Production cross-section of ^{230}Ra in the reaction of 60 MeV/u ^{18}O ions with ^{238}U*

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Abstract A thick natural uranium target was bombarded with a 60 MeV/u ^{18}O beam. The neutron-rich isotope ^{230}Ra as the target residue was produced through the multinucleon transfer reaction(^{238}U-4p-4n). The barium and radium fraction as $BaCl_2$ precipitate were radiochemically separated first from the mixture of uranium and reaction products. Then, the radium fraction was separated from $BaCl_2$ precipitate by using cation exchange technique. The γ-ray spectra of the Ra fraction were measured using an HPGe detector. The production cross sections of ^{230}Ra were obtained by a combination of the radiochemical separation technique and off-line γ-ray spectroscopy. The cross section of ^{230}Ra has been determined to be 66±20 μb.

Key words ^{18}O ion, ^{230}Ra, nature uranium target, multinucleon transfer reaction, cross section

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1 Introduction

Tamaguchi et al.[1] has reported that High-and-intermediate-energy projectile fragmentation has proven to be a powerful tool for producing nuclei far from stability. They used 1 AGeV ^{80}Kr on a Be target to produce the proton drip line nuclei in the mass range $60< A <100$. Xu et al.[2] have synthesized and identified a number of unknown neutron-deficient nuclides in the rare-earth region near the proton drip line by the irradiation of ^{92}Mo, ^{96}Ru, ^{129}Sm and ^{139}Dy with an ^{36}Ar beam. The known nuclei closed to the neutron drip line are only nuclides with nuclear charge $Z < 10$ for the neutron-rich side of chart of the nuclides up to now. Studies of the neutron-rich nuclei have only reached nuclei with a very limited neutron excess for the other region, especially, for the regions of neutron-rich nuclei with $A \geqslant 170$.

There has been a great deal of interest in the use of heavy ion transfer reactions with neutron-rich heavy targets to produce neutron-rich isotopes, especially isotopes with mass number $A \geqslant 170$. Artukh et al.[3] first identified a lot of unknown neutron-rich isotopes below argon in the reaction of ^{40}Ar ions with ^{232}Th targets. New neutron-rich isotopes of chromium-to-nickel[4, 5], heavy lanthanides[6, 7] and actinides[8] formed by multinucleon transfer reactions were investigated at the GSI on-line mass separator. The experiments have demonstrated that multinucleon transfer reactions between the heavy ions are a suitable tool for producing the unkrown neutron-rich isotopes. The experimental studies of producing and identifying new heavy neutron-rich nuclides[9—13] at the Institute of Modern Physics(IMP) also show that multinucleon transfer reactions are a effective way for the synthesis of heavy neutron-rich nuclides with $A \geqslant 170$.

The experimental data on production cross sec-

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tions for heavy neutron-rich target-like residues produced in the multinucleon transfer reactions are still scarce untill now. It is necessary to precisely measure production cross sections of target-like residues, because such data are of extreme importance for the yield estimate of the unknown heavy neutron-rich isotopes, especially when intermediate energy lighter heavy ions are used as a primary beam.

The results of experiments on cross-section measurement of ^{230}Ra in the bombardment of thick natural uranium targets with a 60 MeV/u ^{18}O beam are reported in the present paper.

2 Experimental

2.1 Irradiation

Irradiations were performed at the Heavy Ion Research Fasility at Lanzhou (HIRFL) in the Institute of Modern Physics (IMP). The natural uranium targets with a thickness of 1.5 g·cm^{-2}, in the form of $(NH_4)_2U_2O_7$ were bombarded with 60 MeV/u ^{18}O ions with an average intensity of 30—40 nA. The bombardments lasted 100 minutes for each target. The isotope ^{230}Ra as the target-like residue was produced via the reaction ^{238}Th-2p-4n. After the end of irradiation, the irradiated uranium target was rapidly transferred pneumatically to the chemical laboratory for radiochemical processing.

2.2 Chemical separation

Firstly, Ba and Ra as the form of $BaCl_2$ precipitate was radiochemically separated from the mixture of uranium and the reaction products. Then Ra was separated from Ba by using the ion change technique[14]. It is necessary that Ra was separated from $BaCl_2$ precipitate because yields of Ba isotopes produced in the reaction are higher. Finally, the γ solid radioactive sources of Ra were prepared for γ spectroscopy.

2.3 Measurements

After chemical processing, the single γ-ray spectra of the Ra sources were measured in a lead room using a calibrated HPGe detector by off-line γ-ray spectroscopy. The HPGe detector has 30% efficiency and an energy resolution of 2.3 keV for the 1332 keV line of ^{60}Co. The sources of known radioactivities were used to provide the energy and intensity calibrations. The γ-ray spectra were recorded in multi-spectrum mode in order to obtain half-lives for the interesting nuclides. The time sequence spectra were recorded on magnetic disks with Multi-Parameter Data Acquisition System[15]. The measured γ-ray spectral data were analyzed by employing a set of computer programs.

3 Results and discussion

A part of γ-ray spectrum for the Ra fraction separated chemically from the ^{238}U target is presented in Fig. 1. It can be seen from Fig. 1 that besides γ-rays of Ra and their daughter isotopes, there are also γ-rays of Ba isotopes with shorter half-lives. It is quite difficulty that Ba was separated completely from Ra because they are very similar in chemical properties. Based on the analysis of the γ-ray spectrum in Fig. 1, we can conclude that there are no the other γ-ray peaks arising from impurity elements except for γ-rays of Ba, Ra as well as their daughter isotopes. It explains the chemical separation procedure used in the present experiment can very effectively remove the other impurity elements produced in the reaction.

The production cross sections of ^{230}Ra were obtained based on the target thickness, the beam intensity, activities of ^{230}Ra at the end of bombardment, the chemical yield, and the other relative information. The production cross section of ^{230}Ra has been determined to be 66±20 μb in the ^{18}O+^{238}U reaction. It is the thick-target average production cross section.

There are a few papers on the cross section data of the neutron-rich target residues produced in the interactions of thick neutron-rich heavy target with the below-Z projectiles (^{18}O etc. ions). A series of studies on the distribution of hafnium and lutetium isotopes were performed by Zychor et al.[16] through the bombardment of the thick tungsten targets with ^{40}Ar, ^{84}Kr and ^{136}Xe beams, respectively. The results show the behavior of the isotopic distributions on the neutron-rich side for hafnium and lutetium isotopes produced in the reactions can not be explained in terms of the partial statistical equilibrium model. Moreover, the yields of known neutron-rich hafnium and lutetium isotopes are relatively high in the reaction.

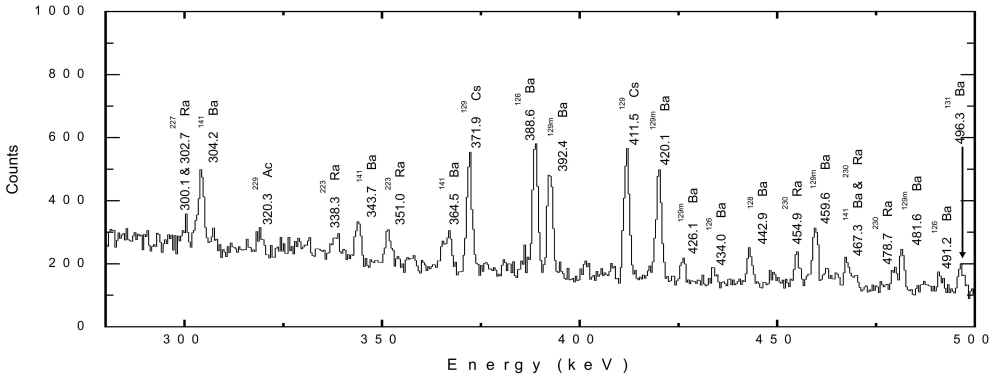

Fig. 1. A part of γ-ray spectrum of the Ra fraction separated chemically from ^{238}U target irradiated with 60 MeV/u ^{18}O ions.

The thick-target average production cross sections of the neutron-rich Hg isotopes arising from the ^{18}O+^{208}Pb reaction were plotted by Zhang Li[17] against Q_{gg} (the ground state-to-ground state Q values). The Q_{gg} dependence of the thick-target average production cross sections (independent) for the neutron-rich Hg isotopes demonstrates the heavy neutron-rich target residues can be produced in multinucleon transfer processes.

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