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ARTIFICIAL RADIOACTIVE ISOTOPES OF CERIUM AND LANTHANUM

James B. Chubbuck

Special Review of Declassified Reports
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ARTIFICIAL RADIOACTIVE ISOTOPES OF CERIUM AND LANTHANUM

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ABSTRACT

A description of some bombardments performed with the 60-inch and 184-inch cyclotrons at Berkeley. These bombardments resulted in the production of the following isotopes: 19.5 hour La^{135} which decays by orbital electron capture and emits gamma radiation of 0.76 Mev energy; 2.1 hour La^{136} which decays by positron emission, the positron having 0.84 Mev energy; La^{137} which has a half-life greater than 400 years; 16 hour Ce^{135} which decays by positron emission; 36 hour Ce^{137} which decays by orbital electron capture emitting conversion electrons of 0.18 Mev energy and gamma radiation of 0.28 and 0.75 Mev energies; and 140 day Ce^{139} which decays by orbital electron capture emitting conversion electrons of 0.15 Mev energy and gamma radiation of 0.18 and 1.8 Mev energies.

To be used as Thesis.

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ARTIFICIAL RADIOACTIVE ISOTOPES OF CERIUM AND LANTHANUM

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INTRODUCTION

In this thesis are described some studies of the radioactive isotopes of cerium and lanthanum lying on the light or neutron-deficient side of stability. It was only with the development of the large accelerators at Berkeley that it became possible to investigate isotopes far on the light side of stability and these are, of course, of interest as new nuclear types. The high energies required for the bombarding particles were not heretofore available. The production of Ce^{135} by bombarding stable La^{139} with deuterons, for example, requires knocking out six neutrons, the (d,6n) reaction. A further point of interest for the particular isotopes investigated here lies in the fact that the fast particle fission of bismuth has produced neutron-deficient radioactive isotopes in this region and the studies in this paper have helped to identify some of these. Finally, these studies fill a few gaps in the table of isotopes and thus give a better picture of the distribution of half-lives and decay properties on the light side of stability.

In these studies radioactive isotopes of cerium were produced by bombarding lanthanum with deuterons in both the 60-inch and 184-inch cyclotrons. Those of lanthanum were produced both by bombarding cesium with helium nuclei in the 60-inch cyclotron and by the decay

of orbital electron capture or positron-emitting isotopes.

In Chapter I, two isotopes of lanthanum, La^{135} and La^{136} are assigned characteristics previously assigned to La^{137} and La^{138} respectively and further characteristics are reported for each. La^{137} is discussed briefly. Evidence is presented for the mass assignments made. Both La^{135} and La^{136} were produced by bombardments in the 60-inch cyclotron. La^{135} was also produced by the decay of the positron-emitting Ce^{135}.

Chapter II is concerned with two new isotopes of cerium, Ce^{135} and Ce^{137}, and evidence is given for their mass assignments. Both cerium isotopes were produced in the 184-inch cyclotron. Further characteristics of Ce^{139} are given. This isotope was produced in bombardments with the 60-inch cyclotron.

Chapter III consists of a summary, and yield data for the various bombardments are tabulated.

These experiments were performed under the direction of Dr. I. Perlman, to whom I am indebted for his continued interest and assistance. I wish to thank Dr. G. Wilkinson, Mr. H. Hicks, Mr. R. H. Goeckermann, Mr. M. Lindner and other members of the chemistry section for their help and suggestions. I wish also to thank Dr. J. G. Hamilton, Dr. D. C. Sewell, Mr. J. T. Vale, Mr. T. Putnam and Mr. B. Rossi for cooperation in operating the 60-inch and 184-inch cyclotrons. This research was conducted under Contract No. W-7405-eng-48 in connection with the Atomic Energy Commission with the Radiation Laboratory, University of California, Berkeley, California.

CHAPTER I

ARTIFICIAL RADIOACTIVE ISOTOPES OF LANTHANUM

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Berkeley, California

INTRODUCTION

On the neutron-deficient side of stability two radioactive isotopes of lanthanum, La^{137} [1,2] and La^{138} [3] are reported in the literature but more recent evidence [4] shows La^{138} to be stable and present in nature to the extent of 0.089 per cent. No lighter isotopes of lanthanum have previously been reported. La^{137} is reported in the references above to decay by orbital electron capture with a 17.5 hour half-life and to have gamma radiation of 0.88 Mev energy. It was produced by the reaction Ba(d,xn). Since barium has five stable isotopes, this mass assignment could easily have been in error. Evidence will be presented below for assigning these characteristics (with some changes) to the mass assignment La^{135}. La^{138} reported above is assigned a half-life of 2.2 hours but no other characteristics are given. Evidence will be given below for the assignment of an activity of this half-life to La^{136} and further characteristics will be given. It is not clear that La^{136} could have been produced in the bombardment of Pool, Cork and Thornton [3].

In all bombardments of lanthanum with deuterons to produce cerium isotopes by the (d,xn) reaction appreciable amounts of La^{140} were produced by the (d,p) reaction. This isotope is so well-known [5] that it has not been discussed in this thesis.

The higher energies now available with the 60-inch and 184-inch cyclotrons permit the bombardment of cesium with helium nuclei to produce lanthanum isotopes by the reaction (α,xn). Since there is only one isotope of cesium present in nature, difficulties of working with an element like barium with its five stable isotopes are avoided.

EXPERIMENTAL

The cesium samples used were in the form of $CsNO_3$, prepared by A. D. Mackay Co. and stated to be of greater than 99% purity. Spectrographic analysis[6] showed rubidium to be present to the extent of less than 0.5% so the cesium was assumed to be of sufficiently high purity. Any appreciable content of rubidium would have greatly complicated the chemistry by producing isotopes of yttrium in the bombardment. The separation of yttrium and lanthanum is time-consuming, and since short-lived lanthanum isotopes were sought, it was essential that the cesium be of high purity.

Cesium in the form of 1.13 gms. of dry, powdered $CsNO_3$ was mounted on a copper backing plate of the 60-inch cyclotron and covered with a 28 mg/cm^2 aluminum foil. This foil was chosen of proper thickness to reduce to 30 Mev the normal beam of 37 Mev helium nuclei. The dry, powdered crystalline $CsNO_3$ was pressed into the central depression of the backing plate and the Al foil placed over it. With the Al foil cemented along the edges of the central depression, no displacement or loss of the target material due to handling was observed.

The sample was bombarded with 30 Mev helium nuclei for two hours. Immediately after the bombardment the target material was dissolved in

water and barium and lanthanum carriers were added. The solution was then saturated with HCl gas in an ice bath, ethyl ether was added and the solution shaken. The precipitated $BaCl_2$ was filtered out, both the precipitate and filtrate being retained. The filtrate was diluted with 10 ml. H_2O, made alkaline with concentrated NH_4OH and the lanthanum precipitated as the hydroxide. The $La(OH)_3$ was washed several times with cold H_2O and dissolved in a few milliliters of concentrated HCl. Barium carrier was added again and the precipitation of $BaCl_2$ with HCl gas and ethyl ether was repeated. This cycle was repeated a third time and the lanthanum again precipitated as the hydroxide. After washing several times again with cold H_2O, the $La(OH)_3$ was dissolved in three ml of 6N HCl and this solution used as stock solution for preparation of samples for decay curves and absorption curves. The chemistry of this bombardment would have been more precise, and less chance for contamination of the lanthanum introduced, if the lanthanum had been precipitated as LaF_3. However, no complications were evident.

The $BaCl_2$ from the first precipitation was retained so that its activity might be checked. Results are discussed below.

COUNTING EQUIPMENT

Electrons and electromagnetic radiations were counted with argon-ethyl alcohol filled Geiger tubes having mica windows of about 3 mg/cm^2 thickness. The pressure in the tubes was 10 cm of Hg, 95% of the pressure being produced by pure argon and 5% by the ethyl alcohol vapor[7]. Geometry factors were assumed as follows[8]: first shelf 30%, second shelf 10%, third shelf 5%, fourth shelf 2% and fifth shelf 1%.

Positrons and negative electrons were differentiated with a magnetic counter, with which the paths of emitted particles are bent by a magnetic field so as to direct the particles into a Geiger tube. Reversal of the direction of the magnetic field permits the differentiation of positive and negative electrons. The magnetic counter also permits an estimation of the energies of the particles. By varying the magnetic field from zero to some maximum value, at the same time recording the number of counts for the applied magnetic field at that particular time, a curve is produced starting at the counter background, rising to a peak(point of maximum counts) and descending to the background. In this paper energies of positrons have been taken as the energy at the visual end point of the magnetic counter curves. Visual end points selected are indicated on the appropriate figures. Calculations of energies were made from the formula $H\rho$ (in gauss-cm) $= (10^4/3)(E^2 + 1.02E)^{1/2}$, where E is in Mev. The energy of conversion electrons from orbital electron capture isotopes was taken as the energy corresponding to the peak of the curve, since these electrons are homogeneous in energy and not distributed as are the energies of β particles. The magnetic counter also shows when there are no charged particles being emitted from a radioactive isotope. The use of this function of the magnetic counter will appear in the results to be discussed below. The energies of positrons and conversion electrons were also determined by beryllium absorption curves. In fact, the energies as determined from absorption curves are probably more accurate, since the magnetic counter has not been calibrated. Counting efficiency of electrons was taken as 100%.

The energies of electromagnetic radiations (x-rays and gamma rays) were determined by absorption in aluminum and lead.

The determination of the presence of L x-rays was made in only one case, La^{135}, since their energies in this region of the periodic table are so low, about 5.2 Kev, that they are usually masked by electron radiation. K x-rays and gamma rays up to 0.5 Mev energy were assumed to have a counting efficiency of 0.5%. For energies greater than 0.5 Mev, the counting efficiency in per cent was assumed equal to the energy in Mev, i.e., a gamma ray of 0.75 Mev energy was assumed to have a counting efficiency of 0.75%[9].

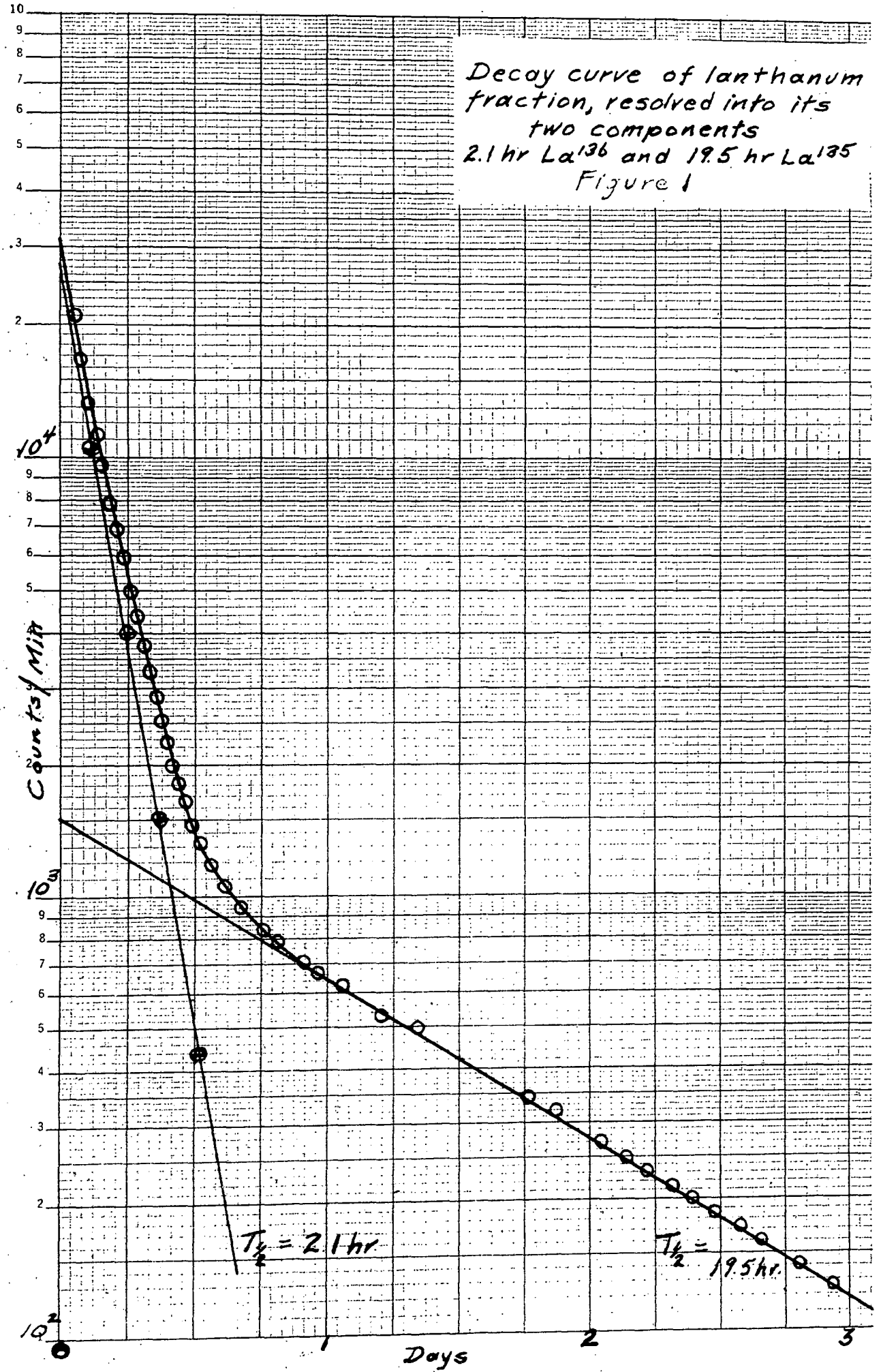
For all absorption curves reproduced in this paper, correction has been made for the mg/cm^2 equivalent of the counter window, the air gap between window and sample and the material covering the sample. The samples are assumed to have been sufficiently thin to require no correction for self-absorption.

CROSS SECTION MEASUREMENTS

Cross sections were calculated on the assumption that the target was thin and that the beam intensity was not diminished appreciably by the sample. The total beam current for the bombardment was obtained from the cyclotron records, the number of atoms bombarded was calculated from the known weight of the sample and the number of atoms transmuted was estimated from counting data.

RESULTS

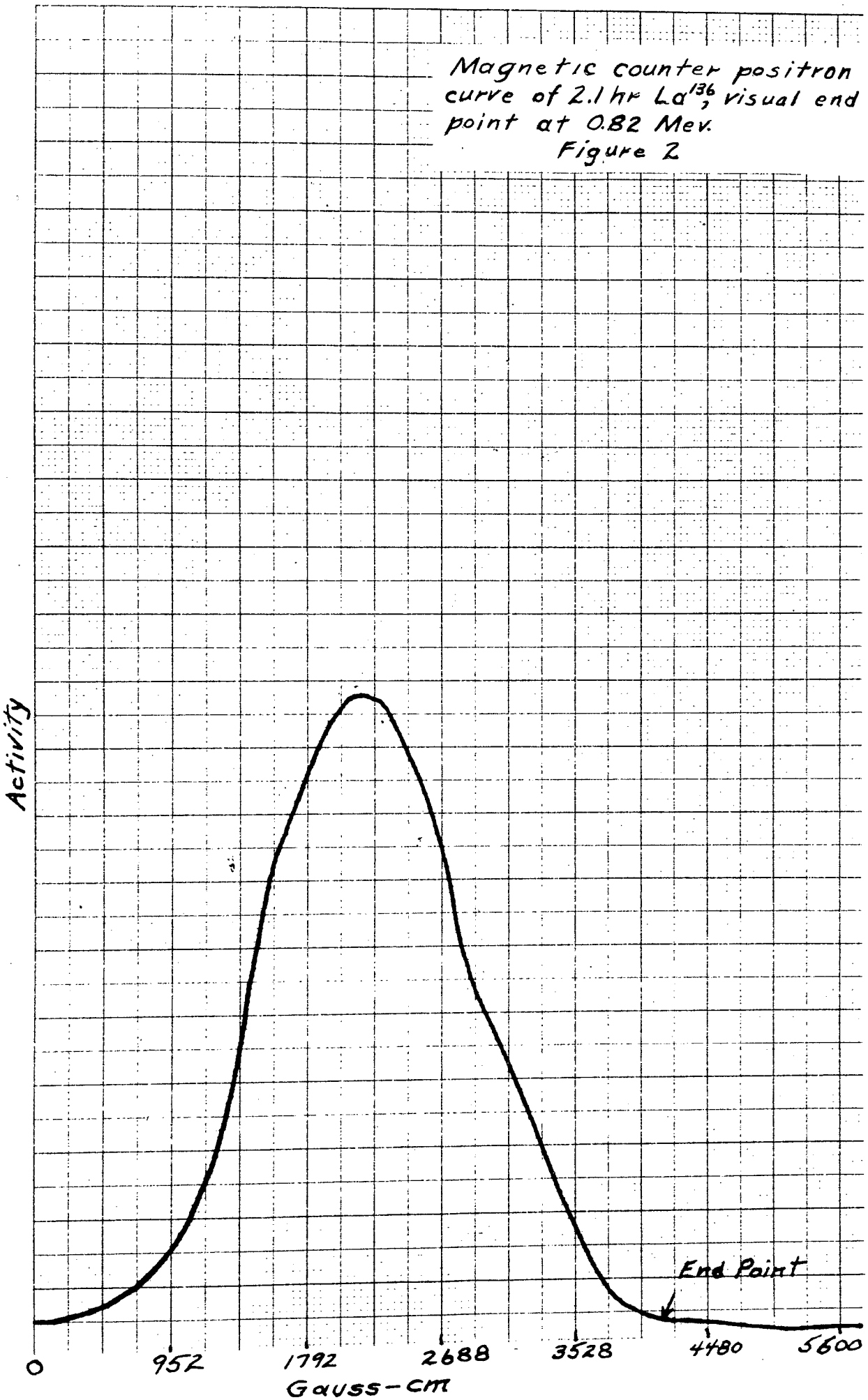
<u>2.1 hour La^{136}.</u> A sample of the lanthanum fraction from the irradiation of cesium with 30 Mev helium ions was followed in its decay, resulting in the decay curve shown in Figure 1. This resolved


Decay curve of lanthanum fraction, resolved into its two components 2.1 hr La136 and 19.5 hr La135
Figure 1
Counts/Min
Days
T½ = 2.1 hr.
T½ = 19.5 hr.
10⁴
10³
10²
0
1
2
3

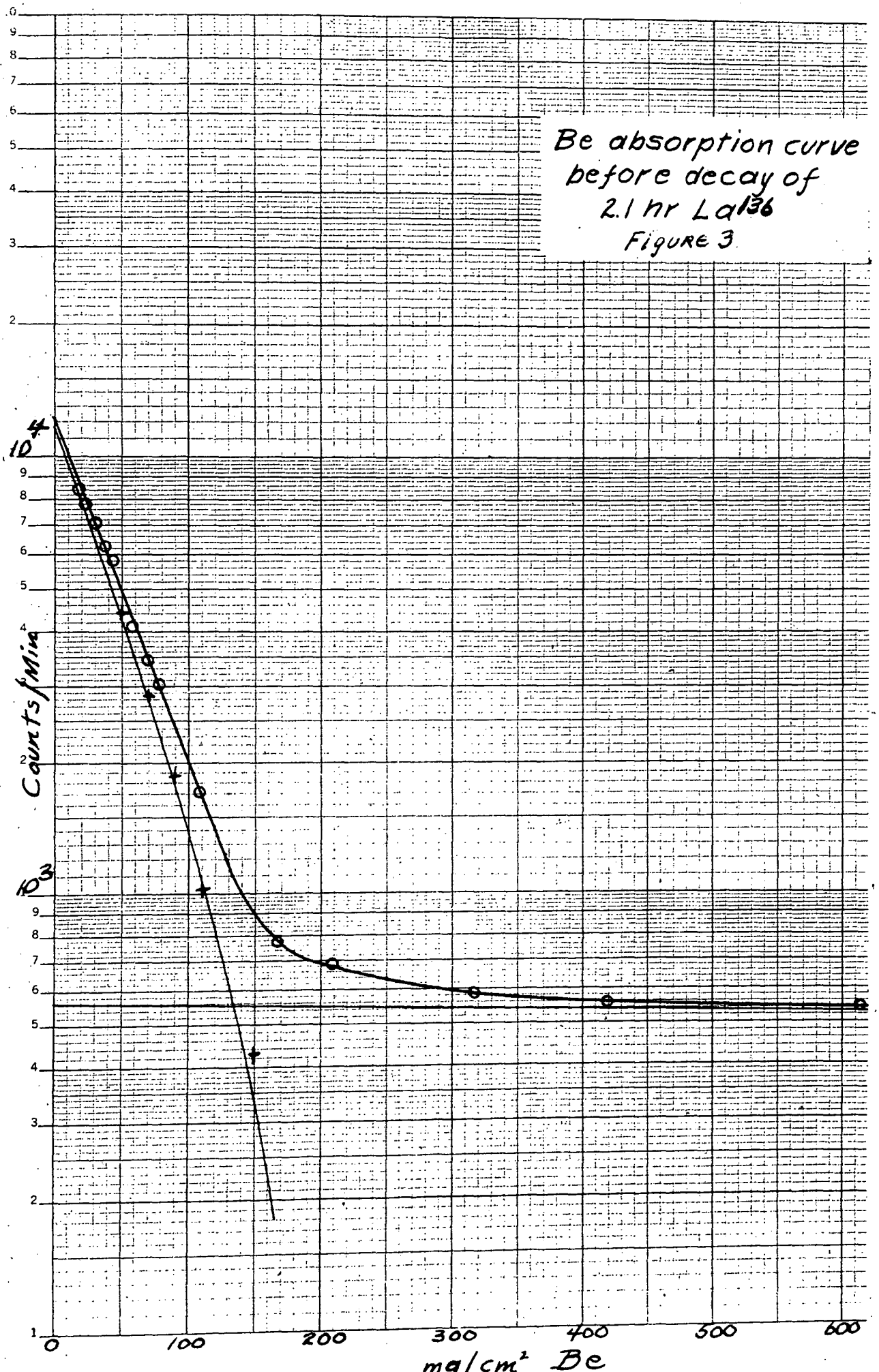
into 2.1 hour and 19.5 hour half-lives. Both of these periods, therefore, must belong to isotopes of lanthanum of mass number 136 or lower.

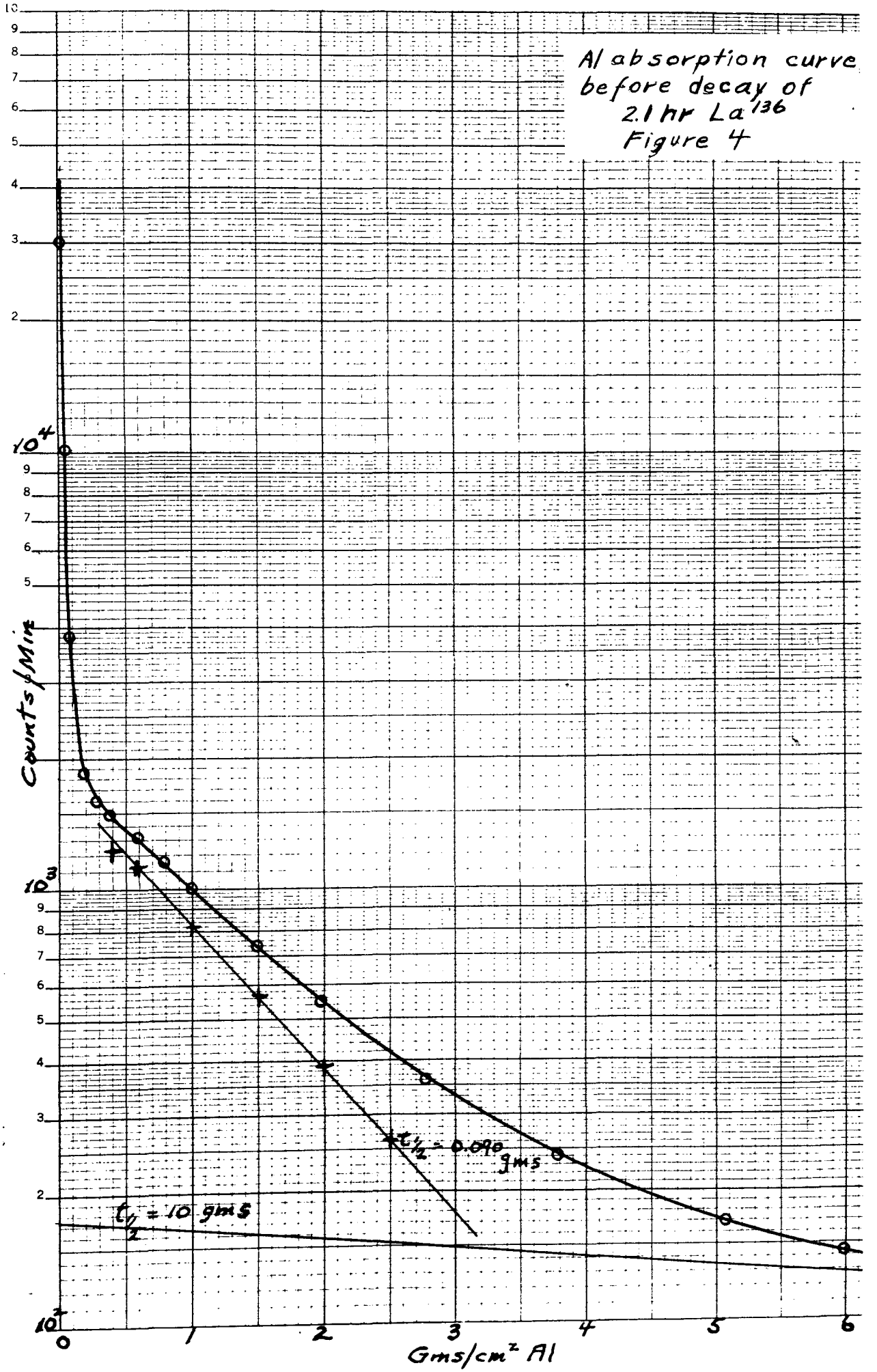
Immediately after the lanthanum was separated a sample was placed on the magnetic counter and a well-defined positron peak was observed. This peak is reproduced in Figure 2. The same sample showed no negative particles. The visual end point corresponded to an energy of 0.82 Mev. A beryllium absorption curve, corrected for decay of the sample during the time necessary to take the absorption data, is shown in Figure 3. A part of the curve does not appear but the line indicating the gamma background is as shown. The high gamma background is caused by the gamma radiation of the 19.5 hour La^{136} also present. A Feather analysis of this curve gives a range in beryllium of 310 mg/cm^2, corresponding to an energy of 0.84 Mev. Allowing more weight to the range determined by the Feather analysis, we take the energy of the positron as 0.84 Mev.

An aluminum absorption curve corrected for decay was also taken shortly after the bombardment, while both components were still present. This curve, Figure 4, could not be accurately resolved in so far as the gamma radiation was concerned. Estimating the position and drawing the line for the gamma radiation at the proper slope for the 0.76 Mev gamma determined in the lead absorption curve, Figure 6, I resolve K x-rays of about 34 Kev. Part of the curve is off the paper, but the curvature continues so the missing part is of no help. The 0.84 Mev positron causes the curve to rise so steeply at the left, and on an expanded scale the positron could be resolved.



Magnetic counter positron curve of 2.1 hr La^{136}, visual end point at 0.82 Mev.
Figure 2


Be absorption curve
before decay of
2.1 hr La136
Figure 3
Counts/Min
10^4
10^3
0
100
200
300
400
500
600
mg/cm² Be

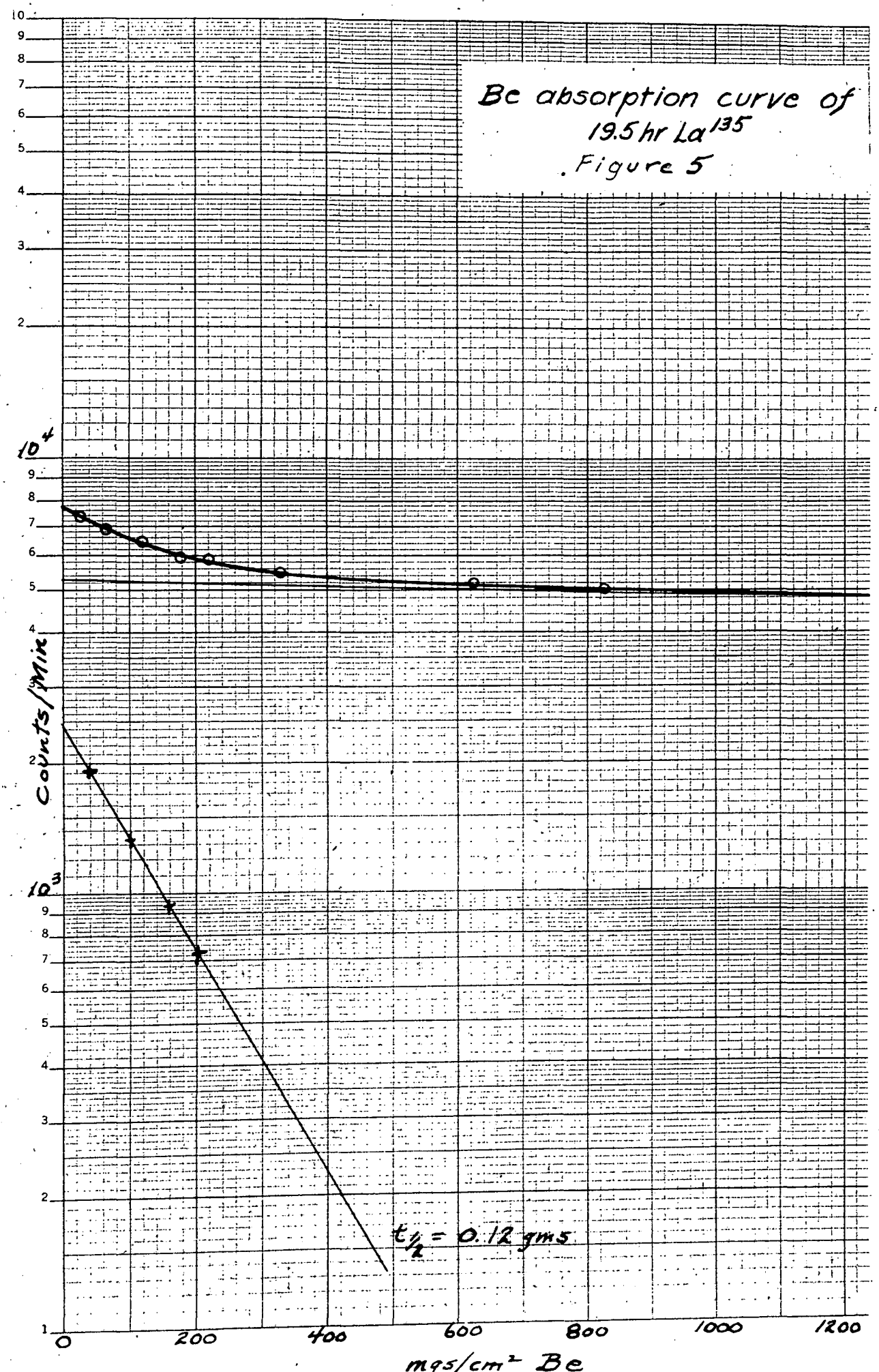

Al absorption curve
before decay of
2.1 hr La 136
Figure 4
Counts/Min
Gms/cm² Al
t½ = 10 gms
t½ = 0.090 gms
10⁴
10³
10²
0
1
2
3
4
5
6

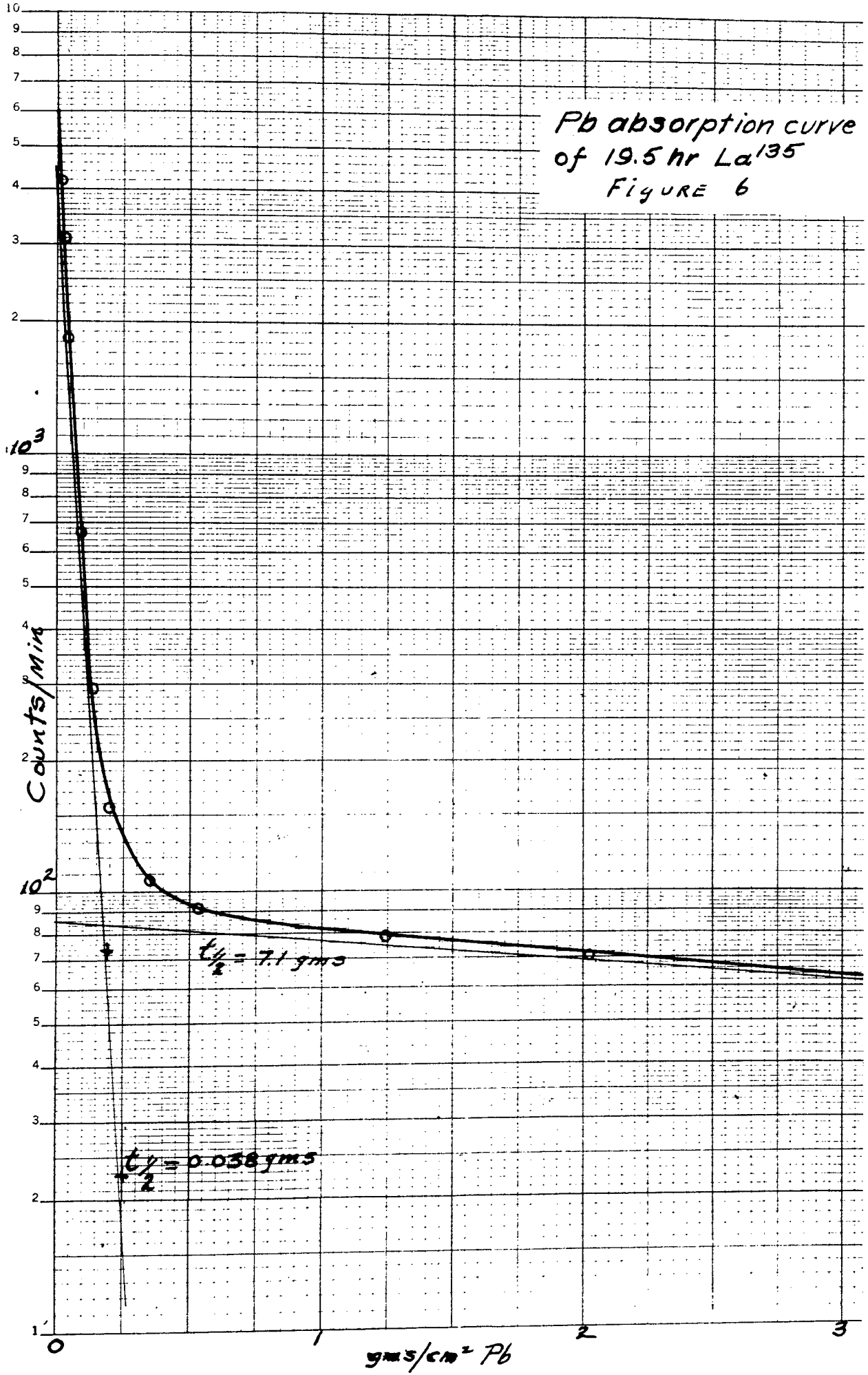
A beryllium absorption curve was taken about twenty-four hours after the bombardment, when the 2.1 hour activity had decayed through about eleven half-lives and could be assumed to have disappeared. This beryllium absorption curve is shown in Figure 5. It is immediately apparent that there are no particles present in the radiation. The curvature is seen to be due to L x-rays. The counting efficiency of particles, too, is so much higher than that of gamma radiation that the curve would have dropped much more before leveling out at the gamma background if any particle radiation had been present. It is evident from this curve that the positron belongs to the short-lived component.

A comparison of the beryllium absorption curve containing both lanthanum components, Figure 3, with that containing La^{135} alone, Figure 5, shows that all the electromagnetic radiation in Figure 3 belongs to the La^{135}. In arriving at this conclusion allowance was made for difference in sample size and decay of the La^{135} during the time between the taking of the two curves. Thus the 2.1 hour La^{136} has no electromagnetic radiation.

A lead absorption curve taken at about this same time is shown in Figure 6. A small part of this curve does not appear. This curve resolves into two components, the K x-rays and a gamma radiation of about 0.76 Mev.

I conclude, therefore, that the 2.1 hour activity is the positron-emitter, and that no other radiation is associated with it. It will be noticed that x-rays are more abundant than gamma rays by a factor of about 50. In other words, there is only about one gamma ray for each 50 disintegrations.


Be absorption curve of
19.5 hr La135
Figure 5
Counts/Min
10^4
10^3
t1/2 = 0.12 gms
0
200
400
600
800
1000
1200
mgs/cm² Be



Pb absorption curve of 19.5 hr La^{135}
FIGURE 6

The Table at the end of this paper shows the yields in terms of cross sections for the various bombardments performed. From this table it appears that La^{136} (2.1 hour activity) was formed in about 1/100 the yield of the La^{135} (19.5 hour activity). With the energy of helium nuclei employed, the (α, 2n) reaction is more prolific than the (α, n) reaction[10]. I conclude that the 2.1 hour activity was formed by the (α, n) reaction and assign it to mass number 136. The fact that La^{136} is an odd-odd isotope is further evidence that the mass assignment is correct, since odd-odd radioactive isotopes in this region of the periodic table may be expected to have greater decay energy and therefore to decay by positron emission and to have shorter half-lives than adjacent odd-even isotopes.

La^{136} is, therefore, a positron-emitter, the positron has an energy of about 0.84 Mev and there is no other radiation associated with the isotope. It has a half-life of 2.1 hours.

<u>19.5 hour La^{135}.</u> The discussion of La^{136} above has brought out the characteristics of La^{135}. It is assumed to decay by orbital electron capture, although the proper absorbers were not available to determine the element to which the x-rays belong.

This same activity, or at least an activity of the same half-life was found in the decay of a cerium isotope, Ce^{135}, to be discussed below. Successive separations of the lanthanum daughter of Ce^{135} all showed the 19.5 hour activity. Since Ce^{136} is stable the 19.5 hour activity could not have been its daughter.

I conclude, therefore, that the 19.5 hour activity decays by orbital electron capture and emits the following radiation: L x-rays and K x-rays which are in agreement with values for barium, and gamma radiation of about 0.76 Mev energy. I assign it to mass

number 135.

La^{137}. In Chapter II, the radioactive isotope of cerium assigned to mass number 137 is discussed. The lanthanum daughter of this isotope was very low in activity. Successive long counts in the Geiger counter showed only 4-6 counts per minute above background. Considering the activity of the cerium parent and its half-life, I conclude that La^{137} is quite long-lived, with a half-life of more than 400 years, if its radiation can be detected. This estimation of half-life is based on a comparison of gamma radiation counts of parent and daughter. Its activity was so low that no other characteristics could be determined. It probably decays by orbital electron capture.

The barium activity produced in this bombardment was followed in its decay and found to have a half-life of about 39 hours. This is obviously Ba^{133} produced by the reaction $Cs^{133}(\alpha,p3n)Ba^{133}$. This isotope is so well-known[5] that it is not discussed here. I calculate a cross section of 0.00073×10^{-24} cm^2 for the formation of this isotope. This is probably a combination of two reactions, Ba^{133} formed directly by the $(\alpha,p3n)$ reaction, and Ba^{133} produced by the decay of La^{133} formed by the $(\alpha,4n)$ reaction. La^{133} is probably very short-lived and would have decayed to Ba^{133} before Geiger counts were taken.

CHAPTER II

ARTIFICIAL RADIOACTIVE ISOTOPES OF CERIUM

INTRODUCTION

Seaborg's Table of Isotopes[5] reports Ce^{140} to have an excited state, decaying by isomeric transition to the ground state with a half-life of 140 days, emitting gamma radiation of 0.21 Mev energy. More recent evidence[11] shows that x-rays also emitted are those of lanthanum, and that, therefore, this isotope is properly assigned to Ce^{139}, which decays by orbital electron capture to stable La^{139}. Evidence will be given below to show that this isotope also emits conversion electrons and that the energy of the gamma radiation is more nearly 0.18 Mev. Ce^{139} is reported[12] to be a positron emitter with a half-life of 2.1 minutes but this is believed to be in error.

Two new isotopes of cerium, Ce^{135} and Ce^{137}, are discussed and evidence is given for their mass assignments. Radiation characteristics are given for Ce^{137}. As will be seen below, Ce^{135} was produced in such low yield that it was impossible to determine its characteristics, other than to say that it is a positron emitter of about 16 hours half-life.

It should be remarked that Ce^{136}, Ce^{138}, Ce^{140} and Ce^{142} are all stable[5].

EXPERIMENTAL

The lanthanum samples bombarded with deuterons to produce cerium isotopes by the (d,xn) reaction were in the form of La_2O_3, prepared by roasting $La_2(C_2O_4)_3$. The lanthanum oxalate was prepared

by Daane at Iowa State College and is stated to be "believed very pure". It is stated that the lanthanum oxalate might contain as much as 1% CeO_2. When bombarded in the 60-inch cyclotron the La_2O_3 was mounted as described above for $CsNO_3$. When bombarded in the 184-inch cyclotron the La_2O_3 was mounted on an aluminum plate which in turn was attached to the probe of the 184-inch cyclotron. For bombardments in the 60-inch cyclotron a 0.00025 inch thick tantalum foil was used to cover the target material. In the 184-inch cyclotron bombardments a 0.001 inch thick aluminum foil was used.

Immediately after the bombardments the target material was dissolved in about three milliliters of 6N HNO_3. Cerium carrier was added, the solution was made up to eight ml with concentrated HNO_3 and solid $KBrO_3$ was added (and dissolved) to oxidize the cerium to the ceric state. The solution was placed in an ice bath, HIO_3 was added and the cerium precipitated as $Ce(IO_3)_4$. After stirring in the ice bath for two minutes the ceric iodate was centrifuged out and washed with H_2O. The ceric iodate was then dissolved in one drop concentrated HCl, one drop H_2O_2 and eight ml of concentrated HNO_3. Lanthanum carrier was added and the oxidation and precipitation of the cerium was repeated. This cycle was performed five times to insure the purity of the cerium fraction. After the fifth precipitation and washing of $Ce(IO_3)_4$, the ceric iodate was dissolved in one drop of concentrated HCl, one drop of H_2O_2, and four ml of concentrated HNO_3. The solution was diluted to ten milliliters with H_2O and $Ce(OH)_4$ was precipitated with concentrated NaOH. The hydroxide was washed with H_2O and dissolved in one ml of 6N HCl.

The solution was diluted to ten ml and residual iodate was reduced to iodide by bubbling SO_2 gas through the solution. The cerium was precipitated as the hydroxide with concentrated NH_4OH, the $Ce(OH)_4$ was washed with H_2O and then dissolved in three ml of 6N HCl. This last solution was used as stock solution from which aliquot portions were taken for decay and absorption measurements.

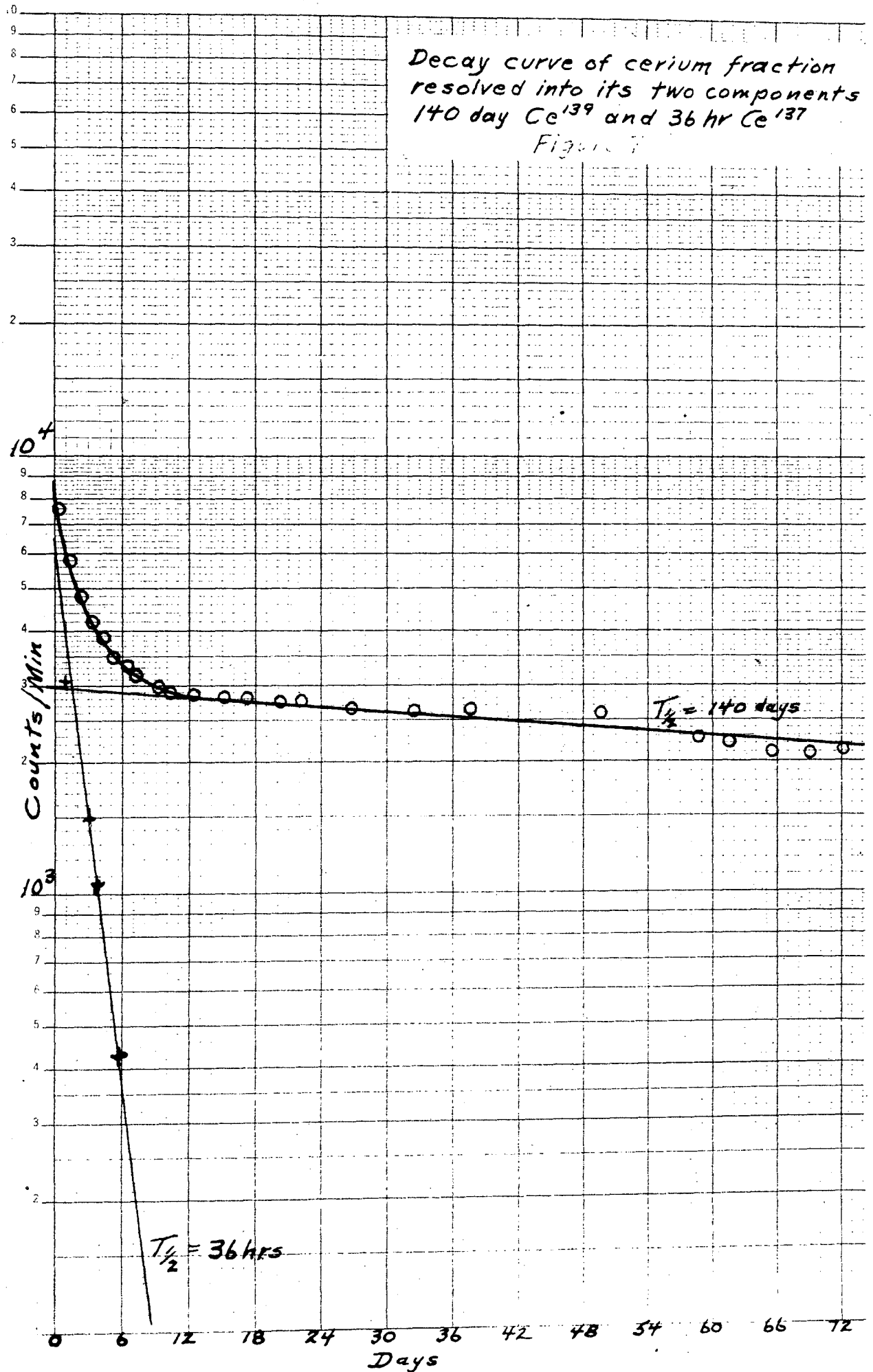
Counting equipment used was the same as that described in Chapter I.

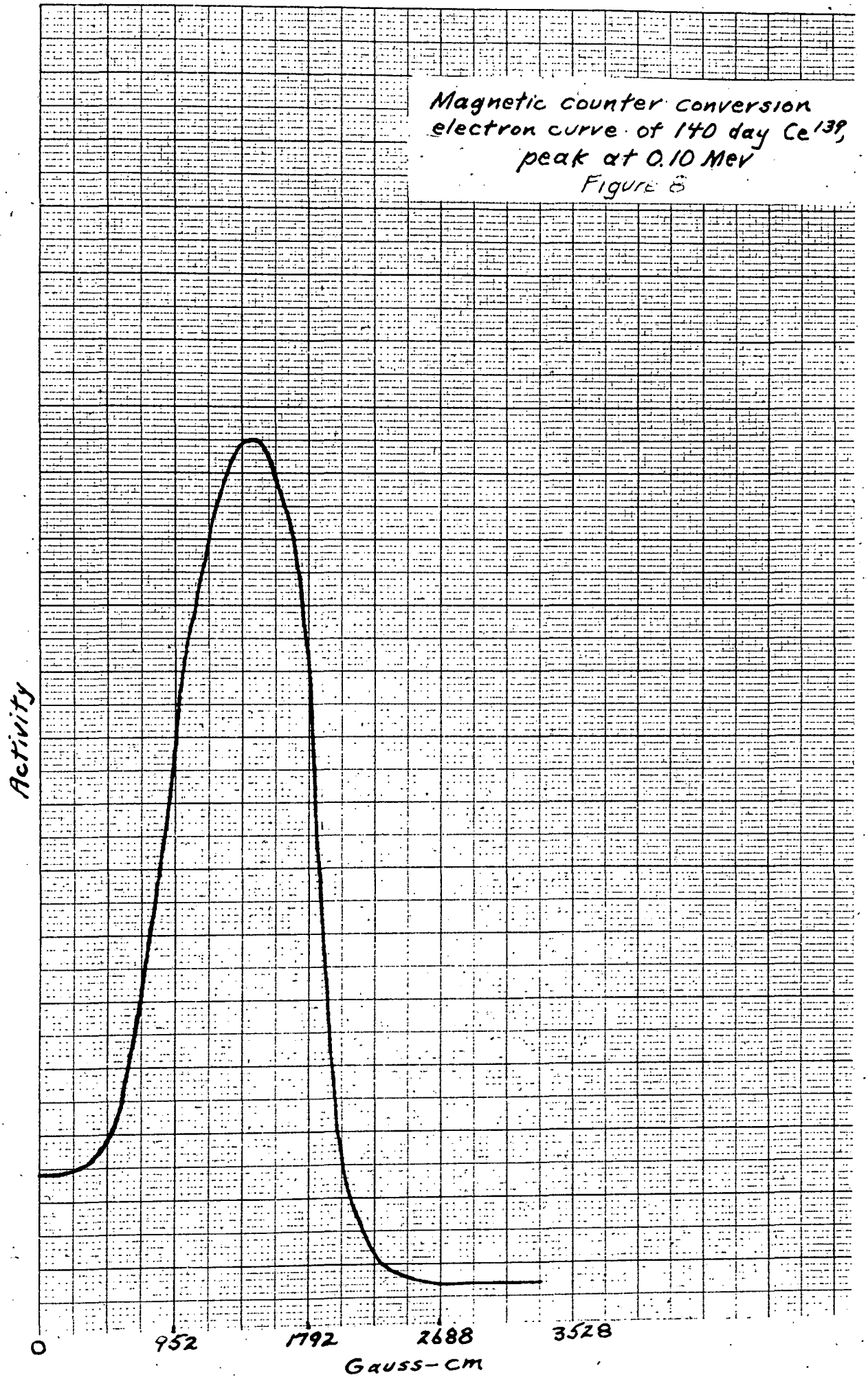
RESULTS

140 day Ce^{139}. La_2O_3, 0.855 gms, was bombarded for two hours with 20 Mev deuterons in the 60-inch cyclotron. A sample of the cerium fraction was followed in its decay resulting in the decay curve shown in Figure 7. It will be seen that points are widely scattered. This is believed due to having to use some six different Geiger tubes during the time of the decay. Seaborg's Table of Isotopes[5] reports the half-life to be 140 days. This was assumed correct and the line representing the long-lived component was drawn with this slope.

The decay curve resolves into two components, the 140 day Ce^{139} and a 36 hour activity which is assigned to Ce^{137} and discussed in detail below.

A sample of the 140 day activity was placed on the magnetic counter two months after the bombardment. A well-defined conversion electron peak was formed. No positron activity was indicated. The magnetic counter curve is shown in Figure 8. Taking the energy at the peak as the energy of the conversion electron, I find 0.15 Mev.


Decay curve of cerium fraction resolved into its two components 140 day Ce139 and 36 hr Ce137
Figure 7
Counts/Min
Days
T½ = 140 days
T½ = 36 hrs
10⁴
10³
0
6
12
18
24
30
36
42
48
54
60
66
72



Magnetic counter conversion electron curve of 140 day Ce^{139}, peak at 0.10 Mev

Figure 8

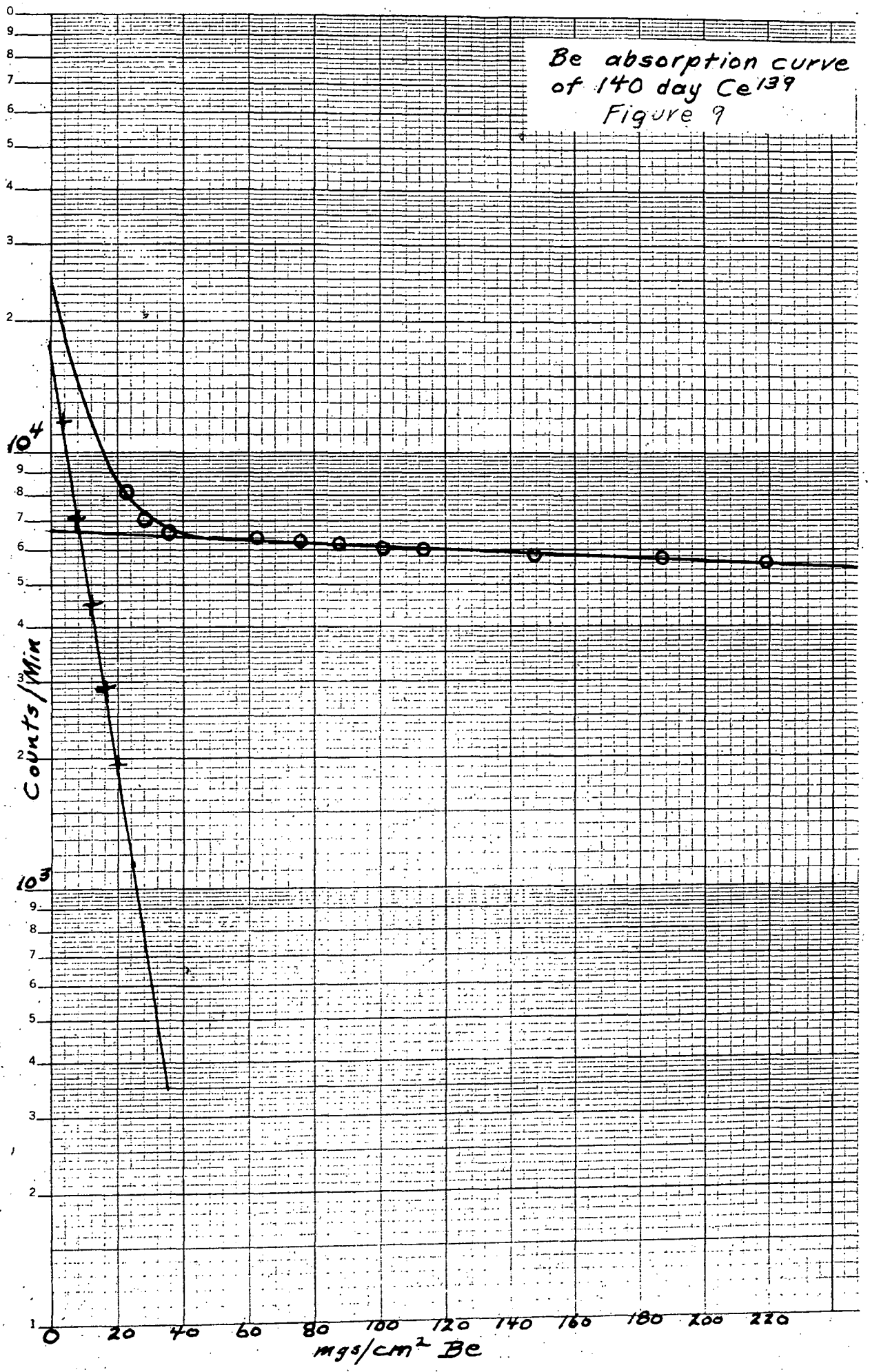
From a beryllium absorption curve taken after decay of the 36 hour activity, Figure 9, I estimate the range of the conversion electron to be about 30 mg/cm^2. This also corresponded to an energy of about 0.15 Mev.

A lead absorption curve taken after decay of the 36 hour activity is shown in Figure 10. In this curve sufficient beryllium was placed below the lead to absorb the conversion electrons and sufficient beryllium was placed above the lead to absorb photoelectrons knocked out of the lead by gamma radiation. This lead absorption curve resolves into K x-rays, gamma radiation of about 0.18 Mev and gamma radiation of about 1.8 Mev energy.

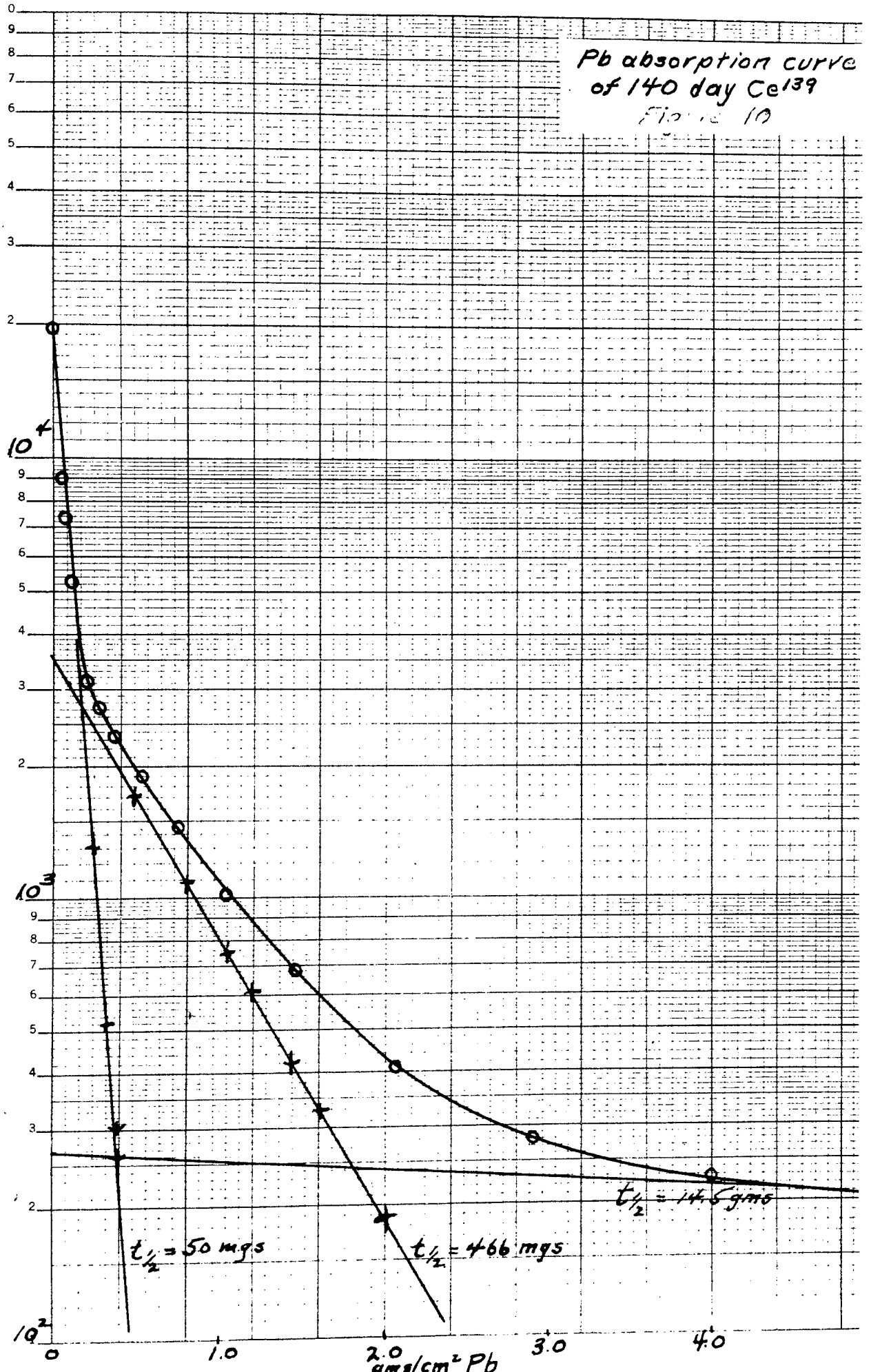
A bombardment of lanthanum with 40 Mev deuterons, discussed below, produced the 36 hour activity in far greater yield compared to the 140 day activity than did the 20 Mev deuteron bombardment. The two cerium activities cannot, therefore, be isomers. I conclude that the 140 day activity is formed by the (d,2n) reaction and assign it to Ce^{139}.

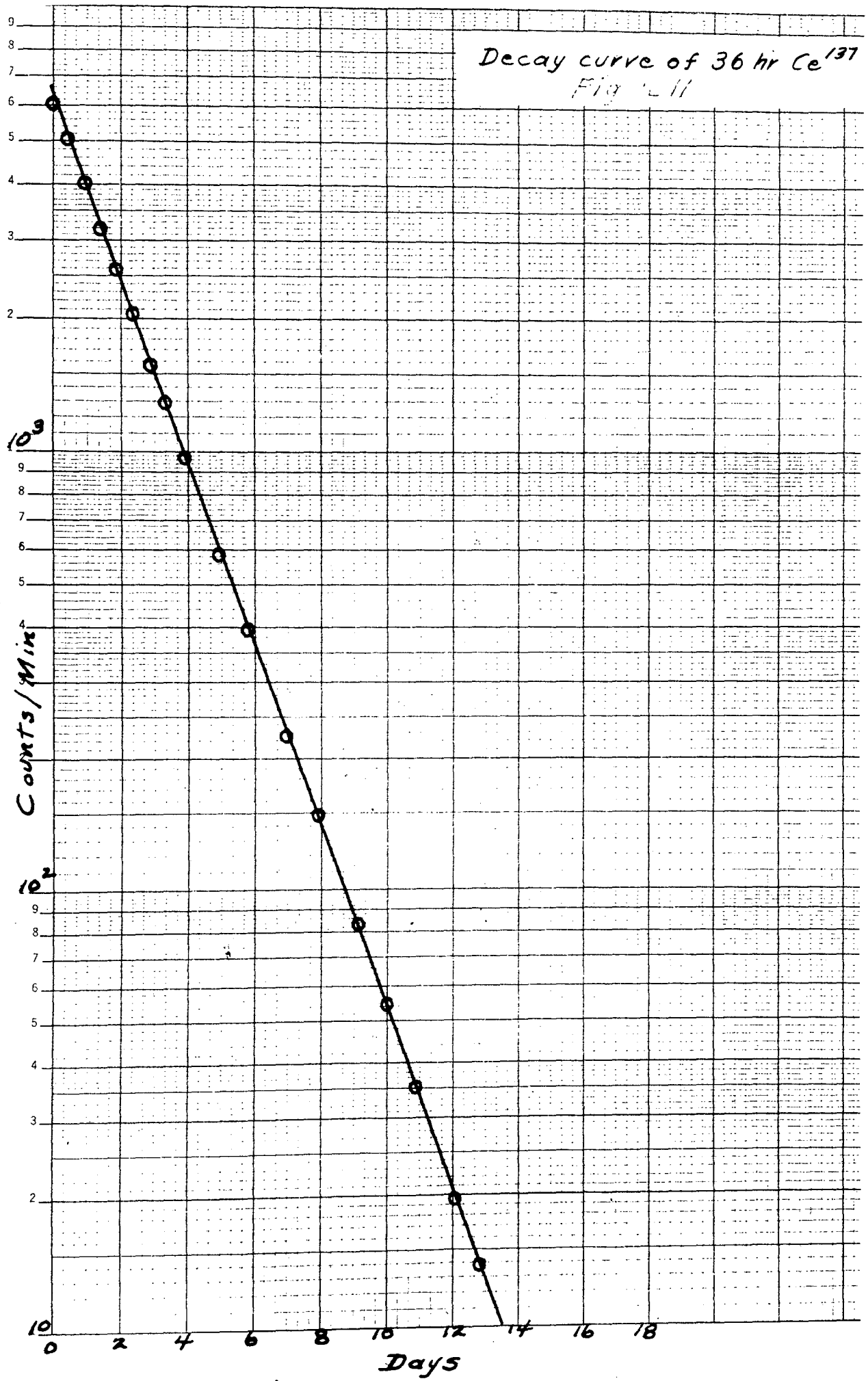
Ce^{139}, then, decays by orbital electron capture with a half-life of 140 days and emits conversion electrons of 0.15 Mev, K x-rays of lanthanum and gamma radiation of 0.18 Mev and 1.8 Mev energy.

<u>36 hour Ce^{137}.</u> La_2O_3, 0.250 gms, was bombarded for one hour and forty minutes with 40 Mev deuterons in the 184-inch cyclotron. A sample of the cerium fraction was followed in its decay, resulting in the decay curve shown in Figure 11. A sample of the same cerium fraction placed on the magnetic counter gave a well-defined conversion electron peak, shown in Figure 12. There was no positron activity with this isotope. Taking the energy at the peak as the energy of the conversion electron, I find about 0.23 Mev.



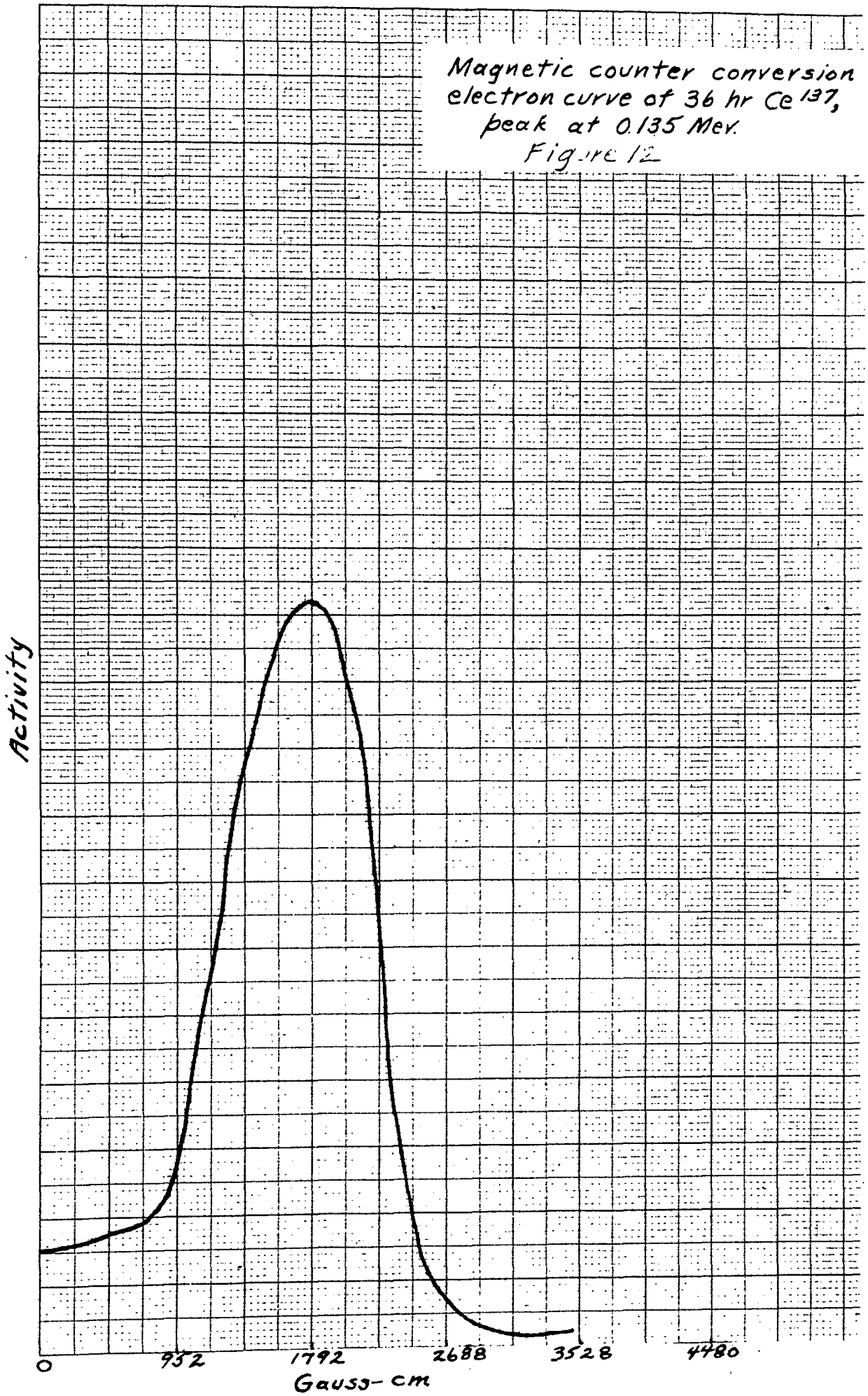
Be absorption curve of 140 day Ce^{139}
Figure 9


Pb absorption curve
of 140 day Ce139
Figure 10
10^4
10^3
10^2
0
1.0
2.0
3.0
4.0
gms/cm² Pb
$t_{1/2}$ = 50 mgs
$t_{1/2}$ = 466 mgs
$t_{1/2}$ = 14.5 gms


Decay curve of 36 hr Ce^{137}
Fig. 11
Counts/Min
10^3
10^2
10
0
2
4
6
8
10
12
14
16
18
Days

Magnetic counter conversion electron curve of 36 hr Ce^{137}, peak at 0.135 Mev.

Figure 12



A beryllium absorption curve is shown in Figure 13. A part of this curve does not appear, but the missing part does not affect the figure or resolution therefrom. From this curve I estimate the range of the conversion electron to be about 45 mg/cm^2, corresponding to an energy of about 0.16 Mev. Allowing more weight to the energy determined from the beryllium absorption curve, I take the energy of the conversion electron to be about 0.18 Mev.

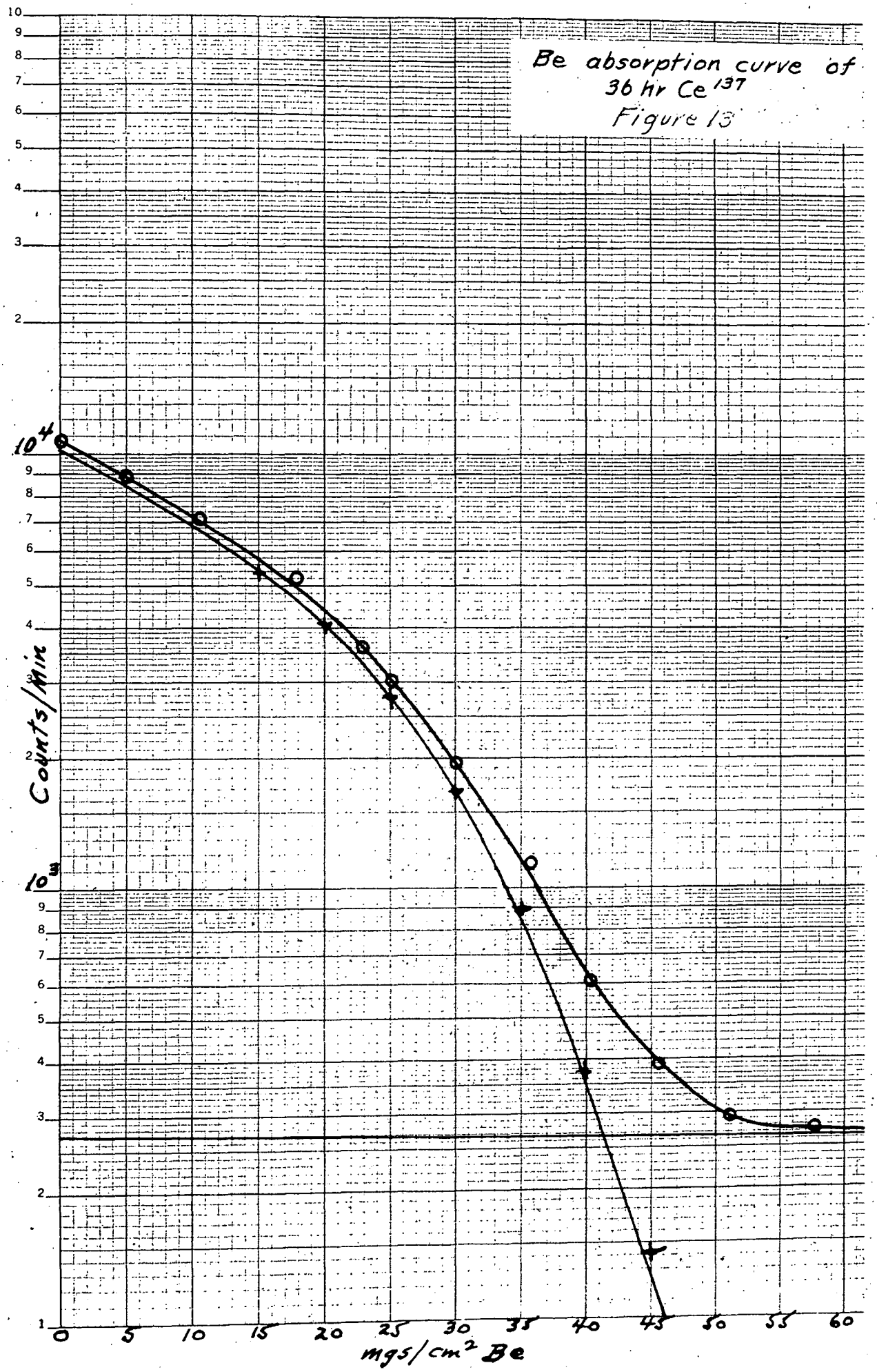
An aluminum absorption curve is shown in Figure 14. A part of this curve does not appear in the figure. From this curve I resolve 34 Kev x-rays.

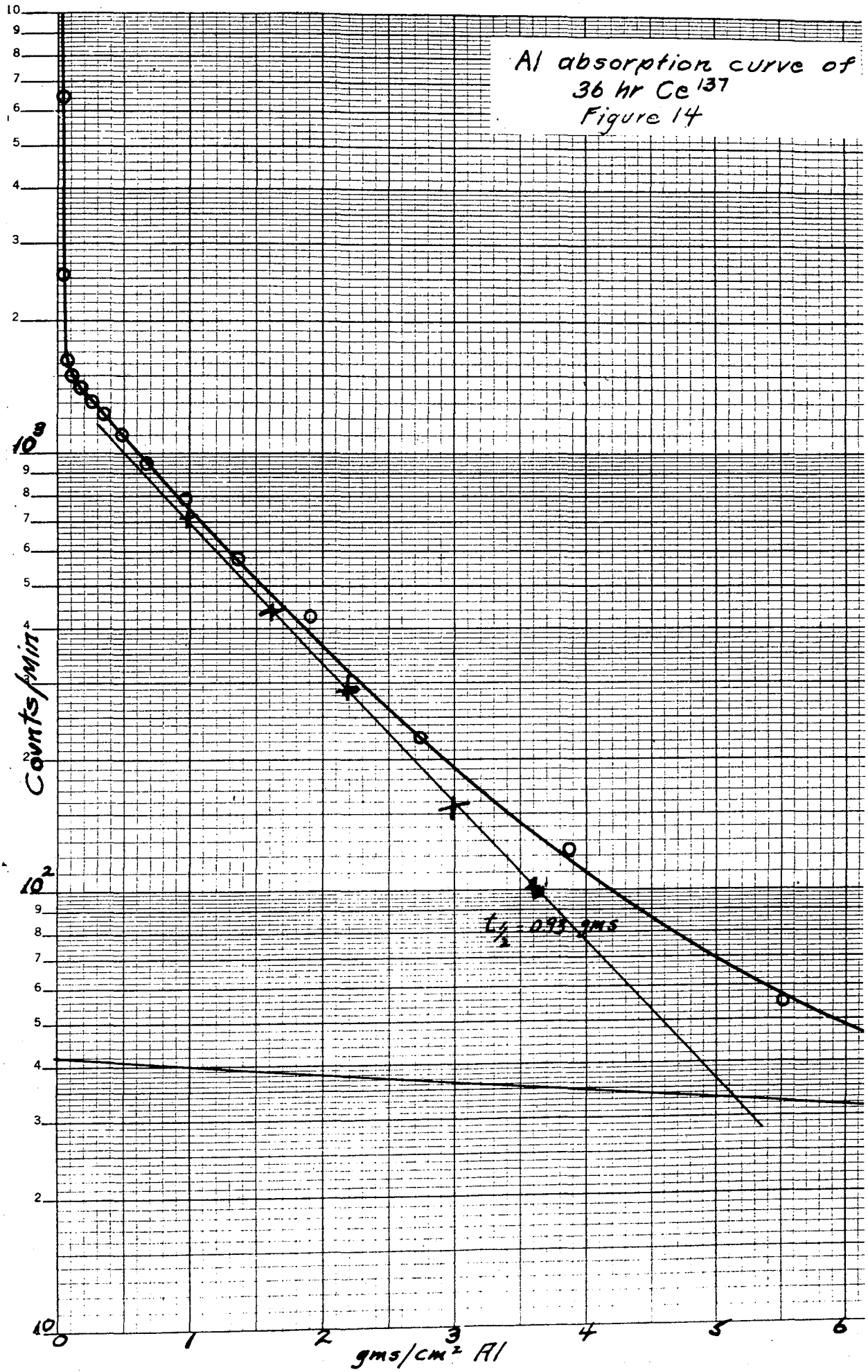
A lead absorption curve for this isotope is shown in Figure 15. This curve resolves into two components, gamma radiation of 0.28 Mev and 0.75 Mev energy.

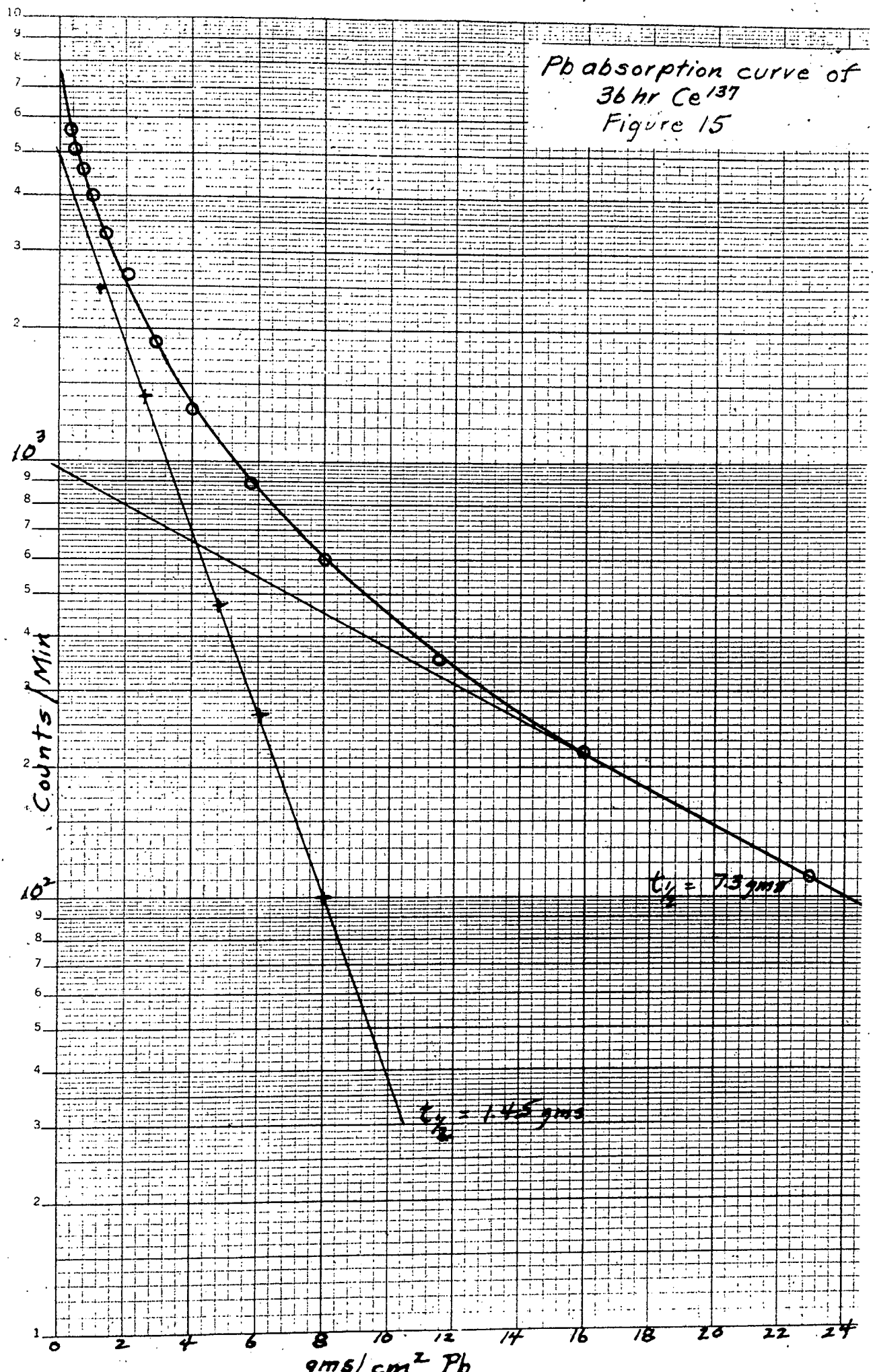
Ce^{137}, then, decays by orbital electron capture with a half-life of 36 hours, emits conversion electrons of about 0.18 Mev, K x-rays of lanthanum, and gamma radiation of 0.28 Mev and 0.75 Mev energy. It was formed by the (d,4n) reaction.

<u>16 hour Ce^{135}.</u> La_2O_3, 0.253 gms, was bombarded for two hours with 60 Mev deuterons in the 184-inch cyclotron. It was hoped that an appreciable yield of Ce^{135} might be obtained by the (d,6n) reaction but results were disappointing. The 36 hour Ce^{137} activity was formed in such high yield that the Ce^{135} activity was completely masked in the decay curve. A gross decay curve of the cerium fraction of this bombardment was exactly like that shown in Figure 11.

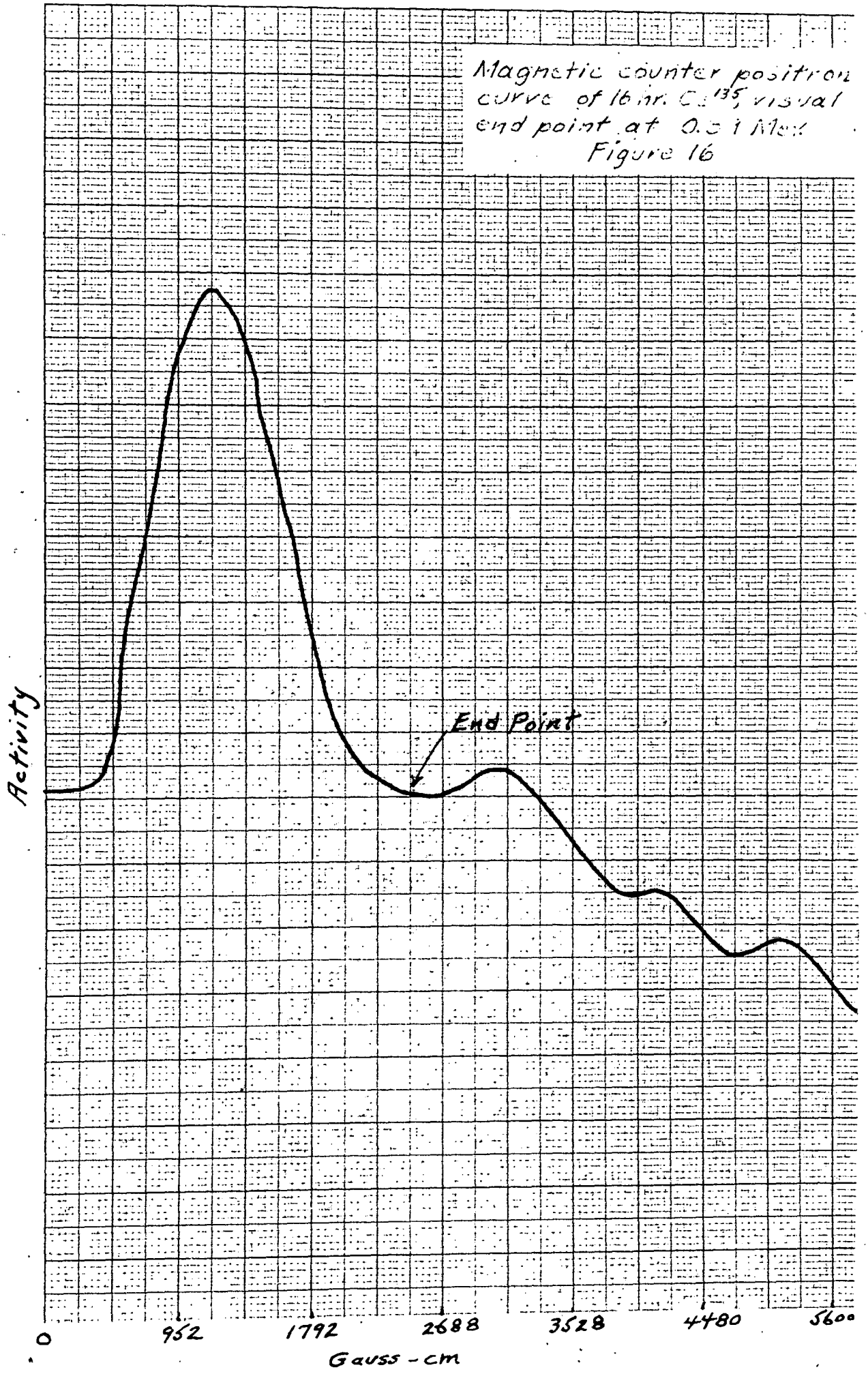
A sample of the cerium fraction placed on the magnetic counter showed positron activity, however. A representative magnetic counter curve is shown in Figure 16. The high background is due to


Be absorption curve of
36 hr Ce 137
Figure 13
Counts/Min
mgs/cm² Be
10⁴
10³
0
5
10
15
20
25
30
35
40
45
50
55
60


Al absorption curve of
36 hr Ce 137
Figure 14
Counts/Min
gms/cm² Al
$t_{1/2}$ = 0.93 gms
10
10^2
10^3
0
1
2
3
4
5
6


Pb absorption curve of
36 hr Ce137
Figure 15
Counts/Min
gms/cm2 Pb
t1/2 = 7.3 gms
t1/2 = 1.45 gms

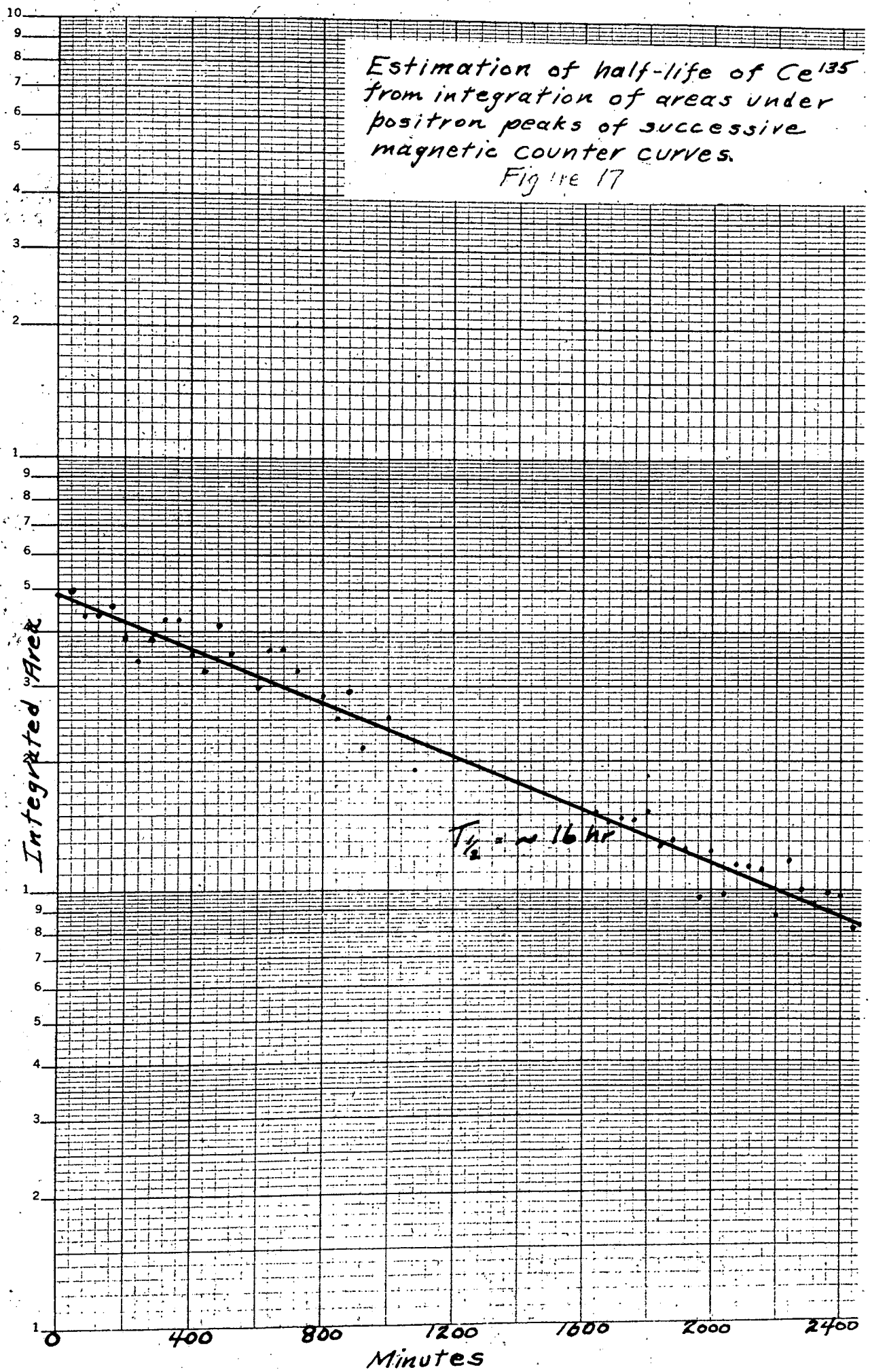
Magnetic counter positron curve of 16 hr. Cs^{135}, visual end point at 0.31 Mev.
Figure 16



scattered radiation. The decrease in background as magnet current increased is due to charged particles being curved into smaller and smaller circles so that they no longer reached the counter tube. The generally high background, much higher than in other magnetic counter curves shown, was also caused by the use of a high counting rate. This high rate was necessary in order to resolve the positron peak. Taking the energy of the positron as that at the visual end point, I estimate the positron to be of about 0.39 Mev energy.

Successive magnetic counter curves were taken for approximately two days. Integration of the areas under the positron peaks as the activity decayed resulted in the scattering of points shown in Figure 17. Through these points I have drawn the representative line shown and estimate the half-life to be about 16 hours.

It was impossible to determine any other characteristics of this isotope. This activity is assigned to Ce^{135} because it had not appeared in bombardments at lower energies. Further evidence for this mass assignment appeared when the lanthanum daughter of the activity was separated. This daughter activity decayed with a 19.5 hour half-life, exactly that of the lanthanum activity assigned above to La^{135}.



Estimation of half-life of Ce^{135} from integration of areas under positron peaks of successive magnetic counter curves.

Figure 17

CHAPTER III

SUMMARY

In the Table at the end of this thesis is a tabulation of the data obtained in the various bombardments discussed above.

In general, cross sections were calculated on the basis of the K x-rays emitted. Counting efficiency was assumed, as mentioned above, to be 0.5%. No calculation of cross section could be made for Ce^{135} because of its low activity and lack of knowledge of the decay scheme.

It is apparent that bombardments of cesium with higher energy helium nuclei in the 184-inch cyclotron would probably produce still lighter isotopes of lanthanum with half-lives which could be observed. La^{134}, an odd-odd isotope, would probably be a positron emitter and might be very short-lived. La^{133}, however, would probably have an easily observable half-life of an hour or two. Competing reactions, spallation for example, might reduce the yields of these lighter isotopes with bombardments at energies of about 100 Mev or higher.

Similarly, bombardments of lanthanum with higher energy deuterons would probably produce lighter cerium isotopes with observable half-lives. Ce^{134}, for example, might be expected to have a half-life of several hours. Again, competing reactions would probably reduce the yields.

Table

Isotope	Type of Radiation	Half-life	Energy of Radiation in Mev		Isotope	Produced by	Cross section $x10^{24}$ cm^2
			Particle	Electro-magnetic			
La^{136}	β^+	2.1 hrs	0.84	None	La^{136}	$Cs^{133}(\alpha,n)$	0.0003
La^{135}	K,γ	19.5 hrs	None	0.76	La^{135}	$Cs^{133}(\alpha,2n)$	0.03
La^{137}		400 yrs			La^{137}	decay of Ce^{137}	
Ce^{139}	K,γ,e^-	140 days	0.15	0.18 1.8	Ce^{139}	$La^{139}(d,2n)$	0.09
Ce^{137}	K,γ,e^-	36 hrs	0.18	0.28 0.75	Ce^{137}	$La^{139}(d,4n)$	0.06
Ce^{135}	β^+	16 hrs			Ce^{135}	$La^{139}(d,6n)$	
					Ba^{133}	$Cs^{133}(\alpha,p3n)$ and decay of La^{133} produced by $Cs^{133}(\alpha,4n)$	0.00073

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