ISOMERIC YIELD RATIOS OF FISSION PRODUCTS MEASURED WITH THE JYFLTRAP*

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Experimental methods to determine isomeric yield ratios usually apply γ-spectroscopic techniques. In such methods, ground and isomeric states are distinguished by their decays. In the present work, several isomeric yield ratios of fission products have been measured by utilizing capabilities of the double Penning-trap mass spectrometer JYFLTRAP, where isomeric and ground state were separated by their masses. To verify the new experimental technique, the results were compared to those from γ-spectroscopy measurements.

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1. Introduction

Nuclear fission is a very complex physical phenomenon. Nevertheless, there are several crucial moments in the process which have to be described by fission models and theories. The moment, when two fragments separate

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from each other, is named a scission point. The angular momentum of primary fission fragments gives us the information about configuration of the system at this point.

Experimentally, the angular momentum of fission fragments can be deduced from the measurement of: (1) angular distributions of prompt gamma rays, (2) energy and multiplicity of prompt gamma rays, (3) intensities of cascading transition to the ground state bands, and (4) isomeric yield ratios [1].

Different techniques exist to measure the independent isomeric yield ratios. They include isotope separator [1], recoil mass separator [2] or radiochemical methods in combination with γ-ray spectroscopy. The bottleneck of all of these methods is the detection of isomeric and ground states by their decays. To estimate the initial ratio between population of the isomeric and the ground state, the information about the decay scheme, the branching ratios *etc.* is required.

A completely different method to measure isomeric yield ratios of fission products was proposed at the Accelerator Laboratory of the University of Jyväskylä (JYFL) [3]. The main idea is to combine the ion guide technique and the unique capabilities of the JYFLTRAP [4] to separate the isomeric and the ground state [5, 6]. In this method, two states are distinguished by the mass difference. Previous experiments have already demonstrated that the resolving power of the JYFLTRAP is enough to perform isomeric yield ratio measurements for several cases [5, 7–9].

2. Experimental method

The experimental measurement of independent isomeric yield ratios of fission products has been recently carried out at the JYFL. The isomeric yield ratios have been determined in 25 MeV proton-induced fission of ^{238}U. Two different methods have been utilized in the experiment. The first technique is based on isobaric separation of the fission products and detection of the isomeric and the ground state by their γ-decays. The main idea of the second method is to separate the isomeric and the ground state with the JYFLTRAP and count ions with microchannel plate (MCP) detector.

The schematic view of the experimental facility is presented in Fig. 1. The uranium target, 15 mg/cm^2 thick, is placed in the fission ion-guide. Ions produced in nuclear fission are stopped in the ion-guide filled with helium gas at a pressure of around 200 mbar. Due to high ionization potential of the buffer gas, after slowing down, a considerable fraction of ions acquires charge state +1. The ions are extracted from the gas cell by gas flow and transported further with a sextupole ion-guide (SPIG) [10]. After an acceleration to 30 kV the continuous ion beam is separated with a 55° dipole magnet. As a result, the isobaric chain with certain mass number A is selected.

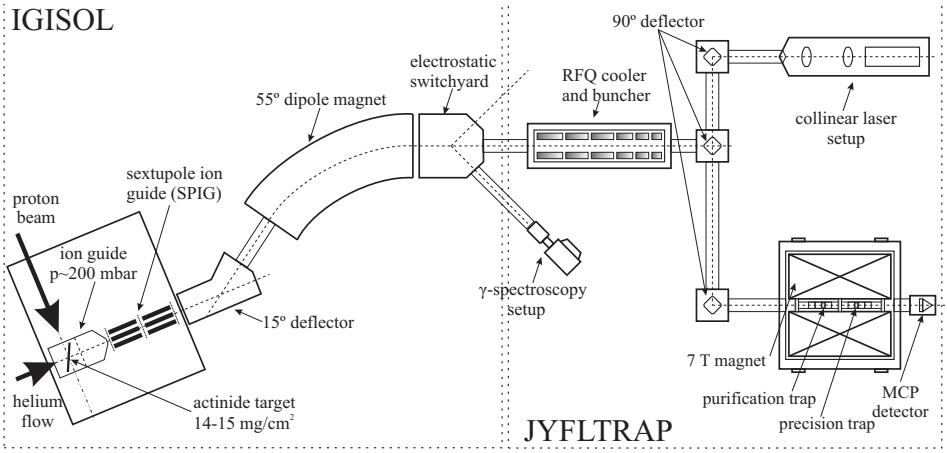

Fig. 1. A schematic view of the IGISOL 4 facility. Due to a new layout, it is possible to make various experiments employing different setups and techniques. The double Penning trap and γ-spectroscopy system were used in the present work.

The new construction of the IGISOL facility at the JYFL [11] gives opportunity to distribute separated beam between different setups. After the electrostatic switchyard, the beam can be sent towards the JYFLTRAP or it can be directed to the γ-spectroscopy setup.

The Penning trap measurements require a specially prepared beam. For this purpose, ions are injected into a gas-filled radio-frequency quadrupole cooler and buncher (RFQ) [12]. The RFQ cools ions and releases them as short bunches to the JYFLTRAP.

The JYFLTRAP consists of two cylindrical Penning traps inside a 7 T superconducting solenoid. The fact that there are two traps in one magnet is very important. It allows us to utilize two-stage purification technique [13] and achieve a mass resolving power about $m/\Delta m \approx 10^6$. However, in the present experiment, the isomeric and the ground states were separated by the purification trap with a buffer gas cooling technique [14, 15].

When ions are inside the trap, dipole excitation is applied to the electrodes. As a result, all ions regardless their mass are moved to a large radius. After that, applying a quadrupole radio-frequency field will center only ions whose cyclotron frequency $f_c(m)$ matches with applied frequency. The cyclotron frequency f_c of an ion with a mass m and a charge q is given as

$$f_c = \frac{1}{2\pi}\frac{q}{m}B\,, \tag{1}$$

where B is the magnetic field.

Centered ions are released from the trap through a 1.5 mm diameter hole and registered by the MCP detector. In the present measurements, full cycle has been chosen as 660 milliseconds. The final spectrum shows how many ions were detected for each quadrupole excitation frequency.

To test the new method and compare results, γ-spectroscopy measurement was done in the same experiment. The constant beam after the dipole magnet (see Fig. 1) was directed to the spectroscopic station. Ions were implanted in the aluminium foil, which was placed in front of the detector. The single γ-spectrum was collected for several hours.

3. Results

In the present experiment, isomeric yield ratios were measured for several cases utilizing Penning trap technique and γ-spectroscopy. Data analysis is still on-going. That is why only preliminary data on ^{81}Ge are presented in this report.

In Fig. 2, the quadrupole frequency spectrum is presented for Ge and As ions. Black circles are experimental points with statistical error bars. The difference between the isomeric and the ground state of ^{81}Ge is 679 keV. This

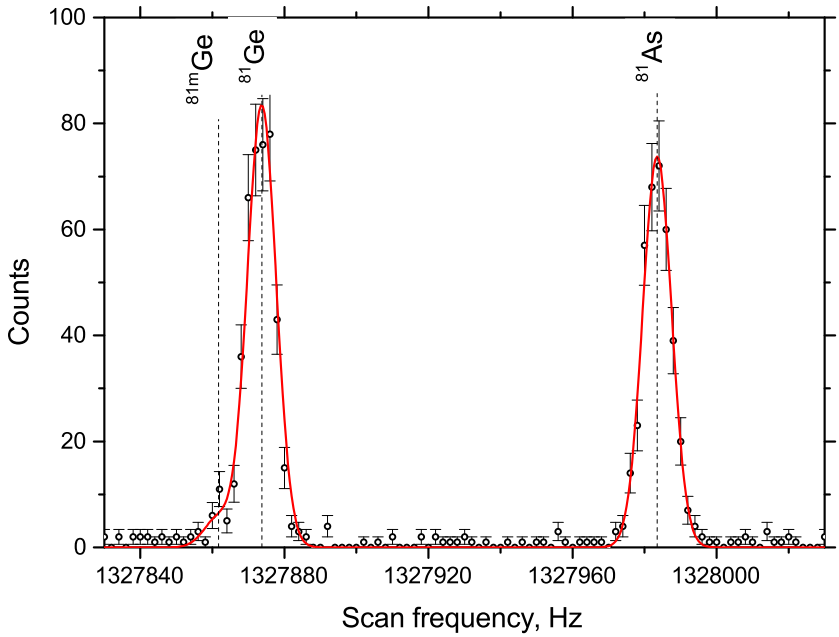

Fig. 2. The quadrupole frequency spectrum collected after the Penning trap. Black circles are experimental points with statistical error bars. Solid/red line is a Gaussian fit of the spectrum. Position of peaks was calculated according to ion masses.

value is very close to maximum resolving power of the purification trap. That is why the peak positions for ^{81m}Ge and ^{81}Ge were calculated according to their masses. The peak position of ^{81}As was taken as a reference. Peak width was chosen equal for all peaks. Using this assumptions experimental data were fitted by Gaussian function (solid/red line in Fig. 2). The ratio between respective peak areas gives us the isomeric yield ratio for ^{81}Ge. It is around 0.07 in the case of ^{81}Ge. The error has not been estimated yet.

Another way to get the same parameter is to measure γ-decays of the isomeric and the ground state of ^{81}Ge. Such measurement was done in the same experiment. A spectrum of γ-rays from isobaric chain with mass number $A = 81$ is presented in Fig. 3. It is more difficult to extract data from γ-spectrum than from data obtained with the Penning trap. In the case of γ-spectroscopy, it is necessary to account detector efficiency, branching ratio of decays, feeding decays of elements which have the same mass number *etc.*

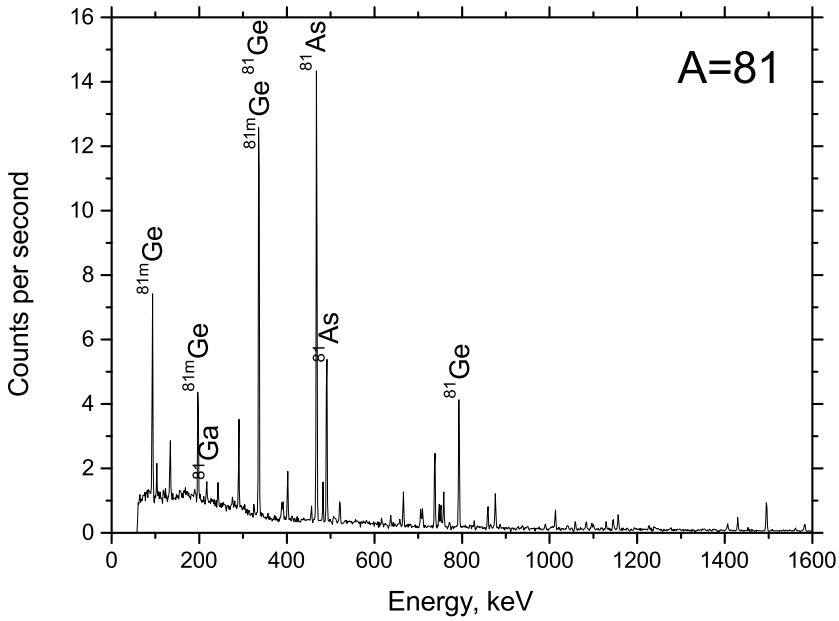

Fig. 3. Spectrum from the decay of all elements produced in 25 MeV proton-induced fission of ^{238}U with mass number 81. Laboratory background was subtracted from the spectrum. Several peaks related to the mass spectrum are identified.

Nevertheless, γ-spectroscopy was the way to perform such measurements in the past. A very similar experiment utilizing IGISOL method and γ-spectroscopy technique was done by Tanikawa *et al.* [1]. Data analysis is in progress and comparison between two different methods and literature values will be done.

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