Observation of β-Delayed Fission from ^{230}Ac *

YUAN ShuangGui YANG WeiFan XU YanBing PAN QiangYan
HE JianJun XIONG Bing LI YingJun
(Institute of Modern Physics, The Chinese Academy of Sciences, Lanzhou 730000, China)

Abstract β-delayed fission for ^{230}Ac was searched. ^{230}Ra was produced via multinucleon transfer reaction by 60 MeV/u ^{18}O ion irradiation of ^{232}Th target. Thin $^{230}Ra \xrightarrow{\beta} {}^{230}Ac$ sources of 10^8 atoms were acquired through radiochemical separations. The mica track detectors were used to record the fission events. The β-delayed fission nucleus ^{230}Ac was identified via the observed two fission events and the measured γ-ray spectra. Its β-delayed fission probability was obtained to be $(1.19 \pm 0.85) \times 10^{-8}$.

Key words β-delayed fission probability, multinucleon transfer reaction, radiochemical separation

Berlovich and Novikov predicted a β-delayed fission (βDF) island[1]. The βDF process can be represented schematically as follows:

$$(Z,N) \xrightarrow{\beta} (Z \pm 1, N \mp 1)^* \xrightarrow{\theta} \sum_i (Z_i, N_i).$$

And βDF region can be obtained from the condition of complying with the following inequalities (1) and (2) using mass value from [2]:

$$T_{1/2}(\beta) \leqslant T_{1/2}(\alpha); T_{1/2}(\mathrm{SF}), \tag{1}$$

$$Q_\beta(Z, N \longrightarrow Z \pm 1, N \mp 1) \geqslant B_f(Z \pm 1, N \mp 1). \tag{2}$$

Thielemann and Klapdor et al. have carried out theoretical investigation of βDF probabilities of the nuclei in the island and shown its role in the production of heavy elements and built of heavy isotopic abundances in astrophysical r process as well as the influence of the delayed fission on the production of cosmochronometers[3,4].

There have been some reports on βDF experiments[5—8]. At first, βDF has been reported to occur in $^{236,238}Pa$ with aprobability of about 10^{-10} for ^{236}Pa and 6×10^{-7} for ^{238}Pa, respectively[5]. However, the latter value was not confirmed by a later study[6] using automated chemical separation procedures in which βDF of ^{238}Pa was not observed. The upper limit for this decay mode was estimated to be 2.6×10^{-8}. Hall et al. performed an experimental research for βDF of $^{256}Es^m$. The βDF precursor $^{256}Es^m$ was identified and its βDF probability was determined to be 2×10^{-5}[7]. An experiment searching βDF of $^{228,230,232}Fr$ and ^{232}Ac showed that no βDF fragments were detected. The upper limits of their βDF probability were given to be 2×10^{-7}, 3×10^{-6}, 2×10^{-6}, and 1×10^{-6} for $^{228,230,232}Fr$ and ^{232}Ac,

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respectively[8]. In this paper, we present the identification of βDF precursor nucleus ^{230}Ac and the determination of its βDF probability. In these experiments ^{230}Ra was produced as target like product via transferring two protons from target nucleas to projectile, i. e., (^{232}Th-2p).

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 intensity of ~40 enA was used to irradiate a "radium free" ThO_2 powder targets (1.5g/cm^2). After irradiation of 3 hours, targets were 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 thorium and other reaction products. Thin $^{230}\mathrm{Ra} \xrightarrow{\beta^-} {}^{230}\mathrm{Ac}$ sources were prepared for observing fission fragments from β-delayed fission of ^{230}Ac. Mica foils were stuck on the sources as fission track detectors. The sources together with mica foils and a HPGe γ detector were placed face to face in a lead room. The sources were exposed to the mica fission track detectors for 10 hours and measured by the HPGe γ detector for 4 hours. These mica foils were etched in a solution of 40% HF at 50℃ for 4 hours. After processing mica foils were scanned by means of an optical microscope. 20 runs were performed.

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 these mica foils

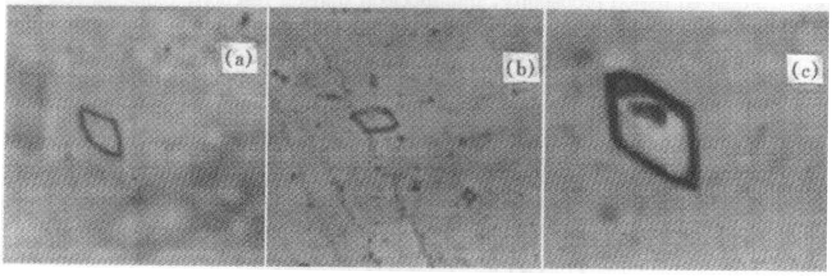

Fig. 1. The observed two fission fragment tracks from β-delayed fission of ^{230}Ac (a) and (b). A track from natural background of fission fragments (c).

were already etched for 10 hours before the experiments. Inspection of the samples by γ-ray spectroscopy showed that except for some impurities of Ba and Sr the radium fractions were radiochemically clean. Besides the more intense γ rays from ^{230}Ra and its daughter ^{230}Ac, there were the γ rays from ^{223}Ra, ^{224}Ra, ^{225}Ra, ^{227}Ra and the daughters of the ^{223}Ra and ^{224}Ra through their α decay in the measured γ spectra, moreover those from other radioactive isotopes of radium were not detectable. According to the theories, βDF will obviously occur only for heavy neutron-rich nuclei far from stability[1,3,4]. In addition, from the systematics of β-decay energies and fission-barrier heights βDF should appear first of all in odd-odd nuclei, since they have the greatest β-decay energies and the daughter even-even nuclei are characterized by high fissility[1,3—8]. Consequently it is confirmed that only the ^{230}Ac could produce βDF among all the radioactive isotopes contained in the thin $^{230}\mathrm{Ra} \xrightarrow{\beta^-} {}^{230}\mathrm{Ac}$ sources. As far as spontaneous fission of ^{230}Th, the daughter of ^{230}Ac β decay, no fission event could occur because of the long half-life(7.54×10^4 a), the minor spontaneous fission probability ($<3.8\times10^{-14}$)[9], and a very limited total number(1.68×10^8) of ^{230}Th in the whole experiments. Furthermore thorium was depleted by factor$>2\times10^4$. This means that during the whole series of experiments less than 2×10^{-5} fission tracks were expected from remaining ^{232}Th impurities. It should be pointed out that the same experiments mentioned above except irradiation of the target materials were carried out so as to check the background, no fission event was found.

All the arguments mentioned above indicate that the obtained two fission events could unambiguously been assigned to the βDF of ^{230}Ac.

A total of 1.68×10^8 ^{230}Ac β decay accepted by the fission track detectors has been determined. Consequently the βDF probability of ^{230}Ac was obtained to be $(1.19 \pm 0.85) \times 10^{-8}$.

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References

1 Berlovich E Ye, Novikov Yu N. Phys. Lett., 1969, **B29**:155
2 Myers W, Swiatecki W. Nucl. Phys., 1966, **81**:1
3 Thielemann F K, Metzinger J, Klapdor H V. Z. Phys., 1983, **A309**:301
4 Klapdor H V. Fortschr Phys., 1985, **33**:1
5 Gangrskii Yu P, Marinescu G M, Miller M B et al. Sov. J. Nucl. Phys., 1978, **27**:475
6 Baas-May A, Kratz J V. Trautmann N. Z. Phys., 1985, **A322**:457
7 Hal H L, Gregorich K E, Henderson R A et al. Phys. Rev., 1989, **C39**:1866
8 Mezilev K A, Novikov Yu N, Popov A V et al. Z. Phys., 1990, **A337**:109
9 Akovali Y A. Nucl. Data Sheets, 1993, **69**:155

^{230}Ac β 延发裂变的观测*

袁双贵　杨维凡　徐岩冰　潘强岩　何建军　熊　兵　李英俊
(中国科学院近代物理研究所　兰州 730000)

摘要　搜索了^{230}Ac β 延发裂变. 由 60MeV/u ^{18}O 离子照射^{232}Th,通过多核子转移反应产生^{230}Ra. 经放射化学分离和薄的^{230}Ra $\xrightarrow{\beta^-}$ ^{230}Ac 源的制备,获得了 10^8 个^{230}Ac 原子. 该源对云母裂变径迹探测器曝光. 借助于所测的 γ 能谱和两个裂变事件,鉴别了 β 延发裂变核^{230}Ac,得到了它的 β 延发裂变几率为$(1.19 \pm 0.85) \times 10^{-8}$.

关键词　β 延发裂变几率　多核子转移反应　放射化学分离

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