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Measurement of kinetic energies of Cs isotopes produced in $^{16}O+^{209}Bi$ nuclear fission by differential range method

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Abstract

Fission of neutron-deficient nuclei of light actinide ^{225}Pa produced by $^{16}O+^{209}Bi$ has been studied by the radiochemical differential range method. The average ranges of several shielded nuclei of Cs were obtained for incident oxygen beam energies of 94 and 103 MeV. Conversion of the observed ranges into energies was performed with reference to spontaneous fission products of ^{252}Cf. The average kinetic energies of the fission products for mass chains were also obtained. Comparison of the observed data for Cs isotopes with the calculated values supports the conclusion that the total kinetic energy of a primary Cs isotope varies with the Q_{gg} value over the observed isotopic distribution.

1. Introduction

Up to now, even though there are many reports on the average kinetic energies of fission products as a function of mass number, only a few reports are available on how kinetic energies vary along an isobaric chain or over an isotopic distribution [1]. The aim of the present work is to obtain an answer to this open question, and to clarify how the average kinetic energy of each isotope changes in relation to Q_{gg} values, where Q_{gg} value is the energy required to produce a given isotope in fission process provided that the pre-neutron fragment nuclei are produced in their ground states.

The kinetic energies of fission products are commonly measured by physical methods, such as two solid state detectors and the double time of flight (TOF) method. These methods allow measurement of the average kinetic energy of fission products for each mass number, but do not allow that of a product of specific atomic and mass numbers. Radiochemical differential range measurements are suitable for this second purpose, so are employed in this work.

2. Experimental details

The experiments were carried out at the Institute for Nuclear Study, University of Tokyo. SF cyclotron, using a ^{16}O beam with an accelerated energy of 115 MeV. The target was ^{209}Bi (1 mg cm^{-2} thick) evaporated onto an Al foil 4 mg cm^{-2} thick. The target and catcher foil assembly for measurements of the differential ranges are shown in Fig. 1. The incident energies were controlled by the thickness of the Al foils used as energy degraders, and were 94 and 103 MeV on the target. Fission fragments were collected in the forward direction (maximum angle was 25°) by stacked thin Al catcher foils (each 0.2 mg cm^{-2} thick). The amount of each product collected in each Al foil was determined by γ-ray spectrometry using a Ge detector. For Cs isotopes, chemical separation was applied after the bombardment and their γ-rays measured.

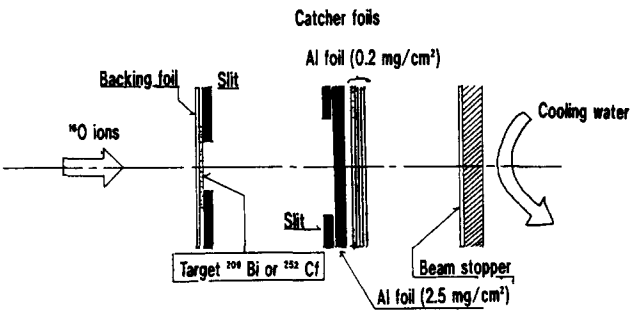

Fig. 1. Experimental set-up for measurement of differential range.

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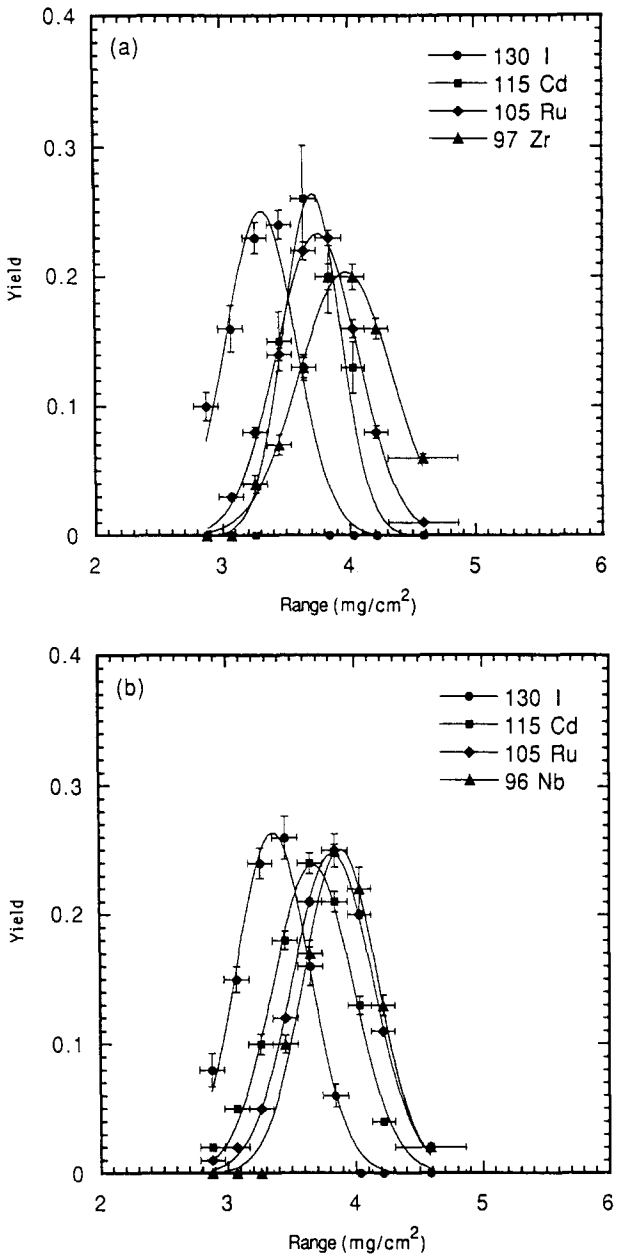

Fig. 2. Differential range distribution of each fission fragment produced in $^{16}O+^{209}Bi$. Incident energy is (a) 94 MeV and (b) 103 MeV.

Conversion of the observed ranges into energies was performed with reference to spontaneous fission products of ^{252}Cf using the range and energy relationship of Lindhard *et al.* [2].

3. Results and discussion

The measured differential range distributions of the fission products are shown in Figs. 2(a) and 2(b). Each distribution was fitted by a Gaussian curve, and the projected mean range at the peak position of the Gaussian curve was deduced. The differential ranges

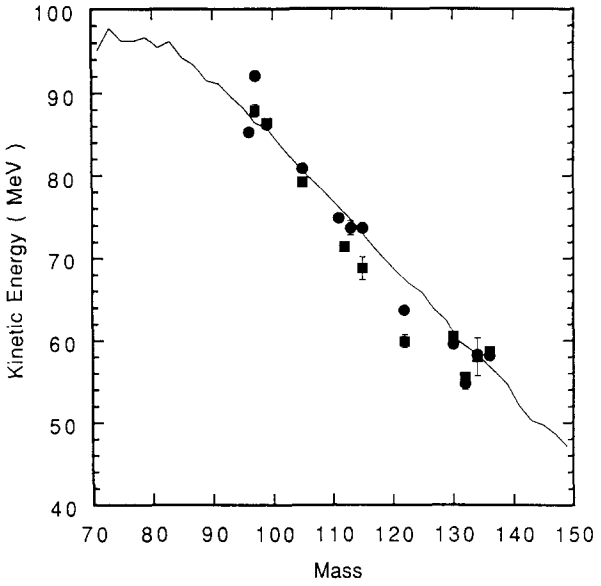

Fig. 3. Kinetic energies of fission products as a function of fragment mass. Full squares and full circles are the data obtained in the work with ^{16}O energies of 94 MeV and 103 MeV respectively. Full line obtained in ref. 3 by TOF.

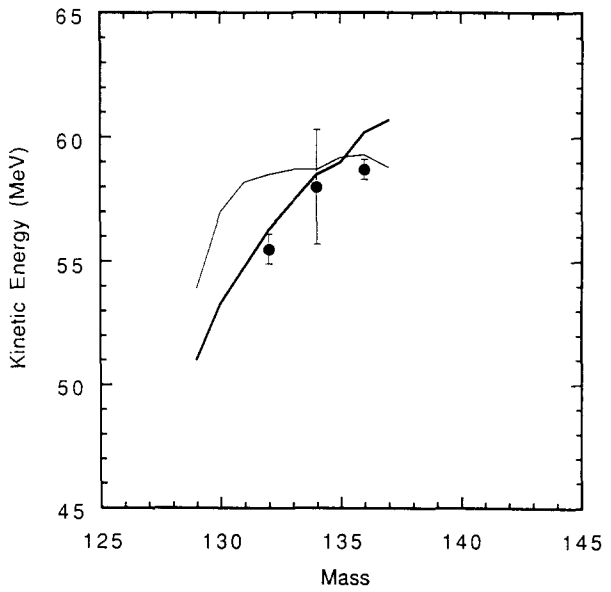

Fig. 4. Kinetic energies of Cs isotopes observed at a ^{16}O energy of 94 MeV. Full circles are kinetic energies observed and lines show calculated kinetic energies; the fine line is with an assumption of a constant total kinetic energy and the bold line is with an assumption of a total kinetic energy which varies with the Q_{gg} value, with a constant difference of 40 MeV.

of the fission fragments were simulated by the Monte Carlo method, by varying the kinetic energies, with an assumption of isotropic emission of the fission products in the Center-of-mass (CM) system, and by conversion from the CM to the Laboratory (LAB) system. The mean kinetic energy in the CM system that could best reproduce the observed differential range distribution was thus obtained.

Figure 3 shows the kinetic energies of fission products, where the kinetic energies obtained by the TOF method [3] are also shown by the full line. The kinetic energies obtained by the radiochemical differential range method are consistent with the values observed by the TOF method for fission products that represent corresponding mass chains. However, for the independent products of Sb and Cs isotopes, the present results deviate from the TOF data.

In Fig. 4 are shown the results for Cs isotopes. The kinetic energy increases with an increase in the mass number of the Cs isotope. To understand this variation of the kinetic energy over the isotopic distribution, and to extract information on the kinetic energies of primary fission products (before neutron evaporation), the conventional statistical calculation was performed for neutron evaporation. In the calculation, the kinetic energy distribution of each primary product of the Cs isotope and the primary isotopic distribution of Cs were first supplied as input data, and neutron evaporation was calculated with an assumption that the total excitation energy was shared between the two complementary fragments, with an additional assumption of equal temperature. The calculation was performed by changing the input values of the kinetic energies and isotopic distribution of the primary products of Cs until the best agreement was obtained between the observed [4] and calculated average secondary kinetic energies of each Cs isotope and the isotopic distribution.

The results of the calculations show that a better agreement can be obtained for both the kinetic energies and isotopic distribution, especially for the lighter Cs isotope, if the total kinetic energy of the fission events leading to the production of each primary Cs isotope is assumed to be smaller than Q_{gg} by a constant value of about 40 MeV over the isotopic distribution of Cs, rather than if it is assumed to be unrelated to Q_{gg} and constant for all isotopes. A comparison of the observed and calculated kinetic energies is shown in Fig. 4 for two kinds of assumption used for the total kinetic energy.

From analysis of the observed data, as discussed above, it is concluded in the present work that the total kinetic energies for primary Cs isotopes are not constant but, instead, vary with Q_{gg} values. Finally, it should be added that, in the present reaction system, the contribution of incomplete fusion fission resulting from α particle emission was less than a few per cent of the observed total fission. This was confirmed by a separate experiment for α fission coincidence measurements [5].

References

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