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Short note

New isotope ^{233}Am

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Abstract. The new neutron-deficient americium isotope ^{233}Am produced via the ^{233}U(^{6}Li, 6n) reaction has been identified using the JAERI on-line isotope separator (JAERI-ISOL) coupled to a gas-jet transport system. The α-decay of ^{233}Am and its subsequent α-decay chain have been observed in the mass-233 fraction. The half-life and α-particle energy of ^{233}Am have been determined to be 3.2 ± 0.8 min and 6780 ± 17 keV, respectively. From these results and a deduced α-decay branching ratio, the observed α-decay is regarded as a favored transition.

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Decay properties of neutron-deficient actinide isotopes provide us valuable information on the nuclear mass surface close to the proton drip line, nuclear structure of large deformed heavy nuclei and fission properties far from stability via the electron-capture (EC) delayed fission. To study the EC/α-decay properties of the neutron-deficient actinide isotopes, we have developed the gas-jet coupled JAERI-ISOL apparatus [1]. In our previous work [2], the EC-decay of the mass-separated americium isotope ^{236}Am was successfully observed with this system. In this paper, the first identification and decay properties of the new americium isotope ^{233}Am are presented.

^{233}Am was produced via the ^{233}U(^{6}Li, 6n) reaction using the JAERI tandem accelerator. A stack of twenty-one ^{233}U targets set in a multiple-target chamber was irradiated with a 63 MeV $^{6}Li^{3+}$ beam (52–60 MeV on targets) with an intensity of 300 particle-nA. Each target, about 100μg/cm^2 thickness, was electrodeposited onto a 0.9 mg/cm^2 thick aluminum foil. Reaction products recoiling out of the targets were stopped in He gas (∼94 kPa) loaded with PbI_2 aerosol clusters. The products attached to the clusters were continuously swept out of the target chamber with a He gas flow (1.4 l/min), and transported to a thermal ion source of the ISOL through a Teflon capillary (1.5 mm i.d. and 8 m length). Atoms ionized in the ion source were accelerated with 30 kV and mass-separated. The mass resolution $M/\Delta M$ of about 850 was achieved for the isotope ^{208}Pb which is a component of the aerosol clusters. The overall efficiency including the gas-jet transport and ionization of americium atoms was measured to be ∼0.3% through the observation of ^{237}Am produced in the ^{235}U(^{6}Li, 4n) reaction [2]. The mass-separated ions were implanted into 10 μg/cm^2 thick polyvinylchloride-acetate copolymer foils placed around the periphery of a four-position rotating wheel. The wheel periodically rotates 90° at 2.5 min intervals, which conveys the implanted sources to three consecutive detector stations. Each of the detector stations was equipped with two Si PIN-photodiodes (HAMAMATSU S3204-09, 18×18 mm^2 active area) placed on both sides of the wheel to measure α-particles with 83% detection efficiency. Another Si PIN-photodiode was placed at the implantation station on the down stream of the foil against the ion implantation. To measure characteristic X-rays following the EC-decay of ^{233}Am, an HPGe detector (LOAX^{TM}51 mm ⌀ × 21 mm thickness, FWHM = 0.66 keV at 122 keV γ-ray) was also placed at the 1st detector station. The energy calibration for the Si detectors was performed using mass-separated ^{221}Fr (E_α = 6341 keV) recoiling out of the ^{225}Ac α-source, and its α-decay daughters, ^{217}At (7067 keV) and ^{213}Po (8376 keV). Measured pulse-height data of α-particles and

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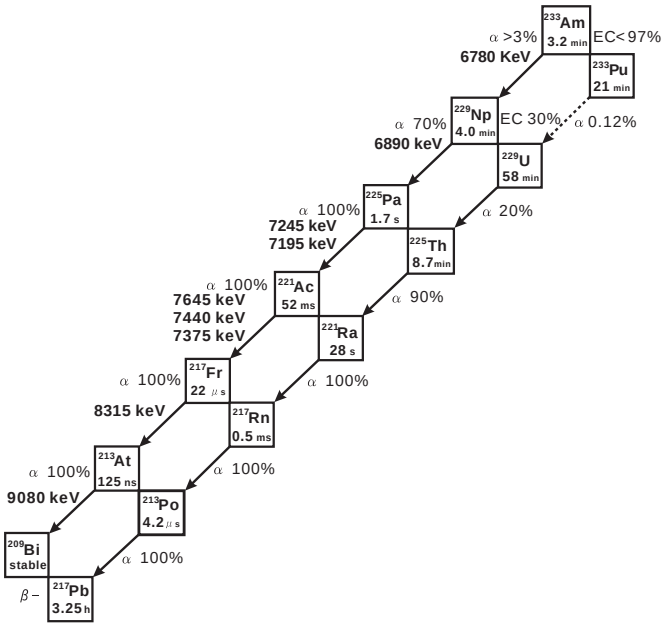

Fig. 1. α-decay chains originating from the α decay of ^{233}Am.

X/γ-rays were recorded event by event together with time information.

The identification of ^{233}Am was carried out through an α-α correlation analysis. Since the α-decay of ^{229}Np, the daughter nuclide of ^{233}Am, is followed by four-successive α-decays with short half-lives, ^{225}Pa (1.7 s) $\rightarrow$ ^{221}Ac (52 ms) $\rightarrow$ ^{217}Fr (22 μs) $\rightarrow$ ^{213}At (125 ns) as shown in fig. 1, the α-α correlations among these five nuclides can be unambiguously identified. In the present experiment, 99 α-α correlation events following the α-decay of ^{229}Np were observed in the mass-233 fraction, indicating that those nuclei originated from the α-decay of ^{233}Am. On the other hand, ^{229}Np has a substantially long half-life of 4.0 min. Thus, if α-counting rates of the detectors are high, random correlations prevent us from identifying the true α-α correlation events between ^{233}Am and ^{229}Np. In the present experiment, the counting rate of a Si detector for non-correlated 6–8 MeV α-particles was as low as about 6×10^{-5} counts/s due to the mass-separation by the ISOL. This extremely low-counting rate condition allowed us to identify the correlations between the α-decays of ^{233}Am and following α-α correlation events.

Figure 2 shows an α-particle spectrum constructed from the observed α-α correlation events. The α-lines of all the nuclides in the decay chain were clearly identified in this spectrum. The intensities of the α-lines of ^{217}Fr and ^{213}At are much smaller than those of their precursors, because the time of conversion and data reading of the present data acquisition system was longer than the half-lives of ^{217}Fr and ^{213}At. The α-particle energies of ^{233}Am, ^{229}Np and ^{225}Pa were determined to be 6780 ± 17 keV, 6893 ± 23 keV and 7252 ± 19 keV, respectively, by the most-likelihood method. The energies of ^{229}Np and ^{225}Pa are in good agreement with the literature values [5] of 6890 ± 20 keV and 7245 ± 20 keV, respectively.

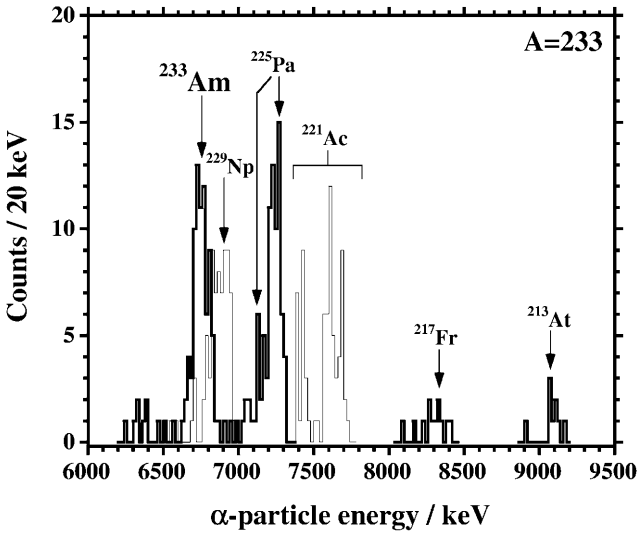

Fig. 2. α-particle spectrum constructed from the measured α-α correlation events associated with the α-decay of ^{233}Am.

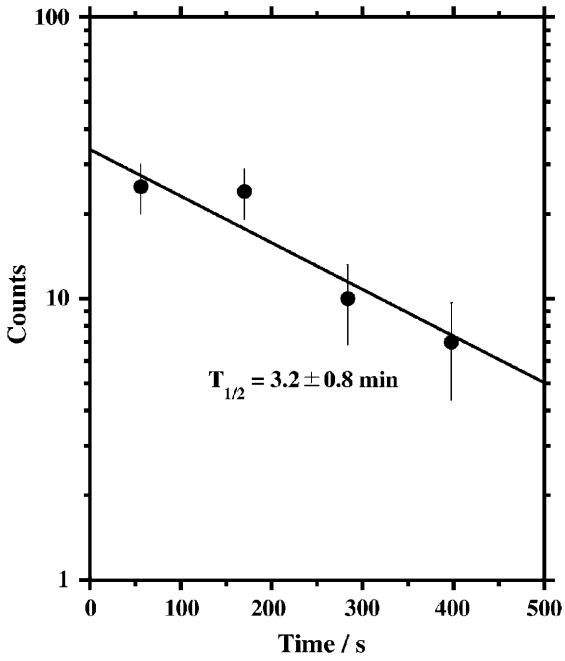

Fig. 3. Decay curve of the 6780 keV α-line associated with the α-decay of ^{233}Am.

The decay curve of the 6780 keV α-line is shown in fig. 3. The half-life value of ^{233}Am was determined to be 3.2 ± 0.8 min. From the time intervals between the α-decays of ^{233}Am and ^{229}Np, the half-life of ^{229}Np was determined to be 4.0 ± 0.4 min which agreed well with the literature value of 4.0 ± 0.2 min [3]. For ^{229}Np, the α-decay branching ratio of $70 \pm 10\%$ was derived from the ratio between the measured α-α correlation events following the α-decay of ^{229}Np and those following the α-decay of ^{225}Th which is accumulated via the EC-decay of ^{229}Np and following α-decay of ^{229}U. This value is consistent with the literature value of $> 50\%$ [3]. For ^{233}Am, no Pu

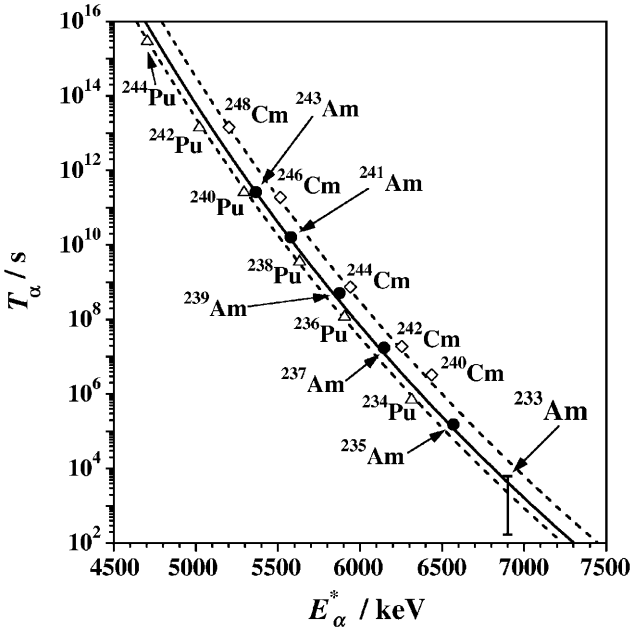

Fig. 4. α-decay partial half-lives for odd-mass americium and even-even plutonium and curium nuclei [5,6] plotted as a function of the released α-decay energy. For plutonium and curium nuclei, ground-to-ground state transitions are plotted. For americium nuclei, the most prominent α-transitions in $^{235\text{-}243}$Am are depicted.

K X-rays originating from the EC-decay were observed in the X/γ-ray spectrum. Based on the detection efficiency for the Pu K X-rays in the present system, the α-decay branching ratio of ^{233}Am was estimated to be larger than 3%.

For α-transitions from the ground state to ground state in even-even nuclei, there is a semi-empirical relation between α-decay partial half-life T_α and released α-decay energy E^*_α as follows [4]:

$$\log T_\alpha = A(Z) \times (E^*_\alpha)^{-1/2} + B(Z) \ , \qquad (1)$$

where $A(Z)$ and $B(Z)$ are the fitted constants to experimental data for each of elements. The E^*_α defined in this equation is derived from the measured α-particle energy E_α through the following equations:

$$E^*_\alpha = A_p/A_d \times E_\alpha + \Delta E_{\rm sc} \ , \qquad (2)$$

and

$$\Delta E_{sc} = 6.5 \times 10^{-2} \times Z^{7/5} \text{ keV} \ , \qquad (3)$$

where A_p, A_d and Z refer to the mass number of the parent and daughter nuclides and the atomic number of the parent nuclide, respectively, and $\Delta E_{\rm sc}$ is the correction factor for the electron screening [4]. Experimental T_α values for ground-state transitions in even-even plutonium and curium isotopes and the most prominent α-transitions in odd-mass americium isotopes $^{235\text{-}243}$Am [5,6] are shown in fig. 4, together with fitted curves.

The T_α values for $^{235\text{-}243}$Am are close to the fitted curve for plutonium isotopes within a factor of about 2.5, indicating that these α-transitions in $^{235\text{-}243}$Am are favored transitions with a hindrance factor $\leq$ 2.5. The T_α value for ^{233}Am plotted in fig. 4 also clearly indicates that the observed α transition in ^{233}Am is a favored transition.

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