40 m) decay measurements were taken through varying thicknesses of aluminum, and an absorption curve was then constructed from an isochrone taken at a suitably chosen time. The Feather comparison technique[3] was employed to estimate the beta ray ranges in aluminum using either the 0.77 Mev β^- from Tl^{204} or 1.71 Mev β^- from P^{32} as references. A recently published[4] range-energy curve was used to estimate the maximum energy of the beta groups. The energies of the beta particles and conversion electrons emitted by the longer-lived activities were measured with a magnetic thin lens spectrometer which had been calibrated in terms of the 0.661 Mev gamma ray from a Cs^{137} source.

(3) N. Feather, Proc. Camb. Phil. Soc., 34, 599 (1938).
(4) L. E. Glendenin, Nucleonics, 2, [1], 12 (1948).

Gamma and x-ray energies were estimated by absorption in lead, tantalum and copper. Two special experiments were conducted to determine if any gamma radiations of greater than 2.2 Mev energy were associated with the tin activities. In one case approximately 20 g of C.P. grade SnO_2 was irradiated with pile neutrons for three hours, and later a second sample weighing 50 g was bombarded for one week. Neither of these sources when placed in a D_2O-filled photoneutron chamber[5] gave a neutron counting rate above background. Accordingly, it was concluded that no tin activity of half-life greater than five minutes decays with the emission of gamma rays of energy exceeding 2.2 Mev.

Slow neutron activation cross-sections for the various tin isotopes were estimated from the corrected beta counting rates, the weights and isotopic compositions of the irradiated samples and from the slow neutron flux determined by means of a cobalt monitor exposed at the same time and in the same place as the enriched tin preparations. Total conversion coefficients of 0.5 and 0.7 were employed in arriving at the estimates of the disintegration rates for Sn^{117m} and Sn^{113}. The cross-section values are believed to be good to within ± 20 percent.

9.5 Minute Sn^{125}

This tin activity was first produced in the deuteron irradiation of natural tin and has long been assigned to mass 125[6]. Investigations of its beta and gamma radiations have been conducted using aluminum and lead absorption measurements from which the conflicting values of 2.2[7] and

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(5) S. Bernstein, F. L. Talbot, J. K. Leslie and C. P. Stanford, Phys. Rev., 74, 1258 (1948). We wish to thank Dr. M. H. Feldman for the use of this apparatus.

(6) J. J. Livingood and G. T. Seaborg, Phys. Rev., 55, 667 (1939).

(7) W. H. Sullivan and E. E. Wyatt, Plutonium Project Report Mon-N-243, 3(1947).

1.3[8] Mev have been derived for the maximum beta energy. Gamma rays of ~0.74 Mev were also seen[7]. Recently, Duffield and Langer[9] have published a quantitative study of this radionuclide using a magnetic lens spectrometer. Three beta groups of 2.04, 1.17 and 0.51 Mev maximum energy together with conversion electrons from a gamma ray of 0.326 Mev were found. An indication of one or more energetic gamma rays, present in low abundance, was also obtained.

Much of this later information is in agreement with the results from this study (which also confirms the mass assignment to 125) wherein the presence of beta rays of ~0.5 and 2.06 Mev maximum energy and gamma rays of 0.38 and 1.86 Mev were demonstrated by absorption techniques (See Figs. 1 and 2). The relative abundance of the gamma rays, determined from the extrapolated counting rates at zero lead thickness together with the known counting efficiencies at these energies, showed the ratio of 0.38 to 1.86 Mev transitions to be 85:1. Since the decay scheme is complex, coincidence counting experiments were performed. These showed the 2.06 Mev β^- to be in coincidence with the 0.326 Mev γ and hence a disintegration energy of 2.37 Mev. Although the sum of the lower energy (~0.5 Mev) beta group and the more energetic gamma ray is approximately equal to this latter value, no evidence of their coincidence could be obtained, possibly because of the low abundance of this decay mode.

The chief point of difference between our findings and those of Duffield and Langer concerns the presence of a 1.17 Mev beta group. Such a group should be in sequence with a 1.20 Mev gamma ray which, if present in low

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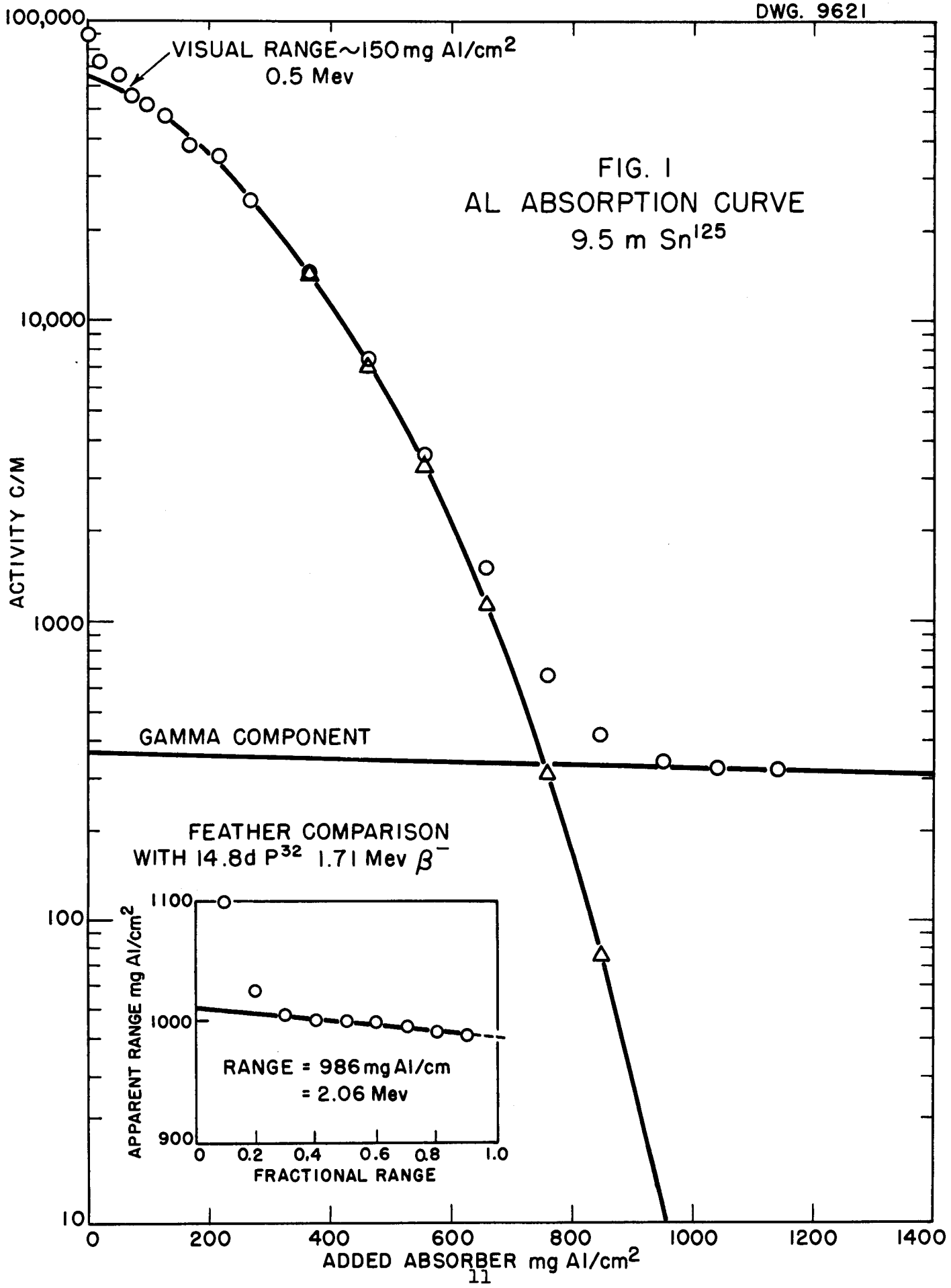
(8) J. C. Lee and M. L. Pool, Phys. Rev., 76, 606 (1949).

(9) R. B. Duffield and L. M. Langer, Phys. Rev., 77, 743 (1950).


VISUAL RANGE~150 mg Al/cm²
0.5 Mev
FIG. 1
AL ABSORPTION CURVE
9.5 m Sn¹²⁵
GAMMA COMPONENT
FEATHER COMPARISON
WITH 14.8d P³² 1.71 Mev β⁻
RANGE = 986 mg Al/cm
= 2.06 Mev
APPARENT RANGE mg Al/cm²
FRACTIONAL RANGE
ACTIVITY C/M
ADDED ABSORBER mg Al/cm²
100,000
10,000
1000
100
10
0
200
400
600
800
1000
1200
1400
1100
900
0.2
0.4
0.6
0.8
1.0

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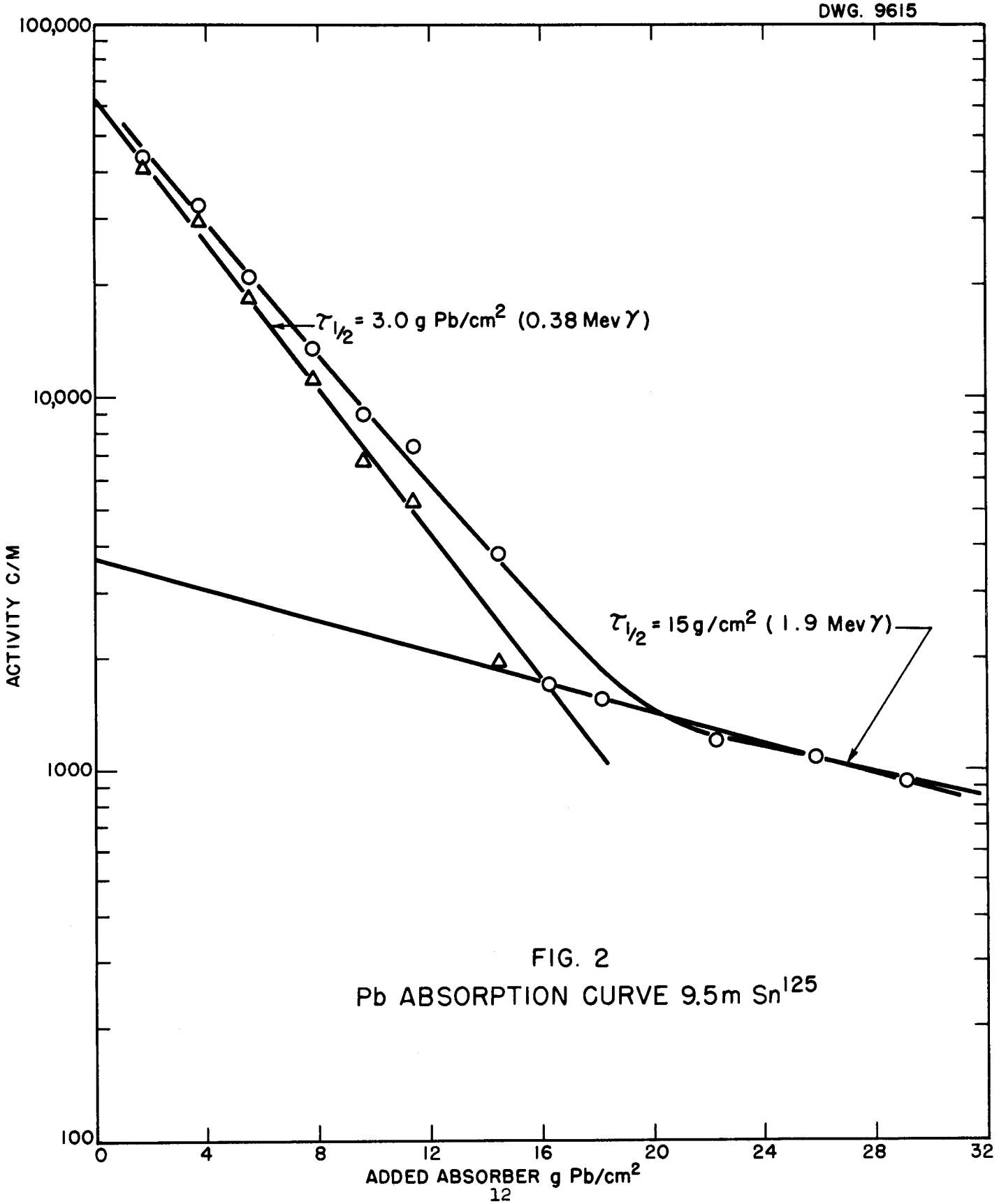

FIG. 2
Pb ABSORPTION CURVE 9.5m Sn^{125}

relative intensity, might not be detected by absorption techniques. The half-life value of 9.5 ± 0.1 m from this study is an average from three experiments made by following the decay through 355 mg Al cm^{-2}. See Fig. 3.

9.4 Day Sn^{125}

A tin activity of roughly ten days half-life apparently was first observed in the deuteron and neutron irradiation of natural tin[6]. Such a period has also been found to occur in uranium fission[10], [11].

The emission of a beta ray of 2.6[11] or 2.5[12] Mev as determined by absorption measurements in aluminum together with gamma radiation of unspecified energy has been reported. Further, the occurrence of x-rays in the decay of this activity has been reported[12]. The mass assignment has been made variously at I^{121}[11] or I^{123}[11], [12]. Recently, however, Lee and Pool[6] have placed this period at mass 125 from considerations based on its increased yield in a (d,p) reaction on a tin isotope preparation enriched in Sn^{124}. These authors also report a beta ray of 2.1 Mev maximum energy. The yield of 9.4 d tin activity produced by slow neutrons in our enriched Sn^{124} preparation, compared with its absence in the enhanced Sn^{122} preparation, supports this latter assignment. Further support has been obtained by demonstrating the growth of the known 2.7 y Sb^{125} and 58 d Te^{125m} into a 9.4 d Sn source after an initial separation of antimony and

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(10) O. Hahn and F. Strassman, Naturwiss., 31, 499 (1943).

(11) J. Seiler, NNES - PPR Vol. 9B, Paper 7.26.1 (1946) To be issued.

(12) K. D. Coleman and M. L. Pool, Phys. Rev., 72, 1070 (1947).

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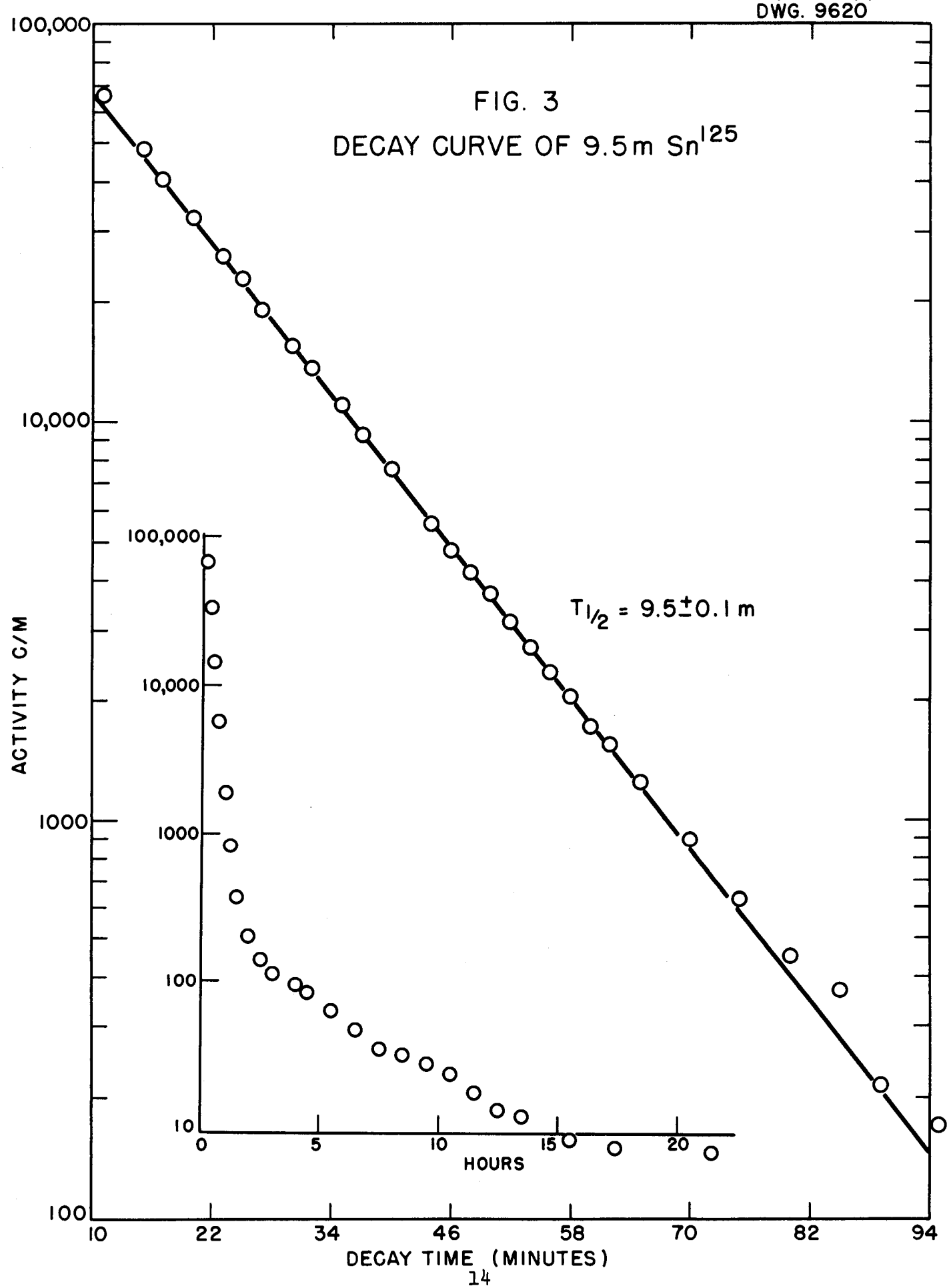
FIG. 3

DECAY CURVE OF 9.5m Sn^{125}



tellurium to remove the sizeable amounts of these activities formed by the decay of the established 9.5 m Sn^{125} activity. A half-life value of 9.4 ± 0.1 d was observed for the decay of the principal beta component in several of our sources. This appears to differ by slightly more than the experimental errors with the value of 10.0 ± 0.3 d given by Lee and Pool. (See Fig. 4).

Quantitative radiation energy measurements using a magnetic lens spectrometer were performed with a source prepared by irradiating Sn^{124} in an intense slow neutron source for 100 days. The momentum distribution and Kurie plots (assuming an allowed transition) of the activities found in the Sn^{124} preparation are given in Figs. 5 and 6, respectively. The conversion electron peaks indicated on the momentum distribution as belonging to the 390 Kev gamma ray of In^{113m} (daughter of Sn^{113}) and to the 152 Kev gamma ray of Sn^{117m} were assigned on the basis of their energies and half-lives. None of these conversion lines decayed with a 9.4 d half-life. These activities were produced by neutron capture in the small amounts of Sn^{112} (ca. 0.1%) and Sn^{116} (4.4%) present in the enriched Sn^{124} and are discussed below. As can be seen (Fig. 6) the Kurie plot for an allowed transition is not linear. To see if the deviation from linearity was caused by the large mass necessarily present in the source, the beta distribution of P^{32} mounted as zirconium phosphate with a comparable mass ($\sim$6 mg cm^{-2}) was determined. An excess of low energy particles was observed in both the P^{32} and Sn^{124} sources which can be attributed to source scattering. In the case of the P^{32} source the curve rose above an extrapolated straight line at the high energy end, whereas for the Sn^{125}, it dropped below. It was concluded, therefore, that the actual beta distribution for the latter differed markedly from that for an allowed transition. Fig. 7 shows the linear Kurie plot obtained assuming a first-

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FIG. 4
DECAY OF β^- COMPONENT FROM Al ABSORPTION CURVES MADE ON Sn^{124} SAMPLE

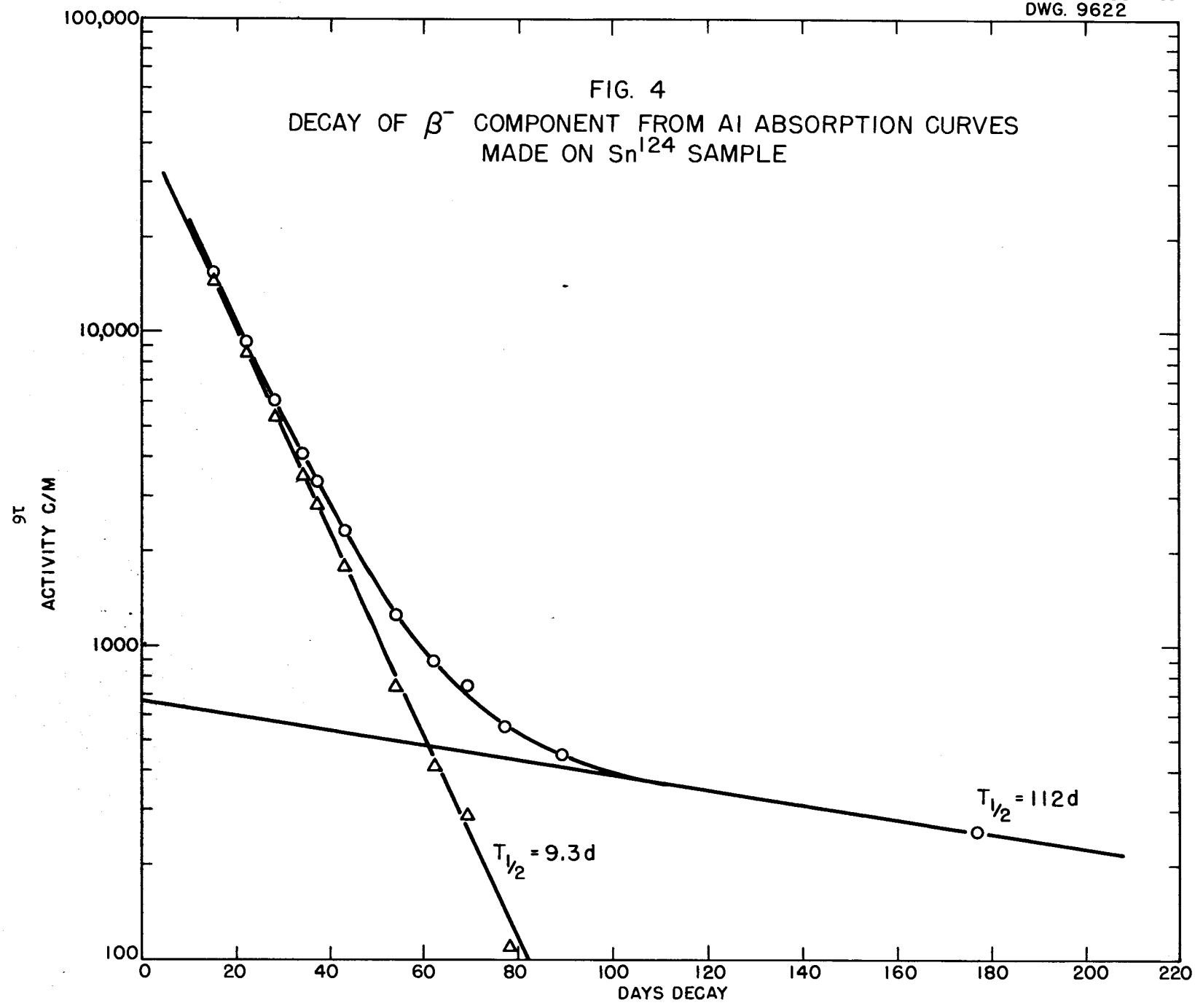

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FIG. 5
9.4 d Sn^{125}

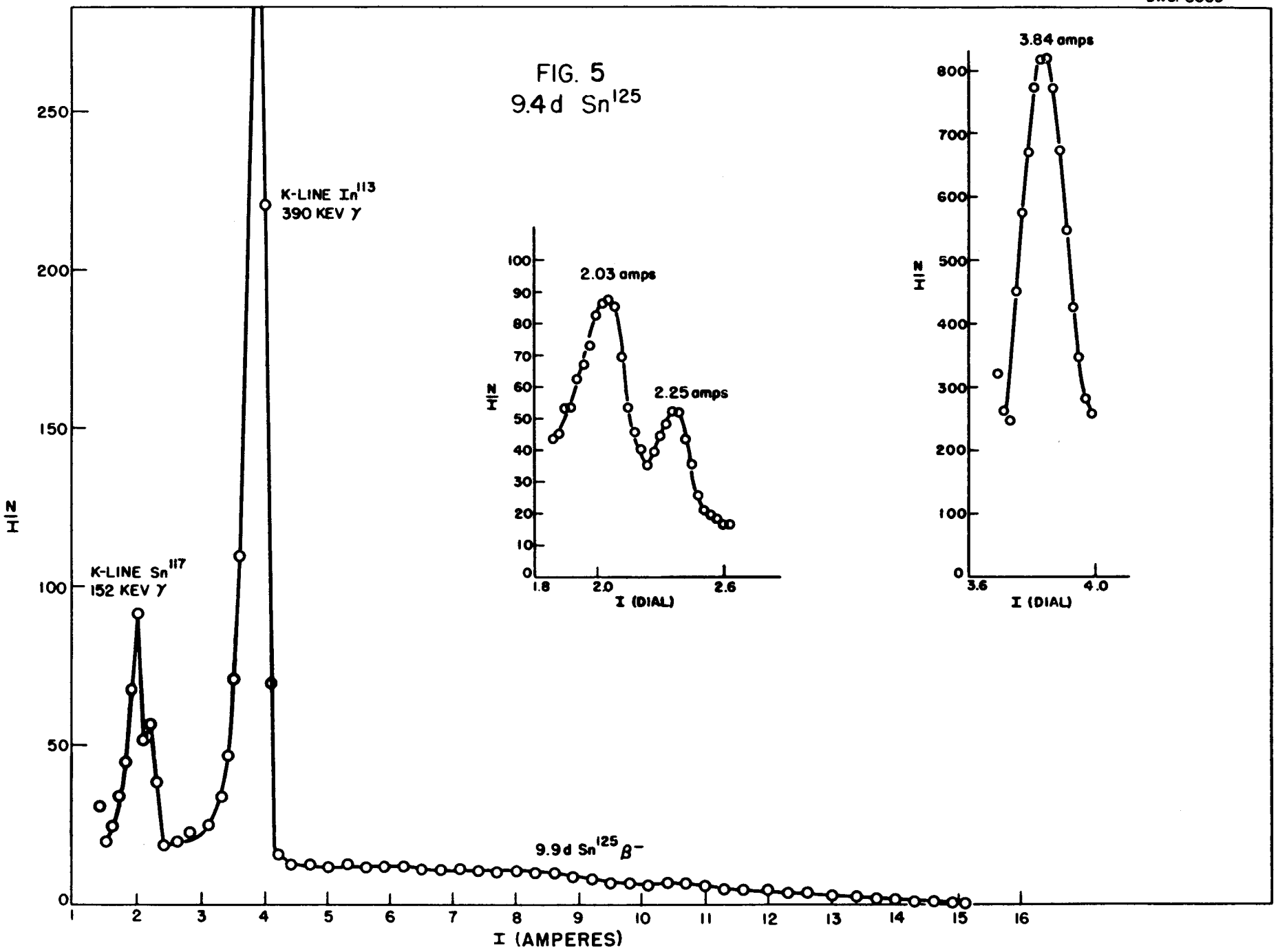

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FIG. 6
9.4 d Sn^{125} – KURIE PLOT
ALLOWED TRANSITION

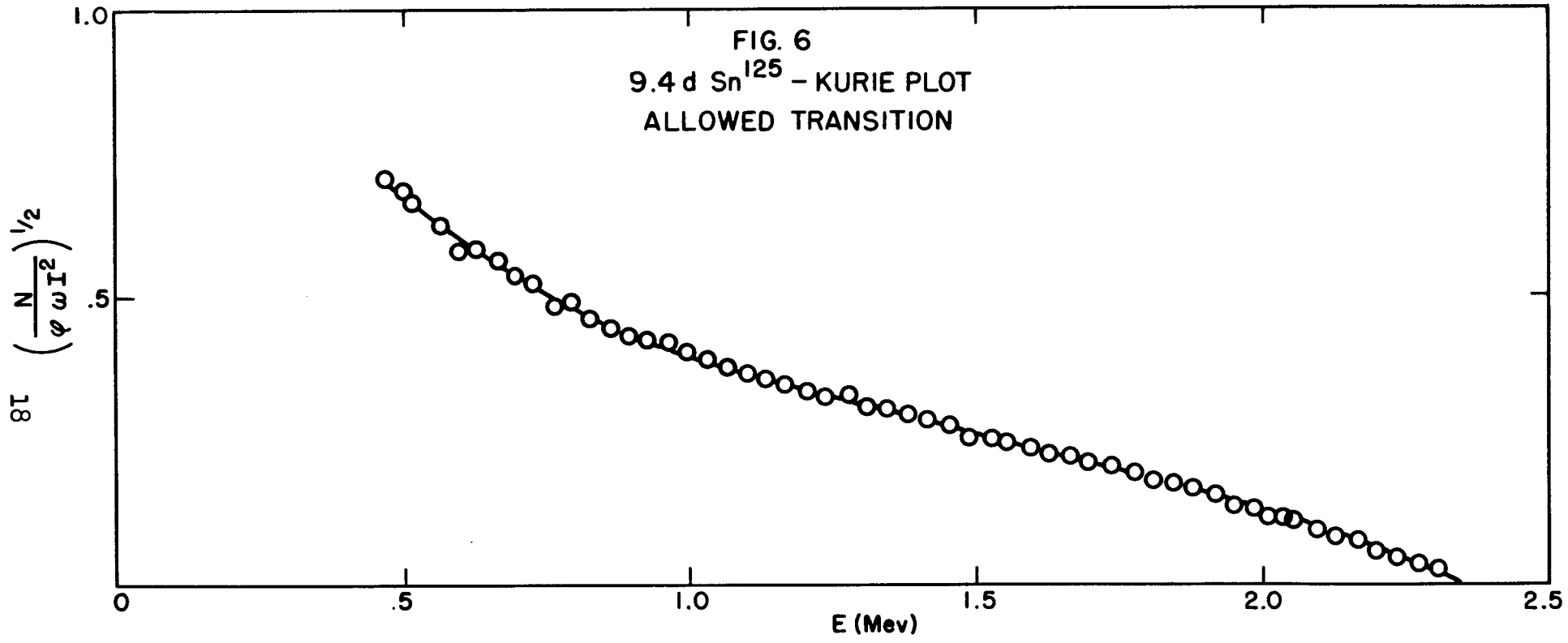

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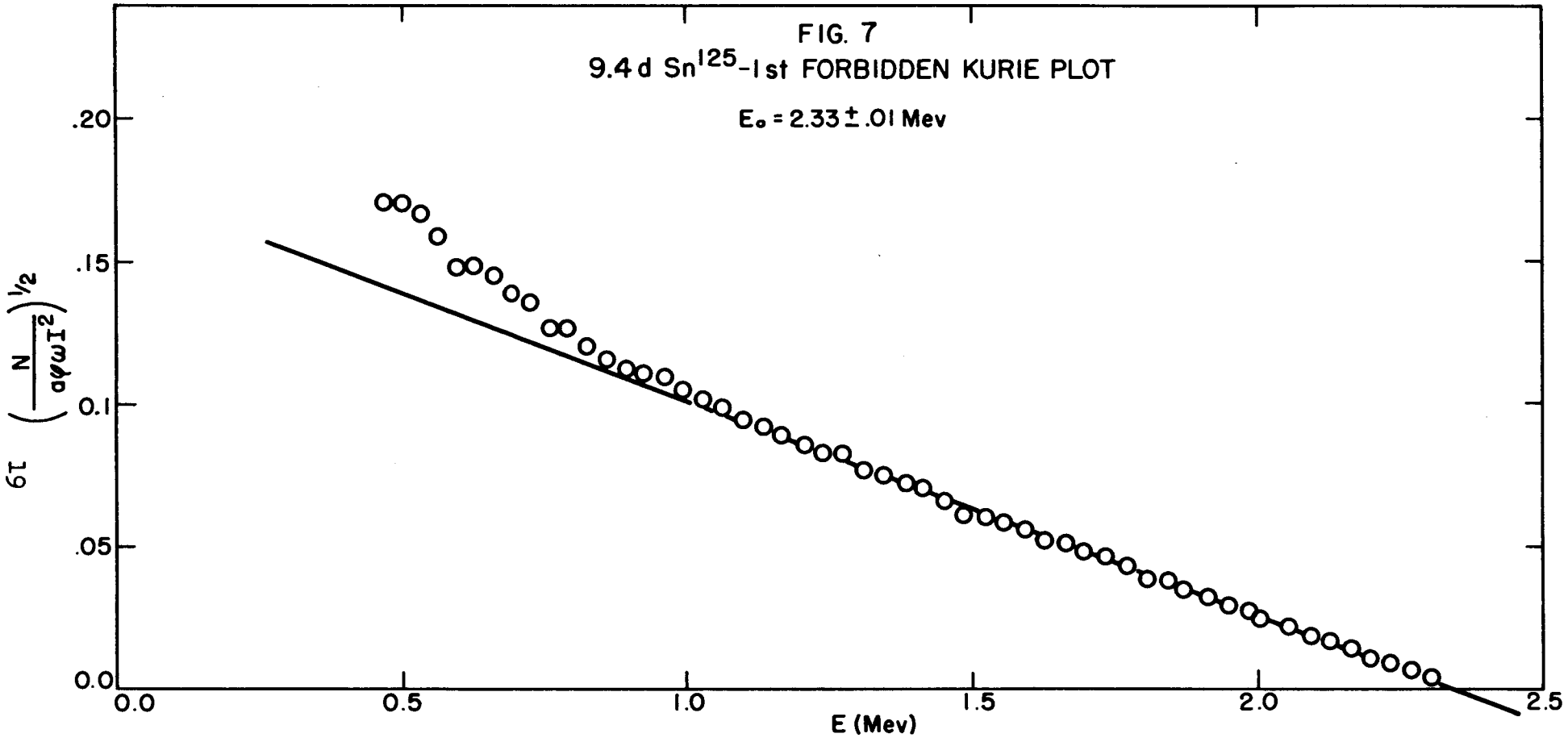
FIG. 7

9.4 d Sn^{125} - 1st FORBIDDEN KURIE PLOT

$E_o = 2.33 \pm .01$ Mev



forbidden transition with a spin change of two and a change in parity. The maximum beta energy is 2.33 ± .01 Mev.

Since our preliminary report of the foregoing observations[13], an independent spectrometer value of 2.37 ± 0.02 Mev has been published[14]. This later work confirms our conclusions regarding the character of the transition and further indicates the presence of a low energy beta-group (0.40 ± .01 Mev) occurring in about 5% of the transitions. We are not able to confirm this latter observation because of the distortion of the low energy portions of our spectrum by scattering effects. However, if the 2.33 Mev beta transition goes to the ground state of Sb^{125}, then a gamma ray of ~1.9 Mev might be expected to follow the soft beta particle. Aluminum and lead absorption measurements taken on our source suggest the possible existence of quantum radiations in very low abundance. However, because of the complications from bremsstrahlen as well as from small amounts of other radionuclides of tin presents in our source (and possibly in that of Hayward), this point cannot be settled without additional measurements.

A tentative decay scheme is proposed in Fig. 8 which is believed to summarize the current status of information about the isomers of Sn^{125}. The spin value assignments for the various levels indicated are believed to be in agreement with the nuclear shell model of M. Goeppert-Mayer[15].

40 Minute Sn^{123}

This period in tin apparently was first produced by irradiating the natural tin with fast neutrons[16], and later with deuterons[6]. Its formation

(13) B. H. Ketelle, C. M. Nelson and G. E. Boyd, Phys. Rev., 79, 242 (1950).
(14) R. W. Hayward, Phys. Rev., 79, 409 (1950).
(15) M. Goeppert-Mayer, Phys. Rev., 78, 16 (1950).
(16) M. L. Pool, J. M. Cork and R. L. Thornton, Phys. Rev., 52, 239 (1937).

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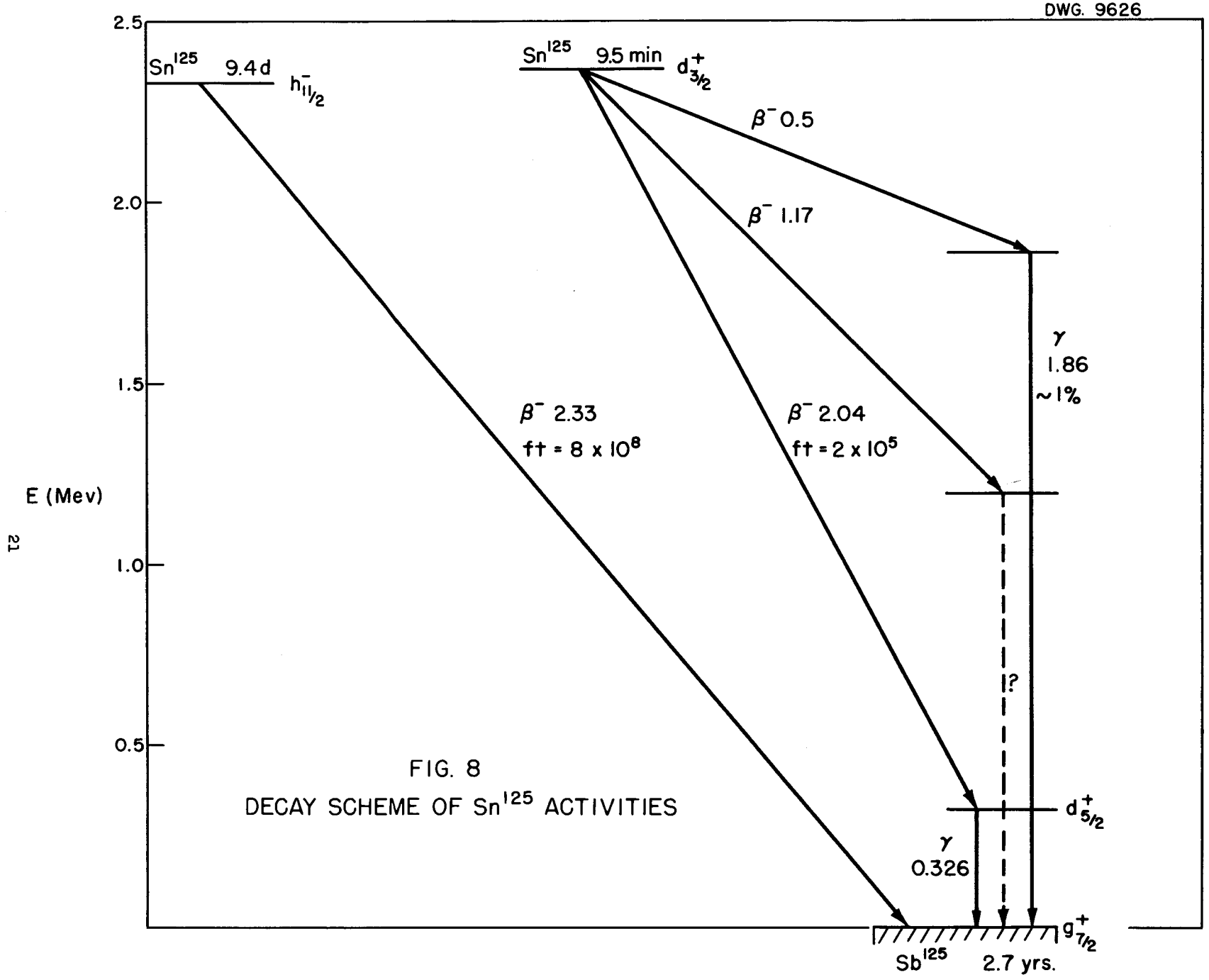

FIG. 8
DECAY SCHEME OF Sn^{125} ACTIVITIES

by a (d,t) reaction with an enriched Sn^{124} preparation has been reported[17] but the value of ~3 Mev given for the maximum beta ray energy differs widely from the recent magnetic lens spectrometer measurements of Duffield and Langer[18] who find 1.26 Mev for the maximum energy of the beta particle emitted by the 39.5 m tin activity produced by the slow neutron irradiation of enriched Sn^{122}. This latter value is in fair agreement with our value of 1.14 Mev derived from absorption measurements with aluminum (Fig. 9) which may be compared also with the value of 1.32 Mev reported[8] for a source produced by fast neutrons on enriched Sn^{124}. A gamma ray of 0.153 Mev has been shown to follow the beta transition[18] and in this work evidence for 0.76 Mev quantum radiation present in low abundance has been obtained (See Fig. 10). A decay curve for the activity produced by slow neutrons on enriched Sn^{122} is shown in Fig. 11. The 40 ± 1 m half-life is in excellent agreement with at least three other published values[8],[18],[19]. The assignment of this period in tin to mass 123 is also confirmed.

126 Day Sn^{123}

This tin activity was first observed in the slow neutron fission of uranium-235 by G. R. Leader[20] who reported its half-life as 130 d, characterized it as a pure beta emitter with a maximum energy lying between 1.5 and 1.6 Mev and tentatively assigned it to mass 121 or 123 after failing to observe any radioactive antimony daughters formed by its decay. Subsequently, these observations were confirmed[21] and this nuclide has since been reported

(17) A. S. Newton and W. R. McDonnell, private communication (Nov., 1948) to G. T. Seaborg and I. Perlman, Rev. Mod. Phys., 20, 585 (1948).
(18) R. B. Duffield and L. M. Langer, Phys. Rev., 76, 1272 (1949).
(19) D. L. Mock, R. C. Waddel, L. W. Fagg and R. A. Tabin, Phys. Rev., 74, 1536 (1948).
(20) G. R. Leader, NNES-PPR Vol. 9B, Paper 7.26.2 (1946) To be published.
(21) W. E. Grummitt and G. Wilkinson, Nature, 158, 163 (1946).

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FIG. 9
AL ABSORPTION CURVE 40m Sn^{123}

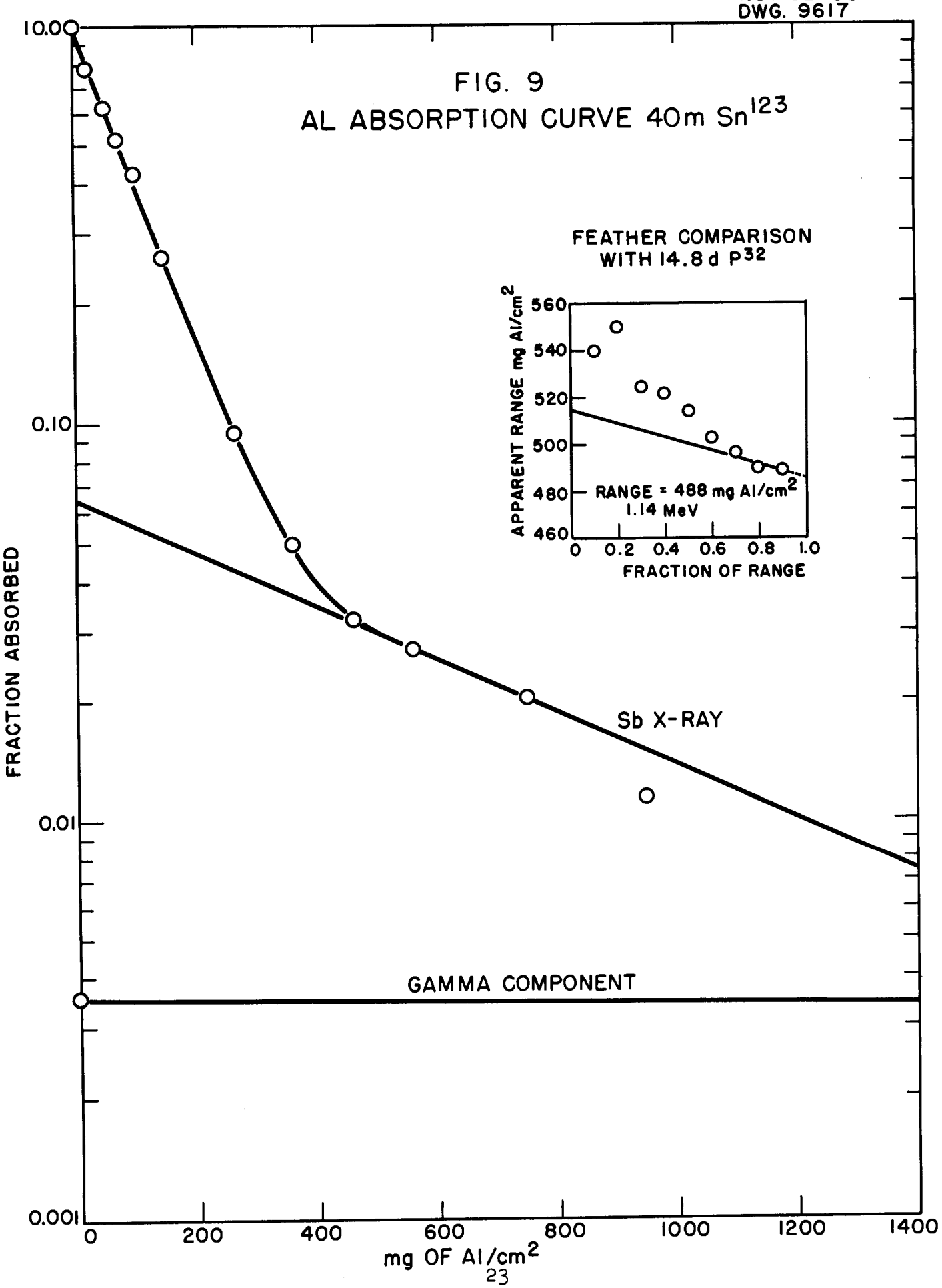

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FIG. 10

Pb ABSORPTION CURVE 40 m Sn^{123}

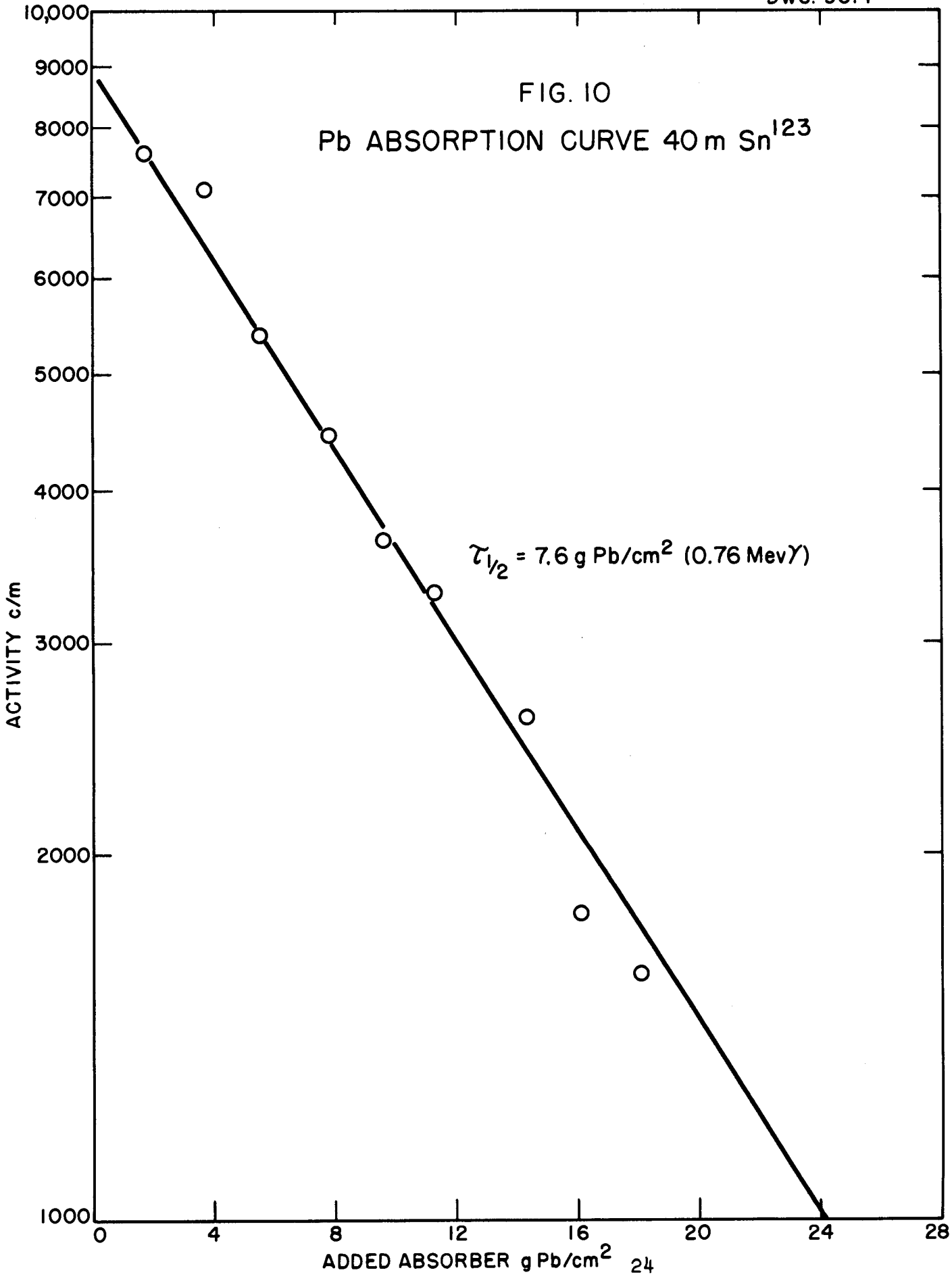

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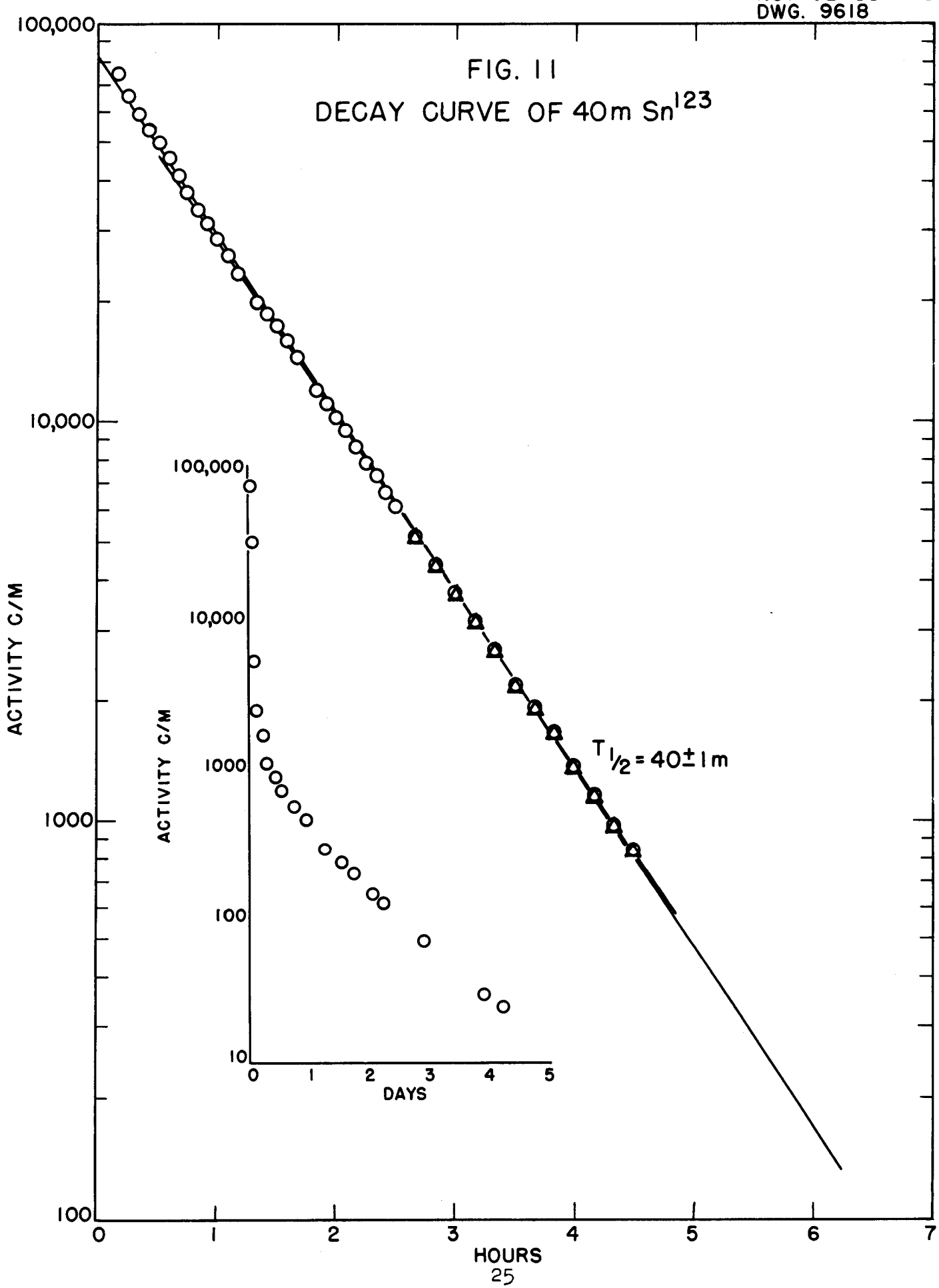
FIG. 11

DECAY CURVE OF 40m Sn^{123}



to occur in the slow neutron fission of U^{233}[22] and in the fission of Th^{232} by 37.5 Mev alpha particles[23].

Recently Lee and Pool have produced this activity with deuterons and neutrons on enriched Sn^{122} and with fast neutrons on Sn^{124}, and therefore have assigned it to mass 123. They also report a half-life of 130 ± 5 days and a beta end point energy of 1.3 Mev with no gamma. This assignment is confirmed by our observation that this period was produced in maximum yield in the slow neutron irradiation of the preparation enriched in Sn^{122}. Our half-life value of 126 ± 5 d (Fig. 12) was obtained by following the decay over 650 days.

Measurements of the beta distribution were performed on a source prepared by a 100 day irradiation of enriched Sn^{122} with an intense source of slow neutrons. As with the 9.4 d Sn^{125}, the beta spectrum for this activity was found to differ markedly from that for an allowed transition (Figs. 13 and 14) while a Kurie plot with a correction term for a first forbidden transition gave a straight line (Fig. 15). Thus, as with the 9.4 d Sn^{125}, in the decay of the 126 d Sn^{123} there is a probable spin change of two and a change in parity. The decay of the 126 d Sn^{123} has been taken to be a simple beta emission of 1.42 ± 0.01 Mev maximum energy in view of the absence of any unexplained conversion lines in the spectrum (Fig. 13). Lead absorption measurements also failed to reveal any gamma rays which decayed with a 126 d half-life[24].

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(22) W. E. Grummitt and G. Wilkinson, Nature, 161, 520 (1948).
(23) A. S. Newton, Phys. Rev., 75, 17 (1949).
(24) J. W. Mihelich and R. D. Hill, Phys. Rev., 77, 743 (1950), have reported a 0.394 Mev gamma ray associated with the 130 d Sn^{123}. It is considered that this may have arisen from small amounts of In^{113m} probably also present in their source which was prepared by the slow neutron irradiation of enriched Sn^{122}.

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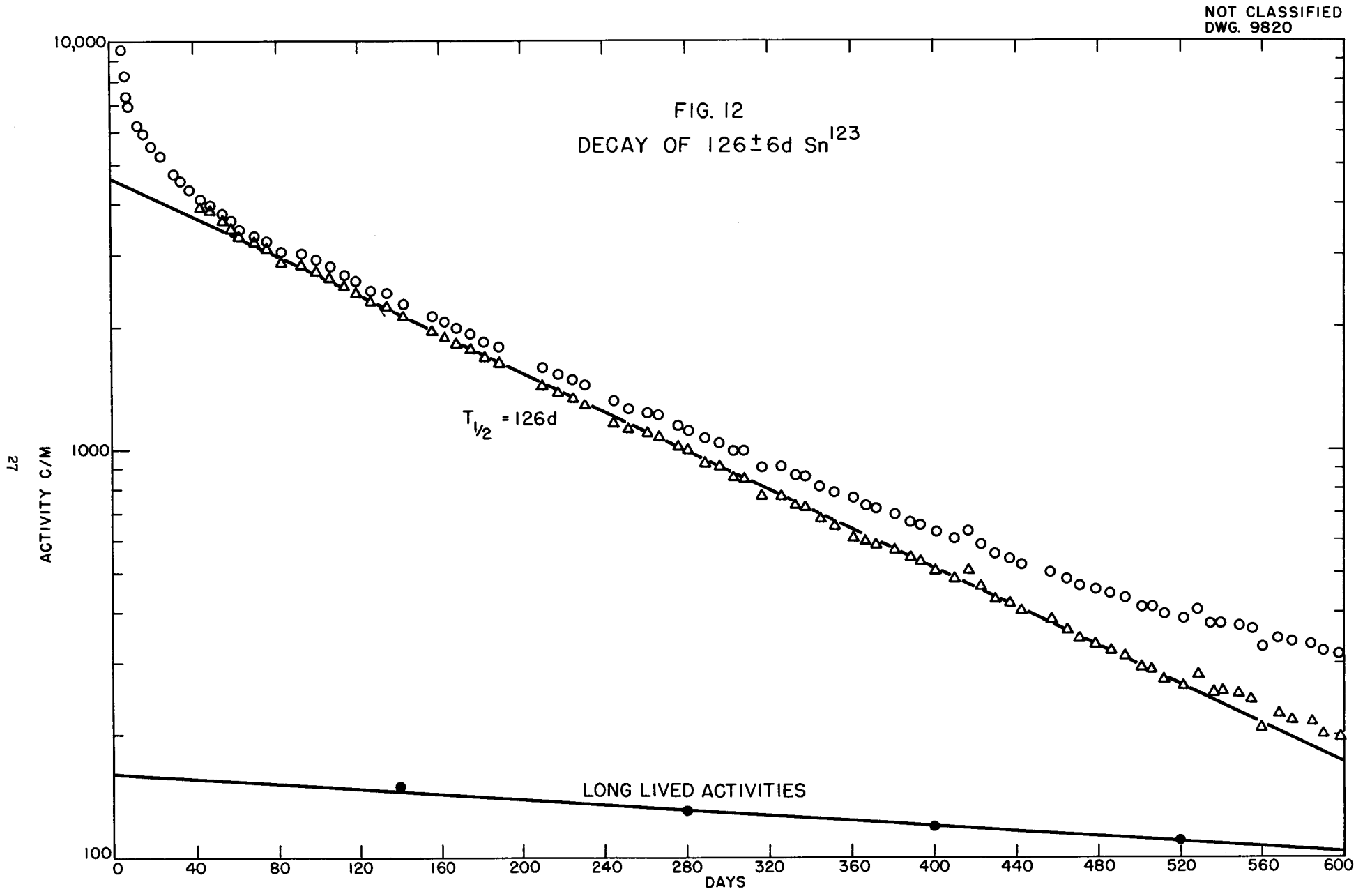

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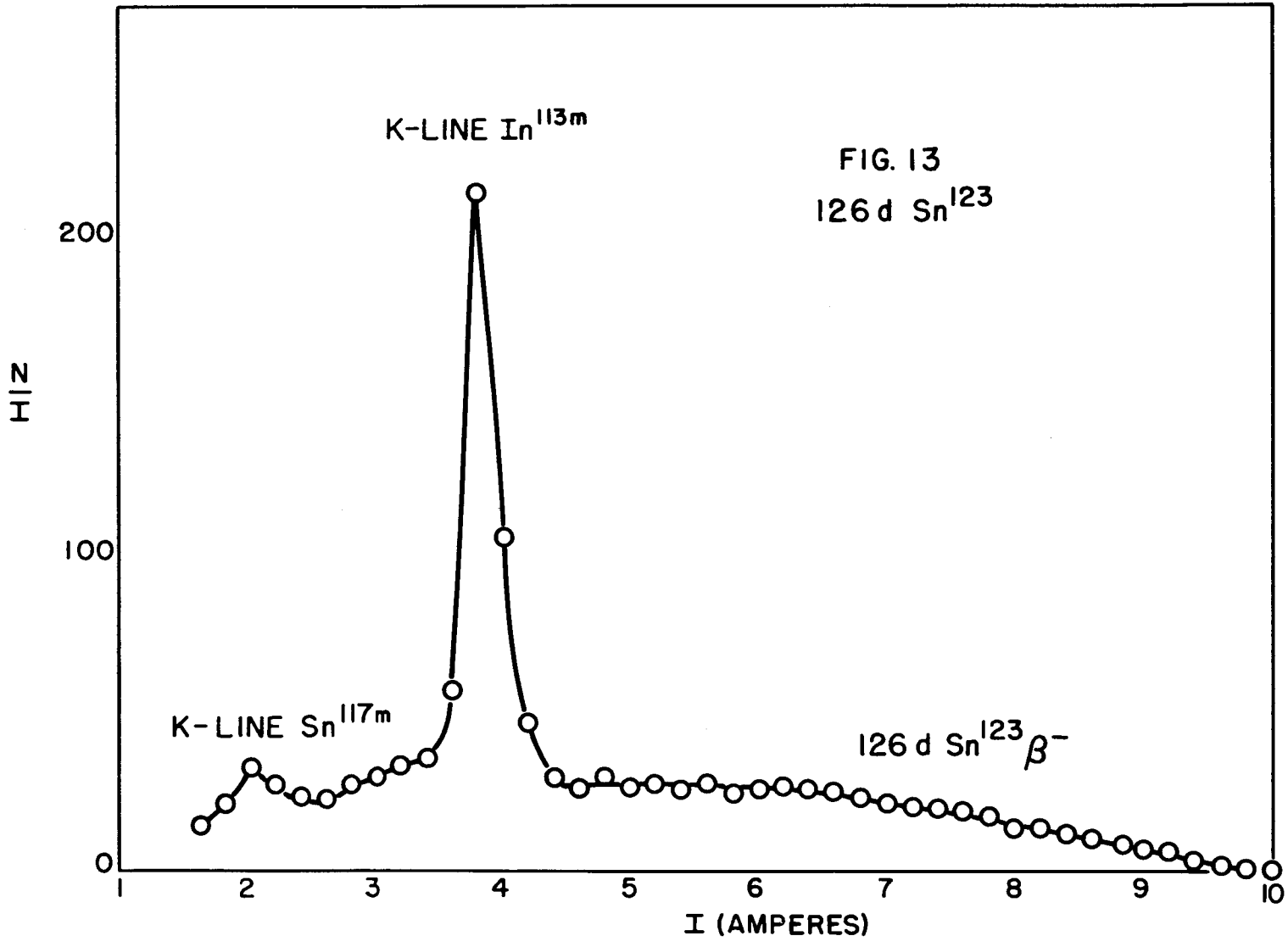

FIG. 13
126 d Sn^{123}

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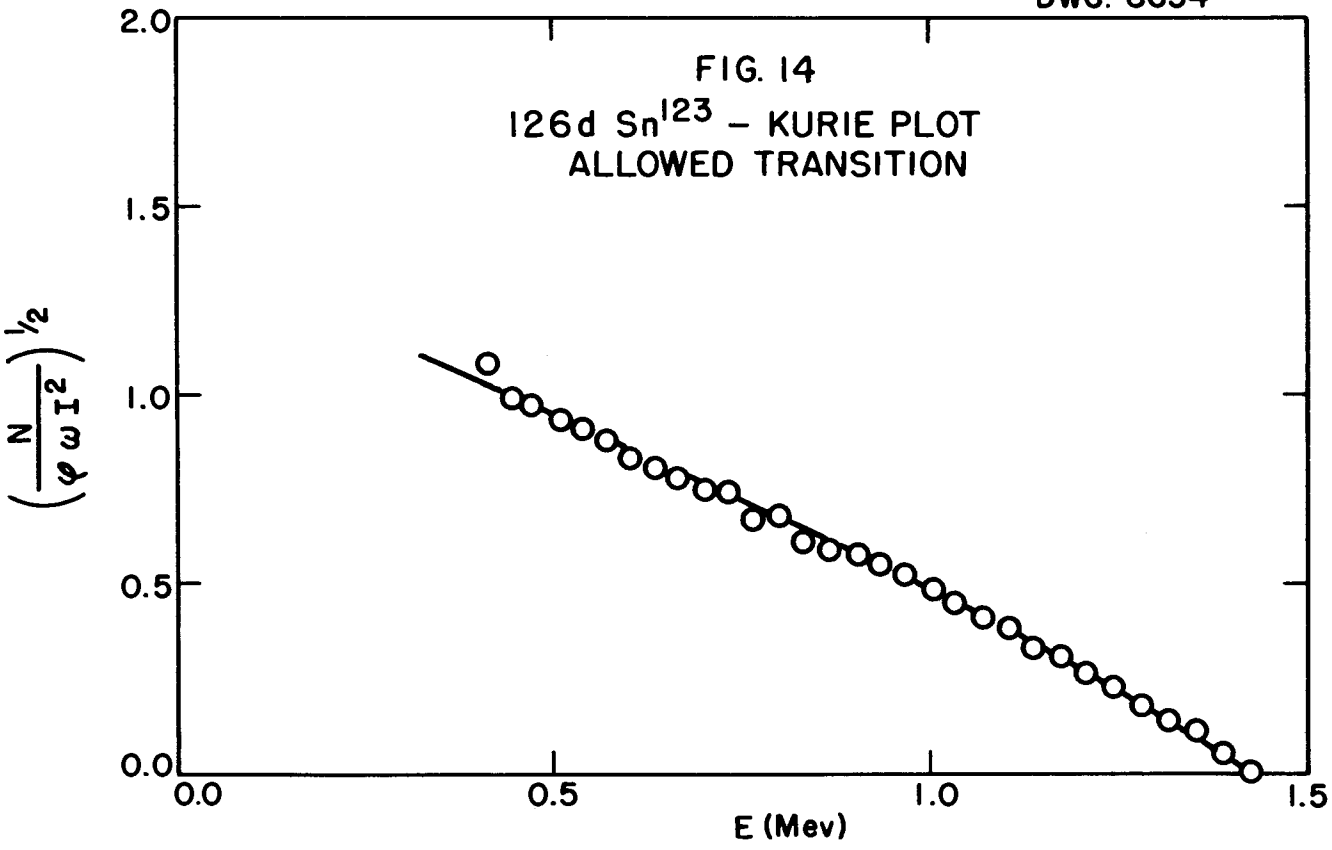
FIG. 14
126d Sn^{123} – KURIE PLOT
ALLOWED TRANSITION



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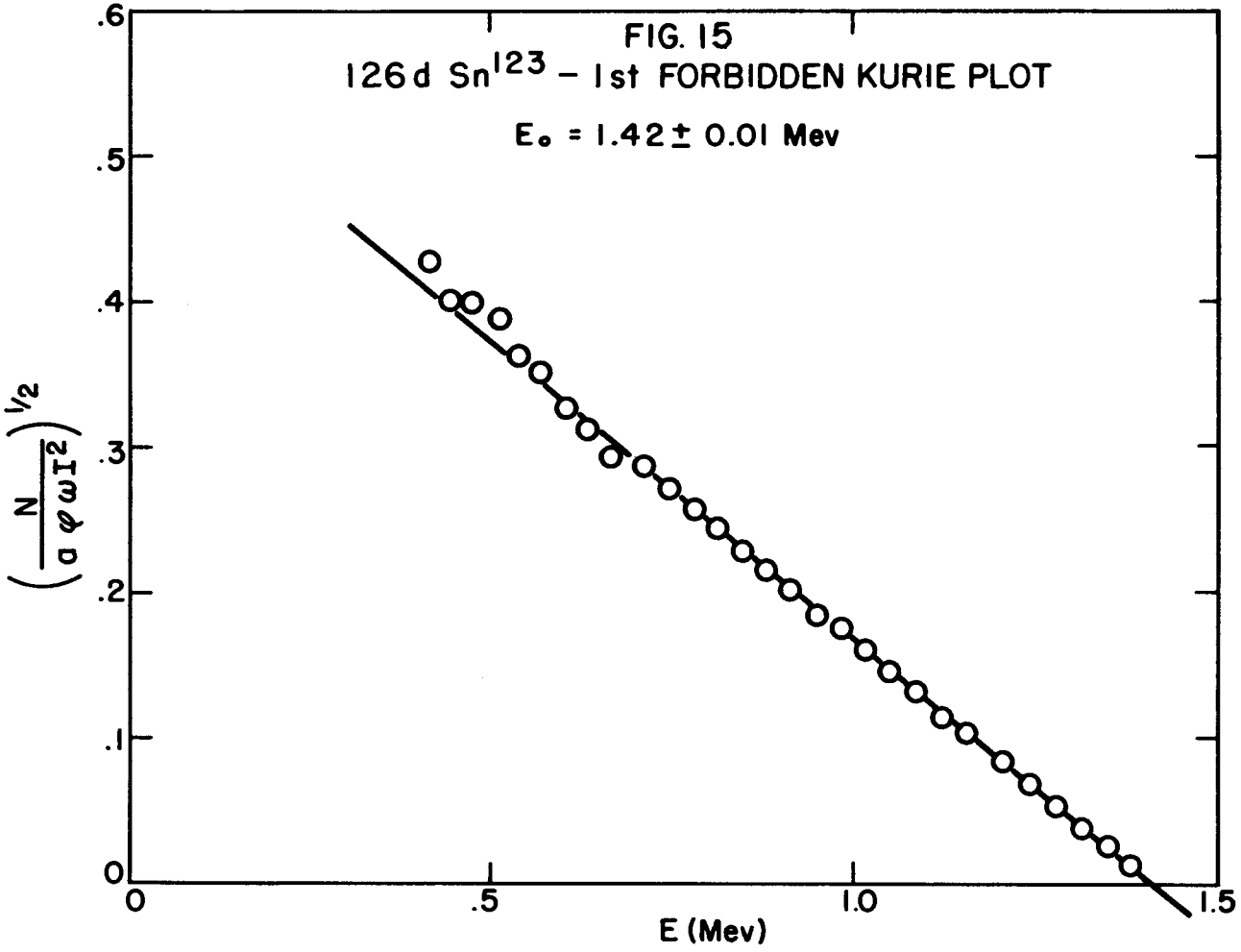

A tentative decay scheme for the isomers of Sn^{123} is proposed in Fig. 16. This, however, may be incomplete since it does not include the 0.76 Mev gamma observed by us in the 40 m period.

27.5 Hour Sn^{121}

This activity was first observed to be produced in the irradiation of natural tin with deuterons and with neutrons by Livingood and Seaborg[6] who assigned it to mass 121. This assignment has since been confirmed[25], [8]. Measurements of the maximum beta ray energy by absorption in aluminum have given 0.40[25] and 0.35[8], respectively, whereas a recent magnetic lens spectrometer determination[18] gave 0.383 ± 0.005 Mev. The beta transition appeared to be allowed and to occur directly to the ground state of Sb^{121} since neither conversion electrons nor gamma rays have been detected. The mass assignment and radiation characteristics are confirmed by this study. A half-life of 27.5 ± 0.5 h was observed from the decay of a source produced by the slow neutron irradiation of enriched Sn^{120} (Fig. 17).

>400 Day Sn^{121}

Preliminary evidence of the existence of a long-lived beta emitter in Sn^{121} has been obtained. In the spectrometer sample of the Sn^{120} preparation (95% Sn^{120}) a beta distribution was found between the conversion lines due to the Sn^{117m} and In^{113m}. After about five months decay (so that the 15 d Sn^{117m} could disappear), the results shown in Fig. 18 were obtained. This beta distribution had not decayed appreciably whereas the conversion line due to Sn^{117m} disappeared with its corresponding half-life. Unfortunately, the In^{113m} is a 105 m daughter of the 112 d Sn^{113}, so that this conversion peak will remain in this source for some time. The amount of activity in this

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(25) M. Linder and I. Perlman, Phys. Rev., 73, 1124 (1948).

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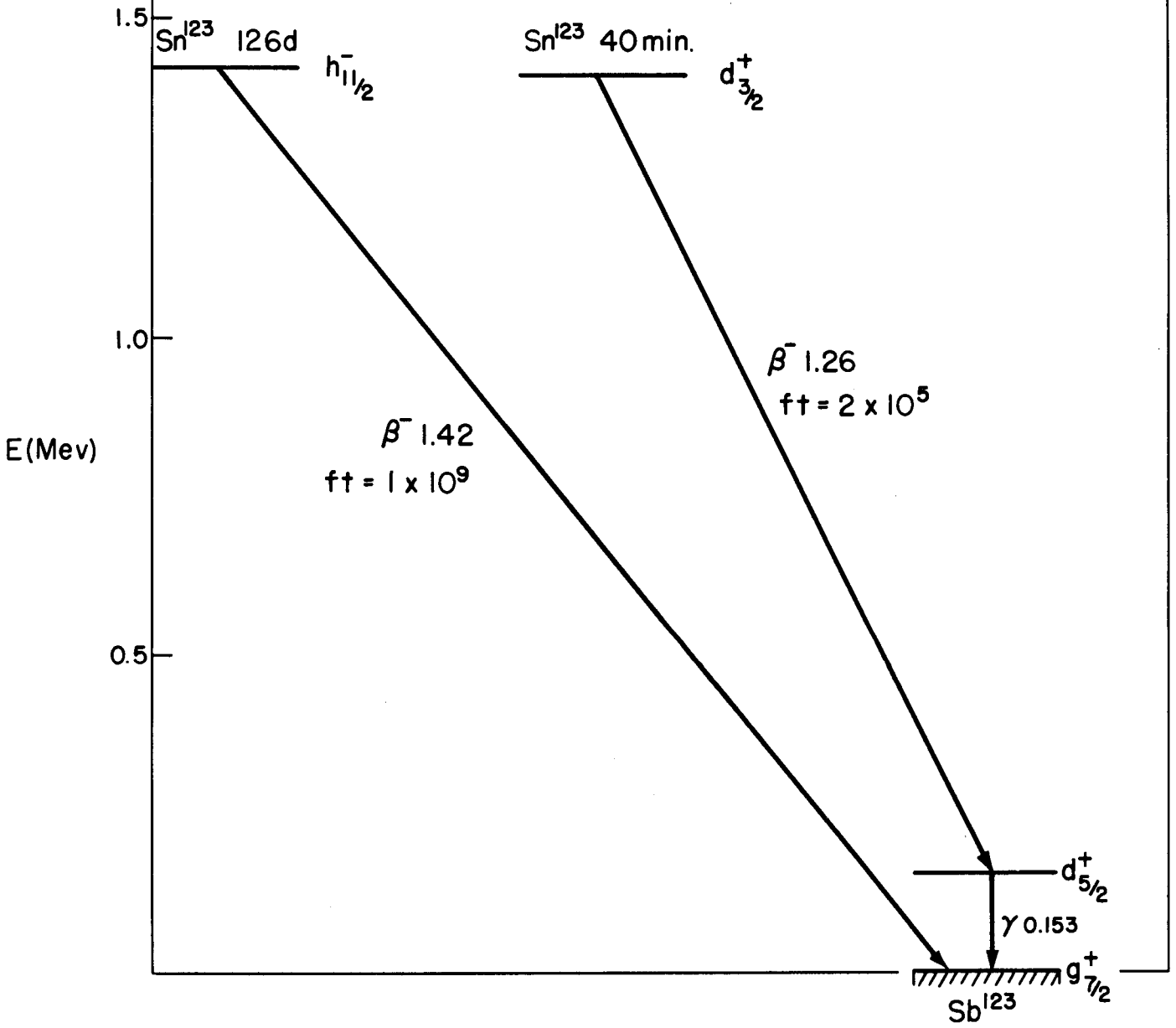
FIG. 16
DECAY SCHEME OF Sn^{123} ACTIVITIES



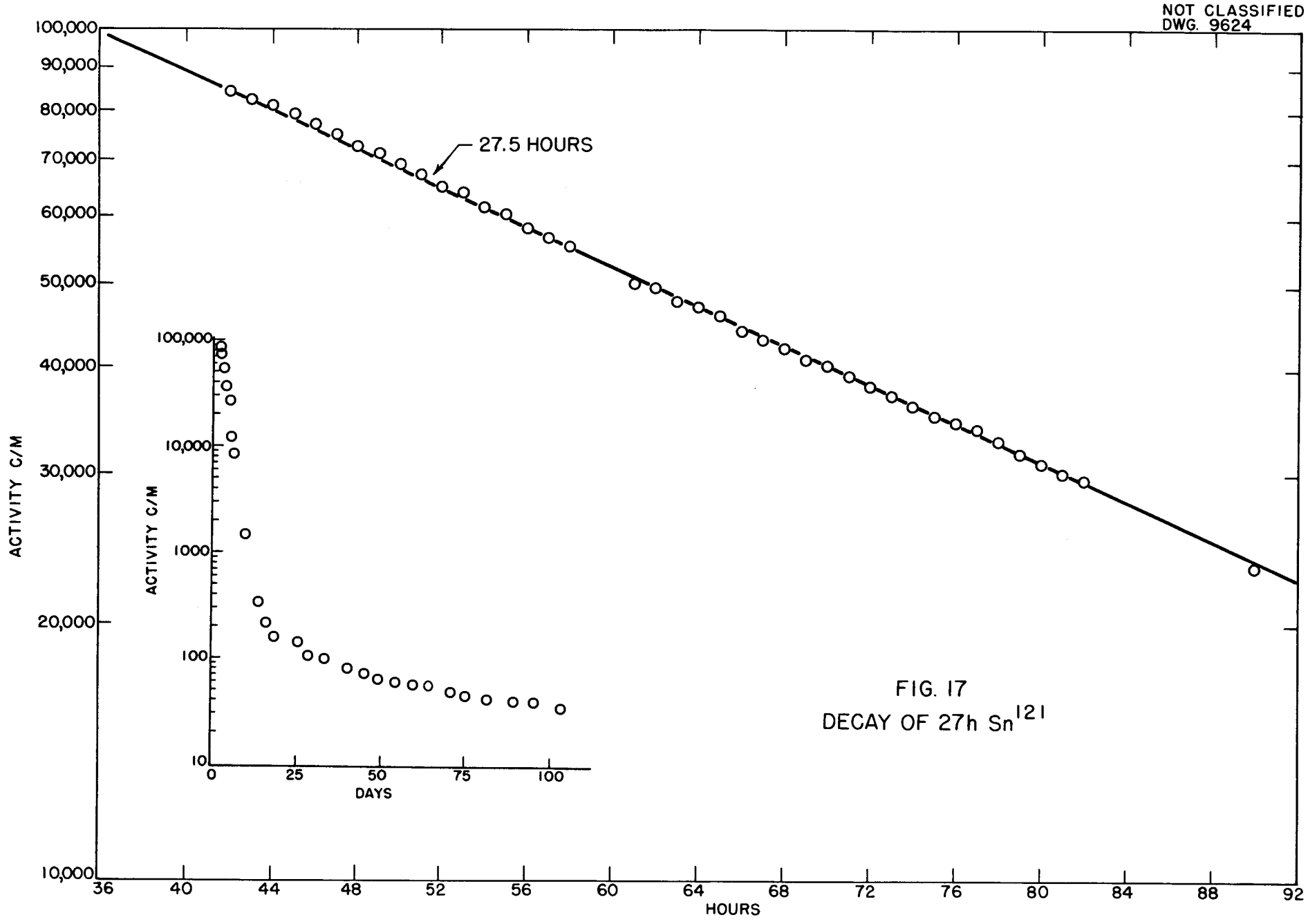


FIG. 17
DECAY OF 27h Sn^{121}

NOT CLASSIFIED
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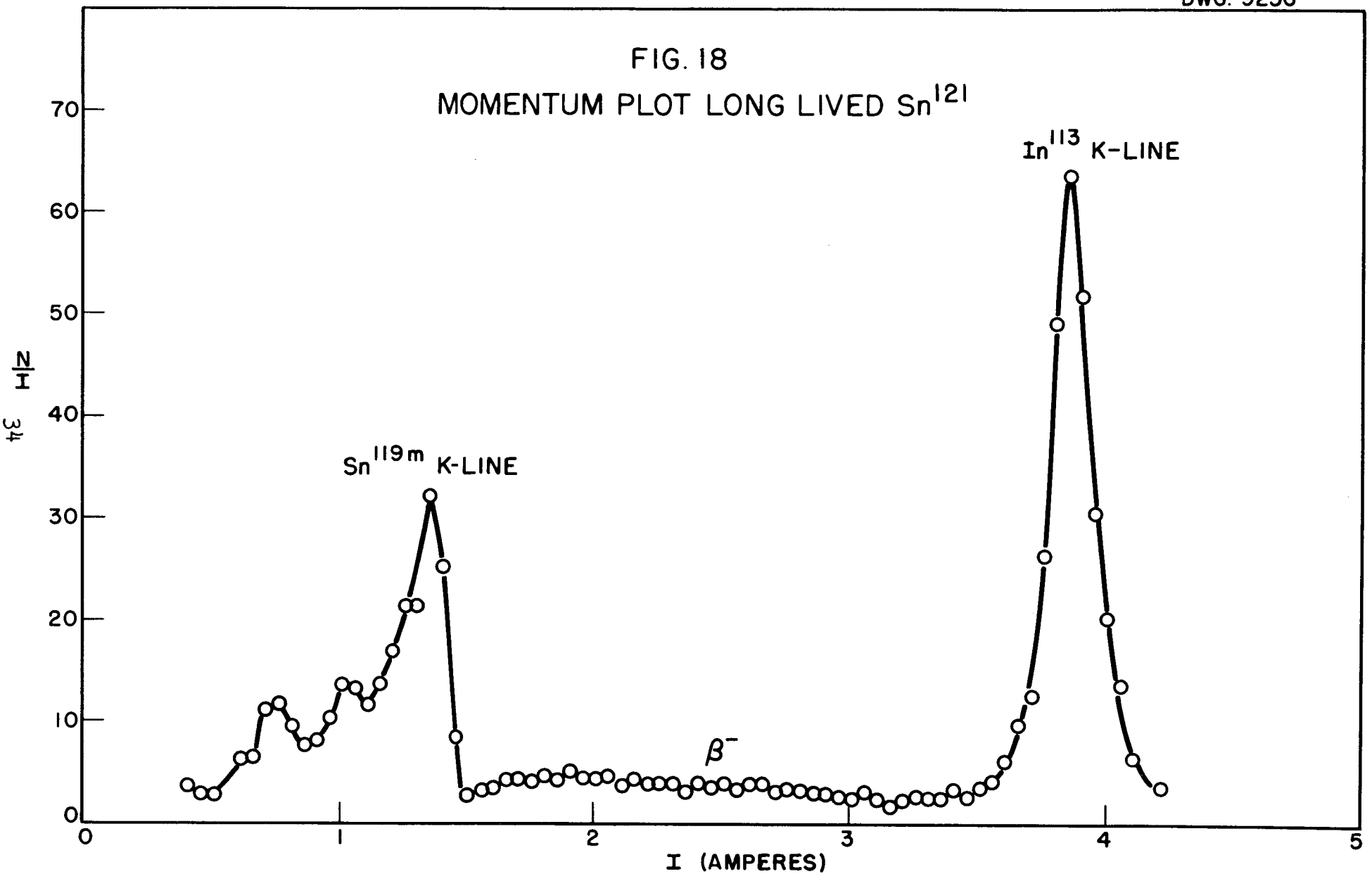
FIG. 18

MOMENTUM PLOT LONG LIVED Sn^{121}



region was larger than could be accounted for from the breadth of the conversion lines of this height. Furthermore, since no beta activity at greater energies than the In^{113m} peak was seen, it was concluded that the activity in the region below the In^{113m} peak could not arise from the presence of any Sn^{123} or Sn^{125}. It seems probable then that a long-lived beta emitter can be assigned to the 121 mass position. Upon plotting the data as for an allowed transition, the Kurie plot (Fig. 19) gives a maximum beta energy of about 0.42 ± 0.02 Mev. An attempt is being made to obtain an approximate value of the half-life from the sample in the spectrometer. A decay scheme for the mass 121 isomers is suggested in Fig. 20.

245 Day Sn^{119m}

In agreement with Mihelich and Hill[24], [26] this period can be assigned to the 119 mass position. The K and L conversion lines from the gamma ray associated with this activity were measured on the lens spectrometer using a flow type G-M counter with a supported window (6 $\mu g/cm^2$) (Fig. 21). An energy of 64 Kev was found for the gamma ray. This value, however, may be slightly low due to electron peak shift caused by source thickness. This isomeric gamma transition has been reported[24] as having an energy of 69 Kev. The value for the K/L ratio as determined from the average of the peak heights and the areas under the peaks is 0.42*. This is subject to considerable error because of the source thickness which was about 1 mg/cm^2 in this case. Since accurate values of the L conversion coefficients are not yet computed, it is not possible to determine the angular momentum change from the K/L ratio. The half-life value of

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(26) J. W. Mihelich and R. D. Hill, Phys. Rev., 79, 781 (1950).

*Correction for self-absorption in the source changes the K/L ratio to 0.82.

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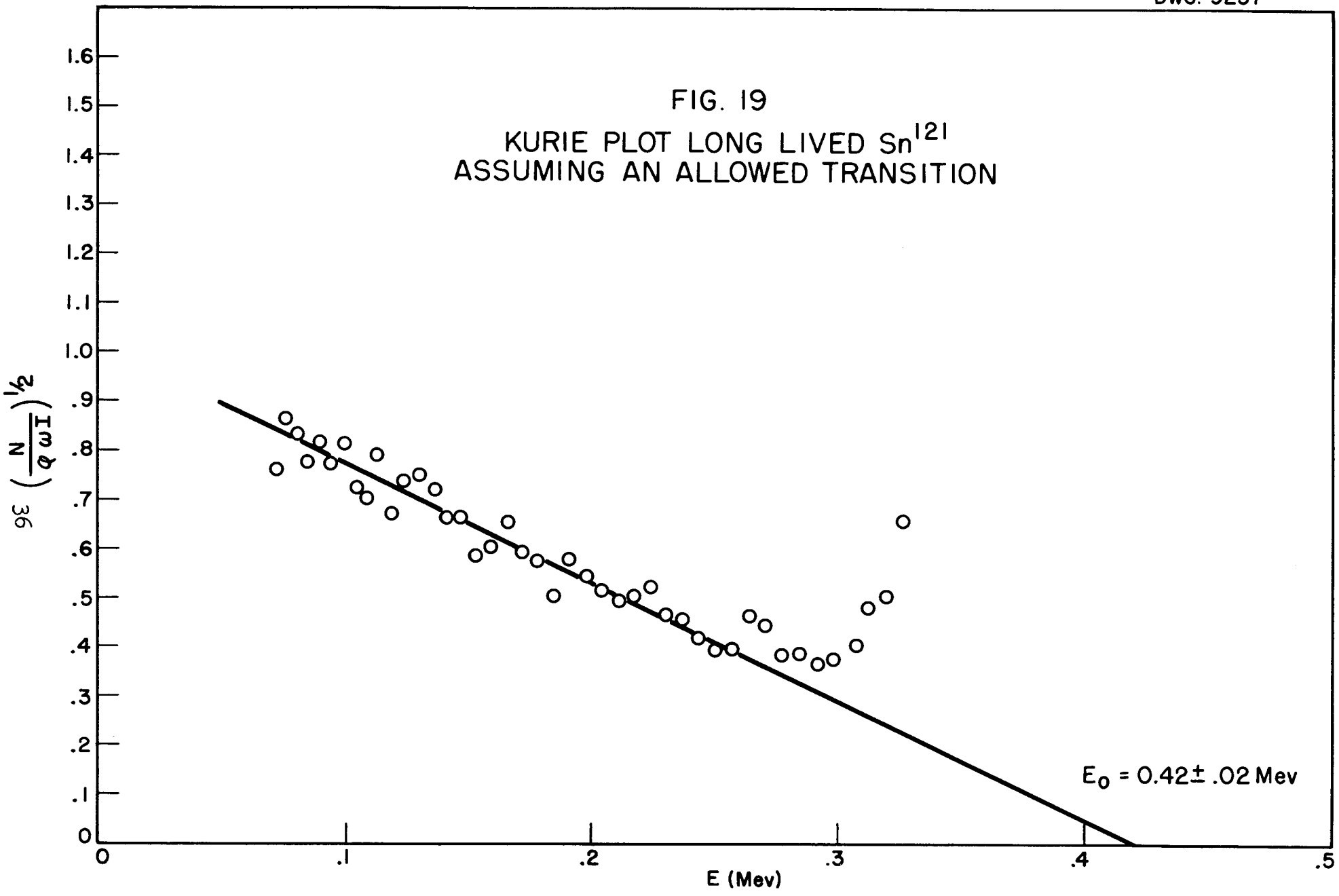
DWG. 9257

FIG. 19

KURIE PLOT LONG LIVED Sn^{121}
ASSUMING AN ALLOWED TRANSITION



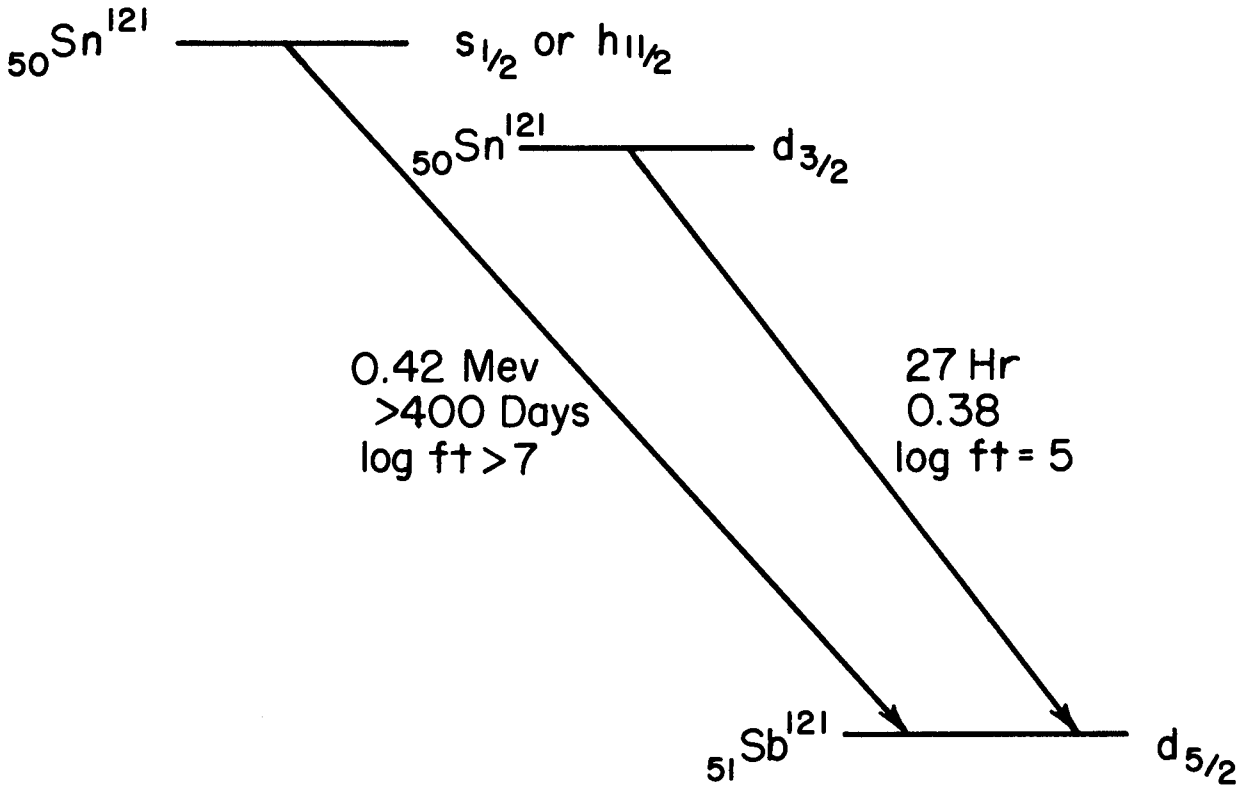


FIG. 20
DECAY SCHEME OF Sn^{121} ACTIVITIES

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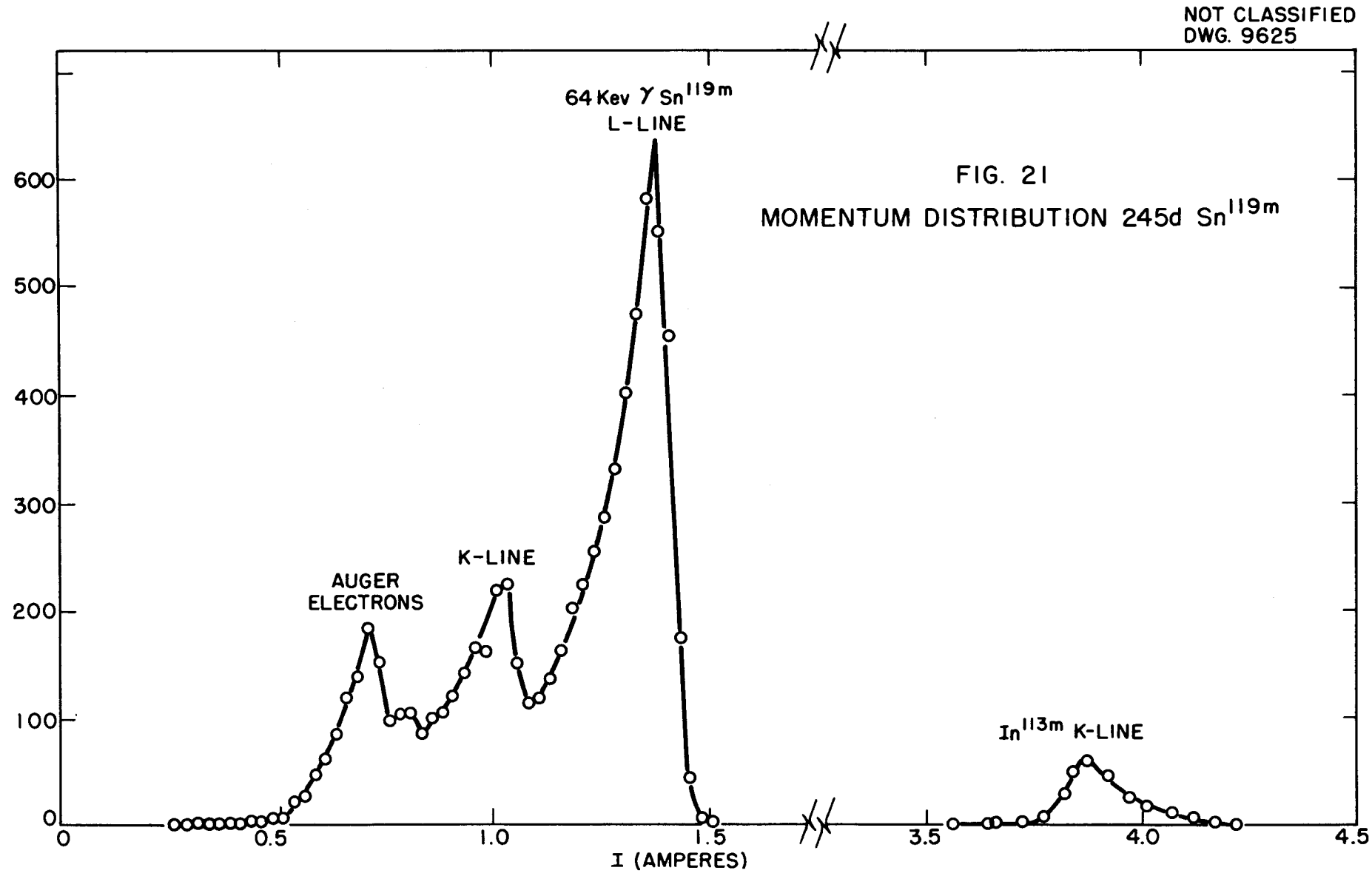

FIG. 21
MOMENTUM DISTRIBUTION 245d Sn^{119m}

245 ± 20 d was obtained from the decay of the L conversion line over a period of 150 days. An attempt to see any unconverted gamma rays using a proportional counter spectrometer[27] was conducted on a source of a high disintegration rate. No quantum radiations other than the Sn and In K_α X-radiations (In x-rays from Sn^{113}) were seen up to 100 Kev. Lead absorption measurements showed no gamma radiations other than the 390 Kev ray from small amounts of 112 d Sn^{113} in the source. Scintillation spectrometer measurements confirmed these findings.

According to the Mayer shell theory the excited state of Sn^{119} should be $h^-_{11/2}$; the ground state is known to be an $s^+_{1/2}$ state. Thus, the prediction would be that the transition involves a spin change of five units and a change of parity. If this be true then the radiation would be 2^5 pole electric, and the conversion coefficient obtained from the extrapolated α_5 curve computed by Rose et al.[28] would be 2000. Therefore, it is not surprising that the unconverted gamma ray was not detected since it would be present in only 0.05% of the disintegrations. The half-life for this transition derived from the plot of half-life vs. gamma energy published by Axel and Dancoff[29] is about 400 days. Since this is in good agreement with the observed half-life, one is inclined to believe that the shell theory prediction is correct.

15 Day Sn^{117m}

This period in tin was first produced in the alpha bombardment of natural Cd[6] and since has been reported to be formed by a (d,α) reaction with antimony[30] which observation suggested its assignment to mass 119. Linder and

(27) C. J. Borkowski and E. Fairstein, Phys. Rev., 74, 1243 (1948); 77, 759 (1950).
(28) M. E. Rose, Phys. Rev., 76, 1883 (1949).
(29) P. Axel and S. M. Dancoff, Phys. Rev., 76, 893 (1949).
(30) M. Linder and I. Perlman, Private communication to G. T. Seaborg, Rev. Mod. Phys., 20, 585 (1948).

Perlman also report conversion electrons of 0.13 and gamma radiation of 0.17 Mev energy, respectively. Recently, this activity has been assigned to mass 117[31] on the basis of the following reactions using enriched isotopes: Cd^{114} (α,n), Sn^{116} (d,p), Sn^{118} (n,2n) and Sn^{117} (n,n). Our work and that of others[26] in which enriched Sn^{116} was irradiated with slow neutrons confirm the assignment to mass 117. Mallary and Pool report the decay to occur by isomeric transition with about 50% conversion of a gamma ray of 0.175 ± 0.006 Mev. Mihelich and Hill, however, give the values of 159 and 162 Kev for two gamma transitions which are assumed to be in cascade. The lower energy transition was postulated to occur with a spin change of four and to be completely converted. The 162 Kev level was estimated to be 10% converted and to involve a unit spin change.

The energies of the K and L conversion electrons from our source were measured (Fig. 22) and an energy of 152 Kev was found, which value may be a few Kev low due to an electron peak shift caused by the thick source employed. The K/L ratio as estimated from the average of the peak heights and areas under the peaks was 2.4 ± 0.3. Evidence for appreciable quantities of unconverted gamma rays from this transition was found in lead absorption measurements. Since the completion of our work a second spectrometer value of 0.157 ± 0.002 Mev has been reported[32], and a K/L ratic of 2.2. Measurements on the decay of the conversion electrons and gamma rays from our source have given a half-life of 15 ± 1 d in agreement with previous work.

Shell theory predicts that the spin change for this transition is five

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(31) E. C. Mallary and M. L. Pool, Phys. Rev., 77, 75 (1950).
(32) R. W. Hayward, Phys. Rev., 79, 542 (1950).

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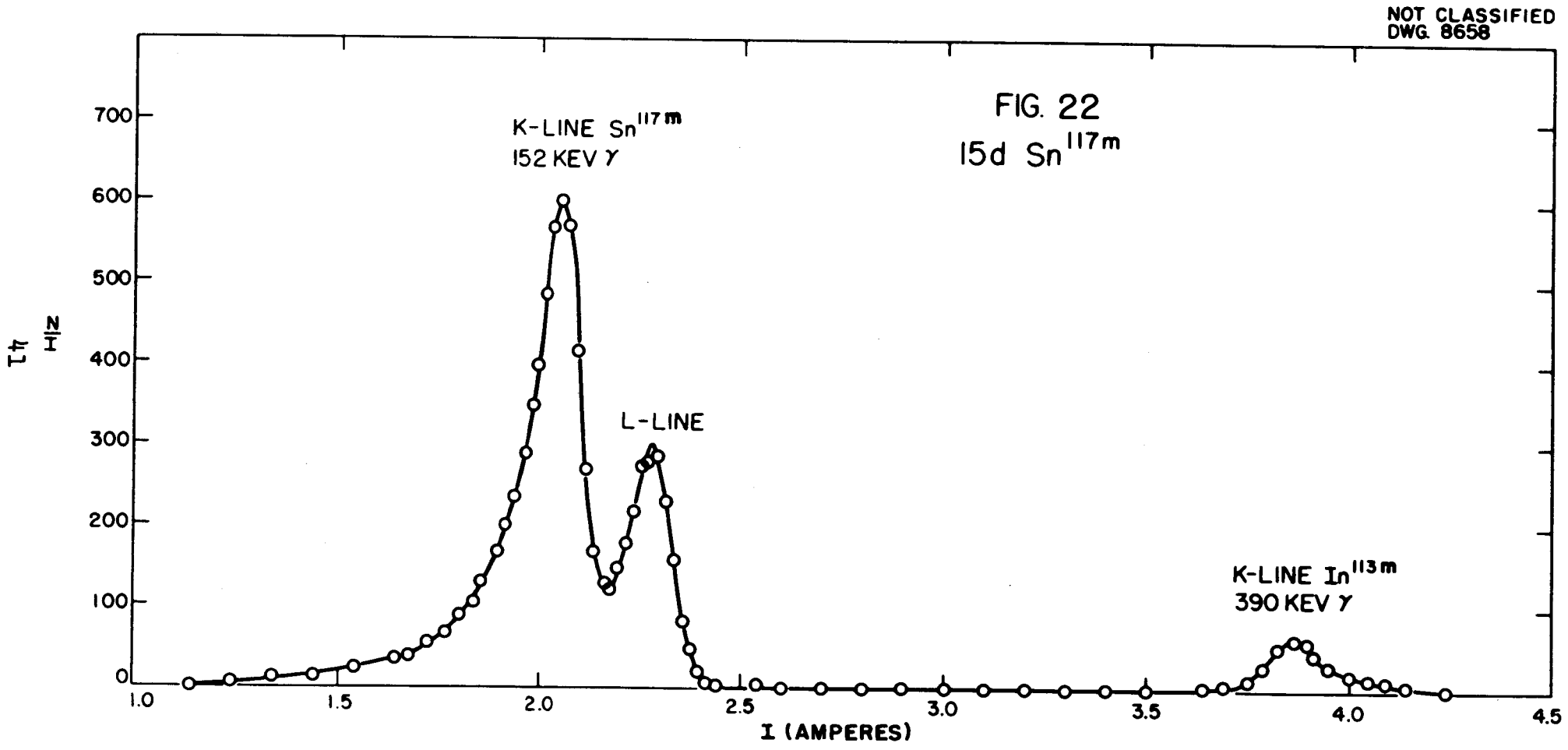

and that there is a parity change. The radiation, therefore, should be 2^5 pole electric. The computed conversion coefficient is 30. The half-life estimated from Dancoff's plot is about ten days if $\Delta \ell = 5$ and of the order of a few minutes if $\Delta \ell = 4$. Therefore, since the observed half-life is 15 d, it is concluded that the transition may be $h^-_{11/2} \longrightarrow s^+_{1/2}$ rather than $h^-_{11/2} \longrightarrow d^+_{3/2}$.

30 Minute Sn^{113m}

Preliminary evidence for the existence of isomers at mass 113 was obtained in that slow neutron bombardment of enriched Sn^{112} samples gave a 30 m period in addition to the well known 112 d Sn^{113} discussed below. An attempt was made to determine the energies of the radiations associated with the 30 m period by means of isochrones with aluminum absorbers. However, the growing-in of the indium daughter activity both from the 30 m Sn and from the 112 d Sn^{112} made the interpretation of the gross absorption in aluminum difficult. The 30 m activity appeared to decay with charged particles (positrons or conversion electrons) of about 1.2 Mev energy, and possibly also by K-capture since x-rays in the In-Sn region were found (Fig. 23). The value of 30 ± 5 m for the half-life was obtained as an average of the decay taken through the various aluminum absorbers.

112 Day Sn^{113}

This Sn activity has been known for some time[11] and, as expected from the relatively large slow neutron capture cross-section[33] for Sn^{112}, quite a large yield was produced in the enriched preparation. The observed activity was practically all due to the In^{113m} daughter with a 390 Kev gamma

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(33) L. Serin, H. N. Friedlander and S. H. Turkel, Phys. Rev., 72, 888 (1947).

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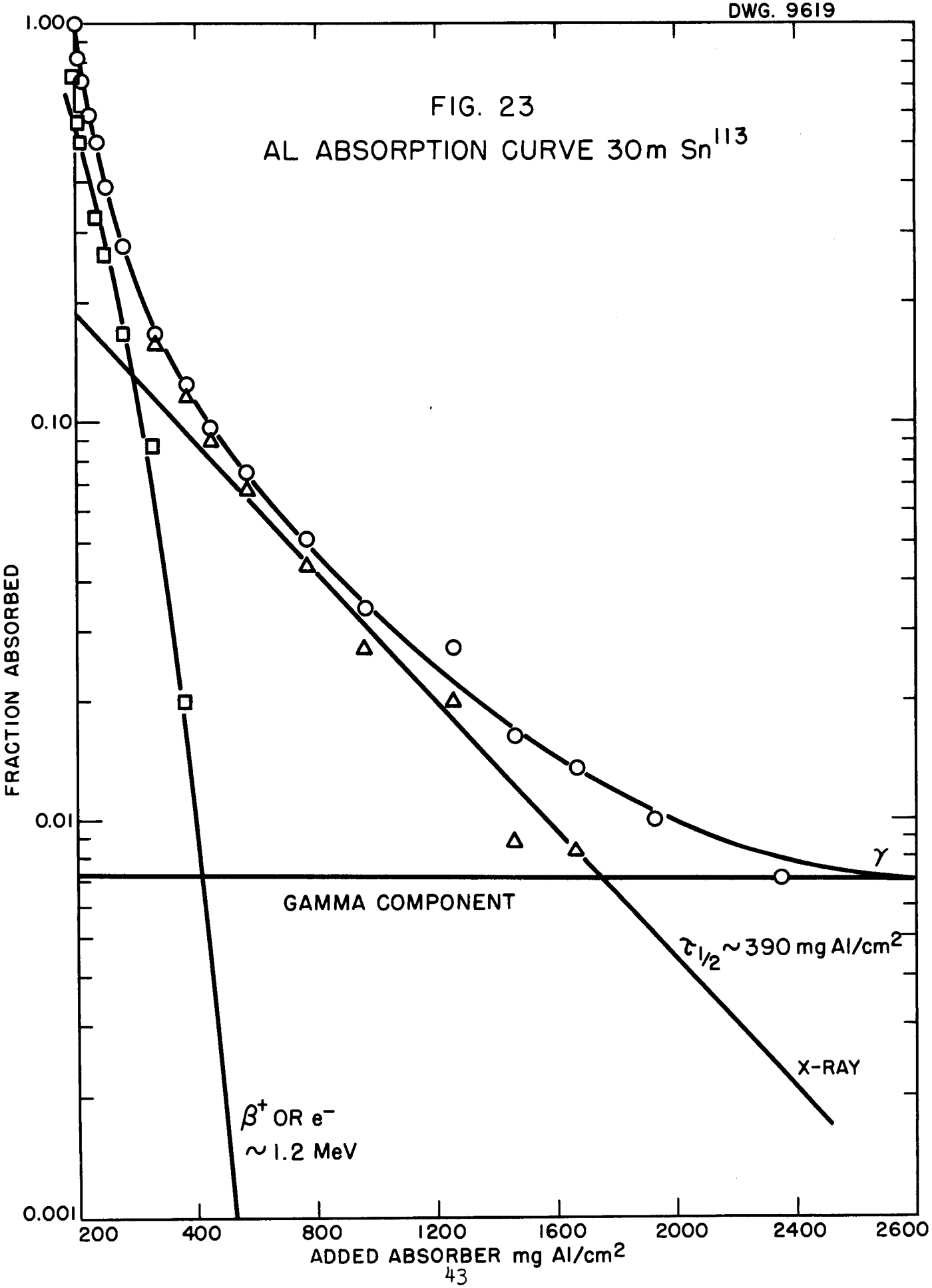
FIG. 23

AL ABSORPTION CURVE 30m Sn^{113}



transition (Fig. 24). A Pb absorption curve (Fig. 25) indicates the gamma ray is only partially converted. A sample, which was over 100 times more active, was placed in the β-ray spectrometer and the coil current was reversed in order to look for positrons. Whereas the instability energy for the ground state of Sn^{113} computed by the Bohr-Wheeler liquid drop model equation is sufficiently high to permit positron emission, no positrons of energies greater than 50 Kev were observed. Therefore, it appears that the 112 d Sn^{113} decays largely by a K-capture process. No conversion lines nor gamma rays apart from those arising from the In^{113m} daughter were observed to decay with a 112 d half-life. Though Barnes[34] reported a 0.085 Mev gamma associated with the K-capture process, Coleman and Pool[12] also did not observe any gamma ray.

A decay curve showing a half-life of 112 ± 1 d is given in Fig. 26.

Discussion

Whereas no clear evidence has been found for a tin activity at the 115 mass position, the existence of isomerism in each of the other tin isotopes of odd mass, and the prediction of closely spaced levels by the shell theory leads one to expect isomerism in this position also. In Sn^{115} the ground level is known to be $s^{+}_{1/2}$ so if the excited level were $h^{-}_{11/2}$ as in the heavier tin isotopes of odd mass number, then the high spin change involved in a transition would make the half-life long as in the cases of Sn^{117m} and Sn^{119m}. However, if the excited level were $d^{+}_{3/2}$, then the spin change would be unity and the half-life would be exceedingly short. Further efforts are being made to determine if isomerism occurs in Sn^{115}.

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(34) S. W. Barnes, Phys. Rev. 56, 414 (1939).

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DWG. 8650

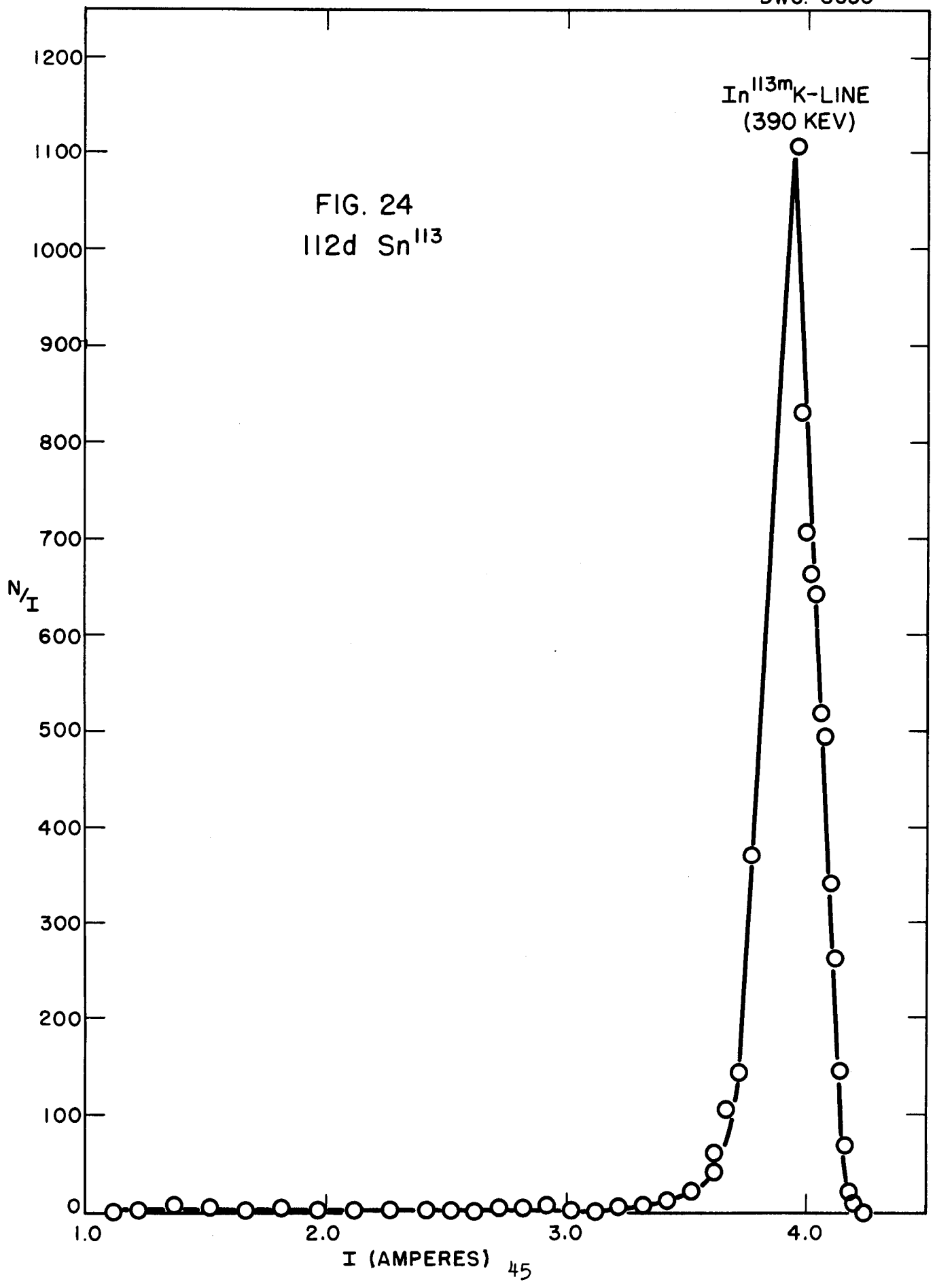

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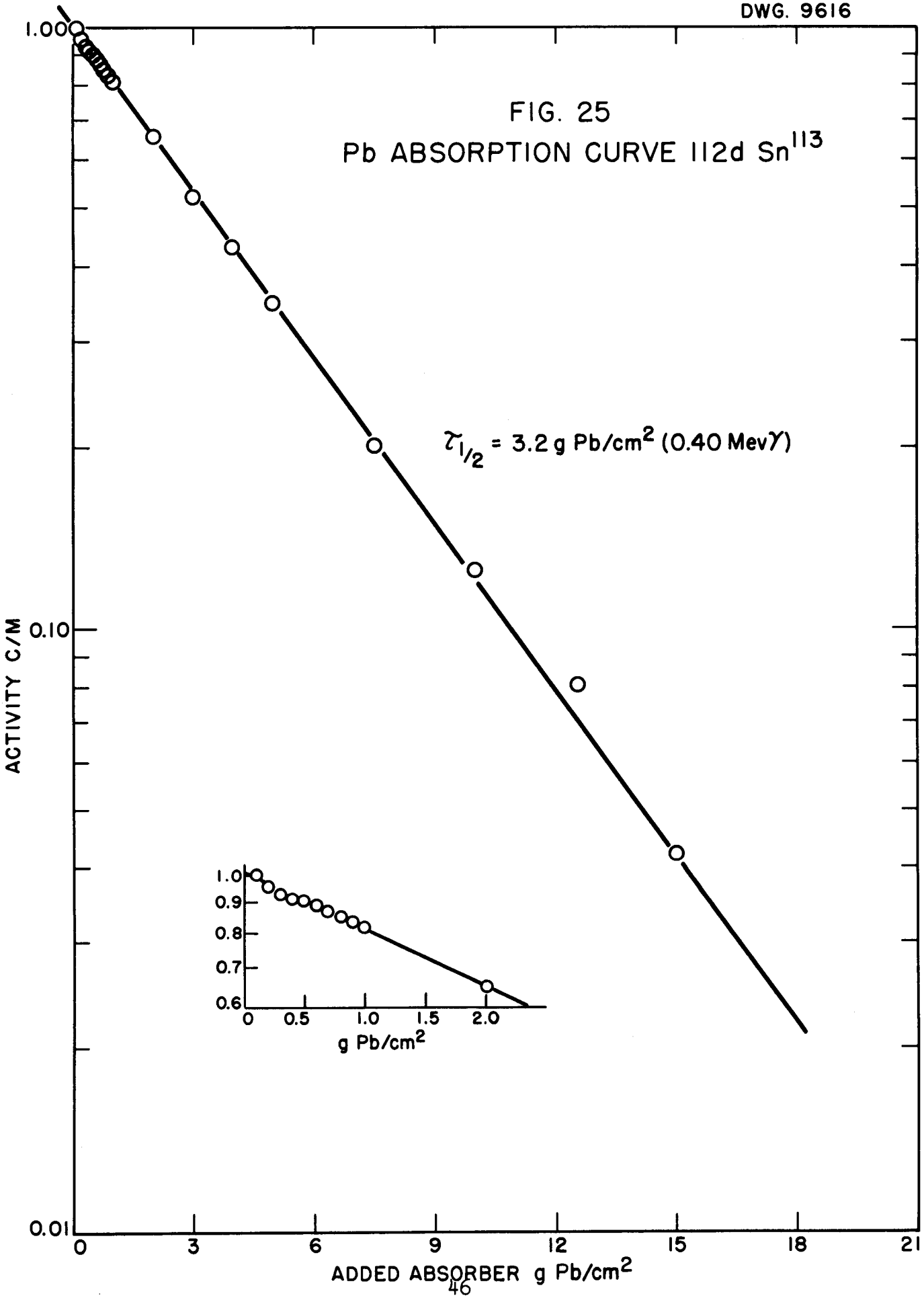
FIG. 25
Pb ABSORPTION CURVE 112d Sn^{113}



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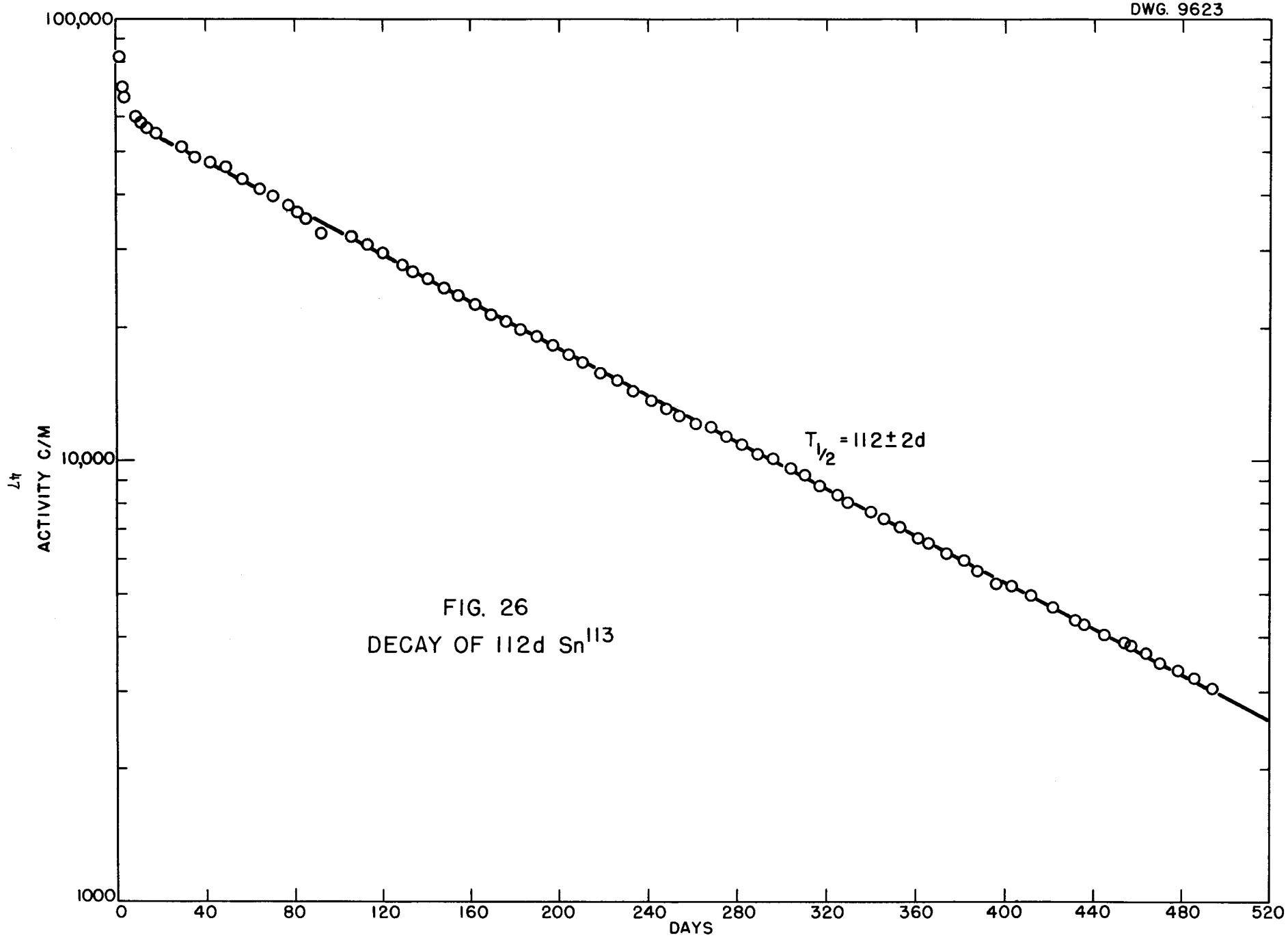

FIG. 26
DECAY OF 112d Sn^{113}

The assignment of the 126 d and 9.4 d periods to masses 123 and 125, respectively, may be employed together with information on their yields in the slow neutron fission of U^{235} to estimate the branching ratio for their formation from their respective radioactive indium parents. Thus, if the fission yields for the 126 and 9.4 d tin activities are subtracted from the total fission yields for masses 123 and 125 taken from the smooth fission yield curve[35] a rough indication of the branching may be obtained. For mass 125 using 0.043% for the total fission yield and 0.0044% for the yield of the 9.4 d Sn^{125} the branching ratio is about 10% by this path and about 90% by the 9.5 m Sn^{125} activity path. Similarly with mass 123 using 0.015% for the total fission yield and 0.0012% for the 126 d Sn^{123}, the branching ratio in the In^{123} parent is about 10% by this path and about 90% by the 40 m Sn^{123} activity path. If a similarly unfavorable branching to form the tin isomer of high spin occurs in the decay of the radioactive indium isotopes of mass 117, 119 and 121, the failure hithertofore to observe the 15 d Sn^{117m}, 245 d Sn^{119m} and >400 d Sn^{121} in fission tin becomes explicable.

Values for the slow neutron activation cross-sections observed in this study are brought together in Table 2. Marked differences between the cross-section values for the various isomeric pairs are evident. Further, it appears that the isomer of lower spin possesses the higher activation cross-section. This behavior has been found with other elements[36]. In this connection it may be remarked that the activation cross-sections for (n,n) reactions between pile neutrons and Sn^{117} and Sn^{119} leading to the 15 d Sn^{117m} and 245 d Sn^{119m}

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(35) Plutonium Project, J. Am. Chem. Soc., 68, 2411 (1946).
(36) E. Segre and A. C. Helmholtz, Rev. Mod. Phys., 21, 271 (1949).

Table II

Slow Neutron Activation Cross-Sections for Tin Activities

Activity	Cross-section x 10^{24} cm^2/atom
30 m Sn^{112m}	(0.02)
112 d Sn^{112}	1.3; 1.1[a]
15 d Sn^{117m}	0.006
245 d Sn^{119m}	0.02[b]
27 h Sn^{121}	0.03; 0.22[a]
>400 d Sn^{121}	~0.001
39 m Sn^{123}	0.1; 0.3[a]
126 d Sn^{123}	0.001
9.5 m Sn^{125}	0.5; 0.6[a]; 0.8[c]
9.4 d Sn^{125}	0.002; 0.15[a]

a. L. Serin, H. N. Friedlander and S. H. Turkel, Phys. Rev., 72, 888 (1942).

b. J. W. Mihelich and R. D. Hill, 77, 743 (1950).

c. M. Studier, Brookhaven Conference on Radiochemistry (1949).

were of the same order of magnitude as the capture cross-sections listed in Table II.

The authors are indebted to Lucille Petty, Edna Hennessee and Georgia Gibson for much help with the numerous beta spectrometer, decay and absorption measurements. Thanks are due also to Q. V. Larson for assistance with the chemical separations.