Production of ^{215}U and ^{216}U and attempt to produce ^{219}Np and ^{220}Pu

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Theory[1)] predicts that nuclei with $N = 126$ exist up to Fm ($Z = 100$) because of the fission barrier arising from the ground-state shell effect. The heaviest $N = 126$ nuclei reported so far is ^{218}U ($Z = 92$). In this program to study nuclei with $N = 126$, we attempt to produce heavier nuclei such as ^{220}Pu. In previous experiments, a new isotope ^{216}U, which is the daughter nucleus of ^{220}Pu and ^{215}U, were observed[2)].

We performed an experiment at the RIKEN Linear Accelerator (RILAC) facility. We used ^{82}Kr ion as an incident beam and $^{136,137,138}BaCO_3$, $^{Nat}La_2O_3$, and $^{Nat}CeO_2$ as targets to study the ^{82}Kr + ^{136,137,138}Ba, ^{139}La, and ^{140}Ce reactions. Each target material was prepared by sputtering on 0.8–1.1-μm-thick aluminum foils so as to achieve a thickness of 300–500 μg/cm^2, and it was also covered with 40 μg/cm^2 of aluminum.The ^{82}Kr beams with energies of 365, 381 and 386 MeV were used to bombard these target foils mounted on a rotating target.

Evaporation residues (ERs) were separated from the beam particles and other products using a gas-filled recoil ion separator (GARIS), and they were implanted into a position-sensitive strip detector (PSD; 58 × 58 mm^2). The PSD was boxed in four Si detectors (SSD) to catch α particles escaping from the PSD. Two timing detectors were set in front of the PSD to measure the time-of-flight (TOF) of the ERs. Time information was also used to distinguish between the α-decay events in the PSD and the recoil implantations. A Ge-detector was placed 6 mm behind the PSD to measure the γ-rays coinciding with the α-decays. The isotopes were identified by using an α-decay chain with known α-decay properties of the descendants and the position correlations between the implanted ERs in the PSD and the subsequent α-decays.

In this experiment, we confirmed the production of ^{215}U and ^{216}U by observing one chain and six chains, respectively, including the candidates of new transitions. For the decay chains of ^{216}U, the α-decay energies and decay times are shown in Fig. 1. These decay events and cross sections are summarized in Table 1, and we labeled the decay energies with $E_{\alpha1}$, $E_{\alpha2}$, and $E_{\alpha3}$ temporarily. For a new transition, $E_{\alpha2}$ of ^{216}U may be a transition from isomer-state in ^{216}U to ground-state in ^{212}Th as well as an isomer state of ^{218}U with the α-decay energy of 10678 keV[3)]. In the attempt to produce ^{219}Np and ^{220}Pu using the ^{82}Kr + ^{139}La and ^{140}Ce reactions, cross section upper limits of 28 pb and 46 pb, respectively, were obtained. Further discussion, such as the interpretation of new transitions, is ongoing.

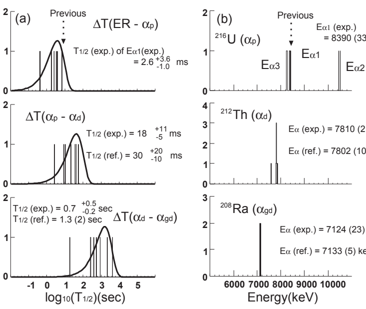

Fig. 1. α-decay time (a) and energy (b) spectra for ^{216}U. The previous results are indicated by dotted arrows. Each ΔT indicates the time difference between each decay generation (α_p, α_d, and α_{gd}). The labeled energies $E_{\alpha1}$, $E_{\alpha2}$, and $E_{\alpha3}$ for ^{216}U are specified. Observed α-decay energies and half-lives are written with reported ones except for ^{216}U.

Table 1. α-decay events of ^{215}U and ^{216}U. The time and position difference between the implanted ERs and the α-decay are ΔT and ΔX, respectively. E_b represents the ^{82}Kr beam energy at the center of the target.

	E_α (keV)	ΔT (ms)	$\lvert\Delta X\rvert$ (mm)	Reaction (E_b) & Cross section
^{216}U ($E_{\alpha1}$)	8408[2)]	6.98	0.2	^{137}Ba+^{82}Kr (366)
	8371	3.95	0.2	→ ^{216}U + 3n
	8379*	0.43	0.5	22^{+14}_{-9} pb
^{216}U ($E_{\alpha2}$)	10518	2.50	0.2	
	10459*	0.43	2.3	
^{216}U ($E_{\alpha3}$)	8254	1.81	0.1	^{136}Ba+^{82}Kr (350)
	8265*	3.40	0.2	→ ^{216}U + 2n
				58^{+77}_{-38} pb
^{215}U ($E_{\alpha1}$)	8436[2)]	5.82	1.0	^{136}Ba+^{82}Kr (373)
				→ ^{215}U + 3n
^{215}U ($E_{\alpha2}$)	8230[2)]	0.64	0.4	31^{+28}_{-18} pb
	8283	2.10	0.2	

* Sum energy of PSD and SSD.

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