New heavy neutron-rich isotope ^{238}Th*

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Abstract A new nuclide ^{238}Th has been produced via multinucleon transfer reaction by 60 MeV/u ^{18}O ion irradiation of the natural uranium. The thorium was radiochemically separated from the mixture of uranium and reaction products. The activity of thorium was measured by using an HPGe detector and a planar HPGe detector. The ^{238}Th has been identified for the first time by measuring the growth and decay of the γ-rays from its daughter ^{238}Pa. The half-life of ^{238}Th was determined to be 9.4±2.0 min. In addition, a new γ-ray of 89.0±0.3 keV with $T_{1/2}$=8.9±1.5 min was found in the γ spectrum gated with X-rays of Pa and assigned to ^{238}Th β^- decay based on measurements of transition energy and half life.

Keywords Multinucleon transfer reaction, Chemical separation, New nuclide, Synthesis and identification

1 Introduction

Half-lives of heavy neutron-rich isotopes are of importance in particular for astrophysical calculation on elements synthesis in the Universe and the age of the Galaxy. Experimental measurement for the half-lives of unknown heavy neutron-rich nuclides could provide a sensitive check for the existed theories. The aim of present work was to search the new nuclide ^{238}Th and to study its half-life. The difficulty in producing ^{238}Th is ascribed to a few reaction mechanism available and small production cross section. Up to now, the reported heaviest isotope of thorium is ^{237}Th produced through ^{238}U(n, 2p)^{237}Th reaction using the 14 MeV neutrons in 1993.[1] This reaction mechanism mentioned above is not able to synthesize heavier isotopes of thorium. The intermediate energy heavy ion-induced multinucleon transfer reaction was proved to be one of the most effective ways by the synthesis and identification of new heavy neutron-rich isotope ^{208}Hg, ^{239}Pa and ^{186}Hf[2~4] in our institute. In the present experiment, the intermediate energy heavy ion-induced multinucleon transfer reaction could satisfactorily overcome the difficulty in synthesizing ^{238}Th. ^{238}Th was produced by 60 MeV/u ^{18}O bombardment on uranium through the reaction (^{238}U-2p+2n).

2 Experiment

The experiments were performed at Heavy Ion Research Facility in Lanzhou (HIRFL) of Institute of Modern Physics(IMP). The 60 MeV/u ^{18}O beam with a current intensity of 30~60 (e)nA was used to irradiate the natural uranium (1.5 g/cm^2). After irradiation of 25 minutes, each target was rapidly transferred to the chemical laboratory 30 meters far away by a pneumatic transport system. Then the radiochemical separation was carried out. The improved chemical separation procedure is summarized as follows:

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1) The irradiated uranium powder was dissolved in the 15 mL of 1.2 mol/L HNO_3. The same volume of 0.05 mol/L PMBP-benzene solution was added and layers were equilibrated for one minute manually. Water phase was discarded after phases were separated.

2) The organic phase was washed by 10 mL of 0.6 mol/L HCl once, then water phase was discarded.

3) The organic phase was re-extracted by 15 mL of 4 mol/L HNO_3 (containing KI and $NaNO_3$).

The water phase was transferred to a centrifuge tube containing the carrier of Te and Br, and then 4 mg Fe^{3+} was added. Sufficient conc. NH_4OH was added to make the solution just alkaline. Centrifuged and discarded supernate.

4) 10 ml of 0.6 mol/L HNO_3 solution was added to the centrifuge tube. After the precipitate of $Fe(OH)_3$ was dissolved, the solution was transferred to a separatory funnel, Th was extracted with 0.05 mol/L BMBP-benzene for one minute and discard aqueous.

5) Step 2 and 3 was repeated. The precipitate of $Fe(OH)_3$ was not centrifuged, but filtered through filter pipe. Solid sources were prepared for γ counting. The chemical yield of thorium was about 70% after the whole flow. Following the chemical separation, about 10 minutes after the end of irradiation, the measurements started by using two HPGe detectors. One of the HPGe detectors has efficiency 30% with energy resolution of 2.0 keV(FWHM) for the 1.33 MeV line of ^{60}Co, and the other one was a planar HPGe detector with energy resolution of about 580 eV for the 122 keV line of ^{57}Co, an active diameter of 32 mm and a sensitive depth of 10 mm. The two detectors were placed face to face on both sides of the source in a lead room. The X and γ time sequence spectra and γ(X)-γ-t coincidence events were recorded with a PC-CAMAC Multi-Parameter Data Acquisition system. Each source was measured for 25 minutes.

A total number of 67 such cycles were performed.

3 Results

It should be mentioned that because of the small yield of ^{238}Th, the large quantity of target material and short separation time, although our procedure for the chemical separation of thorium removed the most of the product elements, a few impurity radioactivities of Po, In and Cs remained in the separated Th fraction. As a consequence, besides those γ-rays from thorium radioactive isotopes and their decay daughters, the γ spectra also contained the γ-rays from actvities of Po, In and Cs isotopes as well as their decay daughters, but they were dominated by the former. The two clearly observed γ-rays with energies 635.0 and 1060.5 keV (Fig.1) were assigned to the ^{238}Pa decay through their half-lives, transition energies, and relative intensities.[5] The behavior of their build up and consequent decay indicate that the activities of ^{238}Pa come from the new nuclide ^{238}Th β^- decay. Because of the lower background and the smaller amount of impurity rays in the relevant high energy region of the spectrum, the γ-ray of 1060.5 keV could be accurately followed. A computer code for analyzing the decay of a radioactive series was used and the half-life of ^{238}Th and ^{238}Pa were extracted to be 9.4±2.0 min and 2.1±0.4 min, respectively(Fig.2). The latter is well consistent with the previous result[5] and the former is in good agreement with the value calculated by using the proton-neutron quasi-particle random-phase approximation (QRPA) with a Gamow- Teller residual interaction determined from the mass formula of Hilf et al

as well as Moellor and Nix.[6]

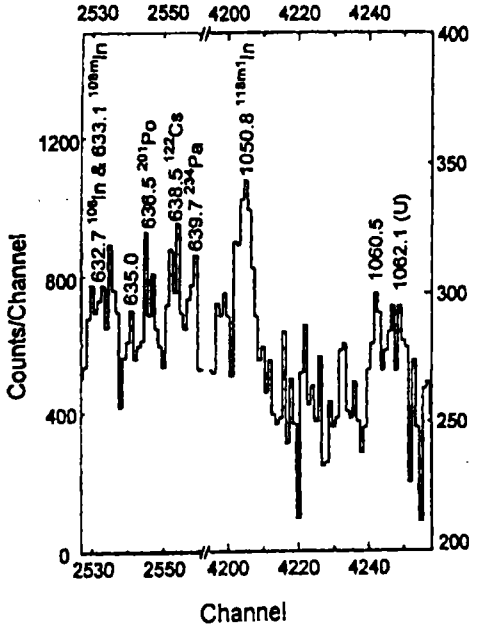

Fig.1 Part of the measured γ spectrum for the separated Th fractions

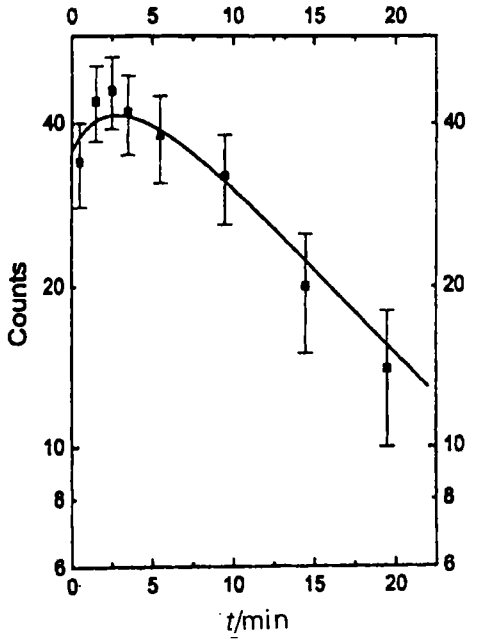

Fig.2 Growth and decay curve for the ^{238}Pa 1060.5keV γ-ray

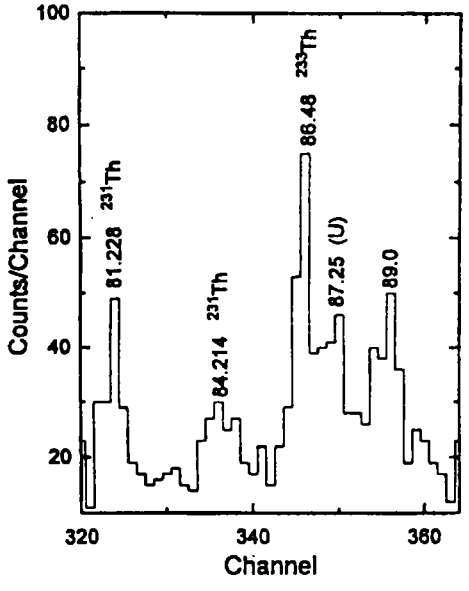

Fig.3 Part of the γ (X)-ray spectrum gated with the X-rays of Pa

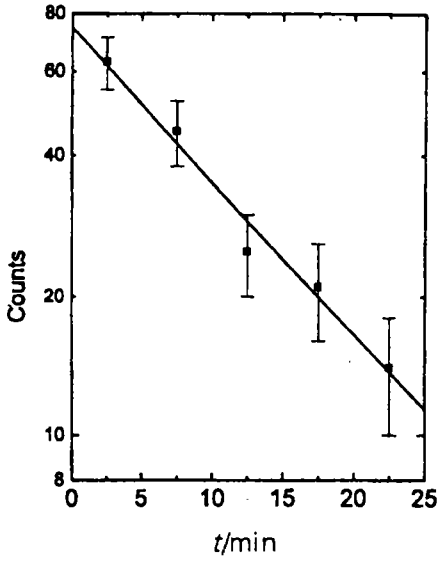

Fig.4 Decay curve of 89.0 keV γ-ray

Furthermore, an unknown γ-ray with an energy of 89.0±0.3 keV (Fig.3) and half-life of 8.9±0.3 min(Fig.4) was found in the γ(X) spectra gated with the $K_{\alpha 1}$ X ray of Pa. It should attribute to decay from one of the uranium neutron-deficient isotopes or thorium neutron-rich isotopes. Considering that uranium isotopes have been removed from the Th fraction after chemical separation, it should only come from thorium neutron-rich isotopes. Known thorium neutron-rich isotopes have no such a transition energy and half-life. The observed 89.0 keV γ ray was tentatively assigned to ^{238}Th β^- decay based on the similar half-life of ^{238}Th obtained above.

All the evidences mentioned above prove that the new heavy neutron-rich isotope ^{238}Th was synthesized and identified in the present experiment, and its half-life was measured to be 9.4±2.0 min.

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