VERY NEUTRON-DEFICIENT ISOTOPES OF SAMARIUM AND EUROPIUM

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Neutron-deficient isotopes of samarium and europium were produced in the ^{112}Sn + ^{32}S (190 MeV) reaction. They were on-line mass separated and studied with the use of Ge X-ray detectors. Three isotopes: ^{136}Sm, ^{137}Eu and ^{138}Eu (with half-lives 40 ± 5 s, 11 ± 2 s and 12 ± 2 s, respectively) were observed for the first time.

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In continuation of our previous studies [1, 2] on very neutron-deficient isotopes of light rare-earth elements, we have identified new isotopes ^{135}Sm, ^{137}Eu and ^{138}Eu. Additionally, we have obtained some information on γ-radiation for a few heavier isotopes of samarium and europium.

The europium and samarium isotopes were produced in the ^{112}Sn + ^{32}S reaction. The tin target was enriched in ^{112}Sn to more than 90%. The beam of 190 MeV $^{32}S^{+5}$ ions with intensity of the order 10^{12} particles per second was provided by the U-300 cyclotron at the Laboratory for Nuclear Reactions in Dubna.

The reaction products were separated according to their masses using the on-line

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BEMS-2 mass-separator [3]. The surface ionization ion source [4] was kept at the temperature of about 2700 K. The average delay time between a reaction event and the release of a rare-earth product from this ion source was 5 to 10 s [4]. Mass-separated activities were collected on a disk which, rotating periodically, transported them to the counting position [5]. The time of transport was less than 0.3 s.

The measurements were carried out with the use of high-resolution intrinsic germanium X-ray detectors. The spectra were recorded in a multispectrum mode (8 groups ×512 channels). Energies of X-rays were measured with the accuracy of 0.1 keV which was sufficient for unambiguous identification of atomic number Z. For individual members of an isobaric chain, half-lives were deduced from the X-ray decay curves. An observation of activities with known half-lives made the mass assignment unambiguous. Additionally, the energies and intensities of γ-rays have been measured. The experimental results are presented in Table I.

TABLE I

Experimental data for the neutron-deficient samarium and europium isotopes

Nuclide	$T_{1/2}$ literature	$T_{1/2}$ (this work)	γ-ray energies (keV) and intensities (this work)
^{136}Sm	unknown	40±5 s	
^{137}Eu	unknown	11±2 s	
^{138}Eu	35±6 s [1]; 1.5±0.4 s [1]	12±2 s	
^{138}Sm	3.0±0.3 m [12]	a)	53.5 (1.7±0.1), 74.7 (2.6±0.2), 145.4 (2.8±0.3), 150.6 (1.8±0.3), 173.7 (2.0±0.3), KX (≡ 100)
^{139}Eu	22±3 s [12]	21.4±0.5 s	
^{139}Sm	2.6±0.3 m [12]; 9.5±1.0 s [13]	b)	
^{140}Eu	1.3±0.2 s [12]; 20 s [9]	a), c)	530 (410±60), KX (≡ 100)
^{140}Sm	15.0±0.3 m [12]	a)	85.3 (4.9±1.0), 121.6 (11±2), 140.9 (25±5), 226.0 (35±7), KX (≡ 100)

The energies of γ-lines were determined with an uncertainty of less than 1 keV.

a) Half-lives from the literature have been approximately confirmed.

b) The existence of the 9.5 s isomer reported in Ref. [13] has not been confirmed in our KX_{Sm} decay experiment.

c) Only the short-lived component has been measured.

The determination of the ^{138}Eu half-life was reported in our previous paper [1]. The experiment was based only on the measurement of the total β-activity decay of the isobaric chain. Two components of this curve corresponding to the half-lives of 35±6 s and 1.5±0.4 s were reported and assigned to the ^{138}Eu decay. To check these results, we have measured X-ray decay curves of samarium with 1.6 s, 4.8 s and 16.8 s collection time per group. In contrast to Ref. [1], in all these measurements we have observed (Fig. 1) only one component of the decay curve, corresponding to a half-life of 12 ± 2 s.

For a half-life determination, the studies of X-rays are more reliable than the non--selective measurements of β-rays. We tend, therefore, to ascribe to ^{138}Eu the half-life of 12 ± 2 s and to consider this isotope as a new one.

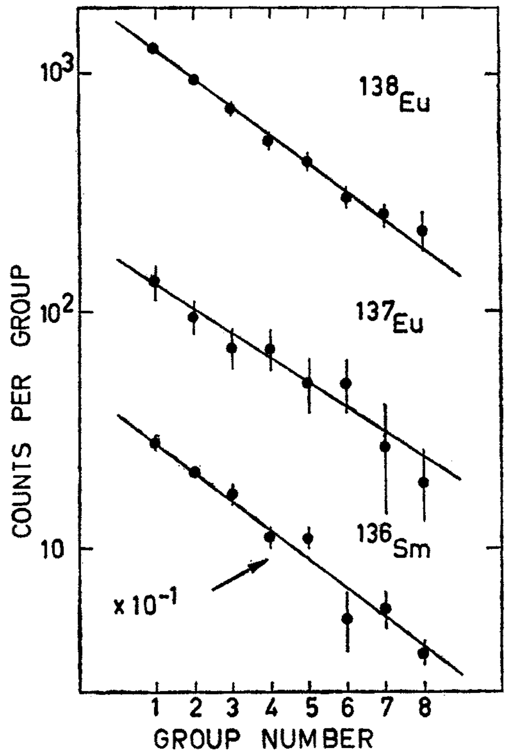

Fig. 1. The KX-ray decay curves for the new isotopes. The time per group was 4.8s, 3.6s and 16.8s for ^{138}Eu, ^{137}Eu and ^{136}Sm, respectively

The half-life data may be analyzed with reference to the average β-strength function [6]:

$$\bar{S}_\beta = [T_{1/2}\int_C^Q f(Z, Q-E)dE]^{-1}.$$

In this formula $f(Z, Q-E)$ is the statistical rate function for the allowed $\beta^+ + EC$ decay, Q is the electron capture decay energy, E is the excitation energy of the daughter nucleus and C is the cut-off energy. For odd-odd daughters, $C = 0$. For even-even and odd-A daughters, C is understood as the lowest energy of 4- and 3-quasi-particle states, respectively (in the concept of average β-strength function it is assumed that the half-life is predominantly determined by β-transitions to such states).

In our calculations we used Q values from the Janecke and Eynon mass formula [7]. The parameter C was chosen equal to 12 $A^{-1/2}$ and 24 $A^{-1/2}$ for odd-A and even-even daughters [8]. The half-life data have been taken from Ref. [9] and the present work.

The $\bar{S}_\beta$ values for the neutron-deficient isotopes of europium (only cases with $(Q-C) > 1.5$ MeV) are plotted in Fig. 2. For even mass numbers the data fall into two groups. Analogous groups have been reported for iodine isotopes in Ref. [10]. We believe that higher $\bar{S}_\beta$ values correspond to 1^+ states, with a $(d_{5/2})_p\,(d_{3/2})_n$ configuration, which

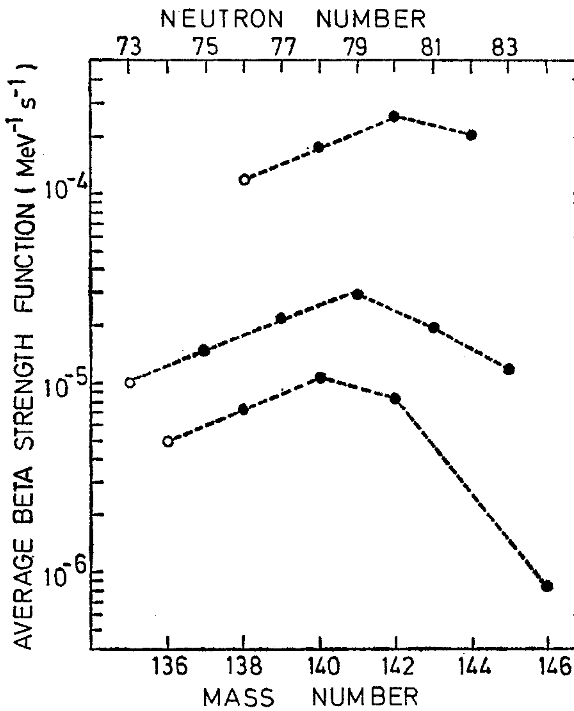

Fig. 2. The systematics of average beta strength function values for the light isotopes of europium (black circles — experiment, open circles — extrapolation)

decay predominantly to the ground and first excited states of samarium isotopes. In the case of slower decays, we deal probably with higher-spin and negative parity initial states with a $(d_{5/2})_p\,(h_{11/2})_n$ configuration, which populate only higher-energy levels of samarium daughters. The ^{138}Eu half-life observed in this work corresponds to the low $\bar{S}_\beta$ value which fits in the second group.

When comparing the two groups of states in even-A europium isotopes one should realize that the $\bar{S}_\beta$ values for presumably 1^+ states are artificially shifted upward because the half-lives are likely to be determined mainly by transitions to the levels below the cut-off energy C which are not of four-quasiparticle nature. According to the concept of the average β-strength function such transitions should be eliminated from considerations. For higher spin initial states the elimination is (at least partly) ensured by forbiddenness of appropriate β-decays.

The relative position of supposed 1^+ and higher spin β-decaying states in question could not be deduced from the experiment. Model calculations also cannot help here because the $h_{11/2}$ and $d_{3/2}$ neutron orbitals are predicted to be almost of the same energy [11].

The $\bar{S}_\beta$ value calculated for ^{137}Eu fits to the systematics for heavier odd-A europium isotopes, as shown in Fig. 2. The same may be said about ^{136}Sm and heavier isotopes of samarium (see Ref. [2]).

An extrapolation of $\bar{S}_\beta$ values toward lower A by one mass unit allows to estimate the half-lives of unknown activities: 10 s for ^{135}Eu, 17 s for the long component of ^{136}Eu and 0.7 s for the short component of ^{138}Eu. A non-observation in this work of the decay of the presumably short-lived 1^+ state in ^{138}Eu may be due to the relatively long hold-up time in the ion source.

The γ-ray data are not complete enough for an interpretation. They are given here because they may facilitate further experiments.

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