TABLE I. Cross sections in barns for deuteron reactions on praseodymium.

Half-life	Deuteron energy 19 Mev	9 Mev	Reaction	Isotope
19.3 hours	0.06	0.1	d,p	Pr^{142}
145 minutes	0.3	0.9	$d,2n$	Nd^{141}
3.3 days	0.08	—	$d,3n$	Nd^{140}

activity appears to be about 1.5 minutes, somewhat shorter than the value of 3.5 minutes reported[2] for Pr^{140}.

Additional evidence for the allocation of the 3.3-day activity to Nd^{140}, and its production by Pr-d-3n reaction has been obtained from yields in the deuteron bombardment of praseodymium. It was assumed that 0.6 of the measured K x-radiation of the 3.3-day activity represent one disintegration of Nd^{140}. In Table I are given the cross sections for production of the isotopes Pr^{142}, Nd^{141}, and Nd^{140}. The yields of the Pr^{142} were calculated from measured beta-particle activity. The absolute values of the yields may be in error in view of the uncertainties in counting efficiencies, etc., but the relative yields of the three reactions at the two bombarding energies should be more reliable.

ACKNOWLEDGMENTS

We would like to thank Professor J. G. Hamilton, Mr. T. Putnam, Mr. B. Rossi, and the crew of the 60-inch Crocker Laboratory cyclotron for their cooperation and assistance in bombardments; we are also indebted to Professors G. T. Seaborg, I. Perlman, and B. B. Cunningham for their continued interest and advice.

This work was done under the auspices of the AEC.

PHYSICAL REVIEW VOLUME 75, NUMBER 11 JUNE 1, 1949

Columbium 96

D. N. KUNDU AND M. L. POOL
Mendenhall Laboratory of Physics, Ohio State University, Columbus, Ohio

(Received February 16, 1949)

Cb^{96} has a half-life of 23.35 hours. It decays with the emission of negative beta-particles of maximum energy 0.67-Mev and 1.03-Mev gamma-rays. No x-rays are emitted. The assignment is made by using enriched isotopes of Zr.

INTRODUCTION

THE proton bombardment of zirconium was reported[1] to have produced Cb^{96} which has a half-life of 4 days. Later workers[2] reported its production by $(d,2n)$ and (d,α) reactions from zirconium and molybdenum, respectively, and changed the value of the half-life to 3 days. Recently[3] by the bombardment of enriched Mo^{98} with deuterons, the half-life has been further changed to 2.8 days and the decay characteristics given as negative beta-rays of 1.8 Mev by absorption in aluminum and gamma-rays of 1 Mev by coincidence absorption in lead.

The data to be presented in this paper are in complete disagreement with the above and will be briefly described.

TABLE I. Percent isotopic constitution of bombarded target samples of Zr.

Sample	Mass numbers 90	91	92	94	96
Natural Zr	51.46	11.23	17.11	17.40	2.80
Zr enriched in 90	91.7	3.5	2.2	1.8	0.8
Zr enriched in 91	6.2	86.6	5.9	1.3	0.1
Zr enriched in 92	2.4	2.2	92.7	2.3	0.4
Zr enriched in 96	8.7	2.2	4.3	10.3	74.6

RESULTS

Isotopes of zirconium separately enriched* in Zr^{90}, Zr^{91}, Zr^{92} and Zr^{96} were bombarded with 5-Mev protons and 10-Mev deuterons. The isotopic composition of the samples are shown in Table I.

A rotating target arrangement[4] was employed by which two isotopes could be bombarded simultaneously under the same beam and thus any activity produced could be associated with one or the other or none of the rotated isotopes. The degree of enrichment is such that the difference in activity between two samples will be a factor between 14 and 870, depending upon the selection made, if the particular activity be produced from either of the rotated isotopes. Deuteron bombardments produce

[1] L. A. DuBridge, private communication quoted by G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[2] L. Jacobson and R. Overstreet, Plutonium Project Report CC-2345 (December 1944).
[3] G. E. Boyd, private communication (October 1948), quoted by G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).

* Kindly supplied by the Y-12 Plant, Carbide and Carbon Chemicals Corporation, through the Isotope Division, US-AEC, Oak Ridge, Tennessee.
[4] D. N. Kundu and M. L. Pool, Phys. Rev. **74**, 1574 (1948).

such a large amount of various activities especially the 17-hour Zr^{97} that in the following study the main emphasis will be laid on proton bombardments.

From the table, Zr^{90}, Zr^{92}, and Zr^{96} are selected for comparative study. In every case a 23.3-hour Cb activity is produced. On rotating Zr^{90} with Zr^{92}, this activity is produced in the ratio 2.6/4.3 which indicates that this half-life is not produced from either of these isotopes. This 23.3-hour activity must be associated with one of the remaining three isotopes which is present in small comparable amounts in each of Zr^{90} and Zr^{92} samples. Bombardment of the Zr^{96} with protons, however, brings out the 23.3-hour activity in amounts larger than any of the previous amounts by a factor of about 190 when Zr^{92} was taken for comparison and about 320 when Zr^{90} was compared. From the table the factors expected under ideal conditions would be 90 and 180 when Zr^{96} is compared with Zr^{90} and Zr^{92}, respectively. The uncertainties introduced in course of mounting the material for measurement and from other sources may amount to a small factor at most. The order of magnitudes, therefore, clearly indicates that the 23.3-hour activity is produced from

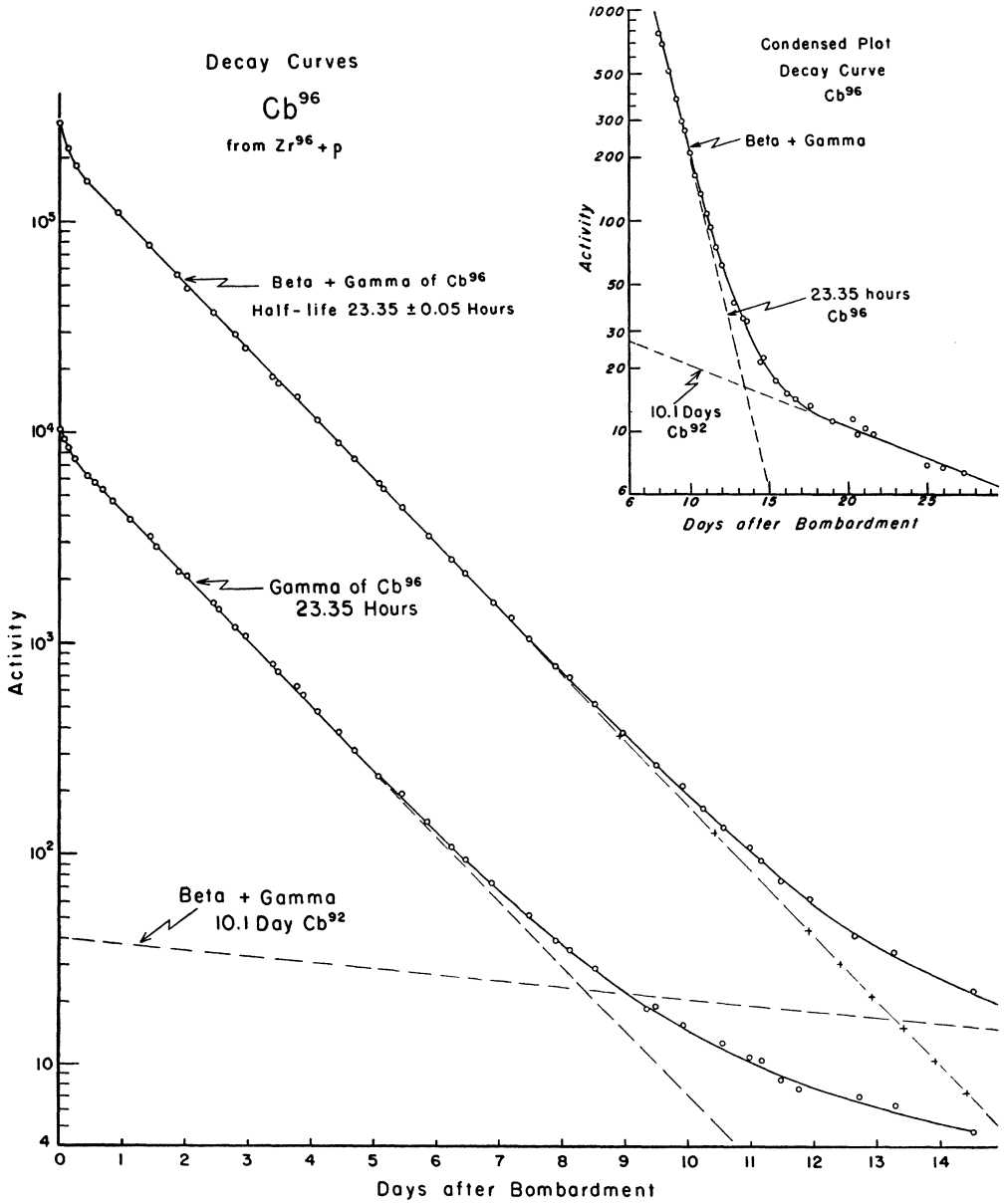

FIG. 1. Beta+gamma- and gamma-decay curves of $Zr^{96}O_2-p$, showing the 23.35-hour Cb^{96} activity. The inset shows a condensed plot in which the 10.1-day Cb^{92} activity is seen but no 2.8- or 4-day activity.

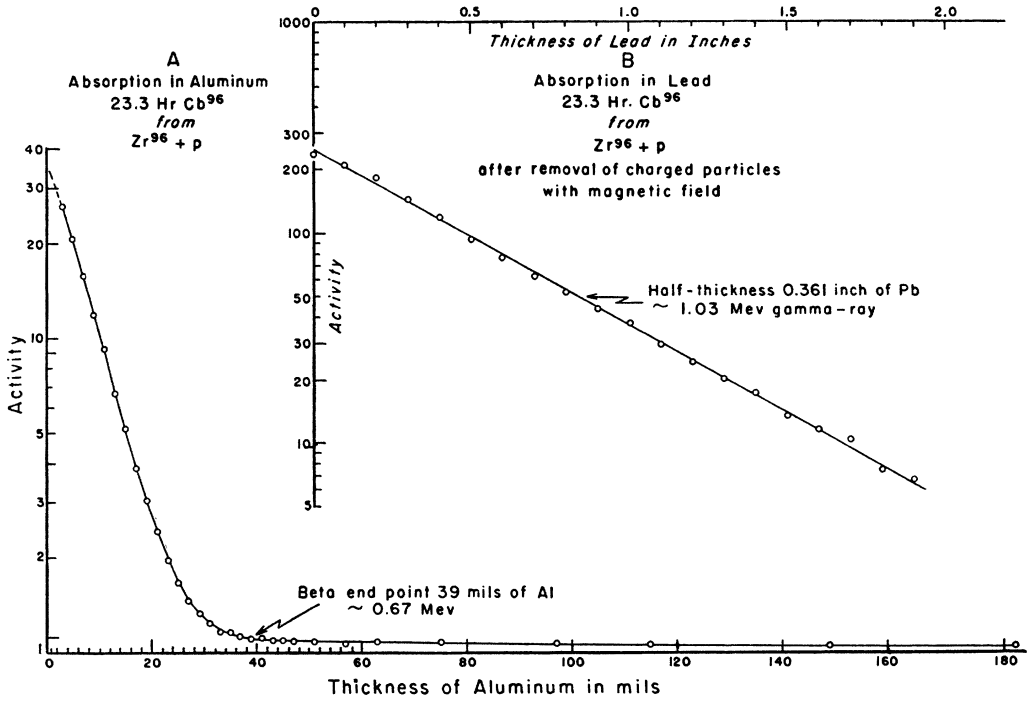

FIG. 2. Absorption curves of Cb^{96}: (A) absorption in aluminum; (B) absorption in lead.

Zr^{96} by (p,n) reaction, since both the isobaric chains 95 and 97 have already been well-established by the study of fission fragments.

The beta+gamma- and the gamma-decay curves of a sample of $Zr^{96}O_2$ bombarded with protons are shown in Fig. 1. From a total interval of fifteen half-lives the value is given as 23.35 ± 0.05 hours. No 4-day or 2.8-day half-life is observed. The curve passes immediately into the 10.1-day Cb^{92} period which has been produced from the small amount of Zr^{92} (4.3 percent) and, perhaps, of Zr^{91} (2.2 percent), present in the enriched Zr^{96} (74.6 percent).

The absorption curves are shown in Fig. 2. The energy of the beta-rays is 0.67 Mev. They are found to be negatively charged by separation in a magnetic field. The gamma-absorption was measured with lead foils after removing the beta-particles away with an electromagnet and the energy is found to be 1.03 Mev. The activity at zero thickness of lead shows that no x-rays are present.

DISCUSSION

Without entering into the question whether the 4-day or 2.8-day activity could be produced by bombarding with particles of energy higher than that used in the present investigation, it may be remarked that with the energies used here, the 10.1-day Cb^{92} has been produced in considerable strength from Zr^{92}. In the study of Mo^{98} with deuterons in this connection, it was found that this molybdenum isotope has such a large cross section for (d,p) reaction leading to the 2.8-day Mo^{99} activity, that it was difficult to chemically remove traces of Mo^{99} from Cb fractions. The 2.8-day activity decays into the 5.9-hour Tc^{99} daughter which disintegrates mainly with x-ray emission. Also by deuteron bombardment of Mo, the 3.75-day Cb^{95} is produced which again decays by emitting x-rays. With such sources of x-rays suspected, energy measurements by absorption in aluminum are liable to error as reported[5] previously. The apparent beta-end point is pushed towards the higher energy side, thus giving a higher value for the maxima beta-energy. In the decay curves on the Mo fraction from Mo+d bombardments where the Mo was enriched in Mo^{92} (92.07 percent) and contained only 1.65 percent of Mo^{98}, the 2.8-day activity was present in very large amounts. Absorption measurements with aluminum foils showed that though the actual beta-end point ought to be at 1.16 Mev, the tail end of the curve could be drawn so as to correspond to 1.8 Mev. When enriched Mo^{98} itself is bombarded, so much of x-ray is present both due to the 2.8-day and the 3.75-day activities, that energy measurements are spurious if not corrected for x-rays.

Acknowledgment is made of the help received from the Development Fund and the Graduate School of the Ohio State University. Thanks are also due the Ghosh Board of the Calcutta University for aid in traveling to this country.

[5] D. N. Kundu and M. L. Pool, Phys. Rev. **74**, 1775 (1948).