TABLE V. Fission-fragment energy of U^{235} bombarded with 14-Mev neutrons.

Counter	$W_{5c}\times10^{-13}$	$R_{5c}\times10^{-5}$	Eq. (9), term A[a]	Eq. (9), term B[b]	Eq. (9), term C[c]	E_{14}[5]	Mev/fission
3	4.467	2.46[d]	172.5	0.6	5.3	178	169
4	4.273	2.11[d]	176.6	0.8	6.1	184	175
4	1.574	0.761[d]	180.3	1.0	6.7	188	179
4	4.092	2.04[d]	174.9	0.7	5.7	181	172
4	3.407	1.67[d]	177.9	0.9	6.3	185	176
							Av $\begin{cases}174\pm2^{e}\\174\pm4^{f}\end{cases}$

[a] Term $A=W_{5c}/(R_{5c}K_{14}{}^{5})$.
[b] Term $B=g[(W_{5c}/R_{5c}K_{14}{}^{8})-E_{14}{}^{8}]$.
[c] Term $C=c\bar{\nu}_{14}(1+g)[(W_{5c}/R_{5c}K_f)-E_f]$.
[d] Average of quadruplicate determinations.
[e] Experimental precision obtained between quintuplicate runs.
[f] Uncertainty including uncertainty in K-factor from Table II.

excitation energy. It seems unreasonable to assume that the centers of charge are closer together at higher excitation energy. We thus may guess that the fragments have kinetic energy at the time of scission in addition to that later acquired from Coulomb repulsion. The remaining 6 to 7 Mev from the incident neutron would appear to be divided between excitation of the fragments and the boiling off of at least one more neutron per fission. Cuninghame[3] has reported $\bar{\nu}$ of U^{238} bombarded with 14-Mev neutrons to be 4.0±0.5.

IV. ACKNOWLEDGMENTS

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New Neutron-Deficient Isotope of Cerium*

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Cerium-132, a positron emitter with a half-life of 4.2±0.2 hours, has been identified through its generic relationship to the known daughter nuclide, La^{132}. An activity of 30-minutes half-life and 4.2-Mev maximum positron energy, which may be due to Ce^{131}, was also observed.

INTRODUCTION

DURING a study[1] of the $Ce^{142}(p,pn)$ and $Ce^{142}(p,2p)$ cross sections at proton energies from 60 to 240 Mev, a new short-lived cerium activity was observed with a half-life of less than an hour. This prompted a search for Ce^{131} and Ce^{132} since these isotopes, and especially Ce^{131}, would be expected to have short half-lives.

The problem of establishing the presence or absence of Ce^{131} and/or Ce^{132} in cerium targets bombarded with protons at 240 Mev was complicated by the large number of cerium isotopes produced at this energy. Daughter activities were an added complication, as was the fact that La^{132} and La^{133} have almost identical half-lives. Special counting techniques were thus necessary to resolve the complicated spectrum of radiations.

EXPERIMENTAL

Specially purified cerous oxalate was bombarded in 100–200 mg quantities in the Rochester 130-inch synchrocyclotron at 240 Mev for 1 hour. Samples suitable for counting cerium activities were obtained by the following chemical separation.[2,3] The target material was dissolved in a minimum quantity of $10N$ HNO_3 and lanthanum carrier added, followed by a few drops

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[1] W. R. Ware and E. O. Wiig (to be published).
[2] Glendenin, Flynn, Buchanan, and Steinberg, Anal. Chem. **27**, 59 (1955).
[3] A. A. Caretto, Jr. (private communication).

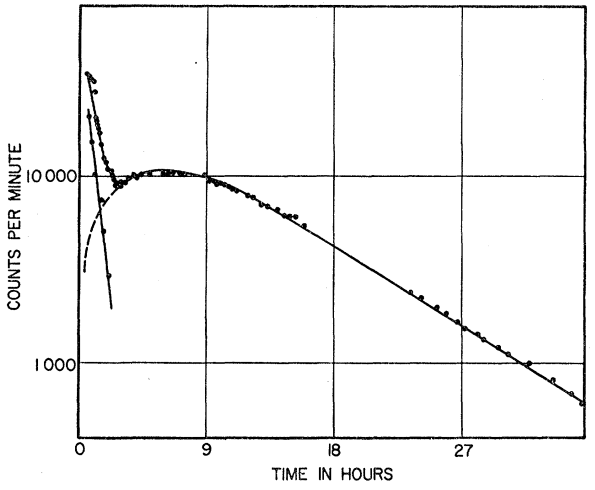

FIG. 1. The short-lived activity in the cerium fraction and the growth and decay of daughter La^{132} from Ce^{132}.

of $2M$ $NaBrO_3$. The oxidized cerium was then extracted with three 150-ml portions of methyl isobutyl ketone which had been previously equilibrated with $10M$ HNO_3 containing $NaBrO_3$. The ketone fractions were combined, washed several times with $10M$ HNO_3 (containing lanthanum carrier for the first two washes), and cerium extracted from the ketone into 15 ml of 5% H_2O_2. The H_2O_2 solution was made basic with conc. NH_4OH, and the cerous hydroxide precipitate washed several times with water. The hydroxide was dissolved in HCl and cerous oxalate twice precipitated from a hot solution with oxalic acid. A counting sample was prepared from the oxalate. This will be referred to as the "cerium fraction."

The procedure for milking lanthanum from cerium was adapted from the above method. As soon as possible after bombardment cerium was separated from lanthanum as just described and the H_2O_2 solution obtained. This was divided into as many parts as required, and a known amount of lanthanum carrier was added to each. These aliquots were allowed to stand for various intervals and lanthanum was then separated by extracting cerium with ketone as above, adding inactive cerium carrier and extracting again, and finally precipitating lanthanum hydroxide from the aqueous solution. Lanthanum was weighed and counted as the oxalate.

Chemical separations were started about 12–15 minutes after the end of the bombardment. The preparation of the cerium fraction required approximately one-half hour, as did the milking procedure.

CERIUM-132

Preliminary experiments indicated that the gross beta-decay curve obtained from the cerium fraction by beta proportional counting was hopelessly complicated, as was the gross decay of 0.51-Mev gamma radiation taken with a scintillation spectrometer. Direct evidence for the presence of Ce^{132} was sought by examining the cerium fraction for the positron radiation of La^{132}, which has a maximum beta energy of approximately 3.5 Mev.[4] This was accomplished by using a scintillation spectrometer of conventional design with a plastic scintillator as detector,[5] and biasing out all radiation of energy less than 3 Mev through integral operation of the pulse-height analyzer. Since La^{132} was the only known nuclide with a maximum beta energy greater than 3 Mev anticipated in the cerium fraction, a relatively simple decay curve amenable to analysis was expected. The resultant gross decay curve, shown in Fig. 1, indicated that the short-lived activity had a maximum beta energy greater than 3 Mev. The growth and decay portions of the curve could be interpreted as the activity of daughter La^{132} from Ce^{132}. The maximum in the curve was consistent with a 4-hour half-life for Ce^{132}, assuming 4.5 hours for La^{132}.[4] Points from this decay curve, after the short-lived activity had decayed away, were subjected to mathematical analysis using the well-known parent-daughter relationships and a 4-hour half-life for the parent was the only assumption giving a constant initial activity for the parent. While this experiment did not prove the presence of Ce^{132}, it provided strong evidence for its existence.

To confirm the presence of La^{132} in the cerium fraction the above experiment was repeated using a 180° magnetic beta-ray spectrometer with a Geiger-Müller detector. Slits and the magnet current were adjusted to provide a window of about 0.5 Mev, cutting out all radiation of energy less than 3 Mev. Results identical with the above experiment were obtained, indicating that the decay curve shown in Fig. 1 was not due to an instrumental effect, and that the radiation consisted of positrons.

In order to demonstrate a generic relationship between La^{132} and the 4-hour activity thought to be Ce^{132}, it was necessary to milk the daughter from the cerium fraction and to show that the daughter activity as a function of time was in accord with that predicted. Using the milking procedure described in the experimental section, samples were obtained uniformly covering a period of 35 hours from the time of initial separation of cerium from lanthanum. The samples were counted with the scintillation spectrometer biased as before to reject beta radiation of energy less than 3 Mev. The plastic detector was used. Semilogarithmic plots of the decay data were linear and gave a half-life of 4.8 ± 0.2 hours for La^{132}. These were extrapolated to the time of milking, and corrected for chemical yield. The results are shown in Fig. 2. The circles represent the observed corrected disintegration rates at the time of milking of the daughter activity. The aliquots were identical and each was milked only once. Using the

[4] M. M. Granden and W. S. Boyle, Phys. Rev. 82, 447 (1951).
[5] Obtained from Pilot Chemical Co., Type Pilot *B*, 0.5 in. thick by 2-in. diameter.

observed half-life of 4.8 hours for La^{132}, various half-lives were tried for the parent, and 4.2±0.2 hours gave a constant initial parent activity for all the experimental points. In Fig. 2, line A is approached by the daughter activity as time becomes large, with the $t=0$ point at $N_p^0\lambda_p\lambda_d/(\lambda_d-\lambda_p)$ and a half-life of 4.8 hours. If the milking curve is subtracted from the line A, the resultant line B has the parent half-life, confirming the numerical analysis of the data. This result was consistent with the work described above with the cerium fraction and is taken as a proof of the generic relationship between a 4.2-hour activity and La^{132}, its daughter. Ce^{132} is the only possible isotope.

The maximum beta energy of La^{132} was determined, using the plastic scintillator, from scintillator spectrometer data obtained from the positron spectrum of a cerium fraction after the short-lived activity had decayed. The spectrum from 3 to 4.2 Mev was scanned manually with a channel width of 0.2 Mev, and this was done repeatedly as the sample decayed. From the set of curves of count rate as a function of time for each 0.2-Mev interval, the beta spectrum could be obtained for any given time. Spectra at various times during the decay were analyzed with Kurie plots and gave 3.8±0.1 Mev for the maximum positron energy, in substantial agreement with the reported value[4] of 3.5 Mev, since aluminum absorption data tend to give slightly low values. It was possible to analyze only the tails of the beta spectra and thus no information regarding the nature of the transition could be derived from the Kurie plots.

The maximum positron energy of Ce^{132} could not be determined. It is clearly <3 Mev, but because of the complexity of the spectra of beta radiation of energy <2.7 Mev and the fact that several other isotopes in the sample had half-lives of about 4 hours, the problem was hopeless with the equipment available. Use of the Coryell[6] beta systematics led to the prediction that the disintegration energy of Ce^{132} should be about 1 Mev, which is consistent with our results.

CERIUM 30-MINUTE ACTIVITY

After the identification of Ce^{132}, the curve shown in Fig. 1 was analyzed more fully to obtain the half-life of the short-lived activity, since the growth portion of the curve masked by the decay of this activity could now be calculated with confidence (dashed line) and subtracted from the gross decay curve. This gave the straight line shown in Fig. 1, which indicated an activity with a half-life of 30±5 minutes.

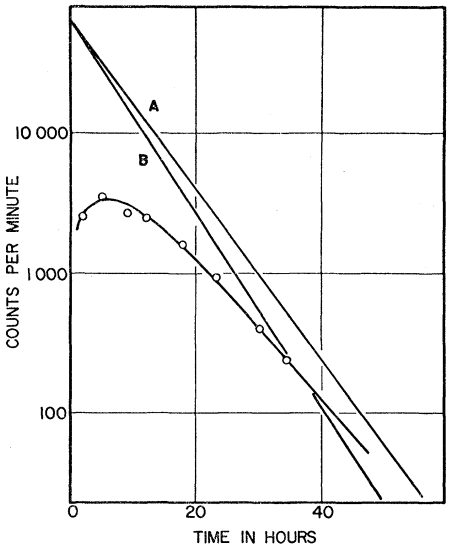

FIG. 2. Growth and decay of La^{132} daughter. A-decay of daughter La^{132} of 4.8-hour half-life. B-decay of parent Ce^{132} of 4.2-hour half-life. Circles indicate points determined in milking experiment.

The identity of the 30-minute activity is open to question. Two milking experiments, similar to those described above, were unsuccessful due to the fact that the yield of 1-hour La^{131} was too low to be determined accurately by beta proportional counting or spectrometer methods. Although La^{131} was probably present the amount was small compared to other activities present in the lanthanum sample and the resolution of the beta proportional data was not sufficiently accurate to establish a correlation between the predicted daughter activity and the observed activity. Also, due to the complexity of the radiation spectrum of the samples, it was impossible to associate maximum beta energy with the activity thought to be La^{131}.

The maximum positron energy of the 30-minute activity was determined through use of Kurie plots as described above for Ce^{132}. The value obtained was 4.2±0.3 Mev. The Coryell[6] beta systematics gave 3.4 Mev as the disintegration energy for Ce^{131}, a value which is not inconsistent with our suspicion that the 30-minute activity is due to this isotope.

ACKNOWLEDGMENT

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[6] C. D. Coryell, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Palo Alto, 1953), Vol. 2, p. 305.