Decay Properties of Neutron-Deficient Actinides

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In continuation of our study on investigation of the neutron-deficient americium isotopes, which had been the identification of ^{236}Am and ^{235}Am, we carried out the experiments aimed to produce new isotopes ^{233}Am and to determine the half-life and α-decay energy of ^{235}Am. The isotopes were identified after mass-separation from the other reaction products by the PbI_2/He-jet coupled JAERI on-line isotope separator (ISOL) and the beneficial detection system for a few events of α-decay from unknown isotopes. The assignment of unknown α-ray against ^{233}Am was made by establishing time correlations between a parent and daughter nuclides belonging to known α-decay chains. In addition the determination of the half-life, α/EC decay branching ratio and α-decay energy of ^{235}Am was made by measuring Pu Kx-rays originating from the EC decay of ^{235}Am and α-ray of the isotopes coincidentally.

1, Introduction

The known nuclides until now from thorium to 112 element in the table of nuclide are showed in Fig. 1. Decay properties of these nuclides in Fig. 1 have been investigated intensely together with the development of a measurement (alpha-ray detector, etc) and an accelerator technique. Despite it, particularly in the region of neutron-deficient actinide

isotopes there are still many unknown nuclides which decay dominantly through electron-capture (EC). Although this region is very difficult to study, the information on nuclear-decay properties of these nuclides has a significant role in the fission properties of far from stability and the mass values of transactinides in nature. For example, we have mentioned three alpha-decay chains, shown in Fig. 1, relative to the mass values of transactinides. It should be possible to determine the mass values which have only been observed as individual events from alpha-decay measurements[1]. But the mass values of ^{255,256}Db and ^{261}Bh included in the chains are entirely unknown. Because the main reason for the undecided masses is that the alpha-decay chains are interrupted because of some unknown alpha-emitters; americium and berkelium in neutron-deficient actinide region. Thus it is impossible to decide the mass values using the known masses for daughter nuclides in the end points of the alpha-decay chains. Indeed it is necessary that the decay properties of neutron-deficient actinides should be investigated. In order to study decay properties of the nuclides, we have developed the PbI_2/He-jet coupled JAERI-ISOL[2]. In this paper, we present the new information on decay properties of new isotopes ^{233}Am and ^{235}Am.

2, Experiment

Experiments have been performed using extracted ion beams of ^{6}Li delivered from 20UR tandem accelerator, Japan Atomic Energy Research Institute (JAERI). The twenty-one targets of ^{233}U with the average thickness of 100 μg/cm^2 per a target were made by being electrodeposited onto a 3 μm thick aluminum backing foil. Thier targets were set in the multiple-target chamber where they could be irradiated simultaneity. The incident energies of the ^{6}Li projectiles were chosen to be 63 MeV for the reaction ^{233}U(^{6}Li,6n)^{233}Am and 45.5 MeV for the reaction ^{233}U(^{6}Li,4n)^{235}Am. The tandem accelerator provided with the average 300 pnA beam intensity of ^{6}Li. The schematic illustration of the PbI_2/He-jet coupled JAERI-ISOL system is shown in Fig. 2. The reaction products recoiling out of the targets which are simultaneously bombarded with ion beams into the multiple-target chamber are attached to an inert gas containing PbI_2 aerosol cluster[3]. And they are transported through a Teflon capillary (1.4 mm ϕ $\times$ 8 m length) and two skimmers (2 mm ϕ and 4 mm ϕ) to a thermal ion source at 2450 K with the surface ionization method. Successively the ions were accelerated with the voltage of 30 kV in order to mass-separate at a mass fragment of interest with an electromagnet. The mass-separated nuclides are implanted respectively into four catcher foils, whose thickness is 4-7 μ/cm^2, of VYNS resin[4] (polyvinylchloride-acetate copolymer) with 45° rotating periodically at Rotating Wheel detection system. This thickness is into the stopping range of all Am^+ products accelerated by ISOL. Each foils are rotated to the detection system equipped with seven PIN-photodiodes and a short coaxial n-type HPGe detectors. The α-ray energies were calibrated by *alpha*-particle energies from known α emitter nuclei, ^{221}Fr, ^{217}At and ^{213}Po, by a α decaying ^{225}Ac source. The energy resolution for each PIN-photodiodes was not worse than 60 keV (FWHM). Singles α-rays and x/γ-rays are recorded event by event

together with time information respectively. The mass resolution $M/\Delta M$ of the ISOL at M=208 was about 850 which was good enough to separate ions of interest from those with the $\pm$1 mass difference. The overall efficiency of ^{237}Am atoms became approximately 0.5% which is 5 times higher than the previous one and the signal-to-noise ratio (S/N) in the x/γray-spectrum was about 3.5 times larger than that in Ref[5].

3, The ^{233}Am isotope

The α-spectrum obtained at the mass-233 fraction is shown in Fig. 3. The data were accumulated for the period of 150 s $\times$ 1500 cycles at all PINphotodiodes. The α-decay chain from the daughter nuclei ^{229}Np ($T_{1/2}$=$\sim$4.0 min)[6] following the α-decay of ^{233}Am up to ^{209}Bi are clearly observed. The α-decay chain originated from the daughter nuclei ^{229}U following the EC decaying the parent nuclei ^{229}Np also are observed. The 6.74$\pm$0.03 MeV α-particle is assigned to be ^{233}Am. By the decay curve of the α-ray intensity fitted by the exponential function, the half-life of ^{233}Am is deduced to be 2.3$\pm$0.6 min preliminarily. Unfortunately Pu Kx rays originated from the EC decaying ^{233}Am couldn't be observed with the present detection system. By this reason we would seek the α/EC decay branching ratio of α $\geq$8% and EC$\leq$92%.

4, The ^{235}Am isotope

The α-spectrum obtained at the mass-235 fraction is shown in Fig. 4. The data were accumulated for the period of 900 s $\times$ 360 cycles at all PINphotodiodes. The 6.44$\pm$0.02 MeV α-particle is assigned to be ^{235}Am. Although ^{235}Am had been identified for the first with detection for Pu Kx-rays following the EC decay by J. Guo *et al.*[7], in 1996, α-decay of ^{235}Am had been unknown than ever. In this present work we had performed to observe both α-decay and EC decay originated from ^{235}Am for the first time. By the decay curves of the α-ray and Pu Kx-rays intensities fitted by the exponential function the half-life of ^{235}Am is deduced to be 9.83$\pm$0.47 min definitely. The α/EC branching ratio is determined to be α=0.4% and EC=99.6%.

5, Discussion

Table 1 shows comparison between the experimental and the calculated half-lives of ^{233}Am and ^{235}Am with the gross theory (GT2)[8], the semi-gross theory (SGT)[9] and the microscopic pn-QRPA (proton-neutron quasiparticle random phase approximation) model [10]. The present values is in good agreement with those from GT2 and SGT within a factor of 1.5.

The relationship between α energy and α-decay partial half-life of their isotopes are represented in Fig. 5. The favorite α energy of ^{235}Am is well reproduced by a systematic line

developed from the favorite α-energies of the other odd-A americium isotopes, ^{237,239,241}Am With respect to ^{233}Am on the assumption that α energy of ^{233}Am is reproduced by the systematic line, the α-decay branching ratio of ^{233}Am is estimated to be $\sim$19%. That values is compatible with the lower limit of the α-decay branching ratio of ^{233}Am.

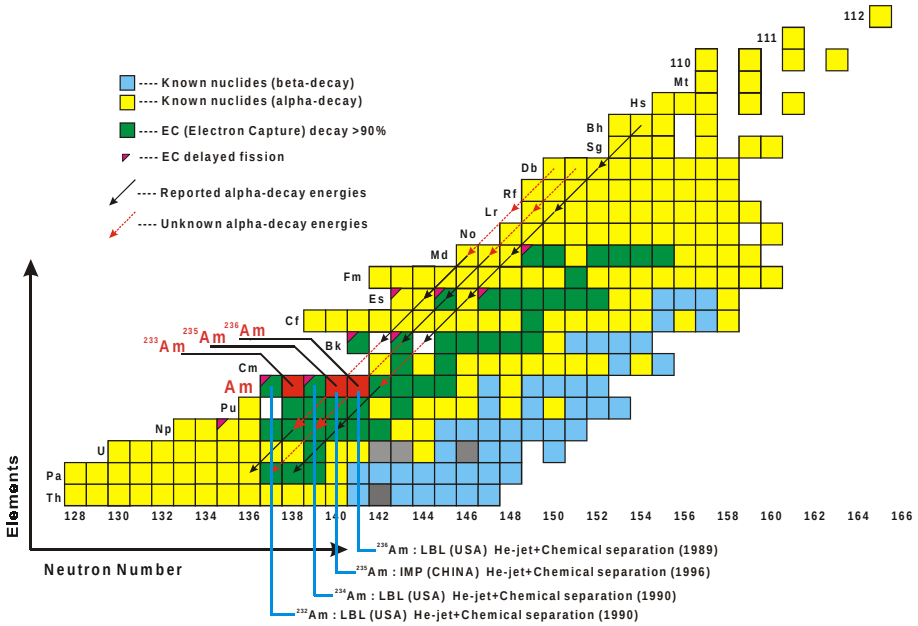

Figure 1. Chart of nuclides that shows actinides and transactinides in the region from thorium to element 112.

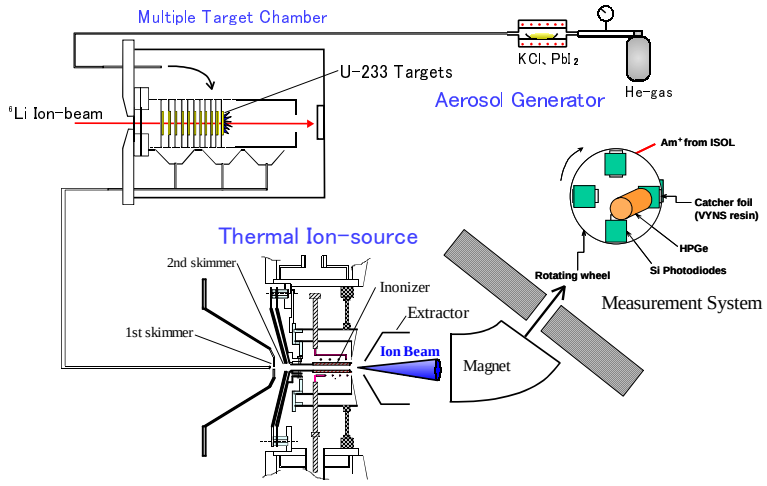

Figure 2. Schematic diagram of the PbI_2/He-jet coupled JAERI-ISOL.

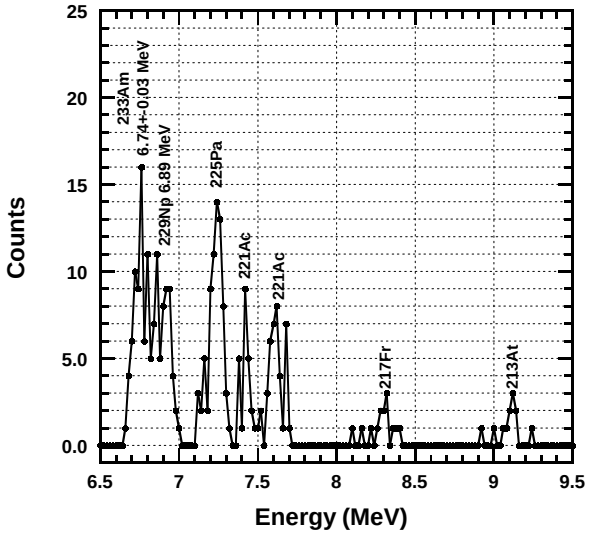

Figure 3. α-ray correlation spectrum observed at A=233 fraction.

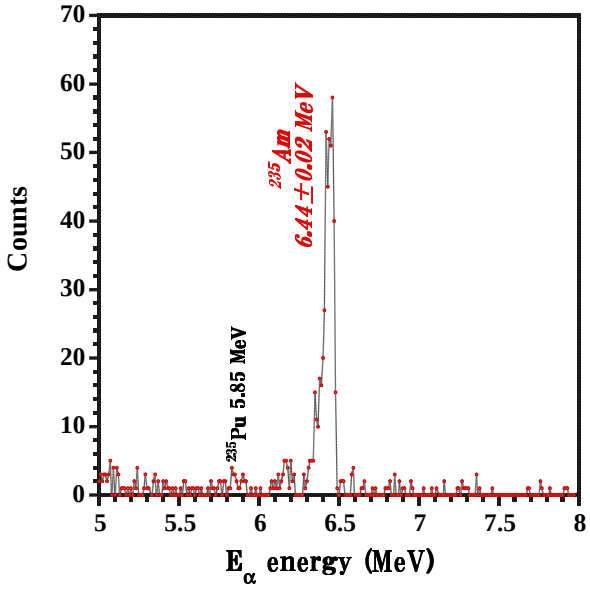

Figure 4. α-ray single spectrum observed at A=235 fraction.

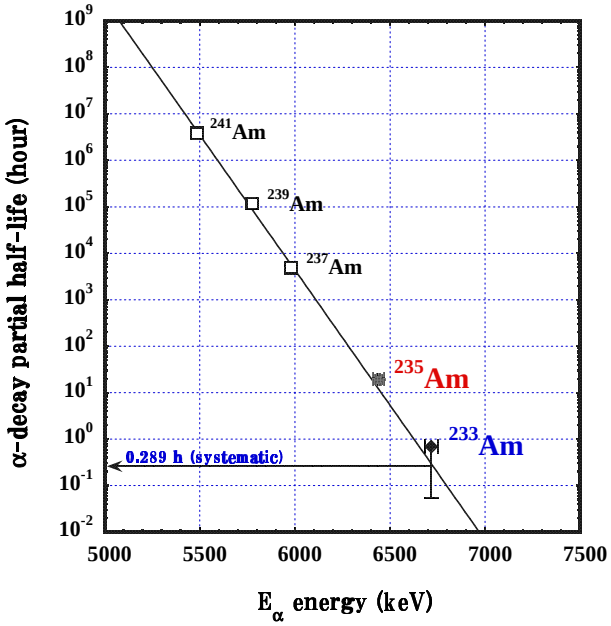

Figure 5. Experimental α-decay partial half-lives vs. α energies for odd-A americium isotopes.

Table 1. Comparison between the experimental and calculated values of half-lives on ^{233}Am and ^{235}Am.

	Present result	GT2[8]	SGT[9]	pn-QRPA[10]
^{233}Am	2.3±0.6 min	1.72 min[a]	1.90 min[a]	0.89 min[b]
	$T_{1/2}$(exp.)/$T_{1/2}$(cal.)	1.34	1.21	2.58
^{235}Am	9.83±0.47 min	6.95 min[c]	14.89 min[c]	3.0 min[d]
	$T_{1/2}$(exp.)/$T_{1/2}$(cal.)	1.41	0.66	3.28

[a] Q_{EC}=3.25 MeV
[b] Q_{EC}=3.24 MeV
[c] Q_{EC}=2.56 MeV
[d] Q_{EC}=2.31 MeV

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