PHYSICAL REVIEW C VOLUME 48, NUMBER 1 JULY 1993

Observation of ^{146}Er electron capture and β^+ decay

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(Received 23 February 1993)

In an investigation of $A=146$ isobars, produced in ^{58}Ni bombardments of ^{92}Mo, the electron capture and β^+ decay of the previously unknown isotope ^{146}Er was identified. This nuclidic assignment was based on the observation of Ho K x rays in coincidence with β-delayed protons as well as in total-projected coincidence γ-ray spectra. From the time distribution of the x-ray events seen in these total-projected spectra the half-life of ^{146}Er was determined to be 1.7(6) s.

PACS number(s): 23.20.Lv, 27.60.+j

Decay properties of $A=146$ nuclides, produced in ^{58}Ni + ^{92}Mo irradiations and mass separated at the Lawrence Berkeley Laboratory OASIS on-line facility [1], have been investigated by using a Si particle and two Ge γ-ray detectors. The first observation of protons emitted following ^{146}Ho electron capture (EC) and β^+ decay was reported in [2]. Here we present evidence for the identification of a new isotope in the same mass chain, namely ^{146}Er.

A 1.92-mg/cm^2 thick metal foil of ^{92}Mo (97.4% enrichment) was bombarded with 280-MeV ^{58}Ni ions from the SuperHILAC. The beam energy at the center of the target was calculated to be 262 MeV. After mass separation the $A=146$ products were collected with a programmable tape system and then transported to a counting station for radioactive assay. At this station, facing the collected active layer, were a Si particle ΔE-E telescope and a hyperpure Ge detector, while on the other side of the tape there was an n-type Ge detector with a relative efficiency of 24.3%. Coincidences between β-delayed protons, γ rays, and x rays were recorded in an event-by-event mode. Events in all detectors were tagged with a time signal for lifetime information. Singles γ-ray data were also taken with the 24.3% Ge detector. A tape cycling time of 12 s was selected for the experiment keeping in mind the known half-lives of ^{146}Ho (3.9 s [3]) and its β-decay daughter ^{146}Dy (29 s [4]).

In Ref. [2], together with information on five other nuclei, it was reported that the observed protons at $A=146$ ranged in energy from 2.3 to 6.3 MeV and that their average energy was 4.13(4) MeV. (The spectrum itself is displayed in a recent thesis [5] together with results of statistical model calculations.) Figure 1 shows the low-energy (5–200 keV) photon spectrum recorded in coincidence with these β-delayed protons using the n-type Ge detector. Characteristic Dy K_α and K_β x rays do indeed dominate the spectrum. However, there is also a peak whose energy corresponds to that of the Ho K_{α_1} x rays, indicating that some of the $A=146$ delayed protons must follow ^{146}Er electron capture and β^+ decay. Evidence for ^{146}Er is further displayed in Fig. 2(a) which shows the same x-ray data in an expanded fashion. Included in the figure is a curve that represents a calculated fit using a computer program [6] written to perform fitting to multiplets of K-x-ray peaks. The Ho K_{α_1} 47.5-keV peak (with a total of six counts) is clearly visible. Figure 2(b) shows a similar fit to x rays recorded with the intrinsic Ge detector in coincidence with delayed protons. Despite the reduced efficiency of this detector one notes that we did observe a total of two counts at the Ho K_{α_1}-x-ray energy.

Based on the relative number of Dy and Ho K_{α_1} x rays seen in Figs. 2(a) and 2(b), we estimate that about 10% of

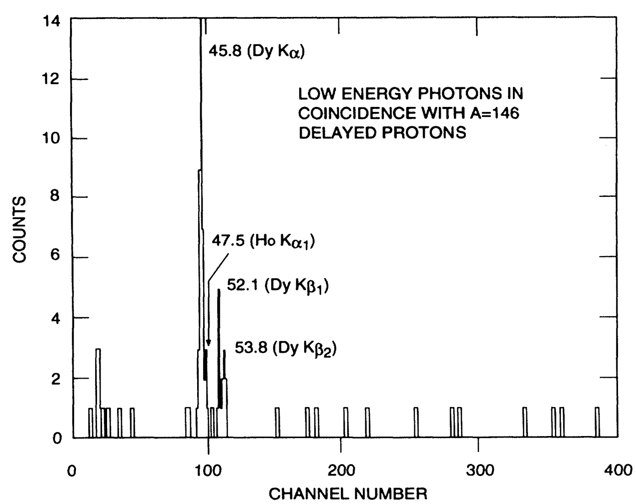

FIG. 1. Low-energy photon spectrum recorded with a 24.3% Ge detector in coincidence with β-delayed protons.

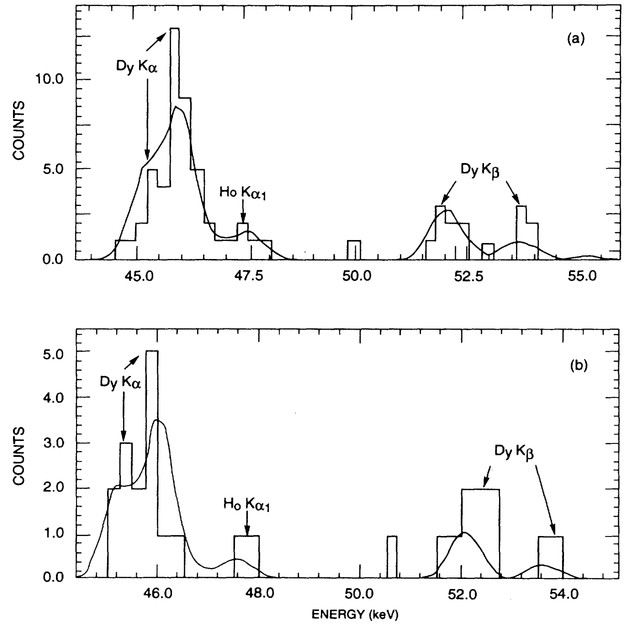

FIG. 2. K x rays observed in coincidence with β-delayed protons as recorded with a 24.3% Ge detector [part (a)] and a planar hyperpure Ge detector [part (b)].

the β-delayed protons observed earlier [2,5] were due to ^{146}Er decay. This percentage is of the same order of magnitude as the ratio of cross sections predicted [7] for the production of ^{146}Er and ^{146}Ho, namely, 1.3 mb/39 mb= 0.033. However, the fact that the experimental ratio is larger probably indicates that the ^{146}Er branch for delayed-proton decay is greater than that of ^{146}Ho. From atomic mass systematics [8], one deduces a $(Q_{\text{EC}}-B_p)$ window of ~6.5 MeV for both isotopes. Indications then are that there must be angular-momentum hindrances involved in ^{146}Ho delayed-proton emission which make that mode of decay more favorable for ^{146}Er.

We did not accumulate multispectrum γ-ray data. The only singles information recorded was one spectrum, measured with the 24.3% Ge detector, whose energy range extended to about 2.5 MeV and whose energy gain made it very difficult for us to observe Ho K x rays. Thus we had to rely on the time-tagged coincidence data to observe the presence of these x rays. Figures 3(a) and 3(b) show all coincident x rays recorded in the n-type Ge detector during the first and second three seconds of counting, respectively. A small peak at the Ho K_{α_1}-x-ray energy does appear in Fig. 3(a) but not in Fig. 3(b). Its intensity distribution as a function of time yielded a half-life of 1.7(6) s for ^{146}Er. In agreement with this value, a maximum likelihood analysis of the eight x-ray events [Figs. 2(a) and 2(b)] seen in coincidence with delayed protons results in a half-life of $1.9^{+1.0}_{-0.6}$ s. These experimental determinations are to be compared with the prediction of about 1 s for the ^{146}Er half-life from the gross theory of β decay [9].

A search for γ rays in coincidence with these Ho K_{α_1} x rays did not reveal any transitions which could be assigned to ^{146}Er. This negative result may simply be a manifestation of the small number of observed Ho K_{α_1} x rays or it may be an indication that the nuclide's decay strength may be fragmented over at least several ^{146}Ho levels. In contrast, the electron capture and β^+ decays of even-even dysprosium, erbium, and ytterbium nuclei with $N=82$, 84, and 86 proceed (see, e.g., Ref. [10]) primarily to single 1^+ levels in their respective odd-odd daughters. The 1^+ levels in turn deexcite to the isotopes' 2^- ground states *via* $E1$ transitions that vary regularly in energy from nucleus to nucleus as a function of both neutron and proton number. Now, with the observation of ^{146}Er electron capture and β^+ decay, there is an uninterrupted chain of known neutron-deficient erbium isotopes out to ^{145}Er [11], a nucleus which is located within two or three mass units of the proton drip line for this even-Z element.

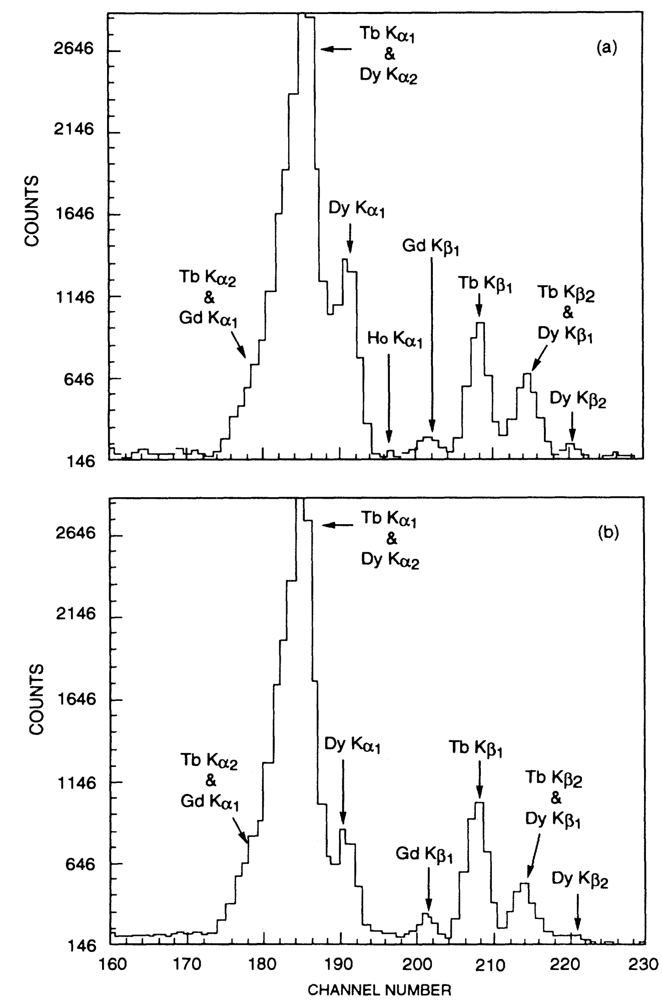

FIG. 3. Total projected coincidence K-x-ray spectra accumulated with a 24.3% Ge detector. Parts (a) and (b) show data recorded during the first and second three seconds of counting, respectively.

The assistance of Y. A. Akovali, L. F. Archambault, F. T. Avignone III, P. K. Lemmertz, A. A. Wydler, and the SuperHILAC staff during this experiment is gratefully acknowledged. Oak Ridge National Laboratory is managed by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under Contract No. DE-AC05-84OR21400. Work at the Lawrence Berkeley Laboratory was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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