The probable error is entirely due to the problem of absolute evaluation of the β-ray standard. Further work on improving the precision of the absolute β^+ count is planned. The internal consistency is ± 0.0004 barn over 8 runs.

The energy scale in Fig. 1 was established by the use of a range-energy relation in polystyrene as computed by Mr. Henrich of this laboratory. To check the correctness of this relation, a run was made substituting Al absorbers[4] to energies down to 20 Mev and using polystyrene absorbers below this point. The resultant points, shown by X in Fig. 1, are indistinguishable from the polystyrene absorber points. The range-energy relation was checked also by absorbing the 32-Mev beam down to the threshold of the $B^{11}(p,n)C^{11}$ reaction which was found to be 2.97 ± 0.1 Mev by Haxby, Shoupp, Stephens, and Wells.[5] We obtain 3.0 ± 0.6 Mev, indicating that the accuracy at the end point of the $C^{12} \rightarrow C^{11}$ reaction is of the order of ± 0.15 Mev. The output energy of the linear accelerator is inferred from frequency and drift tube dimensions to be 32.0 ± 0.1 Mev, an extrapolated range measurement in Al gave 32.1 ± 0.1 Mev. The test by means of the $B^{11}(p,n)C^{11}$ reaction would show up both errors in the accelerator energy, absorber, or range-energy curve.

If we assume that the threshold of the reaction is sharp, then the threshold can be located from the maximum of the second derivative curve (Fig. 1). We place the threshold of the reaction at

$$18.5 \pm 0.3 \text{ Mev},$$

where the probable error includes possible errors in the energy scale. If we take the mass of C^{11} to be 11.01498 (in agreement with the threshold[5] of 2.97 Mev for $B^{11}(p,n)C^{11}$, and the β^+-end point[6] from C^{11} of 0.95 Mev) the calculated threshold of the reaction $C^{12}(p,pn)C^{11}$ corrected for recoil, is 20.2 Mev. The earlier values given by Livingston and Bethe and Barkas[7] for the C^{11} β^+-end point and the mass of C^{11} are about 0.3 Mev higher but are based on earlier measurements[8] probably affected by N^{13} contamination. This means that the reaction $C^{12} \rightarrow C^{11}$ must be a (p,d) reaction, rather than a (p,pn) reaction, at least near the excitation threshold. The only other instance of a specific deuteron yielding reaction known is the reaction $Be^9(p,d)Be^8$.[9] Cosmic-ray evidence in photographic plates[10] makes it appear that such an event is also possible in high energy processes without breakup of the deuteron.

If the incoming proton were captured by the C nucleus, the resultant excited N^{13} would strongly favor energetically the re-emission of a proton over the emission of a deuteron or neutron. The cross section of the p,d reaction by a compound nucleus process should therefore be much smaller than the values observed. The process is therefore likely to take place by a direct interaction, e.g., by direct ejection of a deuteron and subsequent decay of N^{12} with emission of a proton.

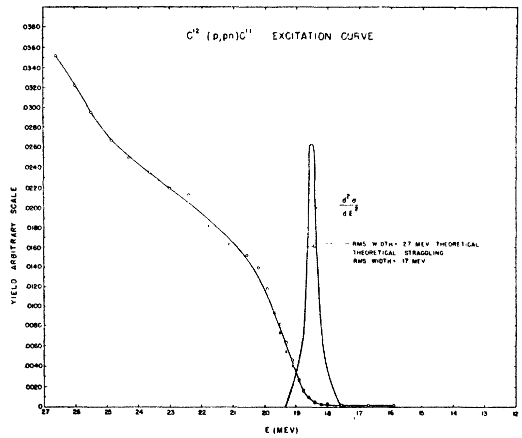

FIG. 1. The excitation curve for the reaction $C^{12}(p,pn)C^{11}$.

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1 W. W. Chupp and E. M. McMillan, Phys. Rev. **72**, 873 (1947).
2 E. M. McMillan and R. D. Miller, Phys. Rev. **73**, 80 (1948).
3 R. Serber, Phys. Rev. **72**, 1114 (1947).
4 J. H. Smith, Phys. Rev. **71**, 32 (1947).
5 Haxby, Shoupp, Stephens, and Wells, Phys. Rev. **58**, 1035 (1940).
6 Delsasso, White, Barkas, and Creutz, Phys. Rev. **58**, 586 (1940). Siegbahn, Arkiv. Mat. Astr. Fysik **30A**, No. 20 (1944); **30B**, No. 3 (1944).
7 Livingston and Bethe, Rev. Mod. Phys. **9**, 245 (1937); Barkas, Phys. Rev. **55**, 691 (1939).
8 Fowler, Delsasso, and Lauritsen, Phys. Rev. **49**, 561 (1936).
9 Allison, Skaggs, and Smith, Phys. Rev. **54**, 171 (1938); J. S. Allen, Phys. Rev. **51**, 182 (1937).
10 LePrince-Ringuet, Cosmic Ray Conference, Pasadena, June, 1948.

Some New Radioactive Isotopes of Tb, Ho, Tm, Lu, Ta, W, and Re

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IN order to allow quantitative interpretation of the reactions of high energy particles from the 184-inch cyclotron with tantalum and heavier elements, a systematic survey is being made of radioactive isotopes of the rare earth elements—hafnium, tantalum, tungsten, and rhenium. Bombardments of various elements are being made using 38-Mev and 20-Mev helium ions, 19-Mev deuterons and 10-Mev protons from the 60-inch Crocker Laboratory cyclotron. Chemical separation of the rare earth elements is made by ion-exchange resin columns. Table I summarizes present data; energies of radiations are determined from absorption measurements; positrons are observed using a "magnetic counter;" mass allocations are made on the basis of measured cross sections. The symbols used in the table are those employed by Seaborg.[1]

Detailed accounts of experimental techniques and of the isotopes will be published.

The allocation of the previously reported β-active

TABLE I.

Isotope	Class	Type of radiation	Half-life	Energy of radiation in Mev: Particles	Energy of radiation in Mev: γ-rays	Produced by
Tb^{152}	*D*	*K*	4.5 hr.		*K*, x-rays	Eu-*α*-3*n*
Tb^{153}	*D*	*K*, e^-	5.1 days	0.15, 0.4	*L*, *K*, x-rays	Eu-*α*-2*n*
Tb^{154}	*D*	*K*, e^-, β^+, γ	17.2 hr.	β^+ 2.6 e^- 0.22, ~1	*L*, *K*, x-rays 1.4	Eu-*α*-*n* Eu-*α*-3*n* Gd-*p*-*n*
Tb^{155}	*D*	*K*, e^-	~1 yr.	0.1	*L*, *K*, x-rays	Eu-*α*-2*n*
Ho^{160}	*D*	*K*?	~20 min.		x-rays	Tb-*α*-3*n*
$Ho^{161,162}$	*C*	*K*?, e^-, γ	60 days	0.16, 0.6	*L*, *K*, x-rays	Tb-*α*-2*n* Dy-*d*-*n*, 2*n*, 3*n* Dy-*p*-*n*
$Ho^{162,161}$	*C*	*K*, e^-, β^+, γ	4.5 hr.	e^- 0.3	*L*, *K*, x-rays 1.1	Tb-*α*-*n* Dy-*p*-*n*
Ho^{163}	*B*	*K*, e^-	7 days	0.4	*L*, *K*, x-rays	Dy-*p*-*n*
Ho^{164}	*D*	β^-	35 min.	0.7		Dy-*p*-*n*
Tm^{166}	*B*	*K*, e^-, β^+, γ	7.7 hr.	β^+ 2.1 e^- 0.24, ~1	*L*, *K*, x-rays ~1.5	Ho-*α*-3*n*
Tm^{167}	*B*	*K*, e^-, γ	9 days	0.21	*L*, *K*, x-rays 0.22, 0.95	Ho-*α*-2*n* Ta-*d*-5*z*-16*a*
$Tm^{167,168}$	*C*	*K*?, e^-	~100 days	0.16, 0.5	*L*, *K*, x-rays	Ho-*α*-*n* or 2*n*
Lu^{170}	*B*	*K*, e^-, β^+, γ	2.15 days	β^+ 1.7 e^- 0.1	*L*, *K*, x-rays 1.5	Tm-*α*-3*n* Yb-*d*-2*n*, 3*n* Ta-*d*-3*z*-13*a*
Lu^{171}	*B*	*K*, e^-, γ	9 days	0.17, 0.7	*L*, *K*, x-rays	Tm-*α*-2*n* Ta-*d*-3*z*-12*a* Yb-*d*-*n*, 2*n*, 3*n*
$Lu^{171,172}$	*C*	*K*?, e^-, γ	>100 days	0.11, 0.22	*L*, *K*, x-rays	Tm-*α*-*n* or 2*n* Yb-*d*-*n*, 2*n*, 3*n*
Ta^{176}	*B*	*K*, e^-, γ	8.0 hr.	0.12, 0.18, 1.2	*L*, *K*, x-rays 1.7	Lu-*α*-3*n* Ta-*d*-*z*-7*a*
Ta^{177}	*B*	*K*, e^-	2.66 days	0.1	*L*, *K*, x-rays	Lu-*α*-2*n* Ta-*d*-*z*-6*a* Hf-*d*-*n*, 2*n*, 3*n*
$Ta^{178,177}$	*C*	*K*, e^- or β^-	16 days	1.1		Lu-*α*-*n* or 2*n* Hf-*d*-*n*, 2*n*, 3*n*
$W^{179,178}$	*C*	*K*, e^-, γ	135 min.	0.15, 0.45	*L*, *K*, x-rays ~0.5, 1.2	Ta-*d*-4*n* or 5*n*
Re^{182}	*B*	*K*, e^-, γ	64 hr.	0.11, 0.27, 0.6	*L*, *K*, x-rays 0.22, 1.5	Ta-*α*-3*n* W-*p*-*n*
$Re^{183,184}$	*C*	*K*?, γ	13 hr.		*K*, x-rays 1.6	Ta-*α*-2*n* or *n* W-*p*-*n*
$Re^{184,183}$	*C*	*K*, e^-, γ	~80 days	0.1	*L*, *K*, x-rays 1.0	Ta-*α*-*n* or 2*n* W-*p*-*n*

isotopes of lutecium with half-lives of 3.75 hours and 6.8 days, to masses 176 and 177, respectively, has been confirmed by measurement of the *d*,*p* cross sections for 19-Mev deuterons in lutecium.

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