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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2650

RADIOAUTOGRAPHIC METHOD FOR EXAMINING DISTRIBUTION OF PARTICLES IN A CYCLOTRON BEAM

By M. L. Pool and S. Fultz

The Ohio State University Research Foundation

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SUMMARY

It has been found that radioautographs of activated metal foil provide a means for obtaining the relative distribution of particles emitted from the foil and hence also provide a means for obtaining the time-averaged distribution of particles in the cross section of the beam which caused activation of the foil. This has been established in particular for Kodak Super Pan Press B film, developed 8 minutes at 78° F in DK-50 developer, provided the maximum photographic density of the radioautograph is kept below 1.1. The method has been confirmed by direct comparison of density values and count rates and has also been verified for higher energy components of the β-rays emitted from the foils.

INTRODUCTION

A radioautographic method is suggested as a convenient method for examining the distribution of particles in a cyclotron beam. For a given energy of particles, the activity produced by them at a point on a foil is proportional to the particle density of the corresponding point of the beam cross section. It is the purpose of the experiments described below to establish the feasibility of the photographic method by showing that the photographic density produced by an active sample is proportional to the β-ray activity of the sample. The work was exploratory in nature, and the experimental measurements were not repeated a sufficient number of times to warrant an estimate of the average random errors.

This investigation was carried out at The Ohio State University Research Foundation under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

EXPERIMENTAL METHOD

Metal foils were fastened to a probe and placed in the beam of the Ohio State University cyclotron inside the vacuum chamber. They were then bombarded with deuterons of 10 million electron volts, and after removal the induced activity was monitored. When it was found that the foils were in the desired decay period, they were placed in contact with photographic films, and radioautographs were thus obtained for various foils and various exposure times.

In figure 1 is shown a print of a radioautograph of copper foil 0.001 inch thick obtained in the above manner.

ESTABLISHING PHOTOGRAPHIC METHOD

Some of the factors which must be satisfied in order that the photographic method be useful as a means for determining the relative activity of a foil at various points in it are:

(a) A linear relation between exposure (activity time) and photographic density

(b) Consistent results for various ranges of energy of the particles being emitted by the source

RELATION BETWEEN DENSITY AND β-RAY ACTIVITY

In order to establish the density range over which the first of these is satisfied, the following procedure was used. Activated foils were cut into a large number of small pieces about 2 millimeters square. These were cemented to a sheet of paper, in position corresponding to their positions in the original uncut foil, but each was now separated and labeled. Radioautographs for various exposures were now obtained (see fig. 2). The pieces of foil were then separately cut out and their β-ray activities measured, all being corrected to the same time of measurement. The corresponding photographic densities produced by the pieces in the radioautograph were found by measuring the densities of the blackened areas produced by each small piece; these measurements were made on a Leeds & Northrup Knorr-Albers type densitometer (catalog no. 6700 P-1) and recorded on special paper by means of a Leeds & Northrup Speedomax Recorder.

Since the measured β-ray activities obtained for each piece were average values for all active points in each piece, the average values of the densities of their corresponding radioautographs were used. Such average values were obtained by taking the density value halfway between the minimum and maximum values obtained by scanning the radioautographs in their directions of maximum density gradient.

A summary of data obtained thus, using Kodak Super Pan Press B film developed in DK-50 developer for 8 minutes at 78° F is given in table I. (A diagram of the positions of the pieces of copper foil is given in fig. 5, top right corner.) Strips are taken parallel to the most dense edge of the radioautograph of assembled pieces (fig. 1). Exposures are given in arbitrary units of β-ray activity times time of exposure.

In table II are given data obtained for Microfile film developed in D-19 developer for 4 minutes at 78° F.

From figure 3 it is evident that an approximately linear relation exists between exposure (β-ray activity times time) and density values to about 1.10, in the case of Kodak Super Pan Press B film. In the case of Kodak Microfile film (fig. 4), this appears to be true up to densities of about 1.0 at least, although insufficient information was obtained to find where the relation becomes nonlinear. It may therefore be concluded that, for these two types of film, density is proportional to exposure to β-rays up to density values of 1.0. This value, therefore, defines a limit within which the radioautographic method can be used for measuring activity.

DIRECT COMPARISON BETWEEN RELATIVE DENSITIES AND RELATIVE ACTIVITIES

A direct comparison between relative densities and relative activities was obtained by normalizing density data to their maximum, normalizing corresponding counting data to their maximum, and plotting corresponding points as functions of position on the same graph. Such a plot for copper foil is given in figure 5. Here activities and density values are plotted as functions of position along a strip, each strip being 2 millimeters wide and cut parallel to the most active edge of the foil. Data for these plots are given in table III. In normalizing density data to a maximum, it is necessary to be sure that this maximum is below density of 1.1. If this is not the case, the calibration curve (fig. 3) may be used to give only a rough idea of density values corrected to the linear portion of the curve. To obtain the best value for this maximum, the density data were plotted and an average curve drawn through the points in the region of the maximum.

In table III it will be noted that the densities of the elements of strip 1 attain values of greater than 1.1 and, hence, according to the calibration curve, are not proportional to activities in this region.

It was therefore necessary to normalize all density values by fitting strip 2 data to the corresponding normalized activity data. The maximum density in this case is 1.15, just slightly beyond the safe limit.

In figure 5 it can be seen that the photographic and counting methods for measuring relative activity agree within the errors of measurement. The data for figures 3 and 4 were obtained with the small pieces of foil illustrated in figure 2. Edge effects with these small radioactive foils are probably the most significant sources of error in these figures. For the intercomparison of the two methods shown in figure 5, it was assumed that each foil was 2 millimeters square. Deviations in actual sizes of the foils undoubtedly account for some of the discrepancies between photographic density and β-ray activity for a given foil.

DISTRIBUTION OF ACTIVITY FOR HIGH-ENERGY β-RAYS

To examine the distribution of activity for various energy ranges of β-rays, four layers of Super Pan Press film were placed over activated copper foil with the emulsion side facing the copper, and exposures were made to obtain a suitable density from a particular film. In figure 6 the distribution of activity from the data of table I is compared with the distribution of activity obtained from the fourth film. The surface density of the film was 31.2 milligrams per square centimeter so that each intervening layer of film reduced the energy of the particles by an average of 0.16 million electron volts, and the three together reduced it by 0.33 million electron volts.

The data of table IV are plotted in figure 6, where they are compared with the activity curves of figure 5. Agreement appears to be good, but curves drawn through the points would be displaced slightly to the right. This is due to an error in estimating the position of the beginning of the strips where these parts are of very low density.

USE OF GOLD FOIL AS A TARGET MATERIAL

Gold foil was used as a target material and bombarded with deuterons of 10 million electron volts. When the activity settled down to that of the 2.8-day half-life, radioautographs were taken and these in turn were microphotometered.

The microphotometer data are given in table V, and plots of these data are given in figure 7.

In figure 7 it will be noted that data from both exposures for the normalized density curves for the first strip are in good agreement, while the points for the 30-second exposure lie slightly above those for the 60-second exposure in the case of the second strip. This is probably due to an error in estimating the position corresponding to the second strip on the microphotometer traces, since microphotometer traces were all made in directions perpendicular to directions of the strips. The reason for choosing this direction is that the dense edge of the radioautograph always provided a good reference point to measure from on a microphotometer trace.

Figure 7 cannot be directly compared with previous figures since a different particle distribution from that in other bombardments was probably obtained.

RESULTS

A survey of the above information reveals the following:

(a) Approximately a linear relation exists between exposure to β-rays and photographic density, for Kodak Super Pan Press B and Microfile films, if densities are below 1.0.

(b) The distribution of relative activity on a foil may be measured by the photographic method, and the errors involved seem to be smaller (see fig. 3) than by the use of a counting method; that is, the data appear more self-consistent.

(c) Simplicity and convenience are features which favor the photographic method in preference to a direct counting procedure.

(d) Choice of film must be governed by the particular nature of the investigation. If it is desired to know particle distributions ranging from very slight to very dense, a film with a wide exposure latitude for β-rays must be used.

If, however, it is desired to see whether or not there are slight deviations from fairly uniform distribution, then a film with a high contrast and short exposure latitude for β-rays must be used. (Kodak Super Pan Press B or possibly NTB emulsion would be more suitable.) The latitude of an emulsion for β-rays cannot be found from data obtained by use of light, but should be determined experimentally using the radiations to be investigated.

DISCUSSION OF RESULTS

The exposure-density relation, obtained for β-rays incident on the films used, is in agreement with the results of other investigators. It was early established (reference 1) that in the region of small exposures this is a straight line passing through the origin. The relation between energy of β-rays and density has also been investigated (references 2 and 3) and is more complicated. The β-rays used in the experiments performed here contained a continuous distribution of energy, so that the density data presented in this report are averaged over these energies.

Cranberg and Halpern (reference 3) have demonstrated that the exposure-against-density relation for electrons of 40 thousand electron volts and incident on Ilford B-2 plates is linear up to density values of 1.70. Hence, such emulsion would be useful for radioautographic work on rhodium foil bombarded with deuterons if wide latitude to conversion electrons were desired. (Activated rhodium emits 40-Kev conversion electrons in a prolific manner.)

The Ohio State University Research Foundation
Columbus, Ohio, September 12, 1949

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2. Langendijk, W., and Ornstein, L. S.: The Application of the Photographic Method in β-Ray Spectroscopy. Physica, vol. VII, no. 5, May 1940, pp. 475-484.

3. Cranberg, L., and Halpern, J.: Calibration of Photographic Emulsions for Low Energy Electrons. Contract N6-ONR-249-03, Office Naval Res. and Univ. of Penn., June 1949.

TABLE I

DATA FOR COPPER FOIL ON KODAK SUPER PAN PRESS B FILM

[Half-life, 12.9 hr; β energy, 0.6 Mev]

Strip	Piece	15-min exposure		71-min exposure	
		Exposure (arbitrary units)	Density	Exposure (arbitrary units)	Density
7	1	0.009		0.043	
	8	.017	0.05	.080	0.19
	15	.032	.07	.150	.28
	22	.039	.06	.185	.32
	29	.037	.14	.175	.35
	36	.025	.11	.118	.36
	43	.040	.09	.190	.32
	50	.026	.09	.123	.23
	57	.010	.05	.047	
	64	.008		.038	.08
	71	.006		.028	
6	2				
	9	0.032	0.01	0.147	0.31
	16	.052	.08	.246	.41
	23	.062	.13	.294	.55
	30	.066	.16	.312	.68
	37	.074	.21	.350	.64
	44	.074	.21	.350	.64
	51	.046	.19	.218	.42
	58	.022	.15	.104	
	65	.008	.07	.037	.11
	72				
5	3	0.024	0.02	0.114	
	10	.056	.13	.265	0.49
	17	.093	.23	.440	.67
	24	.115	.27	.545	.89
	31	.120	.35	.568	.97
	38	.110	.36	.520	.94
	45	.100	.30	.473	.91
	52	.069	.20	.327	.88
	59	.027	.08	.128	
	66	.009		.043	.12
	73				
4	4	0.071	0.15	0.336	
	11	.093	.15	.440	0.47
	18	.180	.47	.851	1.05
	25	.214	.47	1.010	1.15
	32	.234	.56	1.110	1.20
	39	.203	.58	.960	1.15
	46	.197	.46	.910	1.20
	53	.112	.29	.530	
	60	.051	.16	.242	
	67	.010	.01	.047	.16
	74	.006		.028	

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TABLE I

DATA FOR COPPER FOIL ON KODAK SUPER PAN PRESS B FILM - Concluded

Strip	Piece	15-min exposure		71-min exposure	
		Exposure (arbitrary units)	Density	Exposure (arbitrary units)	Density
3	5	0.044	0.11	0.208	
	12	.215	.38	1.03	0.85
	19	.366	.58	1.73	1.10
	26	.442	.74	2.09	1.45
	33	.450	.83	2.13	1.60
	40	.408	.77	1.93	1.50
	47	.381	.47	1.80	1.35
	54	.221	.49	1.05	1.20
	61	.075	.24	.36	
	68	.017	.08	.080	.22
	75	.010	.03	.047	
2	6	0.080	0.24	0.380	
	13	.26	.53	1.23	0.95
	20	.36	.66	1.70	1.03
	27	.60	1.08	2.84	1.65
	34	.61	1.15	2.89	1.9
	41	.60	1.18	2.84	2.0
	48	.58	1.00	2.75	1.50
	55	.18	.72	.85	1.40
	62	.15	.35	.71	
	69	.022	.15	.105	.46
	76	.016	.06	.076	
1	7	0.09	0.28	0.426	
	14	.374	.66	1.770	1.15
	21	.640	1.15	3.03	1.16
	28	.872	1.30	4.13	1.90
	35	.805	1.40	3.81	2.00
	42	1.000	1.45	4.73	2.00
	49	.950	1.25	4.50	1.70
	56	.490	1.15	2.32	2.00
	63	.270	.63	1.28	
	70	.060	.27	.29	.88
	77	.030	.15	.14	

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TABLE II

DATA FOR COPPER FOIL ON MICROFILE FILM

[Half-life, 12.7 hr; β energy, 0.6 Mev]

Strip	Piece	65-min exposure		113-min exposure	
		Exposure (arbitrary units)	Density	Exposure (arbitrary units)	Density
1	1				
	4	0.048		0.084	
	7	.173		.300	0.19
	10	.550	0.35	.956	.61
	13	.951	.57	1.65	1.12
	16	1.000	.84	1.74	1.50
	19	.976	.55	1.70	1.10
	22	.018	.55	.31	.96
	25	.600		1.04	.84
2	2				
	5	0.052		0.09	
	8	.272		.472	0.27
	11	.571	0.41	.990	.62
	14	.786	.61	1.37	.86
	17	.846	.45	1.47	.70
	20	.676		1.18	.62
	23				
	26	.410			
3	3				
	6	0.124	0.19	0.205	0.35
	9	.269		.468	
	12	.198	.16	.344	.39
	15	.164	.18	.285	.22
	18	.173	.27	.300	.20
	21	.060		.10	.11
	24				
	27				

TABLE III

COMPARISON BETWEEN RELATIVE DENSITIES AND RELATIVE

ACTIVITIES FOR COPPER FOIL

Strip	Piece	Position (mm)	Density	Normalized density	Normalized activity
1	7	1	0.28	0.149	0.095
	14	3	.70	.370	.374
	21	5	1.18	.612	.640
	28	7	1.30	.692	.872
	35	9	1.38	.735	.97
	42	11	1.40	.745	1.000
	49	13	1.25	.665	.950
	56	15	1.10	.595	.490
	63	17	.65	.345	.270
	70	19	.27	.14	.060
	77	21	.15	.08	.030
2	6	1	0.24	0.128	0.080
	13	3	.57	.304	.260
	20	5	.66	.350	.360
	27	7	1.08	.575	.600
	34	9	1.15	.612	.612
	41	11	1.08	.575	.600
	48	13	.95	.505	.575
	55	15	.65	.345	.177
	62	17	.35	.186	.147
	69	19	.15	.08	.022
	76	21	.06	.03	.016
3	5	1	0.15		0.044
	12	3	.38	0.20	.215
	19	5	.58	.31	.366
	26	7	.74	.40	.442
	33	9	.83	.44	.450
	40	11	.77	.41	.408
	47	13	.57	.30	.381
	54	15	.49	.26	.221
	61	17	.24	.13	.075
	68	19	.08	.04	.017
	75	21	.03	.01	.010
4	4	1	0.11	0.059	0.071
	11	3	.15	.08	.093
	18	5	.35	.19	.180
	25	7	.47	.25	.214
	32	9	.50	.27	.234
	39	11	.51	.27	.203
	46	13	.42	.22	.192
	53	15	.29	.15	.112
	60	17	.16	.09	.051
	67	19	.01	.005	.010
	74	21			.006

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TABLE III

COMPARISON BETWEEN RELATIVE DENSITIES AND RELATIVE

ACTIVITIES FOR COPPER FOIL - Concluded

Strip	Piece	Position (mm)	Density	Normalized density	Normalized activity
5	3	1	0.02	0.01	0.024
	10	3	.13	.07	.056
	17	5	.23	.12	.093
	24	7	.27	.14	.115
	31	9	.30	.16	.120
	38	11	.30	.16	.110
	45	13	.26	.14	.100
	52	15	.20	.10	.069
	59	17	.08	.04	.027
	66	19			.009
	73	21			
6	2	1	0.01		
	9	3	.08	0.04	0.032
	16	5	.13	.07	.052
	23	7	.16	.85	.062
	30	9	.21	.11	.066
	37	11	.21	.11	.074
	44	13	.19	.10	.074
	51	15	.15	.08	.046
	58	17	.07	.04	.022
	65	19			.008
	72	21			
7	1	1			0.009
	8	3	0.05	0.02	.017
	15	5	.07	.04	.032
	22	7	.06	.03	.039
	29	9	.14	.07	.037
	36	11	.11	.06	.025
	43	13	.09	.05	.040
	50	15	.09	.05	.026
	57	17	.05	.03	.010
	64	19			.008
	71	21			.006

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TABLE IV

DATA FOR β-RAYS AT FOURTH FILM IN STACK

[Energy decreased by 0.33 Mev]

Strip	Position (mm)	Density	Normalized density
2	1	0.06	0.04
	4	.45	.31
	7	.80	.55
	10	.90	.62
	13	.80	.55
	16	.50	.35
	19	.08	.06
3	1	0.03	0.02
	4	.21	.14
	7	.58	.40
	10	.63	.44
	13	.51	.35
	16	.25	.17
	19	.05	.03
4	1		
	4	0.10	0.07
	7	.34	.23
	10	.35	.24
	13	.32	.22
	16	.15	.10
	19	.04	.02

TABLE V

MICROPHOTOMETER DENSITY FOR FILM EXPOSED

TO RADIOACTIVE GOLD FOIL

[Half-life, 2.69 days; β energy, 0.966 Mev]

Strip	Position (mm)	30-sec exposure		60-sec exposure	
		Density	Normalized density	Density	Normalized density
1	1	0.05	0.10	0.06	0.06
	3	.14	.29	.32	.36
	5	.33	.69	.64	.71
	7	.41	.85	.78	.87
	9	.44	.92	.83	.92
	11	.48	1.00	.90	1.00
	13	.46	.96	.85	.95
	15	.42	.87	.75	.83
	17	.33	.69	.62	.69
	19	.15	.31	.30	.33
2	1	0.03	0.07	0.02	0.02
	3	.10	.21	.19	.21
	5	.24	.50	.42	.47
	7	.32	.67	.58	.65
	9	.36	.75	.60	.66
	11	.37	.77	.64	.71
	13	.36	.75	.62	.69
	15	.32	.66	.54	.60
	17	.24	.50	.35	.39
	19	.08	.16	.11	.12

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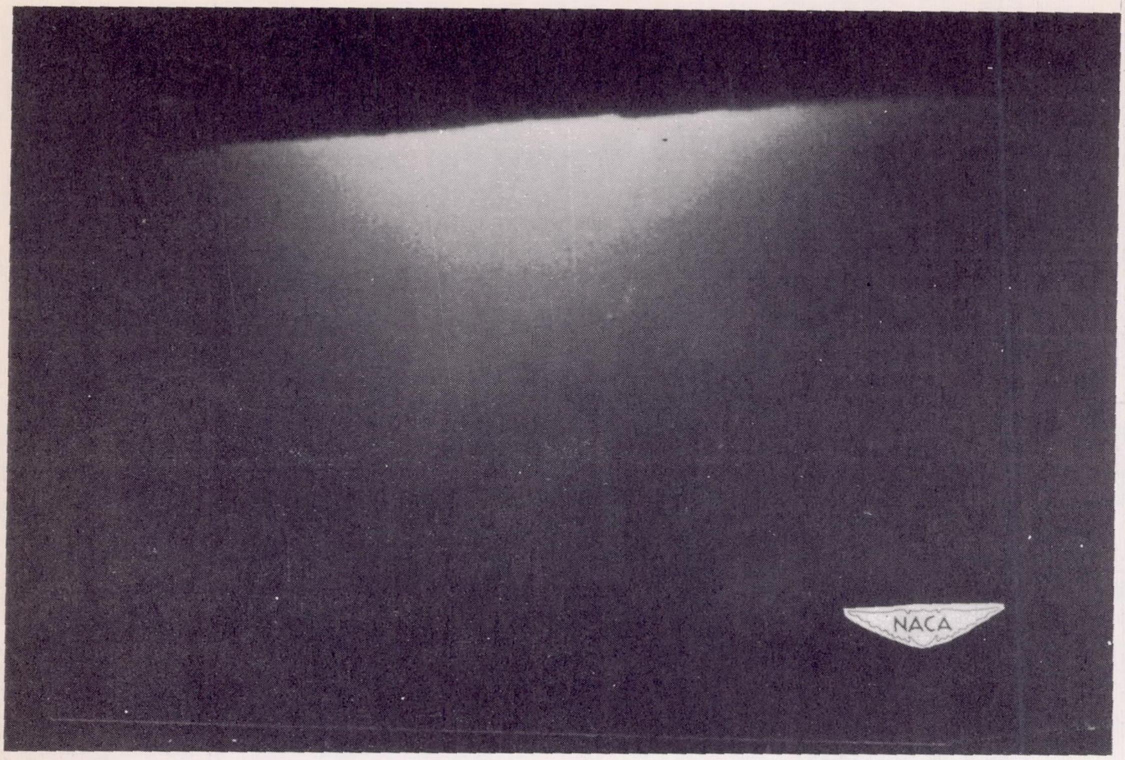

Figure 1.- Print of radioautograph of activated copper foil 0.001 inch thick, X6.

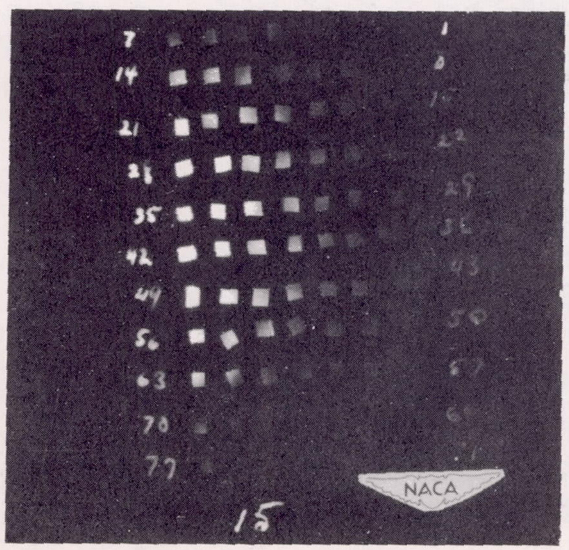

Figure 2.- Print of radioautograph of copper foil of figure 1 showing manner of cutting.

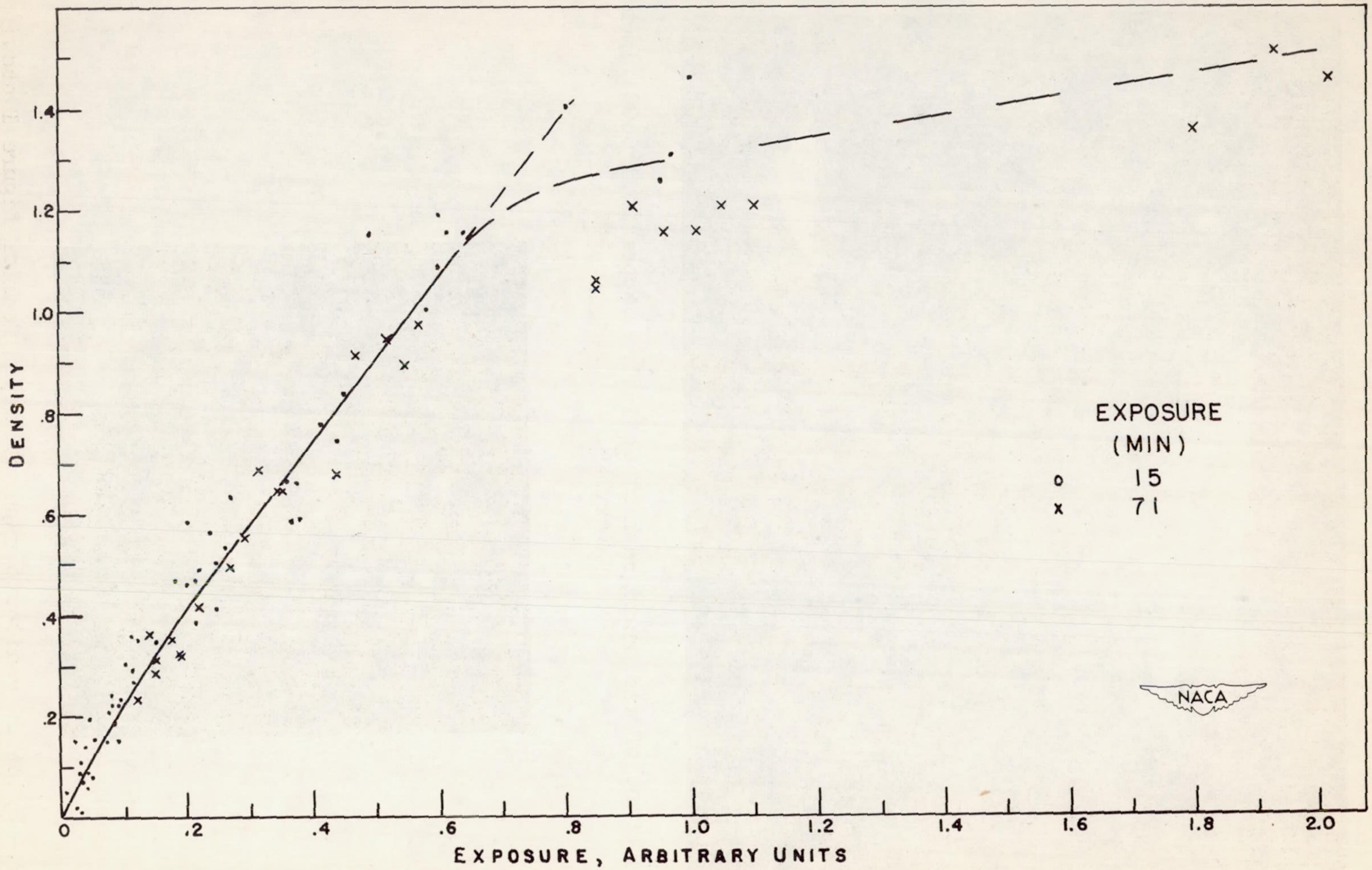

Figure 3.- Relation between photographic density and exposure to β-rays for Kodak Super Pan Press B film developed 8 minutes at 78° F in DK-50 developer. Density measured on Leeds & Northrup Knorr-Albers densitometer using Speedomax Recorder.

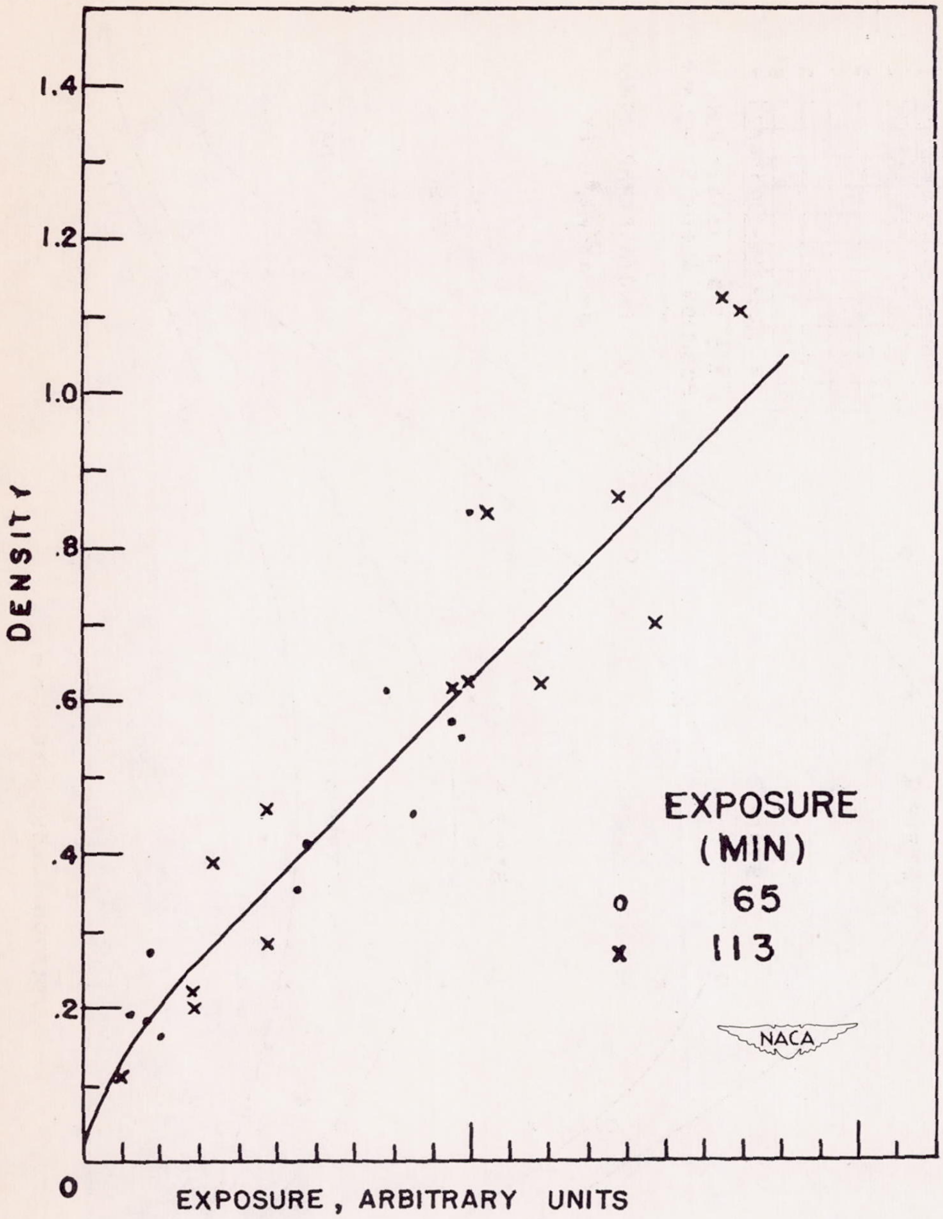

Figure 4.- Relation between photographic density and exposure to β-rays for Kodak Microfile film developed 4 minutes at 78° F in D-19 developer. Density measured on Leeds & Northrup Knorr-Albers densitometer using Speedomax Recorder.

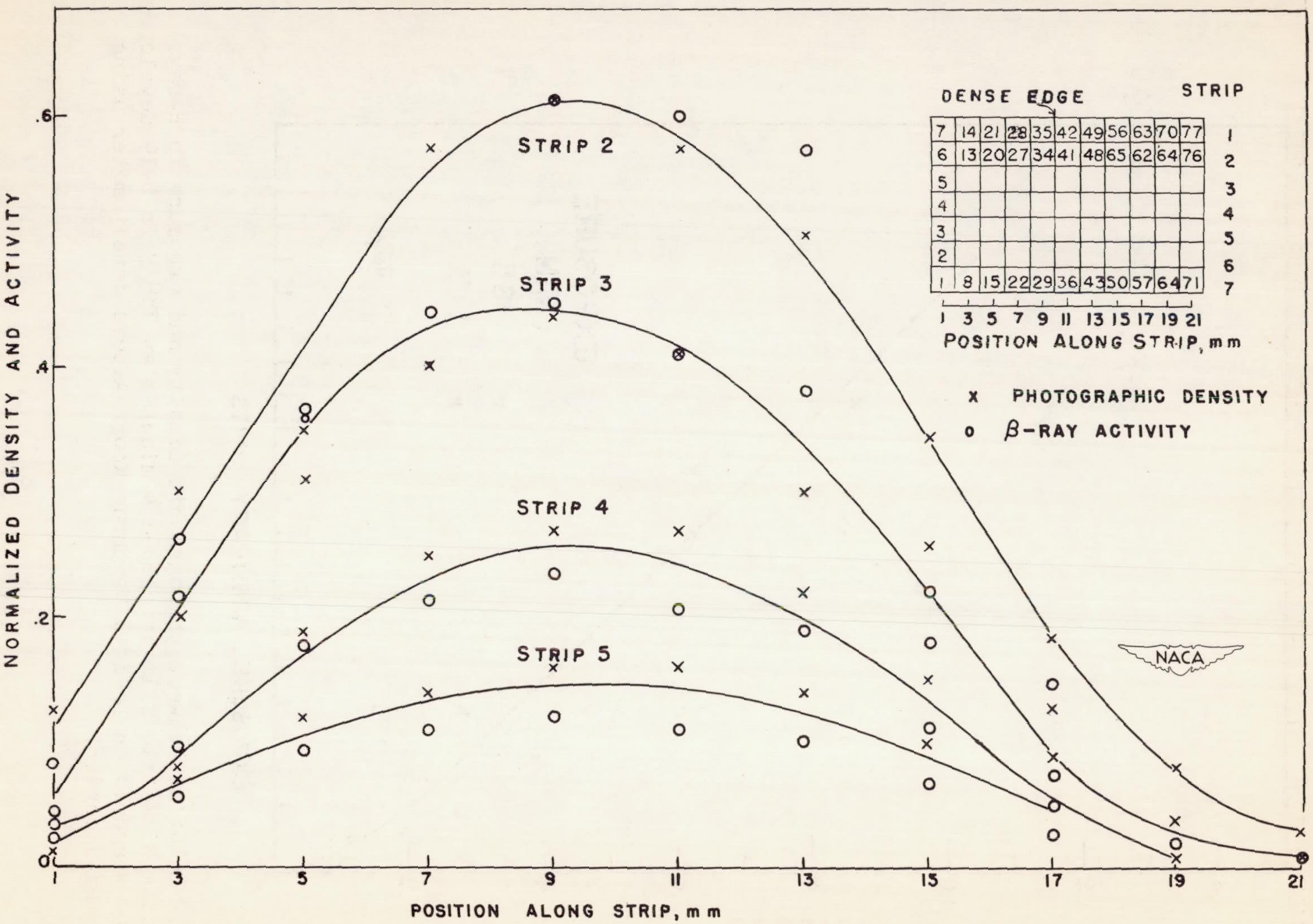

Figure 5.- Relative densities and relative β-ray activities for copper foil 0.001 inch thick. Half-life, 12.9 hours.

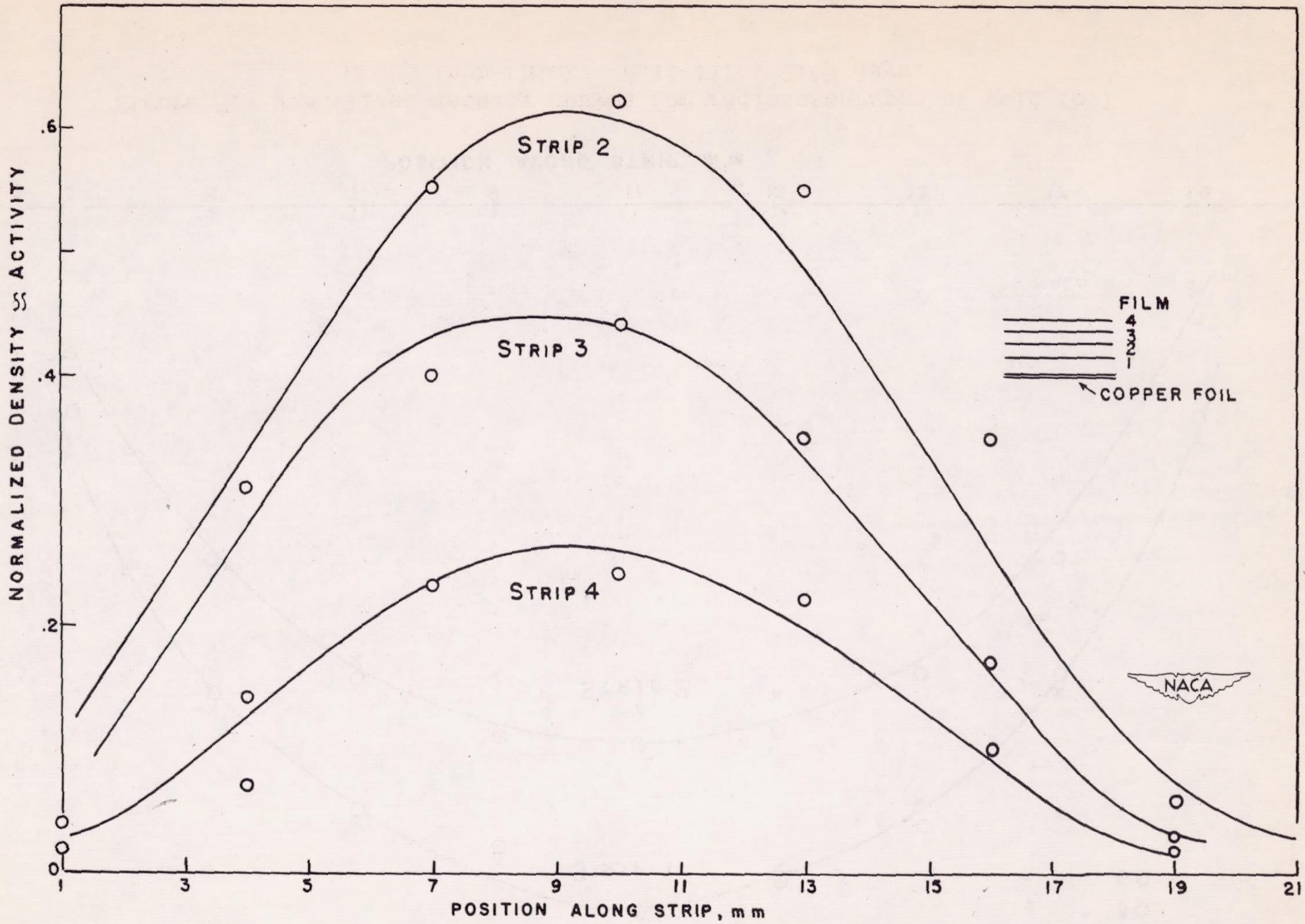

Figure 6.- Distribution of activity for β-rays of approximately 0.32 million electron volts. Test points are for data from fourth film in stack; curves are from figure 5.

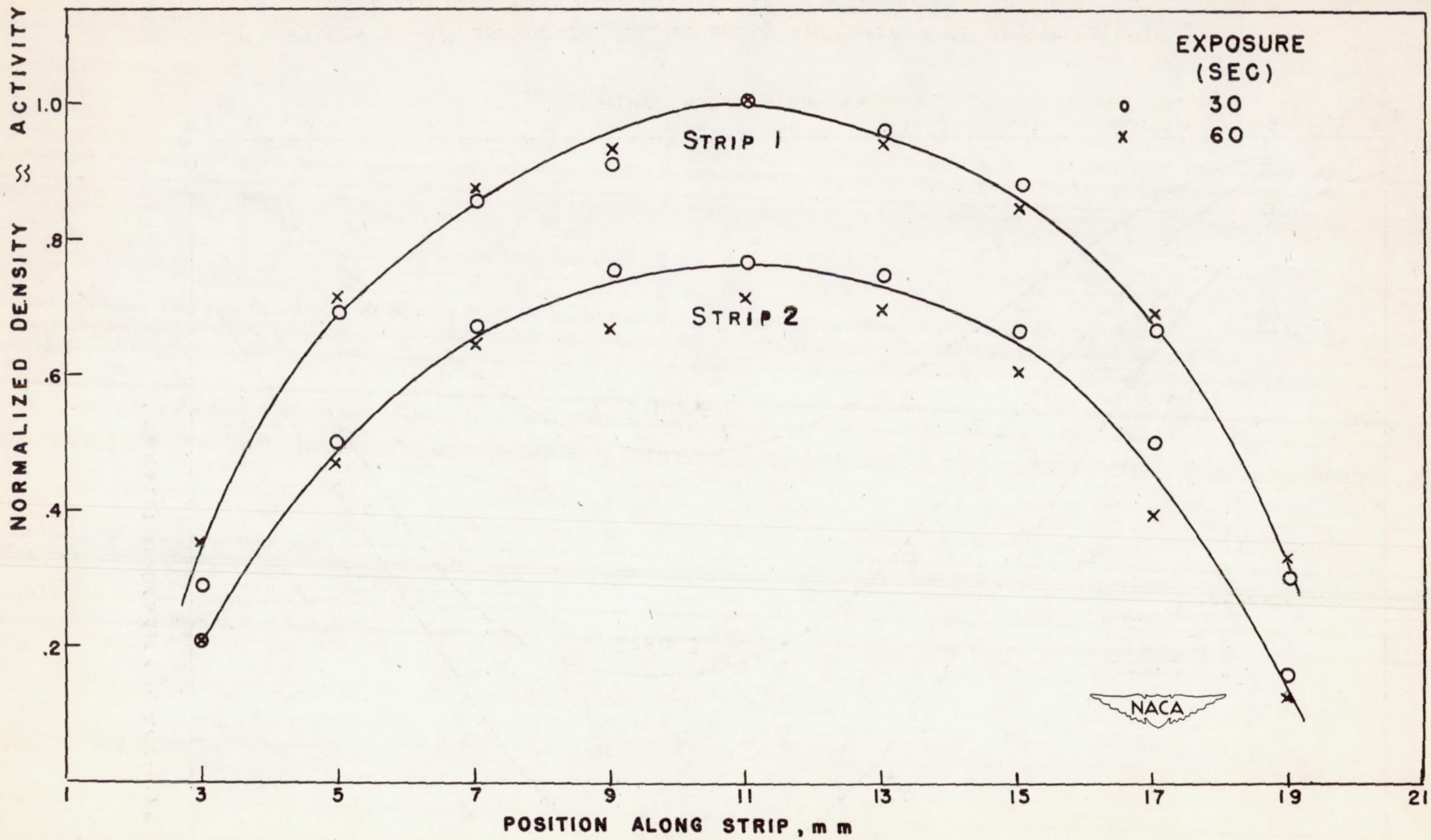

Figure 7.- Normalized density curves for radioautographs of gold foil 0.005 inch thick. Half-life, 2.69 days.

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