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G. M. GORODINSKII, A. N. MURIN, V. N. POKROVSKII,

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**Abstract**

**Full Text**

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### **PHYSICS**

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## **RADIOACTIVE ISOTOPES OF THE RARE EARTHS FORMED IN A DEEP-SPALLATION REACTION**

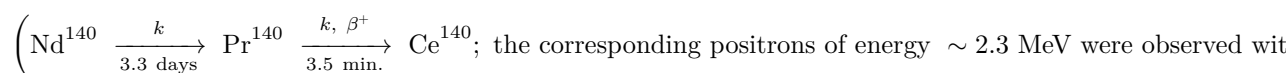
*(Presented by Academician L. A. Artsimovich, 27 X 1956)*

Radioactive isotopes of the rare earths obtained by irradiating tantalum with protons of energy 340 MeV were studied by Nervik and Seaborg (<sup>1</sup>). In this work isotopes of erbium, thulium, ytterbium, and lutetium were isolated; the lighter fractions, with the exception of cerium, were not investigated.

We isolated and chromatographically separated (<sup>2</sup>) long-lived radioisotopes of the rare earths obtained by irradiating tantalum with protons of energy 680 MeV in the synchrocyclotron of the Joint Institute for Nuclear Research.

Determination of half-lives, type and energy of radiation, as well as repeated recording of  $\gamma$ -spectra on a scintillation spectrometer (NaJ(Tl) and CsJ(Tl) crystals), made it possible to identify a number of known radioisotopes, to clarify certain genetic relationships, to discover new gadolinium isotopes, and to indicate a number of new lines in the  $\gamma$ -spectra of the nuclides studied by us. A brief account of the results obtained for the separate fractions is given below.

1. Cerium. The isotopes  $Ce^{134}$  and  $Ce^{139}$  were found; their radioactive characteristics completely coincide with those reported in the literature (<sup>3</sup>).
2. Neodymium. In this fraction the only radioisotope found was  $Nd^{140}$  ( $T = 3.3$  days), whose  $\gamma$ -spectrum had not previously been studied. According to our data, in addition to an intense annihilation gamma line with energy 0.51 MeV



there is a close  $\gamma$ -line of energy 0.5 MeV, detected from the shape of the annihilation line. In the energy region 0.26–0.32 MeV there is a group of weak lines; there is a 0.19 MeV line (apparently double), and, finally, a weak 0.11 MeV line.

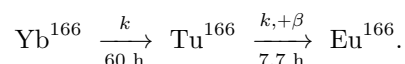
3. Europium. The isotopes  $\text{Eu}^{145}$  ( $T = 5$  days) and  $\text{Eu}^{147}$  ( $T = 24$  days) were found; their  $\gamma$ -spectra are not described in the literature. The  $\gamma$ -spectrum of  $\text{Eu}^{145}$  consists of four weak lines: 0.630, 0.660, 0.730, and 0.890 MeV. Study of the  $\gamma$ -spectrum in the region 0.080–0.300 MeV is hindered by the presence of the intense  $\gamma$ -spectrum of  $\text{Eu}^{147}$ ; in the region 0.30–0.45 MeV there are a number of very weak lines, poorly resolved by the spectrometer. The spectrum of  $\text{Eu}^{147}$  consists of a weak, apparently strongly converted, line at 0.080 MeV and two intense lines at 0.124 and 0.200 MeV.
4. Gadolinium. Activities with half-lives of 1.5 days, 9 days ( $\text{Gd}^{149}$ ), and  $70 \pm 5$  days were found. In the separated daughter substances accumulating in the gadolinium fraction,  $\text{Eu}^{147}$  was found with its characteristic  $\gamma$ -spectrum. Repeated separation of Eu suggests that the parent substance of  $\text{Eu}^{147}$  is a Gd isotope with a half-life of 1.5 days, to which, consequently, mass number 147 should be assigned. The mass number of the other radioisotope ( $T = 70$  days) has not been definitively established, but it has been proposed to be 145 on the basis of the observed

in the daughter fraction from the traces of  $\text{Eu}^{145}$ . In the spectrum of  $\text{Gd}^{147}$  three  $\gamma$ -lines were found, 0.232, 0.373, and 0.385 MeV, with successively decreasing intensity; in the previously unknown spectrum of  $\text{Gd}^{149}$ , four lines (given in order of decreasing intensity): 0.154, 0.292, 0.350, and 0.505 MeV. The spectrum of  $\text{Gd}^{145(?)}$  consists of three lines: 0.115 (weak), 0.638, and 0.750 MeV.

5. Terbium. Activities were observed with half-lives of 20 h ( $\text{Tb}^{151}$  or  $\text{Tb}^{154}$ ), 4.5 days ( $\text{Tb}^{153}$  or  $\text{Tb}^{156}$ ;  $\text{Tb}^{157}$ , according to work <sup>(4)</sup>, has a half-life of less than 10 min or greater than 25 years). The  $\gamma$ -spectrum of the Tb fraction is very complex and is poorly resolved. Lines with energies of 0.345 and 0.465 MeV belong to the Tb isotope with half-life  $\simeq 20$  h. In the daughter fraction, Gd with a half-life  $\simeq 70$  days and with  $\gamma$ -line energies of 0.100 and 0.150 MeV was found. Further study of the Tb fraction is quite necessary.
6. Dysprosium. In the Dy fraction (separated from Y), activity with a half-life  $\simeq 8$  h, which we attribute to  $\text{Dy}^{157}$ , was found. In the  $\gamma$ -spectrum of this isotope,  $\gamma$ -lines of 0.233 and 0.325 MeV were observed, of which the latter agrees with the literature data <sup>(5)</sup>.
7. Fractions of holmium, erbium, and thulium. The principal data agree satisfactorily with the results of Nervik and Seaborg and other authors <sup>(1,3,6,7)</sup>.

The radioisotope  $\text{Ho}^{160}$  ( $T = 5$  h), in addition to the  $\gamma$ -lines indicated in <sup>(1)</sup>, has two weak lines with energies of 0.29 and 0.51 MeV. The structure of the spectrum of  $\text{Tm}^{166}$  is indicated below.

8. Ytterbium. Activity was found with half-lives of 60 h ( $\text{Yb}^{166}$ ) and 31 days ( $\text{Yb}^{169}$ ). In <sup>(1)</sup> the  $\gamma$ -spectrum of the equilibrium mixture was given



Separation of the daughter fraction ( $\text{Tu}^{166}$ ) made it possible to separate the  $\gamma$ -spectra of  $\text{Yb}^{166}$  and  $\text{Tu}^{166}$ . The spectrum of  $\text{Tu}^{166}$  consists of lines 0.080, 0.180, 0.690, and 0.780 MeV. Lines with energies of 0.112 and 0.140 MeV should be attributed to the isotope  $\text{Yb}^{166}$ . The presence is confirmed of a  $\gamma$ -line with energy 0.260 MeV in the spectrum of  $\text{Yb}^{169}$ , indicated in <sup>(8)</sup>.

9. Lutetium. Activities were found with half-lives  $\simeq 2$  days, 7-8 days, about 35 days, and with a longer period. The supposition of Nervik and Seaborg that the Lu radioisotope with a period of 1.7 days (2 days according to our measurements) is the parent substance of  $\text{Yb}^{169}$  with a half-life of 32 days is confirmed, since the spectrum of Yb separated from the Lu fraction fully coincides with the well-studied spectrum of  $\text{Yb}^{169}$ . The activity observed in the Lu fraction with a period of 32 days belongs precisely to this daughter isotope. Thus, the period of 1.7 days corresponds to  $\text{Lu}^{169}$ , which does not exclude the possibility of formation of  $\text{Lu}^{170}$  with a half-life close to the indicated one ( $\simeq 2$  days). The spectrum of long-lived Lu (apparently  $\text{Lu}^{174}$ ) consists of a  $\gamma$ -line with energy 0.265 MeV. Let us note that we observed electrons with an energy of 0.6 MeV, appearing in the transformation  $\text{Lu}^{174} \xrightarrow{\beta^-} \text{Hf}^{174}$ .

A detailed description of the method and discussion of the results will be published.

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*Note: Figure translations are in progress. See original paper for figures.*

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