Half-life measurement of neutron-rich isotope ^{237}Th

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Abstract 60 MeV/u ^{18}O ions were used to bombard natural uranium targets, and the heavy neutron-rich isotope ^{237}Th was produced via multi-nucleon transfer reaction and dissipative fragmentation of the heavy target. A relatively fast radiochemical procedure was used to separate thorium from the mixture of uranium and complex reaction products. The chemically separated thorium fractions were studied by the γ-ray spectroscopic method. The behaviors of the growth and decay of 853.7 and 865.0 keV γ rays of ^{237}Pa decay were observed. The half-life of ^{237}Th was determined to be 4.69±0.60 min.

Keywords ^{237}Th, Half-life, Multi-nucleon transfer, Radiochemical separation

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1 INTRODUCTION

It has been reported[1] that the new neutron-rich isotope ^{237}Th was produced via ^{238}U(n,2p)^{237}Th reaction by 14 MeV/u neutron irradiations of natural uranium and the half-life of ^{237}Th has been given. Some experimental results reveal that in multi-nucleon transfer reaction (MNTR), neutron-rich projectile, neutron-rich target and reasonably higher incident energy favor the production of a heavy neutron-rich nuclei. In addition, dissipative fragmentation of heavy target in the intermediate energy heavy-ion collision can also produce heavy neutron-rich nuclei as target-like residues.[2~4] The results of the synthesized and identified nuclides ^{208}Hg,[5] ^{239}Pa,[6] ^{186}Hf,[7] ^{209}Hg,[8] and ^{238}Th[9] also indicate that intermediate energy heavy ion induced MNTR is indeed one of the best ways for producing heavy neutron-rich nuclei far from stability.

The present paper describes the experimental measurement of the ^{237}Th half-life in order to confirm the identification of ^{237}Th and improve the measured precision of its half-life. In the present experiment ^{237}Th was produced as target-like products via an exchange of two target protons for one projectile neutrons, i.e., (^{238}U-2p+1n).

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2 EXPERIMENTAL METHODS

2.1 Irradiation and chemical separation

The irradiations were performed at the Heavy Ion Research Facility (HIRFL) of the Institute of Modern Physics (IMP) in Lanzhou. In the experiment, ^{237}Th was produced as target-like products via an exchange of two target protons for one projectile neutrons, i.e., (^{238}U-2p+1n). For increasing the content of uranium in the targets, not $UO_2(NO_3)$ but $(NH_4)_2U_2O_7$ was selected as target material. The $(NH_4)_2U_2O_7$ (1.5g/cm^2) targets were irradiated by 60 MeV/u ^{18}O beams with a current intensity of 30~40 enA. Each irradiation lasted 15 minutes. The change of the beam intensity was monitored with a Faraday cup. After the irradiations, the irradiated uranium targets were transferred to the chemical laboratory by a pneumatic transfer system for chemical separation. The irradiated uranium powder was dissolved into 1.2 mol/L HNO_3 solution. The isolation of thorium from uranium and other reaction products was accomplished with an improved chemical procedure, which has been described elsewhere.[10]

2.2 Measurements and Data Analysis

About 10 minutes after the end of irradiations, the measurements started by using a GMX HPGe detector with efficiency of 30% and energy resolution of 2.1 keV (FWHM) for the 1.33 MeV γ rays of ^{60}Co. The acquired γ-ray time sequence spectra were stored in a hard disk and then analyzed by using a computer analysis program. Each nuclide was identified according to the transition energies, relative intensities and half-lives of their γ rays. As γ rays of ^{237}Th were nearly unknown, it was identified by means of measurements for the daughter's γ rays. Based on the observation of behavior of build up and consequent decay for ^{237}Pa activities, ^{237}Th was identified and its half-life was determined.

3 RESULTS AND DISCUSSION

Many kinds of radioactive isotopes can be produced in the interactions of intermediate energy heavy ions with heavy target nuclei and many of them have large cross sections. So it is essential to separate thorium from great amount of target material and mixture of other reaction products. Moreover, the ordinary multi-step separation procedure can not be used, because the half-life of ^{237}Th is only about 5 minutes.[1] In the improved procedure, the 1-phenyl-3-methyl-4-benzoyl-5-pyrazolone (PMBP) extraction provided the selective separation of Th from the other elements. It has advantages of higher extraction efficiency for thorium and shorter equilibrium time. It is seen that the decontamination of the impurity elements in the separated thorium fractions is satisfac-

tory. The decontamination factors of main reaction products are given in Table 1. It is found from Table 1 that the large amount of uranium does not interfere with the extraction of trace thorium under the experimental conditions. In the previous studies, it was almost impossible to remove completely iodine in the separated thorium fractions.[11,12] However, by employing the improved procedure, the activities of iodine and bromine isotopes have been completely removed from the thorium fractions. However a little amount of impurity from radioactive isotopes of Sc, Cd, In, etc. still remained in the thorium fractions. As a result the spectra contained the corresponding γ rays of those impurities in addition to the peaks from ^{237}Pa and Th radioactive isotopes.

Table 1 Decontamination factor of main reaction products

Nuclides	E_γ /keV	I_γ /%	Decontamination factor	Nuclides	E_γ /keV	I_γ /%	Decontamination factor
^{24}Na	1368.5	100	$> 1.1 \times 10^5$	^{112}Ag	617.4	42.5	$> 4.8 \times 10^5$
^{48}Sc	983.5	100	2.1×10^2	^{115}Cd	336.2	49.7	$> 1.1 \times 10^4$
^{56}Mn	1810.7	27.2	2.2×10^2	^{117}In	158.6	86.4	1.5×10^4
^{59}Fe	1099.3	56.5	$> 7.7 \times 10^3$	^{118}Sb	253.7	94.2	$> 1.2 \times 10^5$
^{65}Ni	1481.8	23.5	$> 2.8 \times 10^3$	^{127}Cs	124.7	15.6	$> 3.9 \times 10^4$
^{69}Zn	438.6	94.8	$> 3.7 \times 10^4$	^{131}I	364.5	81.2	$> 1.8 \times 10^5$
^{73}Ga	297.3	80	$> 1.1 \times 10^5$	^{132}Te	228.2	88.1	$> 2.4 \times 10^5$
^{82}Br	1474.8	16.6	$> 4.5 \times 10^3$	^{133}I	529.9	87.0	$> 8.9 \times 10^4$
^{84}Rb	881.6	67.8	3.4×10^4	^{135}Xe	249.8	90.4	6.9×10^3
^{95}Zr	756.8	55.4	$> 6.8 \times 10^4$	^{140}Ba	1596.5	109.9	$> 4.5 \times 10^4$
^{90}Y	202.5	96.5	$> 1.5 \times 10^5$	^{141}Ce	145.4	48.4	$> 2.2 \times 10^5$
^{91}Sr	1024.3	33.4	$>4.4 \times 10^4$	^{233}Pa	311.9	38.6	$> 1.6 \times 10^4$
^{96}Nb	778.2	96.9	$> 5.7 \times 10^4$	^{237}U	208.0	21.7	$> 4.0 \times 10^5$
^{99}Mo-^{99}Tc	140.5	90.7	$> 6.4 \times 10^5$	^{239}Np	277.6	14.5	$> 5.0 \times 10^4$
^{105}Ru	724.2	46.7	3.4×10^4				

Fig.1 summarizes the cumulative γ-ray spectrum for 35 thorium fractions separated from the irradiated uranium targets. Two gamma rays with energies of 853.7 and 865.0 keV, which were attributed to the decay of ^{237}Pa, were identified based on their half-lives, energies and relative intensities. As the decontamination factor of Pa isotopes was higher than 1×10^4, ^{237}Pa produced directly in reactions was negligible in the thorium fractions. The observed ^{237}Pa activities could only come from the decay of the mother nuclei.

Both of the two γ rays of 853.7 and 865.0 keV showed the behavior of growth and subsequent decay. The result confirmed the existence of the mother nucleus ^{237}Th. The most intense γ ray of 853.7 keV was carefully followed. Based on the analysis of the growth and decay curve, the half-lives of ^{237}Th and ^{237}Pa were extracted to be 4.69 ± 0.60 min and 8.60 ± 0.70 min, respectively (Fig.2). The former is in good agreement with the 5.0 min

value obtained in the previous work,[1] and the latter is also consistent with the reference value of ^{237}Pa.[13] The precision of ^{237}Th half-life obtained in the present experiment was obviously improved.

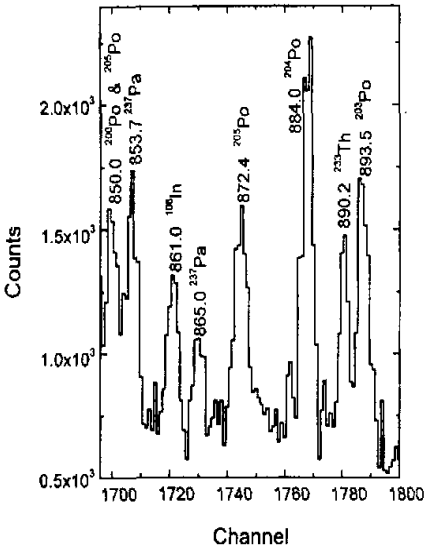

Fig.1 Part of cumulative γ ray spectrum of separated thorium fractions

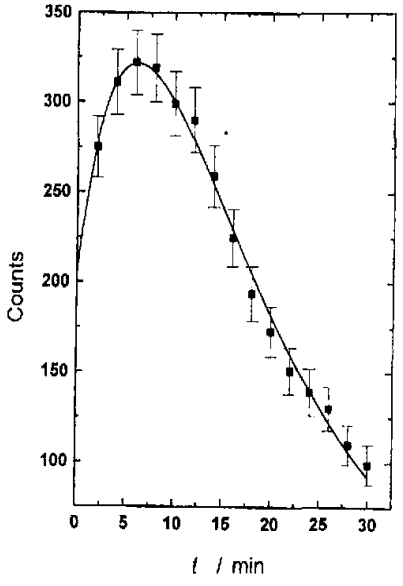

Fig.2 The growth and decay curve of 853.7 keV γ ray of ^{237}Pa

Moreover, we have noted that there are considerable differences in the predicted values of half-lives from different kinds of theoretical calculations, such as QRPA (proton-neutron quasi-particle random-phase approximation) theory,[14] TDA (Tamm-Dancoff approximation) theory,[15] and the gross theory.[16] Among them, the value calculated by using the QRPA theory agrees very well with our experimental result because in this theory a more realistic microscopic description of the β-strength function by applying the proton-neutron quasi-particle random-phase approximation with a Gamow-Taller residual interaction is used.[17] Besides pairing correlations, this model also accounts for the spin-isospin ground-state correlations.[14] In addition, for application of the QRPA model to nuclei far from stability, the mass formulas must be used to estimate Q_β values (and deformation). Among the three kinds of mass formulas (Hilf, Groote and Möller) used, the predictions deducted from Hilf and Möller formula are similar to each other, and it has been proved that they all fit the experimental results quite well by a lot of experiments.[14] Our present experimental result also supports this theoretical prediction. (see Table 2)

Table 2 Comparison of the experimental value of ^{237}Th half-life with theoretical values

Experimental value /min	Theoretical value /min				
		QRPA		TDA	Gross theory
	Hilf[a]	Groote[b]	Möller[c]		
4.69±0.60	3.7	6.5	5.2	1.1	3

Superscripts, [a,b,c] refer to half-lives using the mass formula of Hilf *et al.* Groote *et al.* and Möller *et al.* respectively.

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