satisfies the boundary conditions of the original guide of Fig. 3, so that integration of $\langle \Pi_z \rangle_{Av}$ over its area gives the rate of power dissipation or $\frac{1}{2}V^2/R$ where R is the radiation resistance. Thus we find

$$R = \frac{\mu\omega\beta' ab \ln^2(r_2/r_1)}{8\pi^2 \sin^2(\pi d/a) \sin^2\beta' c} \times [J_0(2\pi r_2/\lambda) - J_0(2\pi r_1/\lambda)]^{-2}. \quad (10)$$

The same result is obtained by the integration of Poynting's vector over the coaxial opening, using $r_1 V[r \ln(r_2/r_1)]^{-1}$ for $\mathbf{E}$ and $\nabla \times \mathbf{A}_{10}$ for $\mathbf{B}$, but the integration is a little more difficult. The integration of Poynting's vector for the other non-transmitted modes over the annular opening should give the output reactance of the line. Unfortunately it does not seem possible to evaluate the resultant integrals analytically.

PHYSICAL REVIEW VOLUME 72, NUMBER 11 DECEMBER 1, 1947

X-Ray Emitting Isotopes of Radioactive Sb and Sn

K. D. COLEMAN* AND M. L. POOL
Mendenhall Laboratory, Ohio State University, Columbia, Ohio
(Received August 8, 1947)

Three new x-ray emitting activities in Sb with half-lives of 2.8 hours, 5.1 hours and 39 hours have been found by the use of the curved crystal camera in conjunction with the x-ray decay curves. The assignments are Sb^{117}, Sb^{118}, and Sb^{119} respectively. All three decay by K-electron capture giving characteristic Sn x-rays. The 2.8-hour Sb^{117} also emits 0.46-Mev electrons while the 5.1-hour Sb^{118} gives 0.20-Mev electrons and 1.5-Mev gamma-rays.

X-ray periods of 1.25 days and 9 days have been found in Sn. The reported decay scheme for Sn^{113} was verified but the 0.085-Mev gamma-ray was not found.

1. INTRODUCTION

Of the several activities which have been attributed to radioactive Sb isotopes, those of half-lives of 2.8 days,[1] 60 days[2] and 17 minutes[1] have been assigned to Sb^{122}, Sb^{124} and Sb^{120}, respectively. The first two activities emit beta-rays and gamma-rays, while the third emits positrons. These three periods have been made by four different reactions.[3]

A 2.7-year activity, emitting low energy electrons and gamma-rays, has been obtained from fission,[4] and tentatively assigned to Sb^{125}. A 3.6-minute positron activity obtained from $In+\alpha$ activation[5] has been assigned to either Sb^{116} or Sb^{118}. In addition, several Sb activities are found in fission fragments[4] with masses greater than 125.

Approximately fifteen activities have been reported as belonging to Sn isotopes.[4,6] Because of the large number of stable isotopes and because of the limited possibilities for making these activities by use of different bombarding particles and target materials, the only one which has been assigned with certainty is the 105-day[7] activity of Sn^{113}.

The present investigation was undertaken to study the application of the Cauchois curved-crystal camera, to the x-ray activities induced in Sn when activated with 10-Mev deuterons. Bombardments were also made using 5-Mev protons on Sn and 20-Mev alpha particles on In.

2. EXPERIMENTAL PROCEDURE

Characteristic x-ray lines were photographed by using a pair of Cauchois cameras[8] equipped

* Major, U. S. Army Air Corps, Research under auspices of Air University, Maxwell Field, Alabama. Now stationed Wright Field, Dayton, Ohio.

[1] J. J. Livingood and G. T. Seaborg, Phys. Rev. **55**, 414 (1939).

[2] E. B. Hales and E. B. Jordon, Phys. Rev. **64**, 202 (1943).

[3] G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944).

[4] Plutonium Project, J. Am. Chem. Soc. **68**, 2411 (1946).

[5] J. R. Risser, K. Lark-Horovitz, and R. N. Smith, Phys. Rev. **57**, 355 (1940).

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

[7] S. W. Barnes, Phys. Rev. **56**, 414 (1939).

[8] J. E. Edwards, M. L. Pool, and F. C. Blake, Phys. Rev. **67**, 150 (1945).

with mica crystals curved to a radius of 15 inches. The two cameras were mounted with their optical axes inclined at an angle of 30°, so that simultaneous photographs could be taken from the same sample. Each camera could be removed independently for calibration and alignment. On photographs taken with the 15-inch cameras, the linear separation between the K_α lines of adjacent elements in the Sn region is 1.8 mm. Because of this wide separation, lines were identified by comparison to a standard film prepared by fluorescence, rather than placing calibration lines on each individual film. Two index marks were placed on each film, to assure proper alignment for comparison.

Because of its low melting point, Sn foil, placed on a standard Cu target holder, melted when exposed to the full deuteron beam. A hollow Sn block was cast and soldered directly to a probe. During bombardment, ice water was circulated through the Sn block for cooling. After bombardment, the surface of the block was scraped to remove the active portion. With this target, the full intensity of the deuteron beam could be utilized.

Chemical separations were performed by fractional distillation using variations of a published procedure.[9] HCl gas was bubbled through the distillation flask, instead of adding HCl dropwise in an atmosphere of CO_2. The Sn and Sb fractions were precipitated as sulfides. Because of the time required for chemical separation, no activities shorter than two hours were studied. For the activities of major interest in this investigation, the distillation method was found to give more certain and complete separation than selective precipitation.

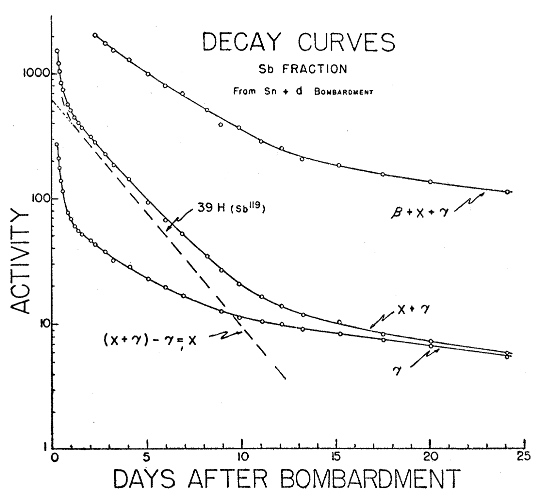

FIG. 1. Decay curve of Sb^{119} from $Sn+d$.

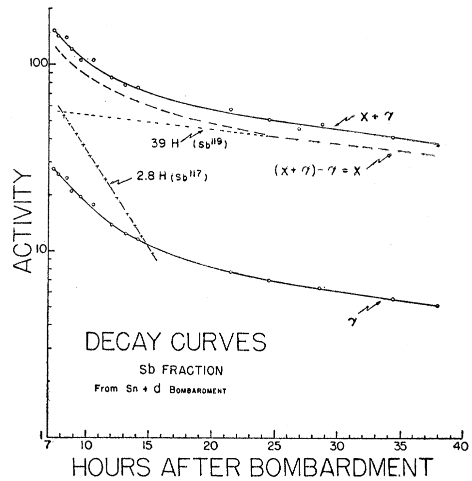

FIG. 2. Decay curve of Sb^{117} from $Sn+d$.

Sb^{117} AND Sb^{119}

When Sn was activated by deuterons, the Sb fraction was found to carry the major portion of the activity, including two strong x-ray periods. Figure 1 shows the decay of this fraction for the first 25 days after bombardment. Analysis of the x-ray decay curve shows the long period to be 39±1 hours. No electrons or gamma rays were found associated with this period. Since the x-ray plus gamma-ray ($x+\gamma$) curve and the gamma (γ) curve are seen to merge after some

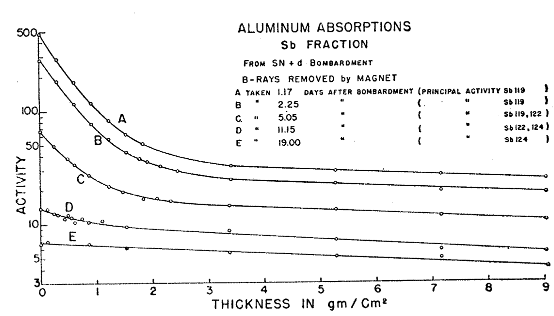

FIG. 3. Al-absorption curves of Sb^{117} and Sb^{119} showing decay of x-ray activity. X-rays have disappeared in curve *E*.

[9] J. A. Scherrer, J. Res., National Bureau of Standards **16**, 253 (1936).

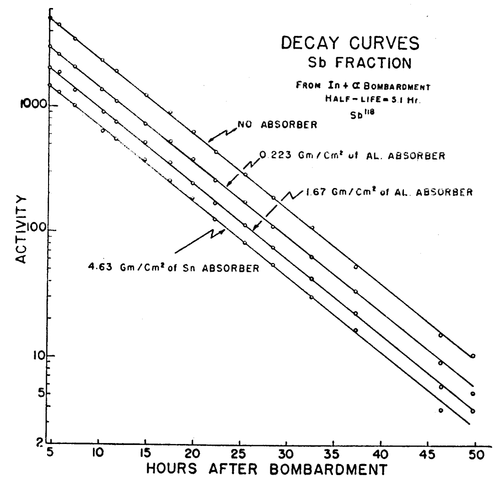

FIG. 4. Decay curves of Sb^{118} from In$+\alpha$.

20 days, there were no x-rays of a period longer than 39 hours of sufficient intensity to be measured.

Figure 2 shows the decay of the Sb fraction for the first 40 hours after bombardment. When the 39-hour x-ray activity is subtracted from the total x-ray decay curve, the short period x-ray activity is found to be 2.8 ± 0.3 hours. From successive aluminum-absorption measurements made with an open ionization chamber, a 0.46-Mev electron was found associated with this period.

Aluminum-absorption measurements, taken at intervals after bombardment, are shown in Fig. 3. In these curves, the beta rays have been removed by an electromagnet. The x-rays are seen to have disappeared after 19 days. By absorption in aluminum, the x-rays were found to be characteristic of the Sn region.

Both the 2.8-hour and 39-hour x-ray activities

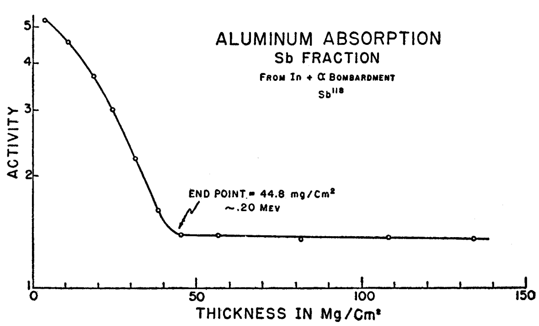

FIG. 5. Al-absorption curve of Sb^{118} showing 0.20-Mev end-point.

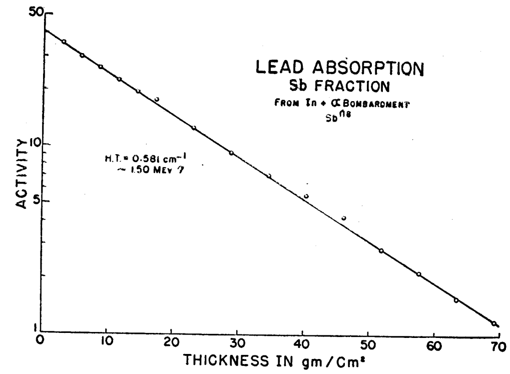

FIG. 6. Pb-absorption curve of Sb^{118} from In$+\alpha$.

were also produced by Sn$+p$ bombardment but not by In$+\alpha$ bombardment. The x-ray saturation intensity ratio of the 39-hour activity to the 2.8-hour activity is 1.70 to 1. By photographing the emission lines, the x-rays have been shown to be characteristic of Sn. Hence the decay process in both cases is by K-electron capture. This decay process indicates an isotopic assignment less than 121. Since the 17-minute positron activity has been assigned to Sb^{120}, and since an In$+\alpha$ bombardment does not produce the x-ray activities, assignment cannot be made to Sb^{116}, Sb^{118} or Sb^{120}. The low percentages of stable Sn^{112}, Sn^{114}, and Sn^{115} present, make the assignment to mass number 115 or less very improbable. This leaves Sb^{117} and Sb^{119} as the logical possibilities. In view of the relative abundances of the stable Sn isotopes, it seems more probable to assign the

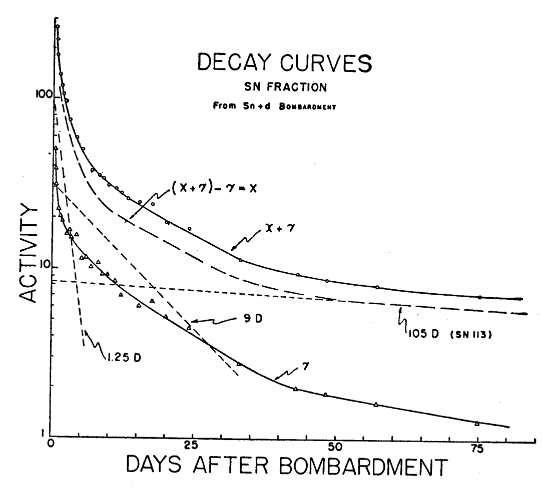

FIG. 7. Decay curves for Sn fraction of Sn$+d$ showing three x-ray periods.

2.8-hour activity to Sb^{117} and the 39-hour activity to Sb^{119}.

Sb^{118}

The Sb fraction of In activated by 20-Mev alpha particles yielded a single activity of 5.1 ± 0.3 hours. The decay curves for this period. extending over 9 half-lives are shown in Fig. 4, The small decrease in activity, as greater amounts of absorber are introduced, show that the emission is principally hard gamma-rays with some x-rays present. The Sb activity has been obtained from In furnished by the Indium Corporation of America and by Adam Hilger, Ltd., Laboratory No. 10,874.

Figure 5 shows an aluminum-absorption measurement made with the open ionization chamber. The end point is found at 0.20 Mev. The relatively large amount of x-ray and γ-ray activities indicates that, in most cases, decay does not involve beta-ray or electron emission. The x-rays have been found, by absorption in aluminum, to be characteristic of the Sn region. The energy of the gamma-ray was found by absorption in lead to be 1.5 Mev, as shown in Fig. 6.

This 5.1-hour activity is observed in the decay curves of the Sb fraction of the $Sn+d$ bombardment only by the gamma radiation. Successive absorption measurements made with the open ionization chamber show the 0.20-Mev end point. The 5.1-hour activity may be due to Sb^{116} or Sb^{118}, of which Sb^{118} seems to be the most probable.

Sn

The x-ray plus gamma-ray $(x+\gamma)$ and gamma-ray (γ) decay curves for the Sn fraction of the $Sn+d$ activation are shown in Fig. 7. Analysis of the subtracted x-ray decay curve shows x-ray periods of 105 days, 9 ± 1 days and 1.25 ± 0.2 days. A beta-ray of 2.5 Mev and a gamma-ray are associated with the 9-day period. A beta-ray and gamma-ray are also associated with the 1.25-day period. The latter two periods are perhaps identified with the previously reported beta emitting 26-hour[6] period, and, beta and gamma emitting 10-day[4] period.

The Sn fraction of $In+d$ showed only the 105-day period assigned to Sn^{113}. This activity was followed through more than 5 half-lives. The decay and energy data previously reported[7] were verified except for the 0.085-Mev γ, which was not found. No evidence was found for a Sn^{113} isomer.

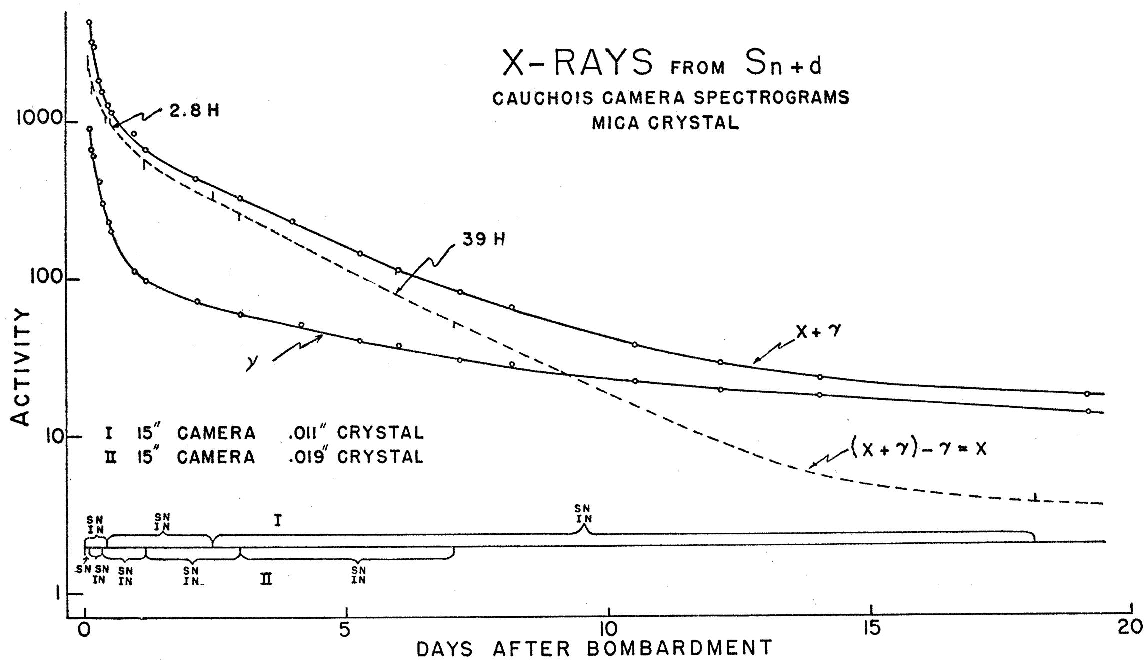

FIG. 8. Photographic analysis of x-rays from $Sn+d$ activation. Exposure periods shown on scale.

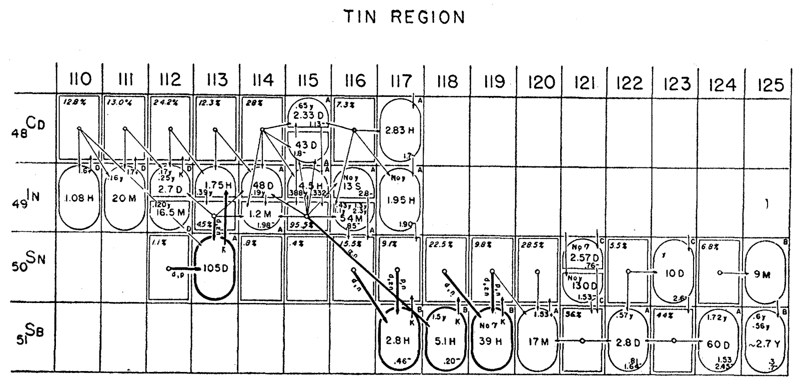

Fig. 9. Nuclear chart in the region of Sn, mass numbers against atomic numbers. The activities studied are indicated by heavy lines. Arrows represent nuclear reactions.

PHOTOGRAPHIC ANALYSIS OF X-RAYS

Figure 8 shows the results of a curved-crystal camera analysis of the x-ray decay of a Sn+d sample. The K_α lines of Sn and In appear in all except the first film on Camera II. The Sn line was initially much stronger than the In line. As exposure time was increased for successive films, the In line remained faintly visible while the Sn line became progressively weaker. An exposure of 60 days following the last one shown in Fig. 8 failed to record either line.

None of the films showed an Sb line. The x-rays from the Sb fraction of a Sn+d bombardment were photographed and showed only the Sn line. Hence the three x-ray activities found in the Sb fraction decay by K-electron capture.

DISCUSSION

The nuclear chart in the region of Sn is shown in Fig. 9, with the periods studied in this investigation indicated by heavy lines. By application of the Cauchois curved-crystal camera, in conjunction with x-ray decay curves, three previously unreported periods of 2.8 hours, 5.1 hours, and 39 hours, are assigned to Sb^{117}, Sb^{118}, and Sb^{119}, respectively. All decay by K-electron capture to Sn, giving characteristic Sn x-rays. In addition, the 5.1-hour period emits a 1.5-Mev gamma-ray.

X-ray periods of 1.25 days and 9 days have been found in the Sn fraction of Sn+d but no assignment is made. However, the latter period is perhaps identified with the previously reported 10-day period shown in the chart. The decay scheme for Sn^{113} was verified but the 0.085-Mev gamma-ray was not found.

The able assistance of Mr. H. L. Finston who performed the chemical separations is acknowledged. The authors are grateful for the support received from Mr. Julius F. Stone, the Ohio State University Development Fund, the Ohio State University Research Foundation and the Graduate School.