

~~SECRET~~

Report CC-579

Metallurgical Laboratory

A. H. Compton, Project Director

\*\*\*

CHEMICAL RESEARCH - RADIOCHEMISTRY

J. Franck, Division Director; C. D. Coryell, Section Chief

\*\*\*

REPORT FOR MONTH ENDING APRIL 17, 1943

\*\*\*

Table of Contents

	This document is <b>PUBLICLY RELEASABLE</b> <i>Hugh Kinser</i> Authorizing Official Date: <u>8-23-2013</u>	Page
00. Abstract		1
0. General Activities of the Section		2
1. Elementary Breakdown of Fission Activity in the Pile Operation up to 170 Days		3
a. Distribution of "Effective $\beta$ Activity"		
b. Distribution of "Effective Soft $\gamma$ Activity"		
c. Distribution of "Effective Hard $\gamma$ Activity"		
2. Heat Generation of Individual $\beta$ and $\gamma$ Activities - L. Winsberg and W. Rubinson		10
3. New Fission Product Activities and Re-evaluation of Old Data		11
a. Discovery of 55m and 30s Rh Activities--Daughters of 30d and 200d Ru Activities - L. E. Glendenin and E. P. Steinberg		
b. 43 Activities in Fission - L. E. Glendenin		
c. Rare Earth Work-- Ce in Fission Chains (cont.)		
4. Theoretical Study of $\beta$ -Absorption Curves and Correlation with Feather Method of $\beta$ -Energy Determination - T. Novey, E. Steinberg, N. Ballou, G. Campbell, and L. Winsberg		16

~~SECRET~~

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C. 50, 51 and 52. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

CLASSIFICATION CANCELLED  
DATE 1/18/56  
For The Atomic Energy Commission  
*A. F. Canale*  
Chief, Declassification Branch

~~SECRET~~

00.

ABSTRACT

1. A continuation of the detailed analysis of  $\beta$  and soft and hard  $\gamma$  activity associated with all fission product elements in a nitrate bombardment is presented. The "cooling" time has been extended to 170 days. The data for the individual elements are presented in tables as counts/min and in figures as percentage of total  $\beta$ , soft  $\gamma$ , and hard  $\gamma$  radiations.
2. Calculations and graphs have been made on the heat generated by the longer-lived fission products. The method of analysis is presented.
3. Two new short-lived Rh fission product activities have been found. They are probably the daughters of the two long lived Ru activities (30d, 200d). Re-evaluation of data on 43 leads to the conclusion that the longest lived 43 activity in measurable yields is the 6.1h (formerly 6.6h). New parent-daughter relationships in the rare-earth activities are given.
4. Theoretical  $\beta$  absorption curves have been made using the Fermi distribution function and linear absorption curves for small energy intervals. A Feather analysis of the absorption curve leads to the theoretical maximum energy.

\*\*\*\*\*

Dr. A. Turkevich joined the Section this month as leader of the group concerned with theoretical problems. Messrs. D. Schover and B. Schloss have entered Dr. N. Elliott's group on electronic development and design; Mr. L. Winsberg, Dr. W. Rubinson's group on separation problems; Messrs. J. D. Knight and E. Steinberg, Dr. N. Sugarman's group on plant problems; and Mr. B. Abraham, Dr. Turkevich's group on theoretical problems.

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C. Sec. 793 and 794. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

~~SECRET~~

~~SECRET~~

C. General Activities of the Section

A report on decontamination problems, with special reference to W material has been prepared by Coryell and issued under the following heading:

GC-576 A Consideration of Decontamination Requirements

Messrs. Gest and Abraham have extended considerably (over section 2 of GN-528) our knowledge of the coprecipitation of Ba by  $\text{LaF}_3$  from 10% nitrate solutions being used to evaluate the general principles of coseparation, and efforts will be made to study other systems of interest with the same view in mind.

Hot radioactive nitrate (S-8 box H) has been furnished to Dr. Balthis for study by the phosphate method. This section is planning to make detailed fission product analyses of the precipitates for studies of specific decontamination of various fission elements.

In collaboration with Dr. Jaffey of Section C-I and with the assistance from Drs. Teller, Fermi, and Wigner, plans have been laid for the improvement of 49 yield at the St. Louis cyclotron. On April 16 and 17 Drs. Jaffey, Brown, Kohman (Section C-I) and Coryell, Elliott, Turkevich and Mr. Engelkemeir (Section C-III) went to St. Louis for extensive monitoring studies of the current 300 lb nitrate mass and of projected alterations involving metal and nitrate or oxide. Due to cyclotron breakdown the projected alterations will have to be tested for capture and fission at a later date. Fission was measured by the radioactivity accumulating in cellophane by recoil from 1  $\text{cm}^2$  of metal; 30m after a 4m irradiation at 50  $\mu\text{m}$  activity of the order of 5,000-12,000 c/m was obtained; 16h later an activity of about 200 c/m was obtained from a stronger sample. Capture was measured by counting the sodium metal acetate precipitate obtained from a solution of the same metal foil.

~~SECRET~~

~~This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C. 50; 81 and 82. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~SECRET~~

1. Elementary Breakdown of Fission Activity in  
the File Operation up to 170 Days

There is presented below the continuation of the study of the distribution of  $\alpha$  and  $\gamma$  activities found in the 100,000 mAh St. Louis uranyl nitrate bombardment which ended October 25, 1942 (called S-3). Earlier data have been reported in Section 1 of CC-342 F and Section 2 of CC-399 D, and the results were summarized for the period from 10 to 110 days cooling in Section 1 of CC-465 B. Data have now been obtained up to 170 days of cooling. In some cases later data have caused slight revisions in the shapes of the best curves through experimental points; the best data are now presented. These changes do not affect any previously reported values prior to 90 days of cooling except in the case of the hard  $\gamma$  from Y. In this instance the hard  $\gamma$  activity at 70d should be 27.3 c/m per gram S-3 instead of 24.7 c/m/g as previously reported. In Fig. 3 of CC-465 B the Y curve should pass through the point 1.4 at 70d instead of 1.3 as shown.

Attention is again called to the corrections that should be made in the La data reported in CC-465 B. The La line of Table I, page B-5 is incorrect at 70, 90, and 110d. The correct values are the following:

70d	90d	110d
14.3	4.9	1.7

In Fig. 1 the correct La curve should be displaced by a constant amount from the Ba curve, corresponding to the experimental ratio of 1.25 La counts per Ba count at 11 mg of absorber. The heading in parentheses for Table II in CC-465 B should read "(counts/min/gm nitrate through 1.9 gm/cm<sup>2</sup> Pb absorber)" instead of "(counts/min/gm nitrate through 1.9 gm/cm<sup>2</sup> Pb Al absorber)" and also the corresponding heading for Table III should read "(counts/min/gm nitrate through 10.7 gm/cm<sup>2</sup> Pb absorber)".

The values here reported for the Zr and Cb activities are based upon a 60d half-life for Zr and a 35d half-life for Cb. The Sr activity includes that of the 60h Y<sup>90</sup> in equilibrium with the long lived Sr<sup>90</sup> reported in CC-529, Section 5 a i.

a. Distribution of "Effective"  $\alpha$  Activity.—"Effective"  $\alpha$  activity is defined as the observed count of the various active elements determined with a total absorption (air gap, cellophane covering, mica window, and self absorption) amounting to 11 mg/cm<sup>2</sup>, which corresponds to the minimum which is practicable. Table I presents the observed values at 20 day intervals from 90 to 170d. All values are reported as counts per minute per gram of S-3.

The activity which was reported in CC-465 B as Pr+Nd is now called Pr+Rare earths, since the only activity which has definitely been identified in this fraction is a 15d Pr.

~~SECRET~~

defense of the United States within the meaning of the Espionage Act, U.S.C. 564 (a) and (b). Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

It is noted that the percent activity accounted for in Table I is low at 150d and 170d. Due to an oversight, values of percent accounted for were not given in Table I of CC-465B (page B-5) for earlier periods of time. The data for the time now studied are:

Cooling:	10d	30d	50d	70d	90d	110d	130d	150d	170d
% Accounted for	92.6	96.3	96.0	95.7	96.9	97.7	96.7	94.9	92.3

It is not known at present whether the falling off is due to experimental error in the low counting rates remaining, or to failure to recognize the presence of certain long lived elements. Since we do not have enough of the S-3 nitrate to mount new samples of the low activities, we shall have to use the activity of the irradiation ended January 23 (S-8) for check and extension work before we can eliminate further discrepancies. The percent of effective  $\beta$  activity associated with each prominent element is given as a function of cooling time from 90-170d in Fig. 1. After 100d Ce becomes the most prominent  $\beta$  emitter. The Cs is slowly gaining in prominence, due to its very long half-life (36y). The  $\beta$  emission from 90d  $Te^{127}$  is obviously very soft, since the  $Te$   $\beta$  decay is largely regulated by the 32d  $Te^{129}$  decay. The Ba-La pair falls to very low values after 120d.

The presentation of the data for "effective"  $\beta$  and  $\gamma$  counting rates has proved of considerable value in rapid laboratory studies and controls in the work of this and other sections, and ought to be of further value in decontamination studies. It has been pointed out in CC-576 that the data for hard  $\beta$  emitters can be multiplied by 0.5 to give the curies of the element in W material containing 250gm of 49 (2,500 KW material from 100d operation, let us say 1 ton). Correction factors for specific elements emitting soft  $\beta$  or  $\gamma$  radiation (Zr or Cb) are also given in CC-576.

b. "Effective Soft  $\gamma$ " Distribution.—The "effective soft  $\gamma$ " counting rate is reported as the counts per minute per gram of S-3 observed with 1.9g of Pb absorber directly on top of the sample. Table II presents the observed values at 20 day intervals from 90 to 170 days and Fig. 2 shows the percent of the observed total count which is due to each activity.

c. "Effective Hard  $\gamma$ " Distribution.—The "effective hard  $\gamma$ " counting rate is reported as the counts per minute per gram of S-3 observed with 10.7g of Pb absorber directly on top of the sample. The contribution due to Bremsstrahlung has not been definitely determined. Table III presents the observed values at 20 day intervals from 90 to 170 days and Fig. 3 shows the % of the observed total count which is due to each activity.

The fall in percentage activity accounted for is greater in effective soft and hard  $\gamma$  activities after 100d than in  $\beta$  activity. It is experimentally much more difficult to get good  $\gamma$  samples, and especial effort will be made to cover this in the new work on S-8 nitrate.

Ce becomes the third most prominent soft and hard  $\gamma$  emitter after 80d (Figs. 2 and 3) due to the high Bremsstrahlung yield in the Pb geometry used. Ru is undoubtedly third in  $\gamma$  in ordinary circumstances. The Te  $\gamma$  decay is set largely by the  $\gamma$  emitting 90d Te<sup>129</sup>. The  $\gamma$  radiation from Cs becomes about as important as that of Te at 170d.

Table I Distribution of Effective Beta Activity Among the Fission Elements

( $10^{-5}$  x counts/min/gram nitrate through 11 mg/cm<sup>2</sup> total absorption)

Element	<u>Days after conclusion of bombardment</u>				
	<u>90d</u>	<u>110d</u>	<u>130d</u>	<u>150d</u>	<u>170d</u>
Sr	79	59.5	44.5	34	25.3
Y	69	53	42	34	27.6
Zr	34.5	27.3	23.0	17.1	13.6
Cb	9.1	8.0	7.0	6.1	5.2
Ru	10.1	8.1	6.7	5.7	5.0
Te	2.56	1.56	1.09	.78	.57
Cs	1.7	1.7	1.7	1.7	1.7
Ba	3.68	1.24	.42	.15	.05
La	4.9	1.68	.57	.21	.07
Ce	74.5	63	55	50.5	47
Pr + Rare earths	4.3	1.64	.73	.41	.29
Totals(a)	299	232	189	159	137
Accounted for:	96.9%	97.7%	96.7%	94.9%	92.3%

(a) The UX contribution has been subtracted from the measurements on the nitrate. It contributes the constant value of 18,000 c/m which is a better estimate than the 17,000 c/m reported in CC-465 B.

Table II Distribution of Effective Soft Gamma Activity Among the Fission Elements

(counts/min/gram nitrate through 1.9 g/cm<sup>2</sup> Pb absorber)

<u>Element</u>	<u>Days after conclusion of bombardment</u>				
	<u>90d</u>	<u>110d</u>	<u>130d</u>	<u>150d</u>	<u>170d</u>
Sr	210	140	94.5	63.5	42.5
Y	87	68	53.5	44	36.4
Zr	980	780	625	495	395
Cb	1370	1180	1010	845	710
Ru	307	219	162	121	92.5
Te	28.3	23.4	19.4	16.2	13.5
I	.7	-	-	-	-
Cs	16.4	16.4	16.4	16.4	16.4
Ba	20.4	7.2	2.6	.91	.54
La	184	66	23.5	8.2	3.2
Ce	315	297	284	274	267
Totals (a)	3690	2980	2450	2110	1840
Accounted for:	95.6%	94.2%	93.5%	89.2%	85.7%

(a) The experimentally observed background of 50 c/m per gram of unbombarded nitrate has been subtracted from the total.

Table III Distribution of Effective Hard Gamma Activity Among the Fission Elements

(counts/min/gram nitrate through 10.7 g/cm<sup>2</sup> Pb absorber)

<u>Element</u>	<u>Days after conclusion of bombardment</u>				
	<u>90d</u>	<u>110d</u>	<u>130d</u>	<u>150d</u>	<u>170d</u>
Sr	120	85.5	61	43.5	31.2
Y	19.8	15.3	12.5	10.4	9.0
Zr	393	309	244	192	151
Cb	510	450	378	312	252
Ru	75	54	39.5	30.2	24.2
Te	10	8.4	7.3	6.3	5.5
Cs	5	5	5	5	5
La + Ba	91	31.7	11.2	3.9	1.3
Ce	139	132	129	128	126
Totals (a)	1450	1160	960	815	710
Accounted for:	94.0%	94.2%	92.4%	89.7%	82.3%

(a) The experimentally observed background of 20 c/m per gram of unbombarded nitrate has been subtracted from the total.

Fig.1 Percent Distribution Beta Radiation among Fission Elements (thru 11 mg/cm<sup>2</sup> Al)

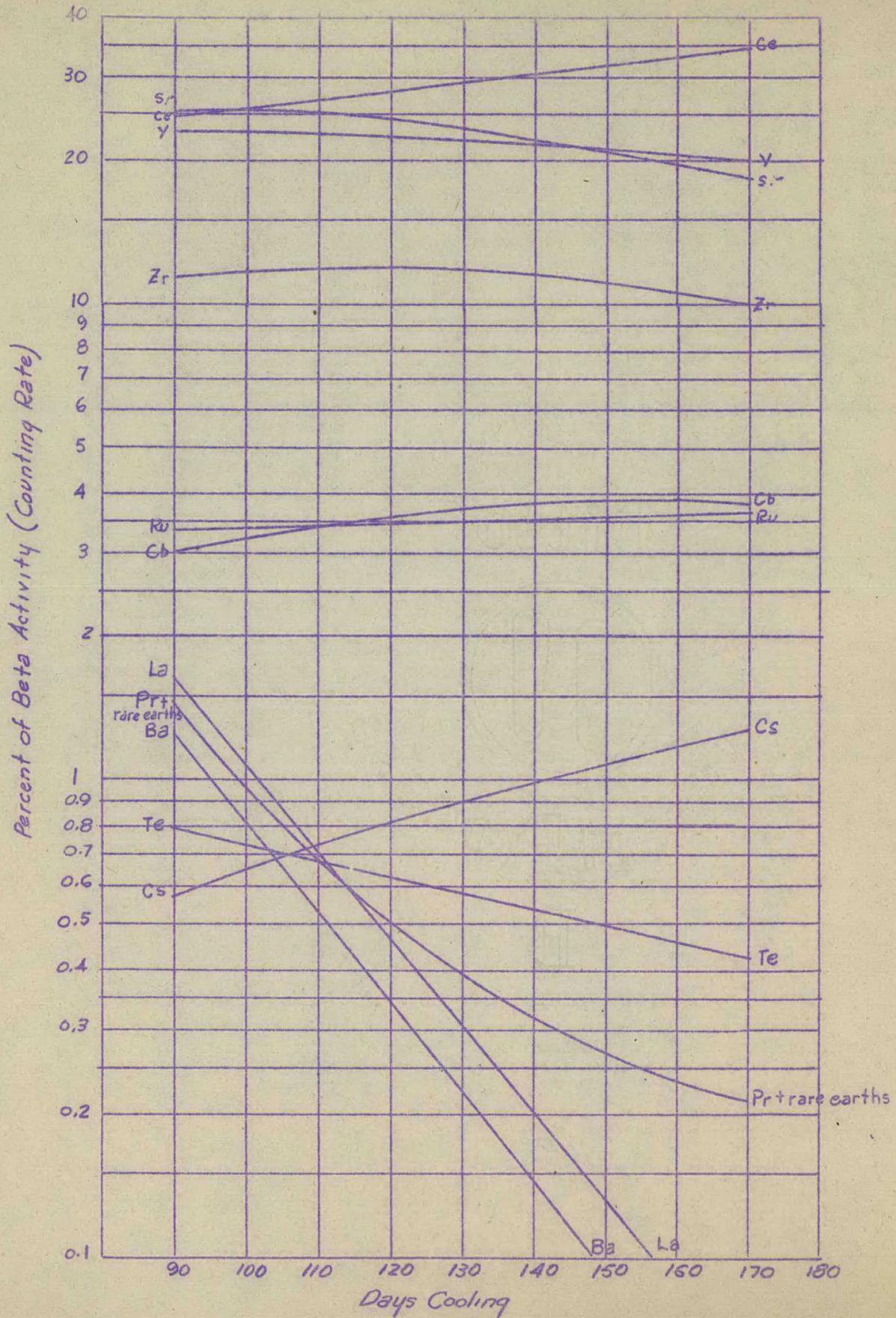


Fig. 2 Percent Distribution "Effective Soft  $\gamma$ " Radiation among Fission Elements (thru 1.9 g Pb)

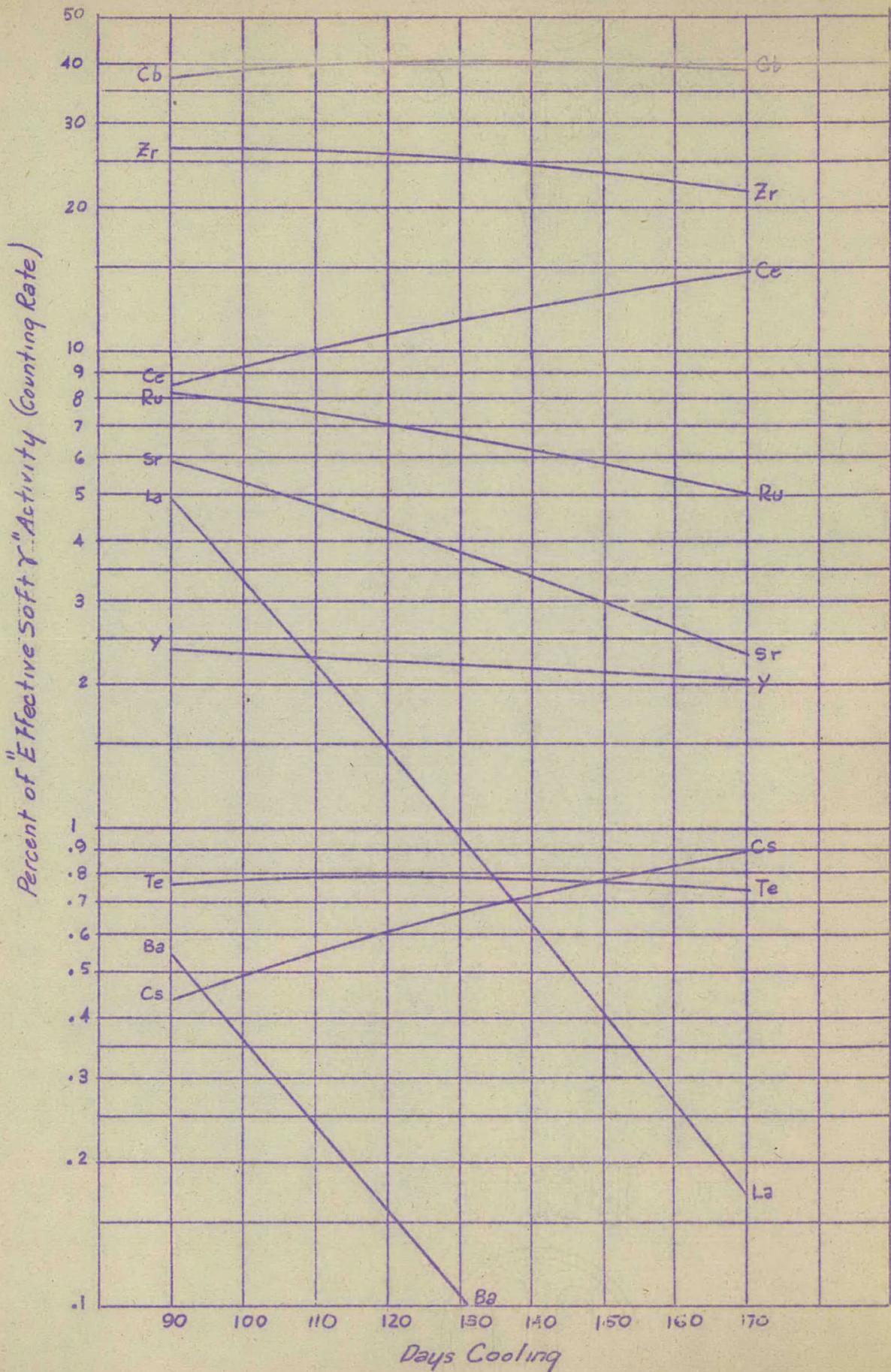
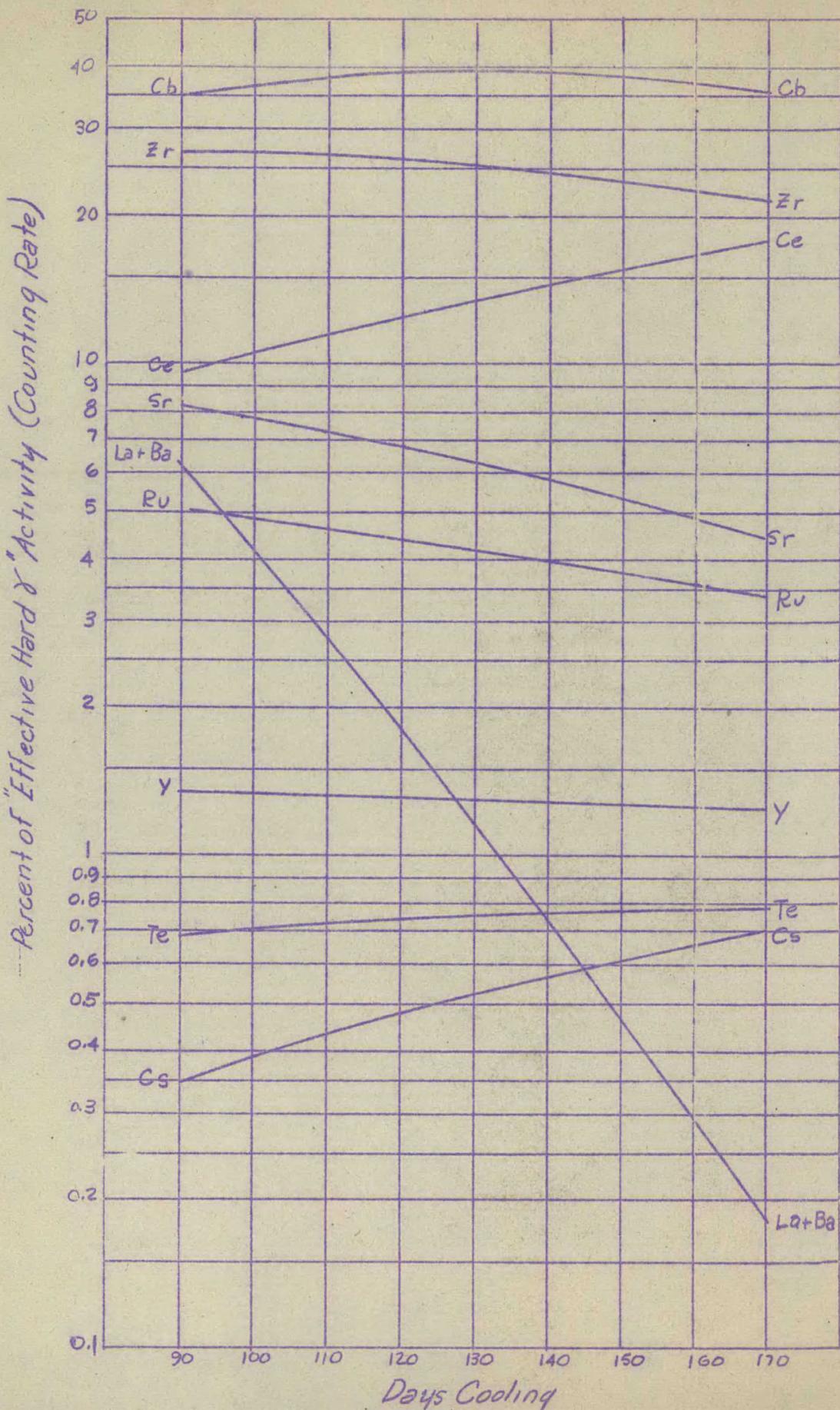


Fig. 3 Percent Distribution of "Effective Hard  $\gamma$ " Radiation among Fission Elements



2. Heat Generation of Individual  $\beta$  and  $\gamma$  Activities (L. Winsberg and Wm. Rubinson).

Calculations have been made of the heat generation of the different individual  $\beta$  and  $\gamma$  activities of eight of the most important fission products as a function of bombardment time and time of cooling, and the results graphed as watts vs days. As a basis for calculation convenient for transformation to any other conditions, we have chosen a pile of 1000 KW power, or  $3 \times 10^{16}$  dis/sec. As bombardment time, we have taken  $T = 5, 10, 15, 20, 30, 40, 50, 60, 80, 100, 120, 150, 200, \infty$  days. The cooling time is taken long enough for the activity to fall to one watt.

We now have available graphs for the following elements and latest data:

<u>Element</u>	<u>Half-life</u>	<u>Fission yield</u>	<u>E <math>\gamma</math></u>	<u>E<math>\beta</math>(max)</u>
Sr	55d	.075	-	1.7
Y	57d	.074	-	1.4
Zr	60d	.04	0.8	(.42 (95%) (1 (5%))
↓				
Cb	35d	.04	.75	.15 (e <sup>-</sup> )
Mo	67h	.08	.8	1.3
Ba	12.5d	.084	-	1.0
↓				
La	40h	.084	2.1	1.84
	28d	.07		0.2
Ce	340d	.10		0.2

For an element formed directly in fission or deriving from a short-lived parent:

$$\text{Watts} = \frac{4.18 \left( \frac{\text{watt-sec}}{\text{cal}} \right) \times 23.054 \left( \frac{\text{cal}}{\text{mole.e.v.}} \right) \times f \left( \frac{\text{fissions}}{\text{sec}} \right) \times y \times \frac{E}{3} (\text{e.v.}) \phi(\lambda, T, t)}{6.02 \times 10^{23}}$$

$= 1.60 \times 10^3 y E \phi(\lambda, T, t)$ , where  $\phi$  is a time dependent function,  $f$  is the number of fissions/sec,  $y$  is the fission yield and  $E$  is the maximum energy of the  $\beta$  particle.  $1/3 E$  is assumed to be the average  $\beta$ -energy. For  $\gamma$  radiations the factor  $1/3$  is omitted.

For an element the life of whose parent must be taken into account the constant factor is different:

$$\begin{aligned} \text{Watts} &= \frac{4.18 \times 23.054 \times f \times y \times \frac{E}{3}}{6.02 \times 10^{23} (\lambda_p - \lambda_d)} \psi(T, t, \lambda_p, \lambda_d) \\ &= 1.60 \times 10^3 y E \frac{\psi(T, t, \lambda_p, \lambda_d)}{\lambda_p - \lambda_d} \end{aligned}$$

### 3. New Fission Product Activities and Re-evaluation of Old Data

a. Discovery of 55 min and 30 sec Rh activities—Daughters of 30d and 200d Ru Activities (L. E. Glendenin and E. P. Steinberg)—In view of the extremely hard  $\beta$  radiation (4 Mev) associated with the 200d Ru activity a search was made for an anticipated short-lived Rh daughter to account for this penetrating radiation. A very active sample of Ru separated from S-8 material (St. Louis bombardment ending Jan. 23, 1943) and containing  $\sim 10^6$  c/m (at 30% geometry) of 30d Ru activity was distilled from  $\text{HClO}_4$ . 10 mg of Cd carrier was added to the residue and  $\text{Cd}(\text{OH})_2$  precipitated with 6N NaOH. This precipitate which carries Rh was mounted and the decay followed on an Eck-Krebs counter. A 55 minute period was observed for several hours which finally tailed-off to a long-lived background. This background activity was first assumed to be incompletely distilled Ru, but an Al absorption curve showed that this was not the case. Two radiations with half-thicknesses of  $\sim 10$  mg/cm<sup>2</sup> and  $\sim 70$  mg/cm<sup>2</sup> were present in the long-lived activity. Neither of these corresponds to any known Ru activity so the background activity remains unidentified. An Al absorption curve of the 55 min Rh indicated a radiation of  $T_{1/2} = \sim 80$  mg/cm<sup>2</sup> as well as  $\gamma$  radiation. The activity of the 55 min Rh extrapolated to time of separation was  $\sim 30,000$  c/m which represented  $\sim 3\%$  of the 30d Ru activity or  $\sim 15\%$  of the 200d Ru.

The experiment was repeated on a Ru sample from S-2 material (St. Louis bombardment ending July 22, 1942). The activity of this sample was  $\sim 10,000$  c/m (at 30% geometry) and consisted entirely of the 200d isotope. No decay in activity was observed in the  $\text{Cd}(\text{OH})_2$  precipitated from the distillation residue. The 55 min Rh is evidently not the daughter of 200d Ru. The parent is very probably the 30d Ru. The decay curve of the 55 min Rh is given in Fig. 4.

Following the discovery of the 55 min Rh a method was devised for finding a very short-lived Rh daughter of the 200d Ru activity. The S-8 Ru sample mentioned above was distilled from  $\text{HClO}_4$ , and the residue in the distillation flask placed immediately near a Geiger counter. Two minutes elapsed from the beginning of distillation to the beginning of the decay curve. Consequently about one minute of decay time was lost. A 30 second decay period was observed over several half lives. The activity then tailed-off to a constant value due to a small amount of incompletely distilled Ru. It is now evident that the 4 Mev  $\beta$  radiation is ascribable to the 30 sec Rh and that the radiation of the 200d Ru parent is so weak that it is not observed. However, there is some evidence from absorption data on the 200d Ru taken in a low absorption counting device (with 0.3 mg/cm<sup>2</sup> of self-absorption) for the existence of a radiation of  $< 10$  mg/cm<sup>2</sup> range. Further work will be carried out on older material in which the only Ru activity is the 200d activity to definitely prove the parent-daughter relationships. Decay and growth curves of the 30 sec Rh are given in Fig. 5 and 5a.

b. 45 Activities in Fission (L. E. Glendenin)—In previous work it was observed that decay curves of 6.6h 45 separated by  $\text{HClO}_4$  distillation tailed-off to longer-lived activities of  $\sim 4$ d and  $\sim 60$ d periods. Later work (cf CC-529) showed that the 60d activity was not due to element 45 but probably due to Ru contamination. It is now evident that the  $\sim 4$ d activity is also due to contamination chiefly by 67h Mo which follows element 45 in small quantities in the distillation method of 45 separation.

Fig. 4  
55 m. Rh Daughter of 30d Ru

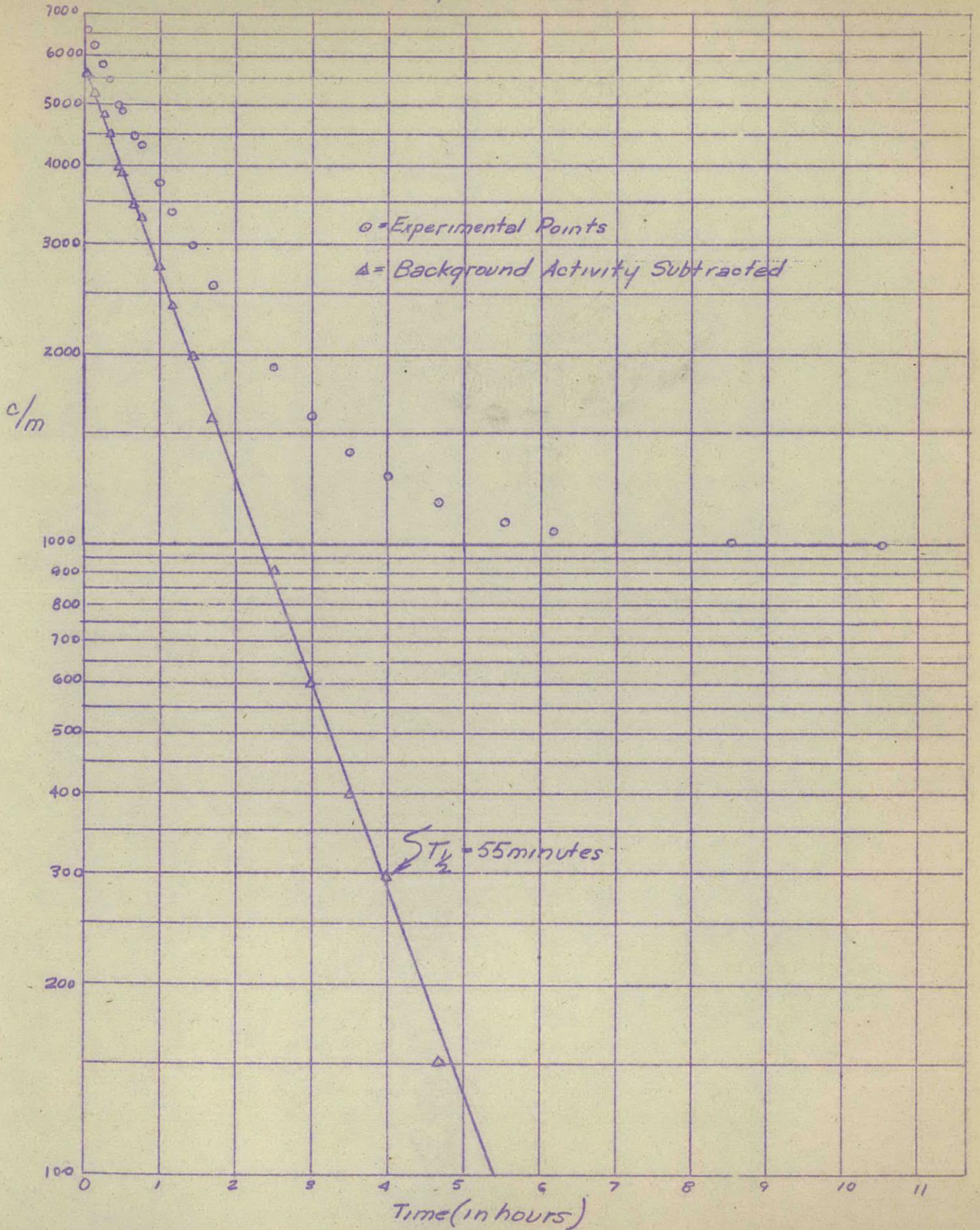
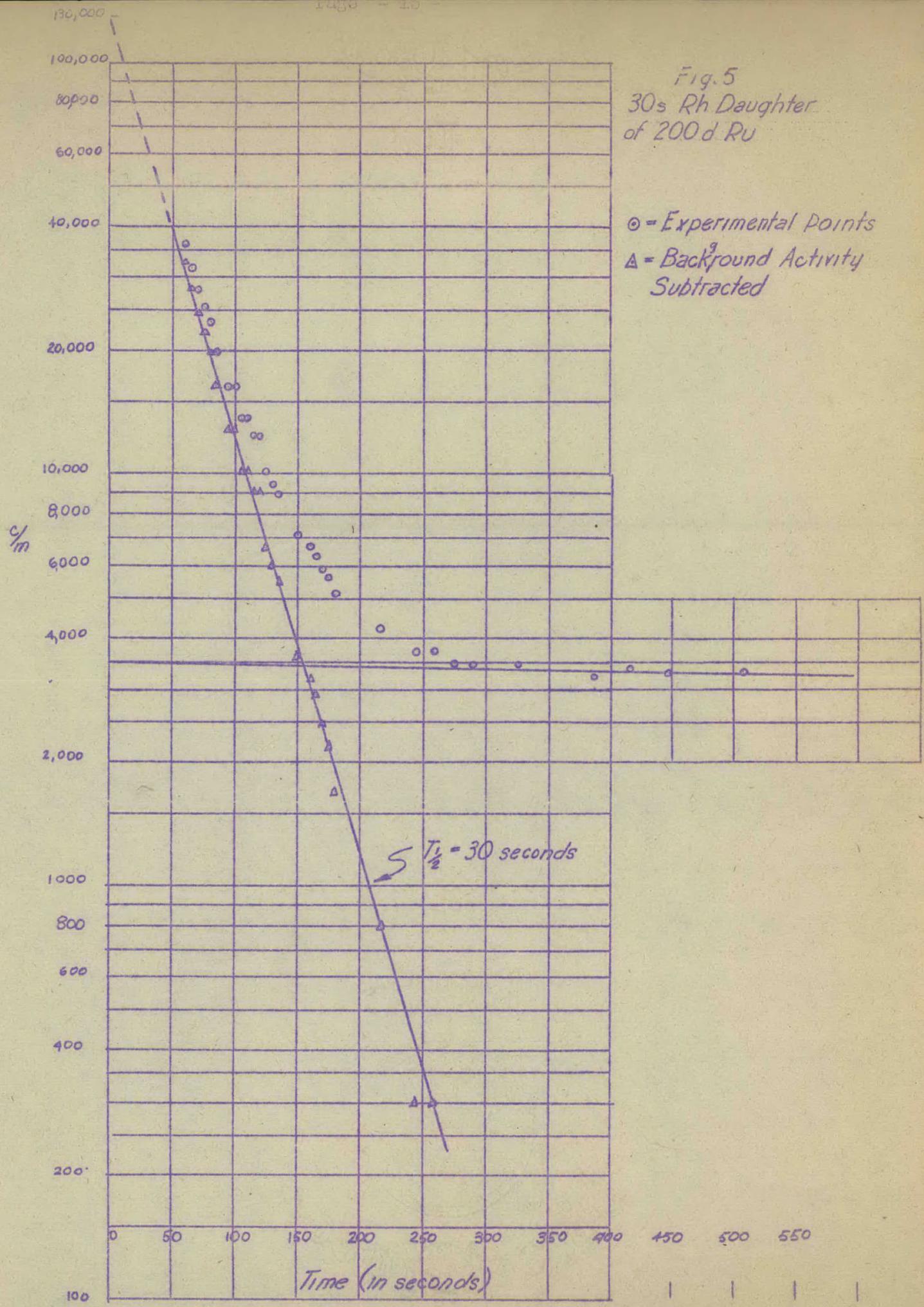
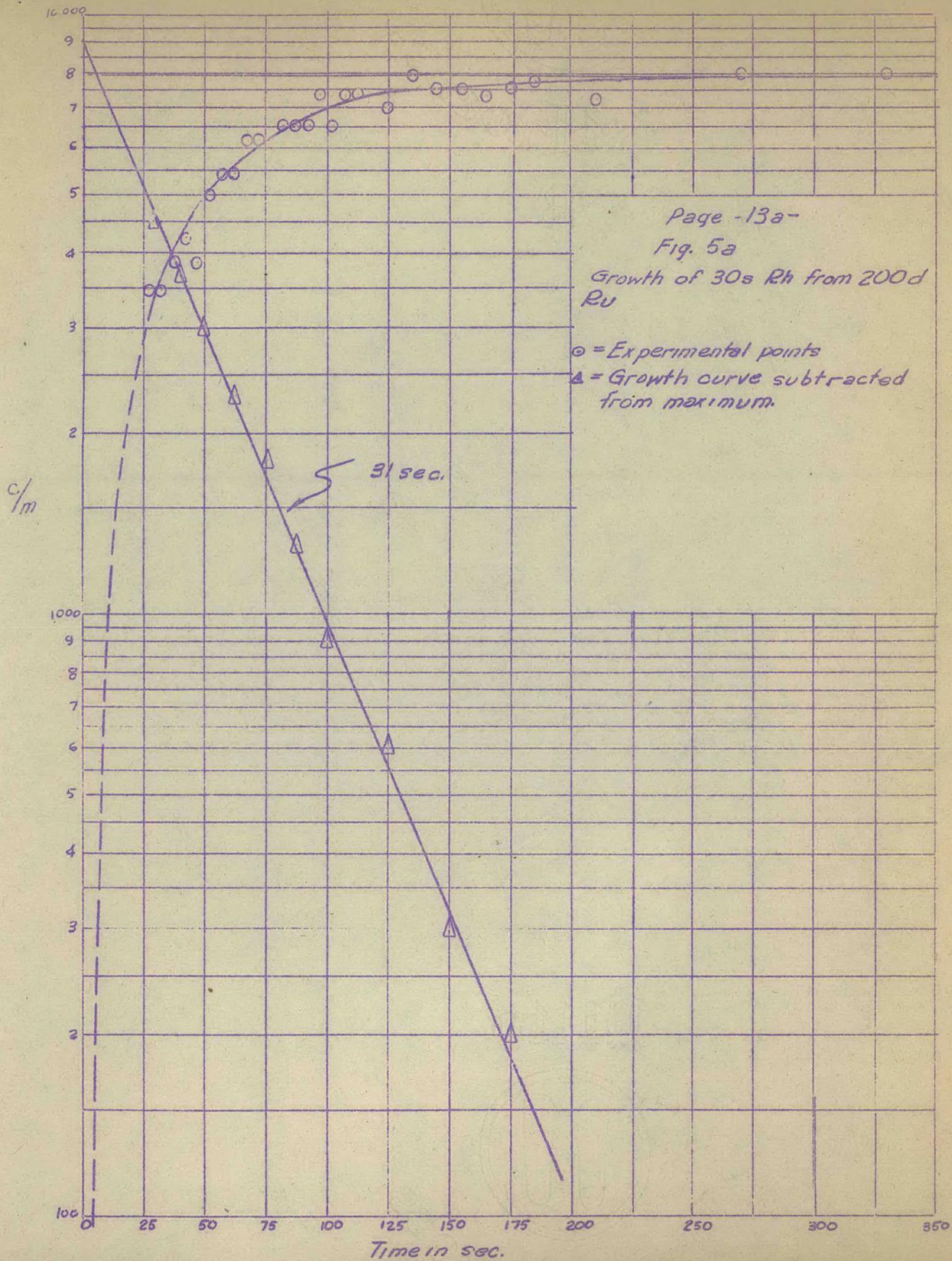
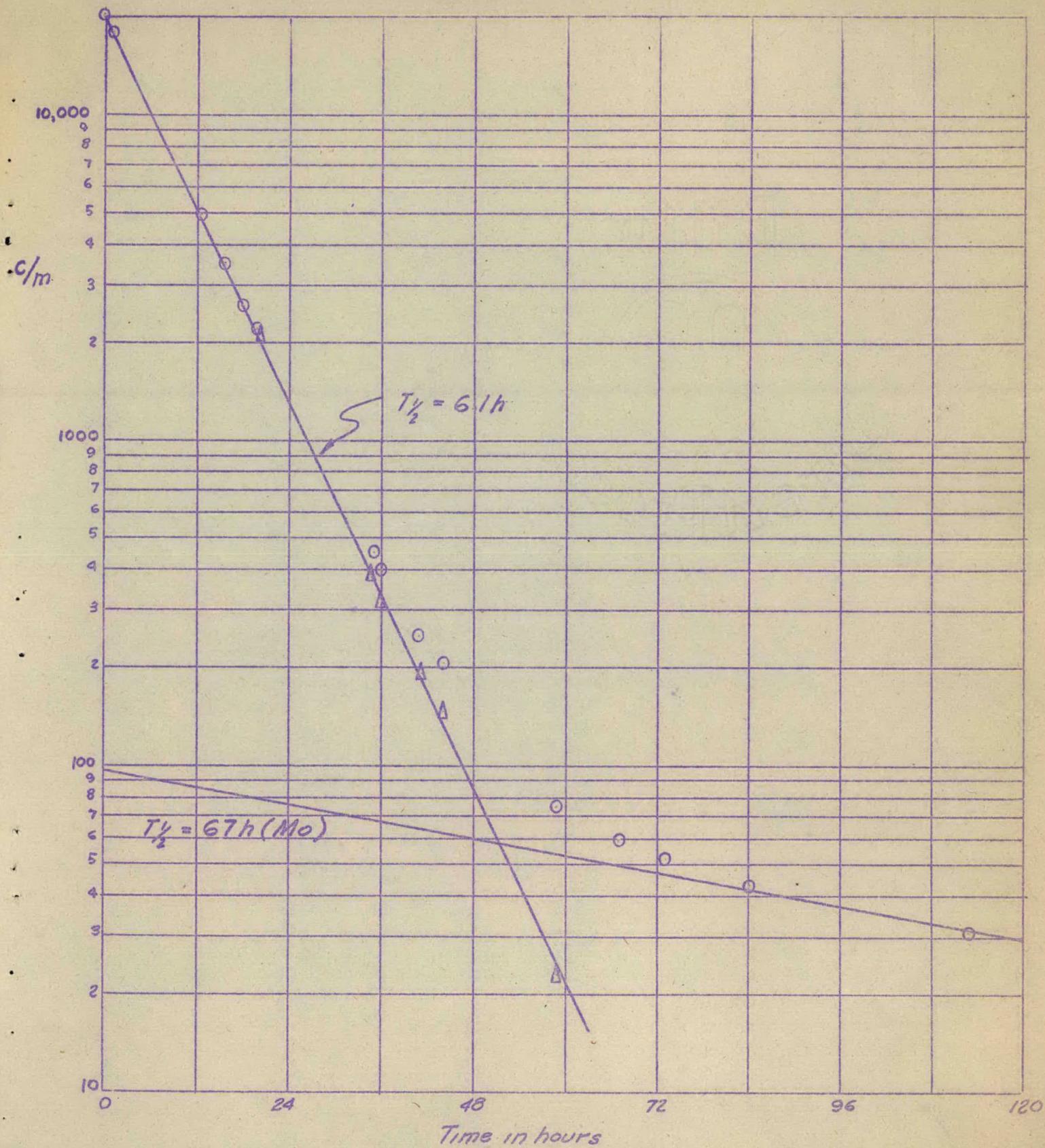


Fig. 5  
30s Rh Daughter  
of 200d Ru





6.1 h 93 (daughter of 67h Mo)



A  $Ru_2 S_3$  precipitation was made from 25gm of S-11 material (St. Louis bombardment ending Mar. 13, 1943). This was dissolved in aqua regia and distilled from  $HClO_4$ . The distillate was boiled with ethanol which precipitates the Ru as an oxide. The filtrate from this oxide was made ~ 5N in  $H_2SO_4$ , 5 mg of Re carrier was added, and  $Re_2S_7$  precipitated with  $H_2S$ . The  $Re_2S_7$  was dissolved in a little aqua regia, and a nitron perhenate precipitation made. This precipitate was dissolved in hot 5N  $H_2SO_4$ , and  $Re_2S_7$  reprecipitated with  $H_2S$ . The sample was mounted and its decay followed closely. The 6.6h  $^{43}$  tailed-off to a ~ 3d activity and finally to a much longer-lived background. The ~ 3d activity represented ~ 0.5% of the total  $^{43}$  activity at time of separation, and the long-lived background was 0.02% of the initial  $^{43}$  activity. When this background was extrapolated and subtracted from the decay curve, the 3d activity was found to be 66h which suggested that it was 67h Mo. An Al absorption curve of the 66h component showed that it was indeed the 67h Mo. Evidently, small quantities of Mo either distill with Ru and  $^{43}$  or are carried over in spray and coprecipitate with the  $^{43}$ . The low intensity long-lived activity is probably a slight contamination by Ru. It is seen from this work that there is no activity present other than the 6.6h ascribable to element  $^{43}$ . Our best value for the half-life of  $^{43}$  based on several decay curves of  $^{43}$  from fission material is  $6.1 \pm 0.2h$  (Fig. 5a).

c. Ce in Fission Chains (cont.) (N. E. Ballou)--Studies to determine the parentage of the Ce activities are being continued.

A sample of the nitrate was irradiated with slow neutrons for 50 ~ ah on March 31, 1943 and the La fraction was rapidly isolated (according to procedure of report CC-258). Successive Ce extractions were made from this La fraction at intervals of some hours, and the decay curves followed. These curves are quite complex, but they indicate that both the 1.8h Ce (which has a 4.5h Pr daughter) and the 28d Ce (which forms a stable Pr) have La parents of 1 hour or longer. It will be necessary to follow the curves longer before definite assignments of parentage of the 1.8h Ce and the 28d Ce can be made.

Attention should be called to the report by M. L. Pool and J. D. Kurbatov, appearing in the Bulletin of the American Physical Society, 18, 9 (1943), on the various Ce activities from cyclotron bombardment. They obtained a 30d  $Ce^{141}$  which goes to stable  $Pr^{141}$ , and a 36h  $Ce^{143}$  which decays to 13.5d  $Pr^{143}$ . These half-lives and isotopic assignments agree with previous work done by us and reported in CC-529, CC-465, and CC-389. They also obtained a 140d  $Ce^{140}$  which decays by isomeric transition with the emission of a 0.21 Mev  $\gamma$  to the stable  $Ce^{140}$ . It was formed in the two reactions,  $Ba^{137} (\alpha, n) Ce^{140}$  and  $La^{139} (d, n) Ce^{140}$ . The 140d Ce does not appear to be formed to any appreciable extent in fission as the daughter of 40h  $La^{140}$ . Glendenin has followed a gamma decay curve of 12.5d Ba (which is the parent of 40h La) through 1.9 gm of Pb for about 3 months. It was calculated that about 60% of the total observed activity at the end of this 3 month period would be due to  $Ce^{140}$  if it were formed in this chain. In the calculations the effect of 1.9 gm of Pb on the counting efficiency of the 0.2 Mev  $\gamma$  was taken into consideration. Since the decay curve did not flatten out, 140d  $Ce^{140}$  is not formed in appreciable extent as the daughter of 40h  $La^{140}$ .

4. Theoretical Study of  $\beta$ -Absorption Curves and Correlation with Feather Method of  $\beta$ -Energy Determination (T. Novey, E. Steinberg, N. Ballou, G. Campbell, and L. Winsberg)—Theoretical curves for the  $\beta$  energy distributions for various maximum  $\beta$  energy were obtained from the Fermi theory of  $\beta$ -disintegration. These curves have been used to estimate the average  $\beta$  energy corresponding to a given maximum  $\beta$  energy. Tyler (Phys.Rev. 56, 125, 1939) has shown the validity of the Fermi distribution curve for the  $\beta$  radiation from thin samples.

We have also been interested in correlations between range and energy. The absorption curve for monoenergetic electrons is nearly linear with absorber thickness; using the theoretical  $\beta$  distribution curves calculated, a synthetic absorption curve can be made for a  $\beta$  emitter. We have done this below, using the Sargent range-energy relation (Coryell, Seaborg Lecture Notes CL 440). This curve is closely similar to the experimental RaE curve obtained in our apparatus (CC-529, section 3 a 1) which we use in the Feather Method for analyzing  $\beta$  absorption curves (CC-529, section 3 b).

The probability,  $W$ , for the emission of electrons of energy in the range  $E$  to  $E+dE$  is given by the Fermi theory as:

$$W = A E^{\frac{1}{2}} (1+2E) (1+E)^{\frac{1}{2}} (E_m - E)^2 dE$$

where  $A$  is a constant for a given activity,  $E$  is the  $\beta$ -energy, and  $E_m$  is the maximum  $\beta$ -energy, both expressed in Mev. This equation is an approximate one, good to  $\sim 2\%$  (Pollard & Davidson, Applied Nuclear Physics, App.4). A less exact, but simpler, equation, good to within 15% for values of  $E$  less than 2 Mev is:

$$W = B(E) (3+2E) (E_m - E)^2 dE$$

where  $B$  is a constant for any one activity. The constants  $A$  and  $B$  are chosen to normalize the distribution function, i.e.,

$$\int_0^{E_m} W = 1$$

The  $\beta$  distributions for  $E_{\max} = 0.5, 1, 2, 3$  Mev were calculated from the second formula and are given in Fig. 6. The most probable energy is found to be proportional to the maximum energy, being at .4 of the range. The average energy was also calculated and was found to be .42 of the maximum energy from  $E_m = 0.5$  Mev to  $E_m = 3$  Mev.

In calculating the absorption curves from the distribution curves, it was assumed that for small energy intervals the absorption in Al would be linear. That this is almost true for monoenergetic electrons in Al except near the range is shown in some work done by W. Wilson as given by Rutherford, Chadwick, and Ellis, p.414 (1930). The fact that the tail of the curve falls off the linear curve is of no great concern since the center of the absorption curve is the most important part for  $\beta$ -energy determinations.

Linear absorption curves were drawn for small energy intervals taking the value of  $W$  as the activity at no absorber and the Sargent value of the range for the particular energy interval under consideration. The total absorption curve was then obtained by adding these individual curves for the small energy intervals and is given in Fig. 7 A.

One calculation of an absorption curve using the more exact Fermi equation was made for  $E_m = 1$  Mev. This is the lower curve in Fig. 7 A from which it is seen that no great error is introduced by using the less exact equation.

The absorption curve was then subjected to a Feather analysis (Fig. 7 B), i.e., compared with the RaE absorption curve by the method outlined in CC-529, section 3b and in p.54 of CL-440. The data give a surprisingly good breakdown by this method, particularly since it has been shown that the shape of an Al absorption curve of a  $\beta$  emitter is a function of the counting geometry (Fig. 3-3 of report CC-529). (It must be recalled that we have based our synthetic absorption curve approximately on the geometry used by Varder with absorbers placed in the electron path in the magnetic spectrograph giving monoenergetic beams.)

The average range shown in Fig. 7 C is  $430 \text{ mg/cm}^2$  (broken horizontal line) which corresponds to a maximum  $\beta$  energy of 1.09 Mev (Feather range-energy curve Fig. A of C-200 or CL-440). This Feather energy is higher than any Sargent  $\beta$  energy assumed. The maximum range by the Sargent curve is however  $430 \text{ mg/cm}^2$  for 1.0 Mev. The extrapolated range (continuous curve of the figure) leads to the range  $380 \text{ mg/cm}^2$ , corresponding to a maximum energy of 0.99 Mev.

In CC-529 (section 3b) we adopted for the present the convention of averaging the Feather range over the fractions of range observed. The empirical nature of the synthetic curve of Fig. 7 C prevents its use as an argument against this convention. Further work is in progress in the field of analysis of  $\beta$  curves.

Fig. 6 Fermi distribution curves for various values of  $E_{max}$ .

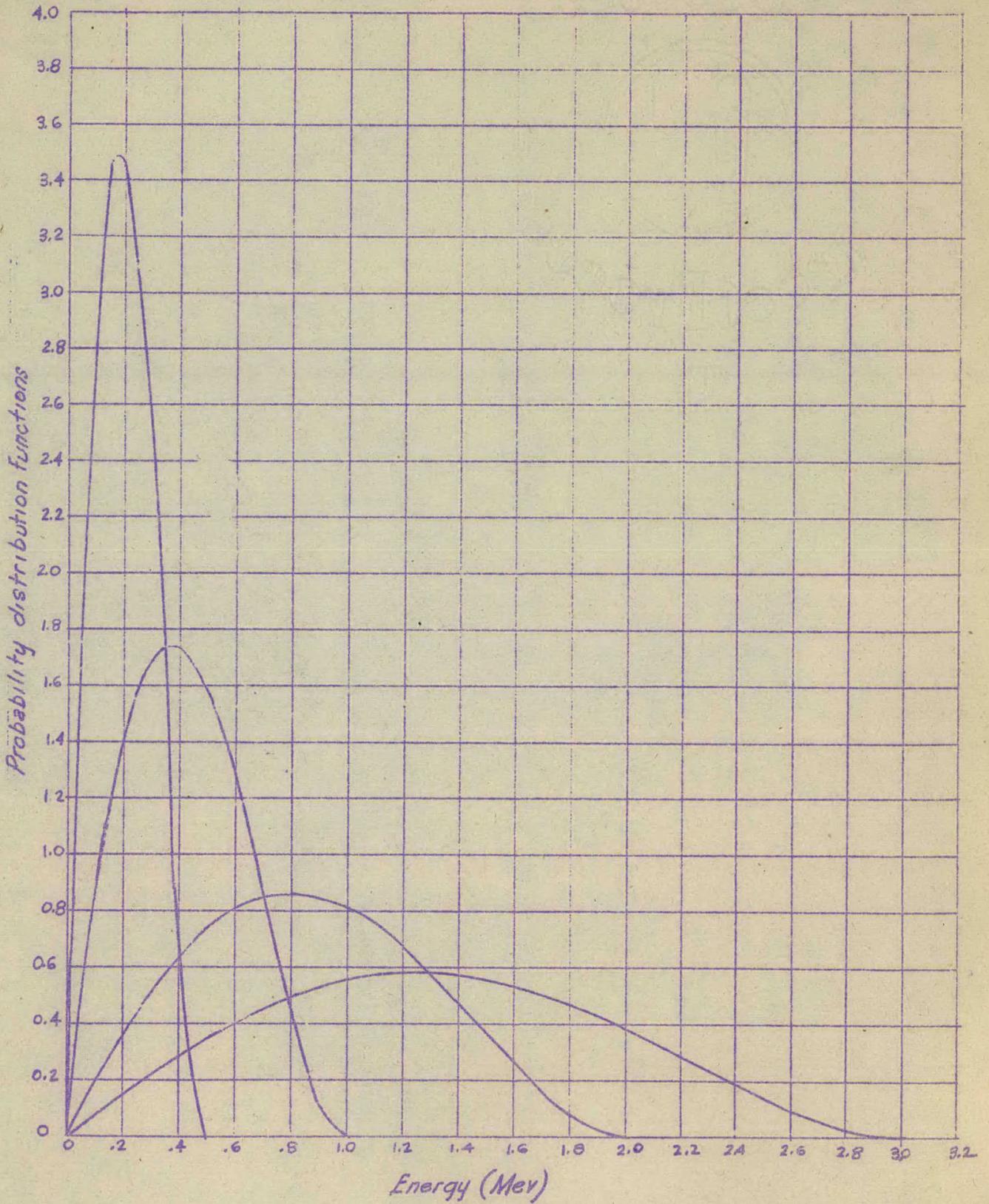


Fig. 7

Theoretical Absorption Curves for 1 Max  $\beta$

Sargent Range = 420 mg Al/cm<sup>2</sup>  
Feather Range = 385 mg Al/cm<sup>2</sup>

learning analysis

