CERN-INTC-2010-056 / INTC-I-122
21/05/2010

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Experiments Committee for experiments with HIE-ISOLDE

High Energy Actinide Beams for Fission Yields Studies in Inverse Kinematics (FYSIK)

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Abstract

We propose to use high-energy exotic beams of actinides to study the fission fragment element yields, mass yields and total kinetic energy, as well as the fission probability, as a function of the excitation energy.

1. Introduction

The field of fission fragment yields investigations has followed a regain of interest in the last decade. On one hand, the design of new generation nuclear power plants have appointed that the experimental data are often sparse and leading to contradictory information. In addition, the different model predictions on the fission fragment yields are showing large discrepancies, preventing from good accuracy calculation on safety or waste management, leading to important increase of the security costs [1]. On the other hand, recent results based on the in-flight fission of secondary actinide beams at GSI [2] have shown that several important issues of the commonly accepted ground for the modelling of the nuclear fission process are destabilized by new experimental observations. Among these issues, the leading role of the neutron shell effects on the partition of the low energy fission has been put under question. Indeed, for the first time the complete element distribution of the fission fragments could be observed for a wide range of fissioning isotopes. On the contrary to what could have been expected, the average number of protons in the heavy fission fragments has been observed constant [3], independently of the fissioning system. Accordingly, the average neutron number has been deduced to vary with the fissioning system, in contradiction to the presence of deformed neutron shell effects in the potential energy surface of the fissioning nucleus [4]. A second important issue has been the discovery of even-odd staggering in the element yields of odd-Z fissioning systems [5], evidencing that the staggering is not as directly as assumed previously, a consequence of the number of broken pairs during the deformation from saddle to scission, and cannot be simply related to the dissipated energy. More recently, a systematic study on even-odd staggering revealed that the asymmetry of the fission fragment distribution plays a more important role than previously thought [6] and that symmetric splits present a rather constant and moderate amplitude of the even-odd staggering, independent of the fissioning system. This topic is important for the understanding of the nuclear process, as it is directly connected to the dissipation endured by the nucleus through its deformation, and to the description of the fission dynamics.

These two issues, that have been revealed by the use of innovative techniques, i.e., the use of high energy beam to induce low-energy fission in inverse kinematics, show that the understanding of the nuclear fission process has to be revised to some extend. In addition to the excellent resolution induced by the inverse kinematics, this technique allows for enlarging the systematic of fission studies to highly radioactive actinides, which cannot be investigated in direct kinematics, as their handling for target production are prohibited.

2. Physics case

Several ambitious experiments or projects are aiming at studying the fission fragment distribution using the inverse kinematics technique. In GANIL, fission is induced in multi-nucleon transfer. The in-flight fission is detected with the VAMOS spectrometer [7]. In this experiment, the full isotopic distribution of the light and heavy fragment over the complete fission yields is observed, for heavy actinides between ^{238}U and ^{244}Am. Another experiment (SOFIA) is under preparation at GSI, using secondary actinide beams that are undergoing fission in electromagnetic interaction. The isotopic identification of the fragments is completed with the ALADIN spectrometer and set-up [8]. These two experiments are complementary, as in the GANIL case the fission of heavy actinides is studied, whereas in the case of GSI experiment, the systematic is focusing on light actinides produced by the in-flight fragmentation of a 1 GeV/u ^{238}U beam. Finally, there is a longer term project associated to the ion-electron collider facility planned at FAIR (ELISE), where it is planned to study the isotopic distribution of fission fragments produced in the interaction of the electron and the secondary actinide beams [9]. All these projects show the vitality and the interest in the field, the promises for new type of data, which will surely continue to transfigure the field of nuclear fission.
In this context, HIE ISOLDE is an exceptional facility to study fission in inverse kinematics, as it provides high intensity actinide beams, at an energy that ensures an excellent resolution for the fragment element distribution, and over an unprecedented range in isotopic chains and intensities. We propose to enlarge the systematic of fissioning systems studied up to now, and to obtain high statistics data on the fission element yields as a function of the excitation energy. In addition, the mass distribution and the kinetic energy will be measured. This experimental programme will provide important information on the evolution of the even-odd effect with the asymmetry of the distribution, with the fissility of the fissioning nucleus, and as a function of the excitation energy. In addition, the fission probabilities will be measured. The strong points of the HIE ISOLDE facility rely in the high intensity (up to 10^9 pps), compared to the maximum 10^5pps in the preceding GSI experiment, and the wide systematic in species compared to the GANIL facility, where only ^{238}U beam is available.

3. Experimental setup

The principle of the experiment is to impinge a light target (d, Be, C) with an exotic actinide beam delivered by the HIE Isolde facility. The fission is induced via transfer reaction. With this kinematics (10 MeV/u for the incoming beam), the recoiling target-like particles are emitted at the grazing angle, which is larger than the angular aperture of the fission-fragments, focused in forward direction over an ellipsoid of 20°. An annular silicon telescope of the type used in the experiment at GANIL [7] provides good identification of the target-like particle, with an excellent efficiency (>50%) and lets the fission fragments flying in its large central hole. The fission-fragment identification is based on an energy-loss, residual energy and time-of flight for both fragments in coincidence, at both sides of the beam direction. The beam that did not interact in the target ends in a beam-dump.
The mass resolution $dA/A= (dE/E + 2dv/v)$ is limited by the energy resolution, which cannot exceed 1.5%. The flight path distance is defined to get a velocity resolution of the same order. The time-of flight detection is based on one Multi Channel Plate as a start detector, and a SED [11] detector for the stop. The fission fragments have a maximum energy of 15 MeV/u. A flight path of 2 m length, ensures a velocity resolution better than 0.5%. Two ionization chambers, one behind the other with drift times in perpendicular direction give a precise knowledge of the nuclear charge Z and the angle. A silicon wall is placed behind for the measure of the residual energy. Each detector ensemble has a diameter of 35 cm, and is placed at 35 cm of the beam axis, which corresponds to a solid angle covering 9% of the fission events.

3.1 **Spectrometer for isotopic identification of fission fragments**

The experimental set-up could be improved by the addition of a spectrometer that would allow for a better mass resolution, which is of a high concern in the field of fission fragment yields. At the present phase of the project, we do not want to consider the construction of a spectrometer dedicated to the identification of the secondary reaction products (in our case the fission fragments), as it complicates significantly the experimental set-up, and the time-scale of the proposed experimental programme. In addition, very valuable information can be obtained with time-of-flight, energy and energy-loss techniques as described above. However, we are convinced that other collaborations could benefit from a spectrometer and we are strongly willing to participate to the development of such equipment.

4. Beam requirements

The isotopes of interest are the most neutron rich isotopes of each Rn, Fr, Ra actinide, as they present the most prominent shell effects in the fission yields [2]. In this respect, the HIE ISOLDE facility is of particular interest, as it provides neutron-rich isotopes that could not be accessed by the in-flight fragmentation of ^{238}U beam in GSI. In this former experiment, the heaviest Ra isotope was ^{219}Ra, and the heaviest Fr isotope was ^{218}Fr. With the HIE ISOLDE facility, it is possible to investigate beams of $^{218\text{-}228}$Fr with intensities higher than 10^7 pps, and of $^{221\text{-}228}$Ra with intensities higher than 10^6 pps (up to several 10^7 pps). The element distribution for these actinides will be measured for the first time, and the appearance of shell effects in the fragment distribution may be assessed. In addition, these actinides present large even-odd staggering in their element distribution [10], and are thus of particular interest for this issue.
Transfer reactions allow for accessing heavier elements, up to 2 protons transfer with large cross section. However development of Ac, Th and Pa beams produced by spallation reactions in the ISOLDE target will be of the highest interest.
Due to the different fission probabilities of different actinides, the beam purity is an issue.
Considering a 100mb cross section for transfer reaction and a target of the order of 10^{20} at/cm^2, we expect a fission rate of 10^{-5} per beam particle, of which 5% would be detected in coincidence with the recoiling target particle. A minimum beam intensity of 10^6 pps beam leads to 0.5 fission event detected per second, that leads to 10^6 fission fragments detected in a typical beam time of 10 days, insuring a high statistics in the lowest element yields of 0.5%. The high intensity actinide beams delivered at HIE ISOLDE (often above 10^7 pps) provide a unique opportunity to investigate with high accuracy the fission fragment yields over an unprecedented large range.

5. Safety aspects

The detection system is standard for nuclear physics experiment, using low-pressure isobutene detector and few kV high voltage. The long-lived beam radioactivity will be collected in a beam dump and will accumulate. A procedure has to be defined for the beam-dump handling.

6. References

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