Title
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Abstract:

The heaviest known erbium isotope, 3.3(2) min. ^{174}*Er, has been identified using on-line isotope separation and by* β *and* γ*-ray spectroscopy. Twelve* γ *rays were placed in a preliminary decay scheme. The mass of the new isotope was established by the separator and the Z was deduced from Tm K x ray coincident* β *and* γ *rays. In addition, the heaviest known isotope of holmium* ^{171}*Ho was observed with a half-life of 49(5) s.*

There has been much progress recently in the search for new neutron-rich isotopes in the rare-earth mass region.[1-5] The experiments can be classified according to the different production techniques. Several rare-earth isotopes have been produced using on-line isotope separation of ^{252}Cf[1] and ^{235}U[2] fission products; however, low fission yields limit this approach to the lighter neutron-rich isotopes. The heaviest known neutron-rich isotopes of Tm, Yb, and Lu have been produced at GSI using multinucleon transfer reactions followed by on-line mass separation. In this method, ^{nat}W/Ta targets are bombarded with ^{136}Xe[3,4] or ^{186}W[5] to produce target-like neutron-rich isotopes. Similar multinucleon transfer reactions have been explored at the OASIS mass-separation facility[6] on-line at the Lawrence Berkeley Laboratory SuperHILAC. Since the targets are located in the high temperature region of our ion source, the only target choices are heavy refractory materials like W or Ta. To overcome this restriction, projectiles of the heaviest stable lanthanide isotopes, such as ^{176}Yb, were used to produce projectile-like neutron-rich rare-earth isotopes.

Natural tungsten targets were bombarded with 8.5 MeV/u ^{176}Yb ions and multinucleon transfer reactions were used to produce projectile-like isotopes of Ho, Er, and Tm. Using the stable mass marker ^{174}Yb to calibrate the separator, the reaction products were mass analyzed and A=174 isobars were transported ionoptically to a shielded counting area, collected with a fast-cycling tape system, and transported (within 70 ms) to a detector array for β and γ-ray spectroscopy. A 718 μm Si detector and a planar hyperpure Ge (HPGe) detector faced the radioactive layer to detect x rays, low-energy ($\leq$400 keV) γ rays, and β particles (utilizing the two detectors as a β telescope). A 1-mm thick plastic scintillator, for electron detection, and a 52% Ge detector, for high efficiency x-ray and γ-ray detection, were located on the opposite side of the tape. A 24% Ge detector was located 4.5 cm from the radioactive source, perpendicular to the other detectors, to give γ-ray intensities essentially free of summing effects. Coincidence events registered in the various detectors were recorded in an event-by-event mode while singles spectra were acquired from all three Ge detectors concurrently. The singles spectra from the 52% Ge and the HPGe detectors were acquired in a time resolved multispectrum mode where the 512-s tape cycle was divided into eight equal time intervals for half-life determinations.

Twelve γ rays with energies, relative intensities, and coincidences listed in Table I are assigned to the decay of the new isotope ^{174}Er based on the following observations: the γ rays decayed with a 3.3(2) min. half-life which does not match any of the known half-lives in this isobaric chain, the γ rays were observed in coincidence with Tm K x rays, the γ rays were measured in coincidence with β^- particles (in the β telescope) having energies up to ~1.3 MeV, and the γ rays were not in coincidence with any of the known[7] γ rays from the decay of ^{174}Tm. The first two points are consistent with a possible isomer of ^{174}Tm or the new isotope ^{174}Er; however, the ^{174}Tm isomer is ruled out by the last two points. The 58.5-keV γ transition was not seen in the singles data due to interfering x-ray activity at that energy, but it was clearly identified in the coincidence spectra. The low energy part of the HPGe detector singles spectrum is shown in figure 1. Based on the coincidence and intensity information, we propose the ^{174}Er decay scheme in figure 2. The two strong β transitions from the ^{174}Er 0^+ ground state to the 766.9- and 772.9-keV levels are similar to the 0^+ to 1^+ and $(1)^-$ β transitions in ^{172}Er decay.[8] Assuming then a spin difference of one unit between the the ^{174}Er ground state and the 770-keV levels, the observed strong γ transitions to our proposed ground state in fig. 2 are inconsistent with a tentative 4^- assignment for the ^{174}Tm ground state from ref. 7.

An average half-life of 3.3(2) min. was measured for the γ rays and the Tm K x rays (excluding the 58.5-keV transition). This is longer than the theoretical prediction of 1.3 min. by Klapdor *et al.*,[9] and shorter than the value of 15 min. calculated by Takahashi *et al.*[10] However, recalculations with the gross theory of β decay[10] using the more recent mass predictions of Jänecke and Masson[11] (Q_{β^-}=1.99 MeV) yield a half-life of about 3.3 min., in much better agreement with experiment.

During the same experiment, some preliminary data on the A=171 mass chain were obtained. We detected erbium K x rays with a half-life of 49(5) s. These x rays were seen in coincidence with β^- particles having energies up to ~2.5 MeV and in weak coincidence with the known[12] 198- and 280-keV γ transitions in ^{171}Er. Previous authors[13,14] reported a 45(5) s component in the electron spectrum recorded with a thin plastic scintillator and weak erbium K x rays in coincidence with electrons in the A=171 mass chain, and made a tentative assignment of this activity to a new isotope ^{171}Ho or a new isomer ^{171m}Er decaying by a strongly converted transition. Based on our measurements of the Er x rays in coincidence with β^- particles and ^{171}Er transitions, we can unambiguously assign the 49(5) s activity to the β^- decay of ^{171}Ho and eliminate the ^{171m}Er alternative interpretation.

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Table I. Gamma-ray energies, intensities, and coincidences in the decay of ^{174}Er.

Energy[a] (keV)	I_γ[b] (%)	Coincident γ rays[c] (keV)
58.5[d]	--	--
71.7	15(1)	X,(58.5),(122),637,643
100.4	100(1)	X,152
121.8	39(6)	X,(58.5),(71.7),130
130.4	42(8)	122,637,643
151.8	91(15)	X,100.4
636.7	27(5)	X,(58.5),(71.7),130
642.7	25(2)	X,(58.5),(71.7),130
708.4	93(7)	(58.5)
714.4	56(6)	(58.5)
766.9	92(9)	--
772.9	75(8)	--

[a] The uncertainty in γ-ray energies is ± 0.2 keV.

[b] Intensities are relative to the 100.4-keV γ intensity.

[c] X=Tm K x rays. ( ) denotes a weak coincidence.

[d] Not seen in the singles data. See text.

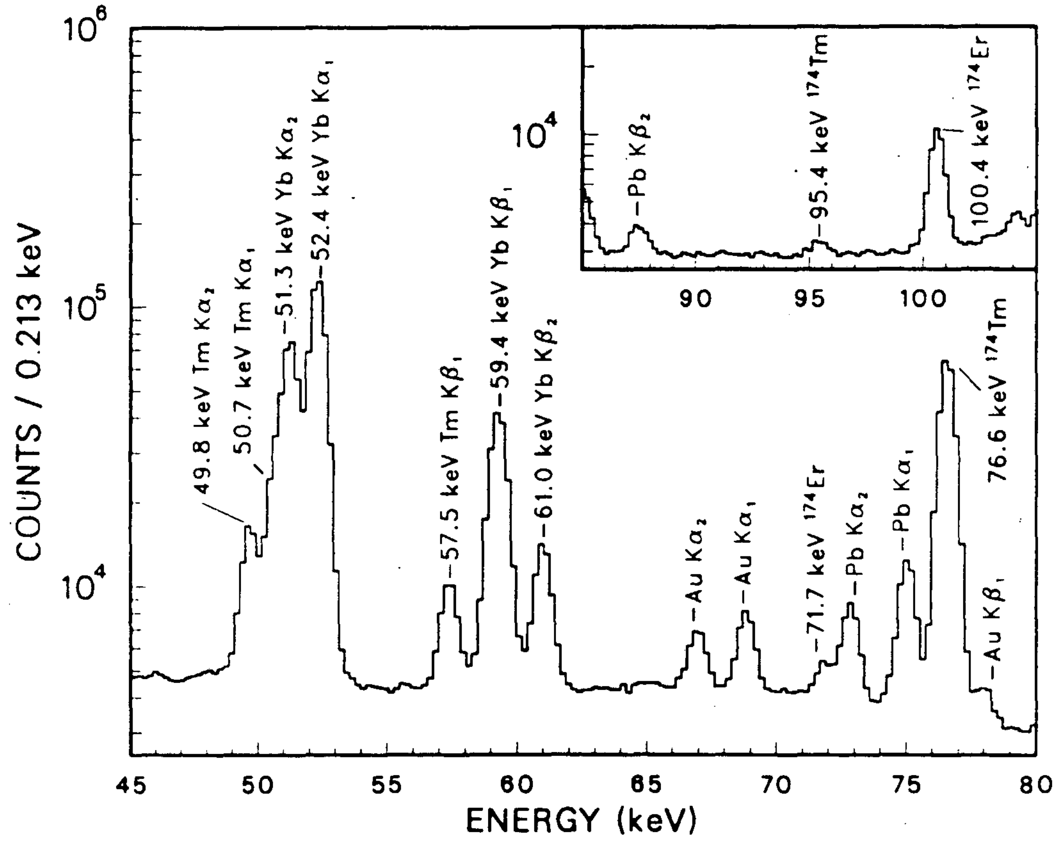

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Fig. 1. Low-energy part of the γ-ray spectrum from the A=174 activities.

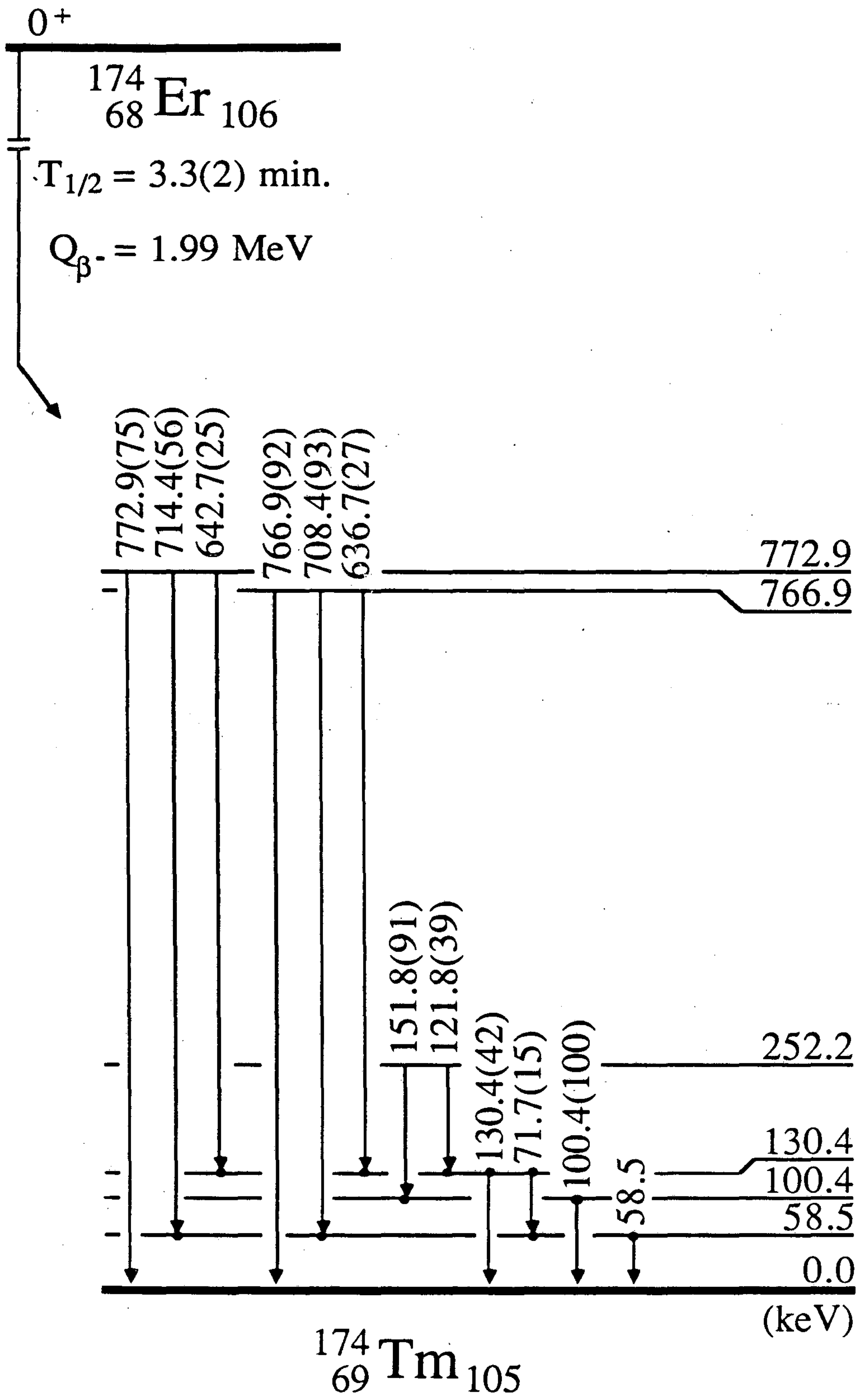

Fig. 2. Proposed decay scheme for ^{174}Er. Intensities are relative to the 100.4-keV transition. The beta decay energy is taken from reference 11.