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Mass yield and angular distribution of rare earth elements produced in proton-induced fission of ^{244}Pu

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Abstract

In the fission system ^{244}Pu+p, formation cross sections of rare earth products were observed in the proton energy range 10 to 16 MeV, and their angular distributions were measured in detail of proton energy of 15 MeV. The highest mass number of rare earth products was 162 which corresponded to a highly asymmetric mass division of $A_H/A_L \approx 2$. The incident energy dependence and angular anisotropies of rare earth products were found to be the same, even for highly asymmetric mass division, and no clear evidence was observed for the effect of neutron numbers 50 and 97 on cross section and angular anisotropy. These observations lead to the conclusion that the fission process, leading to highly asymmetric mass division, experiences the same saddle point in the course of deformation toward scission as that for other typical asymmetric mass division.

1. Introduction

Asymmetric mass distribution has been observed in the low-energy fission of actinides ($90 < Z < 100$) and the peak and valley regions of the mass yield curves have been discussed [1]. However, only a few studies of the highly asymmetric region (especially in the region $A < 150$) have been reported [2, 3], and there is no systematic study available. In this work, we investigated the fission properties of highly asymmetrically divided products by observing their excitation functions and angular distributions. The reaction system we chose was low energy proton-induced fission of ^{244}Pu, because of the larger expected yields on the heavier wing of the asymmetric heavy mass yield peak. As most of the fission products to be investigated are rare earth nuclides and their half-lives are short, a rapid chemical separation of rare earth products was essential. A computer-controlled rapid ion-exchange separation system was developed [4] and used for the present purposes.

2. Experiments

For study of the excitation functions, an electrodeposited ^{244}Pu target of thickness 61 μg cm^{-2} on an aluminium backing foil was bombarded for 10–20 min or 1 h at the Japan Atomic Energy Research Institute (JAERI) tandem accelerator to ensure adequate production of fission products. The incident proton energy was varied from 10 to 16 MeV at a beam current of about 1.5 μA. The fission products were collected by an aluminum catcher foil of thickness 5.4 mg cm^{-2}.

Angular distributions of fission fragments were measured by the recoil-catcher foil method. An aluminum catcher foil of thickness 4.9 mg cm^{-2} was placed on the wall of a semicylindrical holder. Proton bombardment was performed for about 10 h. After bombardment the aluminum catcher foil was removed and sliced in strips of an appropriate width corresponding to some solid angle.

The main fission products were determined by direct γ-ray measurements. Asymmetric rare earth products were separated chemically from other fission products by the computer-controlled rapid ion-exchange separation system [4, 5], and identified by γ-ray spectrometry.

3. Results and discussion

Some of the excitation functions observed are shown in Fig. 1. The degree of asymmetry of mass division

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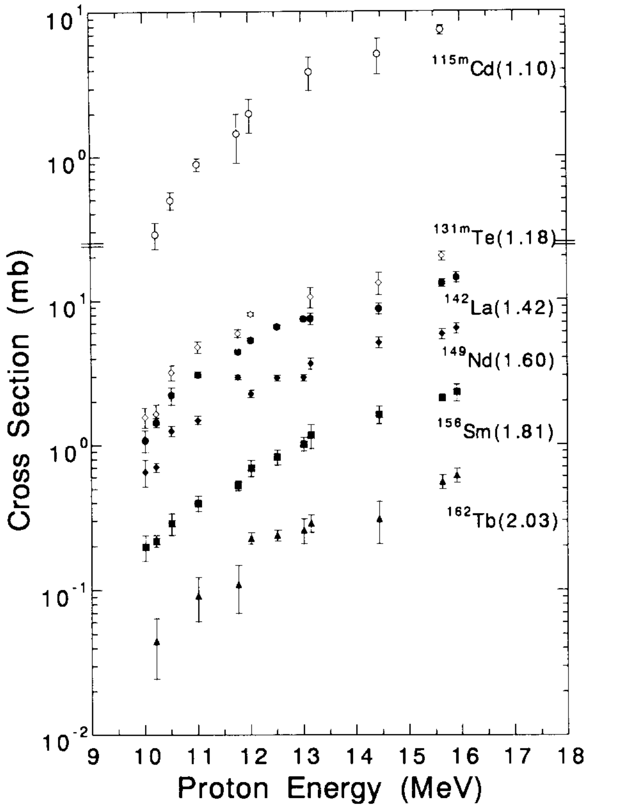

Fig. 1. Excitation function of fission products in proton-induced fission of ^{244}Pu.

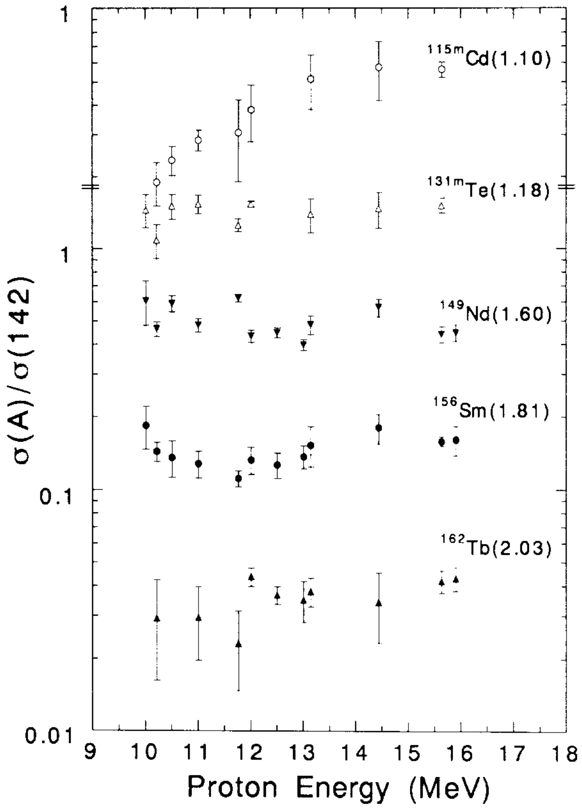

Fig. 2. Ratio of the formation cross-section of products with mass number A relative to that of ^{142}La in proton-induced fission of ^{244}Pu.

is defined in terms of the ratio (A_H/A_L) of the mass of a heavy fragment to that of the complementary light fragment. Conventional corrections for neutron emission have been applied to estimate the mass fragment before neutron emission. We could measure excitation functions of fission products up to the mass number $A = 162$ ($A_H/A_L \approx 2.03$). Figure 2 shows cross-section ratios of products with respect to ^{142}La as a function of proton energy. As can be seen from the figure, the ratios are independent of the proton energy, at least in the energy range studied, although they show small local fluctuations. This observation suggests that even highly asymmetric mass division experiences the same threshold energy or barrier height in the course of deformation toward scission as the other asymmetric division that occurs with a higher probability. No clear evidence of the effect of N = 50 and N = 97 was observed from the present study of excitation functions, which were considered responsible for the presence of the Standard III channel in Brosa's model [6].

In the experiments to measure the angular distribution, the values of $W(\theta)$ at 13 different angles from each irradiation were fitted to the equation $W(\theta) = a + b\cos^2\theta$ by least square analysis. The anisotropy of each product was defined as $1 + b/a$, that is $W(180°)/W(90°)$.

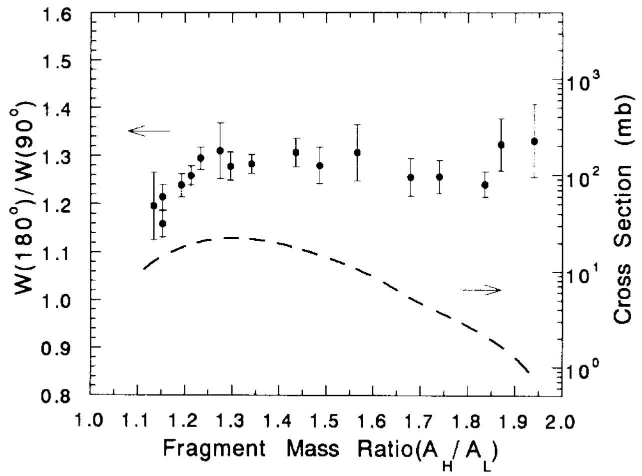

Fig. 3. Dependence of angular anisotropy on the fragment-mass ratio for 15 MeV proton-induced fission of ^{244}Pu. The dashed curve is the mass yield curve for the 15 MeV proton-induced fission of ^{244}Pu.

The correlation between the angular anisotropy and the fragment mass ratio is shown in Fig. 3. From the figure, the anisotropies of small mass ratio products ($A_H/A_L < 1.25$) are found to be smaller than those of more asymmetrically divided products. The anisotropy of the products with $A_H/A_L \geqslant 1.25$ is roughly constant. This observation points to the fact that all the asymmetric mass division studied in this work experiences the same saddle point, as the angular distribution of fission products is generally considered fixed at the saddle point.

In conclusion, it has been found in this work that the fission process which leads to a highly asymmetric mass division ($A_H/A_L \approx 2$) experiences the same saddle point in the course of deformation toward scission as that for other typical asymmetric mass divisions.

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