FISSION OF RELATIVISTIC SECONDARY BEAMS * **

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A new method is described to study nuclear fission of short-lived radioactive isotopes induced by electromagnetic excitations. Secondary beams of fissile nuclei were produced by fragmentation of ^{238}U projectiles at 1 *A* GeV. After being separated and identified in the fragment separator of GSI they impinged on a secondary lead target. Nuclear-charge distributions and total kinetic energies of fission fragments produced in low-energy fission have been measured for a number of neutron-deficient uranium, protactinium, thorium, actinium and radium isotopes. First experimental results are presented.

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1. Introduction

Low-energy fission yields interesting information on nuclear structure because the potential-energy surface, governing the fission process, is strongly modified by nuclear shell effects. Structural effects are seen in fission-fragment mass, charge and kinetic-energy distributions as well as in the fission probabilities. More than 50 years after the discovery of nuclear fission, the number of isotopes whose low-energy fission properties are known is still very limited due to experimental restrictions. Most experimental techniques need stable targets or at least targets consisting of long-living radioactive isotopes. Secondary beams at relativistic energies overcome these

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restrictions for a large number of fissile nuclides [1]. By projectile fragmentation of ^{238}U, it is possible to prepare about 100 mainly proton-rich, fissile and unstable isotopes between uranium and lead as secondary beams. Due to an in-flight identification, several isotopes can be investigated simultaneously. The fission properties of these nuclei are interesting for two main reasons: First the transition from asymmetric fission-fragment mass distributions near uranium to symmetric distributions near lead might be studied in detail. Secondly, the influence of the spherical 126-neutron shell on the fission probabilties of highly fissile nuclei repesents a unique test case for the synthesis of spherical superheavy nuclei. The present contribution details the review [2] given on the reasearch activities with secondary beams carried out at GSI.

2. Experimental technique

At GSI Darmstadt the heavy ion synchrotron SIS is able to deliver a beam of ^{238}U at 1 A GeV with an intensity of up to 10^7 particles per second. This primary beam was used to produce a number of secondary beams in a 680 mg/cm^2 Be target, equipped with a niobium foil downstream for maximizing the portion of bare ions. With the fragment separator FRS [3] the secondary beams were separated and identified with respect to mass and charge. The purified secondary beams left the separator with an energy of about 600 A MeV. Typical intensities for secondary beams were about 100 particles per second. The details of the identification and separation procedure are described elsewhere [4]. In view of the low secondary-beam intensities, a very efficient excitation mechanism had to be chosen to induce low-energy fission. For this purpose, electromagnetic interactions with a heavy target material were used to mainly populate the giant dipole resonance which may decay by neutron evaporation or by fission. This gives rise to first- and second-chance fission from excitation energies around 11 MeV where fission is expected to be strongly influenced by shell effects. A layer of 3.03 g/cm^2 lead as well as a plastic scintillator served as secondary targets. The nuclear charges of the fission fragments produced in either of these targets were determined by measuring the energy-loss signals in an horizontally subdivided ionisation chamber. The velocity dependence of the energy loss was corrected for by a time-of-flight measurement. Favoured by the relativistic energies, the forward-focussed fission fragments could be detected with high efficiency. In addition to the nuclear-charge distribution, the total kinetic energy released in the fission process was determined from the time-of-flight values and from the emission angles of the fission fragments registered by the ionisation chamber. A detailed description of the experimental setup may be found in Ref. [4].

3. Results

In order to study fission induced by electromagnetic excitations, a background of nuclear-induced fission events had to be suppressed. Since most nuclear collisions lead to a loss of protons, the data could be highly purified by the condition that the fission fragments carry all protons of the secondary projectiles. A remaining background due to neutron-loss nuclear reactions was subtracted by taking the appropriately normalized fission events induced in the plastic target as a reference where nearly no electromagnetic excitation is supposed to take place. The details of this method can be found in Ref. [5]. The nuclear-charge-yield distribution for electromagnetic-induced fission of ^{226}Th is shown in Fig. 1 (upper part). The pronounced

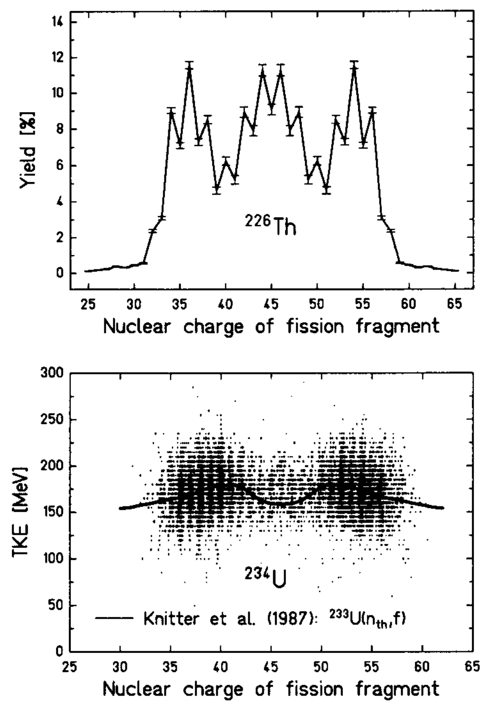

Fig. 1. *upper part:* Nuclear charge yield of electromagnetic-induced fission of ^{226}Th. The odd-even effect is $(18 \pm 4)\%$. The tripple-humped structure indicates the coexistence of two different fission modes. *lower part:* Measured total-kinetic-energy distribution in electromagnetic induced fission of ^{234}U as a function of the fission- fragment charge. Except for symmetric fission, the center-of-gravity fits nicely to data for thermal-neutron-induced fission [8].

proton odd-even effect and the triple-humped structure of the distribution are clear indications for low-energy fission. The competition between asymmetric and symmetric fission was studied over more than 30 isotopes between ^{234}U and ^{218}Ra. The first important result is that the proton number as well as the neutron number have a significant influence on the two fission modes. Adding or removing a single nucleon to the nuclides in the transition region modifies the shape of the nuclear-charge spectrum strongly. For the case of ^{234}U which can be compared to data from neutron-induced fission, Fig. 1 (lower part) demonstrates that also the total kinetic energy released in the fission process is accessible in the secondary-beam experiment. When fully analyzed, the TKE values are expected to give specific information on the scission configuration. The present work provides the first experimental data on nuclear-charge distributions in this interesting transitional region. It completes previous investigations [6, 7] on mass distributions and total kinetic energies of a few specific nuclei in ths region. The analysis of data on charge distributions, total kinetic energies, and fission probabilities for a number of even more neutron-deficient fissile nuclei is in progress.

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