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Short note

Search for β-delayed fission of the heavy neutron-rich isotope ^{230}Ac

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Abstract. The ^{230}Ra has been produced via multinucleon transfer reaction and dissipative fragmentation by 60 MeV/u ^{18}O ion irradiation of ^{232}Th targets. The radium was radiochemically separated from the mixture of thorium and reaction products. Thin Ra sources were prepared and exposed to the mica fission track detectors, and measured by a HPGe gamma detector. It is likely that the β-delayed fission of ^{230}Ac was observed for the first time and the β-delayed fission probability of ^{230}Ac was tentatively found to be $(1.19 \pm 0.40) \times 10^{-8}$.

PACS. 27.90.+b $220 \leq A$ – 23.40.-s β decay; double β decay; electron and muon capture – 21.10.Tg Lifetimes – 25.70.Hi Transfer reactions

Nuclei far from stability are characterized by a number of new phenomena. The β-delayed fission (βDF), *i.e.*, fission from an excited state populated by β-decay, is one of the intriguing decay modes in very heavy mass region. A β-delayed fission island was predicted to occur in heavy neutron-rich region by E.Ye. Berlovich and Yu.N. Novikov in 1969 [1].

βDF provides the possibility for the study of very heavy neutron-rich nuclei, which are not accessible with ordinary techniques. For example, βDF allows the study of the fission of heavy neutron-rich nuclei from excited states, which can be used as a basis for predictions of fission properties of heavier neutron-rich nuclei [2,3]. Measurements of the probability for βDF also provide a sensitive probe of the structure of the fission barrier since the probability (thus the half-life) of the fissioning level is exponentially dependent on the magnitude of the fission barrier [3].

βDF is also of astrophysical interest [1,3–8]. The measurements of the gross properties, including delayed fission probabilities of heavy neutron-rich nuclei, are important for the determination of r-process path [3–7]. The predictions, searches, and measurements of βDF in the neutron-rich actinide nuclei are crucial for the estimation of the Universe age using the nuclear cosmochronology by the heavy chronometers [4–8]. Yu.P. Gangrskii *et al.* [2], A. Baas-May *et al.* [7], H.L. Hall *et al.* [3], and K.A. Mezilev *et al.* [8] successively performed intensive experimental searches and studies for βDF in neutron-rich actinide and the nearby region.

In view of the very low production cross-sections in this mass region, efficient reactions with high enough production rate are crucial for the study of βDF. A.G. Artukh *et al.* first reported the possibility of producing neutron-rich isotopes through multinucleon transfer reaction (MNTR) [9]. MNTR well above the Coulomb barrier has turned out to be an efficient reaction to produce heavy neutron-rich nuclei [10,11]. Some experimental results reveal that in MNTR both neutron-rich projectile and target, and reasonably higher incident energy, favor the production of heavy neutron-rich nuclei [12–16]. 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 [17].

In the present work, the ^{230}Ra was produced as target-like product via MNTR, transferring two target protons to projectile, *i.e.*, (^{232}Th-2p), and via dissipative fragmentation of the heavy target.

The experiments were performed at Heavy Ion Research Facility in Lanzhou (HIRFL) of the Institute of Modern Physics (IMP). The 60 MeV/u ^{18}O beam with a current intensity of 40 enA irradiated a "radium free" natural ThO_2 powder target (1.5 g/cm^2). After irradiation of 3 hours, each target was rapidly transferred to the chemical laboratory 30 meters away by a pneumatic transport system. Isotopes of Ra produced in the reactions were radiochemically isolated from the mixture of tho-

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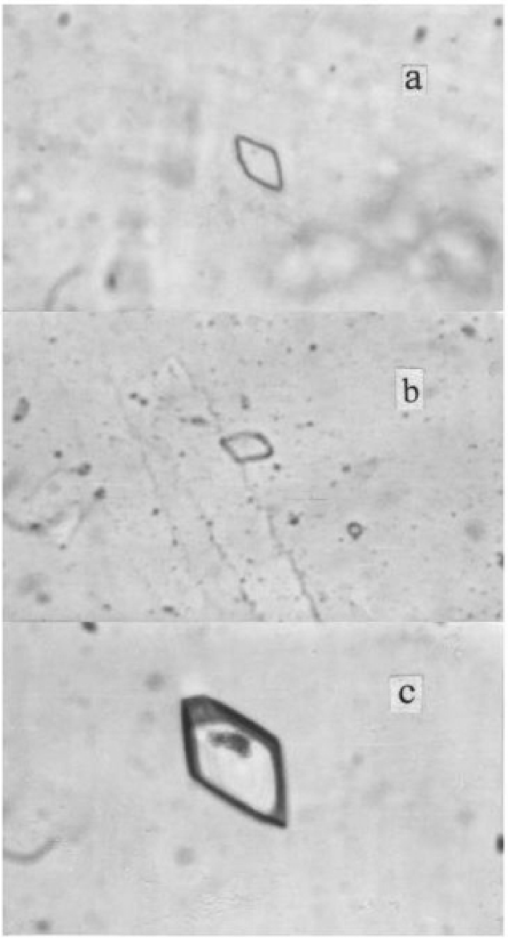

Fig. 1. The observed two fission fragment tracks from β-delayed fission of ^{230}Ac (a) and (b). A track from natural background of fission fragment (c).

rium and reaction products by $BaCl_2$ precipitation. Thin Ra sources were prepared for measurements of fragments from β-delayed fission. Mica foils were stuck on the sources as fission track detectors. The sources together with mica foils and a HPGe gamma detector were placed in a lead room. The sources were exposed to the mica fission track detectors for 10 hours and measured by the HPGe gamma detector for 4 hours. Moreover, those from other radioactive isotopes of radium were not detected. 20 separate runs were made.

The 20 mica foils etched already for 10 hours before the experiments were etched in a solution of 40% HF at 50 °C for 4 hours. The processed mica foils were scanned by an optical microscope. As a result of scanning the foils, two fission fragment tracks were observed (fig. 1), which differ clearly in size from those of natural background (fig. 1) since the total etching time for natural fission tracks was 14 hours whereas it was only 4 hours for tracks due to fission events from the source. It is likely that the observation of fission fragment tracks provide the first evidence for the delayed fission of ^{230}Ac based on the following arguments:

1. The same experiments mentioned above except irradiation of the target materials were carried out, no fission event was found.

2. Inspection of the samples by gamma-ray spectroscopy showed that, except for some impurities of Ba and Sr, the radium fractions were radiochemically clean. In the spectra one can see the gamma rays from ^{223}Ra, ^{224}Ra, ^{225}Ra, ^{227}Ra and the daughters of the ^{223}Ra and ^{224}Ra through their alpha decay, in addition to the intense gamma rays from ^{230}Ra and its daughter ^{230}Ac.

3. βDF should obviously appear in heavy neutron-rich nuclei far from stability [1,4–6]. In addition, based on the systematics of β-decay energies and fission-barrier heights, fission events are attributed to ^{230}Ac rather than ^{230}Ra because even-even nuclei have a higher fissility than odd-odd nuclei and odd-odd nuclei have high β-decay energies [1–8].

4. The possibility of the spontaneous fission of ^{230}Th, the daughter of ^{230}Ac, could be excluded, because of the long half-life (7.54×10^4 years), the minor spontaneous fission probability ($< 3.8\times10^{-14}$) [18], and a very limited total number (1.68×10^8) of ^{230}Th in the whole experiments. In fact thorium was depleted by factor $> 2\times10^4$ which means that during the whole series of experiments less than 2×10^{-5} fission tracks were expected from remaining ^{232}Th impurities.

All the arguments mentioned above indicate that the two fission events observed in the experiments might be assigned to the βDF of ^{230}Ac.

βDF probability was defined as the number of delayed fission events divided by the number of β-decay of the parent:

$$P_{\beta\mathrm{DF}} = \frac{N_{\beta\mathrm{DF}}}{N_\beta}.$$

A total of 1.68×10^8 ^{230}Ac β-decay registered by the fission track detectors has been determined through peak areas and branching ratios of the gamma rays of ^{230}Ac [18] in the measured spectra. Consequently, the βDF probability of ^{230}Ac was tentatively determined to be $(1.19\pm0.40)\times10^{-8}$.

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