New Erbium Isotope, ^{155}Er†

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A new erbium isotope ^{155}Er was produced by bombarding enriched ^{156}Dy with α particles accelerated in the Oak Ridge Isochronous Cyclotron. In the experiments, recoil nuclei ejected from the thin target were collected on beryllium foils. After bombardment, the activity collected on the catchers was assayed with an α-particle Si(Au) spectrometer. The new isotope was found to have a half-life of 5.3 ± 0.3 min; its α-decay energy was measured to be 4.01 ± 0.03 MeV. The mass assignment of ^{155}Er was established by measuring an excitation function for its production for α-particle bombarding energies from 59.2 to 72.6 MeV.

I. INTRODUCTION

In an earlier publication,[1] we reported on α-particle spectra of holmium nuclides produced in the reactions ^{156}Dy$(p, xn)^{(157-xn)}$Ho. The half-life and α-decay energy of ^{153}Ho were established (previously conflicting values had been available in the literature[2–5]) and a new isotope ^{154}Ho was discovered in that investigation.[1]

The α emitters $^{152-154}$Er were first characterized by Macfarlane and Griffioen[6] in heavy-ion induced reactions. The next heavier erbium nuclide according to α-decay energy systematics should also have a detectable α-decay branch. Excitation functions calculated by using the statistical theory[7] of nuclear reactions indicated that ^{155}Er could be produced by bombarding ^{156}Dy with helium ions in the energy range 60–80 MeV. Since helium ions with these energies are available at the Oak Ridge Isochronous Cyclotron (ORIC) a search was undertaken for the α activity of this new nuclide.

II. EXPERIMENTAL PROCEDURE

To facilitate the detection of the short-lived erbium radionuclides the experiments were performed online at the ORIC. The target assembly has been described in a previous publication.[8] It provides for the collection of recoil nuclei ejected from the thin target followed by their rapid assay. Absorbers that decrease the beam energy, and beryllium catcher foils, are mounted on movable wheels that can be remotely driven. One can thus select and automatically position any appropriate combination of absorber and catcher for a given irradiation. After irradiation, the wheel can be automatically turned in $\lesssim 10$ sec to place the beryllium catcher near a surface barrier Si(Au) detector for assay of the α-particle radioactivity.

The targets consisted of thin layers of dysprosium oxide, $\sim$0.6 mg/cm^2, electrodeposited onto platinum supporting foils. The isotopic composition of the enriched dysprosium was such that the target nucleus of interest ^{156}Dy made up 12.6% of the material. During irradiation, the target was positioned so that first the platinum backing and then the dysprosium oxide deposit intercepted the beam. Evacuation of the space between target and catcher ensured that the recoil nuclei, all emitted in the forward direction, would reach the catcher foil. Helium gas cooled the target backing.

α-particle spectra were obtained with the Si(Au) detector coupled through a low-noise charge preamplifier, linear amplifier, and postamplifier to a 1600 multichannel analyzer. This pulse-height analyzer served as sixteen 100-channel analyzers to store spectra as a function of decay time. A precision pulser in conjunction with a ^{244}Cm source mounted on the recoil-catcher wheel was used to set the energy scale of the spectrometer. Initial experiments demonstrated that the β-γ activity induced in the beryllium was sufficient to affect adversely the resolution of the α spectrometer. Double differentiation in the linear amplifier was employed to minimize pile up between this β-γ background and the α pulses of interest. With these 0.75-μsec-wide bipolar pulses, the full width at half-maximum (FWHM) of standard α peaks was $\sim$50 keV. Under actual irradiation conditions, the FWHM increased to $\sim$155 keV mainly because of the penetration of recoil nuclei into the catchers. It was, therefore, necessary to use internal calibration standards to determine previously unknown α-particle energies.

III. RESULTS AND DISCUSSION

After the helium ions from the ORIC had passed through window and target-backing foils, the maximum

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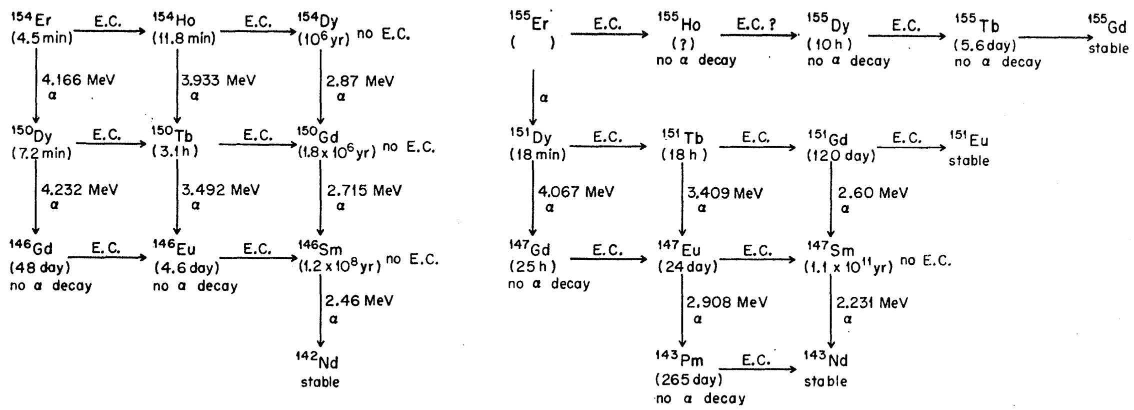

FIG. 1. The ^{154}Er and expected ^{155}Er decay chains.

available energy was 72.6 MeV. An initial series of bombardments showed little α activity produced at energies below $\sim$60 MeV. The main effort was, therefore, directed at the study of α spectra produced by helium ions in the energy range 59.2–72.6 MeV. Calculated excitation functions indicated that the predominant reactions at these energies would be $(\alpha, 5n)$ and $(\alpha, 6n)$. The ^{156}Dy$(\alpha, 6n)$ product ^{154}Er has been identified[6] earlier as a 4.5-min α-emitter in heavy-ion-induced reactions. The ^{156}Dy$(\alpha, 5n)$ reaction would lead to the previously unreported isotope ^{155}Er. In Fig. 1, we indicate the ^{154}Er and expected ^{155}Er decay chains. While a total of 13 α emitters are present in the two decay chains most of these would not be observed due to long half-lives and/or low α-decay branching ratios. It was, therefore, expected that in the bombarding energy range investigated five α emitters would be seen: ^{154}Er, ^{154}Ho, ^{150}Dy, ^{155}Er, and ^{151}Dy. A previous search for the α-decay of ^{155}Ho, the electron-capture daughter of ^{155}Er, had yielded negative results.[1]

Preliminary measurements at $\sim$63 MeV, where, according to the statistical-model calculations, little if any ^{154}Er should be made, indicated the presence of an α-emitter which decayed with about a 5-min half-life. A series of 5-min bombardments, each followed by 101 min of counting, was then made to determine the excitation function for the production of this new α emitter. Figure 2 shows spectra measured at 61.8, 70.5, and 72.6 MeV. Lower portions of the figure were obtained by summing the first three 4-min counts; upper portions of Fig. 2 represent the sum of the last four 16-min counts. The spectrum obtained at early counting times is much less complex at 61.8 MeV than at 70.5 and 72.6 MeV. This observation is consistent with the calculated excitation functions which indicated that ^{154}Er should begin to be produced in substantial amounts above 65 MeV.

A calculation, based on the theory of Lindhard *et al.*,[9] was made of the range of the erbium recoils in beryllium. The calculation which assumed full-momentum transfer from the incoming helium ions showed that the burial of these erbium recoils in the beryllium would lead to a line broadening in the detected α peaks of about 120 keV. This value when added to the intrinsic resolution of the detection system is close to the FWHM ($\sim$155 keV) measured for α peaks observed below 65 MeV. Decay curve analysis of these data yielded a half-life of 5.3 ± 0.3 min and a small amount of a longer-lived component 18–20 min, which was assigned to ^{151}Dy decay. The shape of the peaks observed below 65 MeV was then used to resolve the the more complex α spectra measured at 67.6, 70.5, and 72.6 MeV. Analysis of the decay data for the remaining portions of the spectra at these three energies indicated unequivocally the presence of the three alpha emitters in the ^{154}Er decay chain.

A recent study[10] of rare-earth α emitters in this same region has been made with a magnetic spectrograph. The α energy reported for ^{154}Er is 4.166 ± 0.005 MeV.

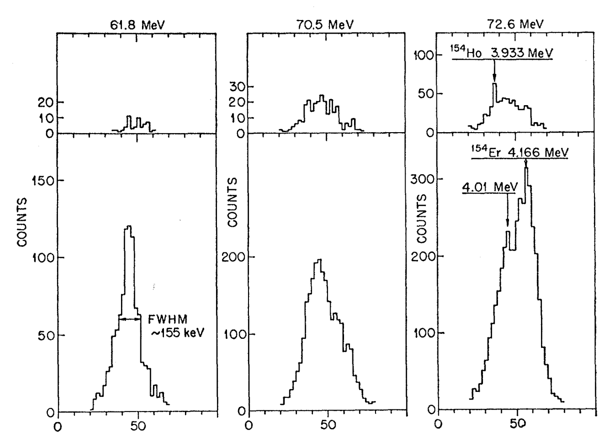

FIG. 2. α spectra measured at 61.8, 70.5, and 72.6 MeV. Lower portions of the figure represent the sum of the first three counts taken between 0.5 and 18.0 min after bombardment. Similarly, the upper portions represent the counts taken between 35 and 101 min. Energies given for ^{154}Er and ^{154}Ho are taken from Ref. 10.

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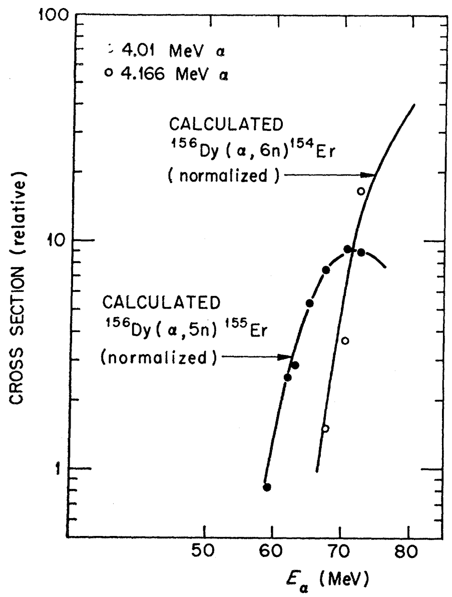

FIG. 3. Data points indicate the relative excitation functions determined for the 4.01- and 4.166-MeV α groups. Excitation functions calculated on the basis of the statistical model for the reactions ^{156}Dy(α, $5n$) and ^{156}Dy(α, $6n$) are indicated by curves normalized to the data points.

This value, together with our experimental number of keV per channel, yielded a calibration scale which was used to determine an energy of 4.01±0.03 MeV for the new α emitter. The 30-keV uncertainty is due to the large widths of the α peaks in our spectra. A corroborative piece of evidence for the accuracy of the energy determination was obtained. The 11.8-min nuclide ^{154}Ho recently observed[1] in our proton bombardments of ^{156}Dy was also seen in the present study. The peak assigned to ^{154}Ho is prominent in the 72.6-MeV upper spectrum (see Fig. 2). By using the same method of energy determination, we arrive at an energy of 3.93±0.03 MeV for Ho^{154}. This value is in agreement with the energy of 3.933±0.005 MeV reported in the magnetic spectrograph work.[10]

A relative excitation function (see Fig. 3) was obtained for the production of the 5.3-min 4.01-MeV α emitter. The ordinate scale in Fig. 3 represents the cross section in relative units because only the α-decay branch of the nuclide was observed in this experiment. The calculated ^{156}Dy(α, $5n$) excitation function, therefore, was normalized to the data points. It is seen that the energy dependence exhibited by the data is reproduced well by the calculated curve. The particular values of the level density and radius parameters used in the calculations were $a=A/20$ and $r_0=1.5$ F, respectively; other choices did not change the curve drastically. The excitation function for the 4.5-min ^{154}Er is also shown in Fig. 3 with the calculated (α, $6n$) curve normalized to the data points. Again, it is seen that the calculated curve follows the experimental points.

The 4.01-MeV α peak which decays with a 5.3-min half-life is assigned to ^{155}Er on the basis of the following evidence:

(a) The peak was not observed[1] in 20–60-MeV proton bombardments of ^{156}Dy. It is, therefore, most likely not a holmium isotope. This information coupled with the fact that its decay energy and half-life do not correspond to those of any known α emitters with atomic numbers ≤ 66 strongly suggests that it is an erbium isotope.

(b) The shape of the calculated ^{156}Dy(α, $5n$) excitation function followed closely the experimental excitation function for the production of this 4.01-MeV peak. A mass number of 155 appears thus likely for this new α emitter. The mass assignment is supported by the agreement observed between the shape of the calculated ^{156}Dy(α, $6n$) excitation function and the increase in the amount of ^{154}Er α activity measured from 67.6 to 72.6 MeV.

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