Vol. 42 (2011) ACTA PHYSICA POLONICA B No 3–4

NUCLEAR STRUCTURE STUDIES OF NEUTRON-RICH NUCLEI PERFORMED BY JYFLTRAP*

J. Rissanen

and the JYFLTRAP Group

Department of Physics, University of Jyväskylä
P.O. Box 35 (YFL), 40014 Finland

(Received January 26, 2011)

A wide range of studies on neutron-rich fission fragments have been performed at the University of Jyväskylä by using the JYFLTRAP double Penning trap setup coupled to the Ion Guide Isotope Separator On-Line (IGISOL) mass separator. Experimental results from high-precision mass measurements and decay spectroscopy measurements enables investigation of the nuclear structure of exotic neutron-rich isotopes.

DOI:10.5506/APhysPolB.42.529
PACS numbers: 21.10.Dr, 23.20.Lv, 27.60+j

1. Introduction

The IGISOL mass separator has provided radioactive ion beams already over two decades [1, 2] enabling studies of short-lived exotic isotopes. The IGISOL method is fast and chemically nonselective. In addition, since the light-ion-induced fission yields are reasonably high between the magic numbers $Z = 28$ and $Z = 50$, the production of the refractory elements become possible. Those elements are difficult to produce in conventional ISOL-facilities.

When studying the properties of very neutron-rich nuclei, the reduction of the background generated by the nuclei within the same isobaric chain becomes very important issue. This isobaric background can be significantly reduced by using a Penning trap as a high-resolution mass filter to separate the nuclei of interest from the isobaric contaminants. By looking the gamma and beta radiation emitted from isobarically pure samples, one can build decay schemes to see a structure of the excited states fed by the beta-decaying parent nuclei.

---

[*] Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", August 30–September 5, 2010, Zakopane, Poland.

When combining these two techniques, the IGISOL mass separator coupled to the JYFLTRAP double Penning trap setup, an unique tool for nuclear structure studies is formed. It allows the nuclear decay studies and the precise atomic mass measurements of vast variety of different isotopes. In this conference proceedings some selected examples have been presented.

2. Experimental setup

The experiments discussed in this paper have been performed at the Ion Guide Isotope Separator On-Line (IGISOL) facility [1,2] in the Accelerator Laboratory of the University of Jyväskylä, Finland. These experiments took place before the move of the IGISOL to the new accelerator hall, which started on June 2010.

The neutron-rich nuclei were produced by bombarding a thin uranium target by a beam of protons or deuterons from the K-130 cyclotron. The fission products were stopped in helium gas and then transported out from the gas cell by a gas flow. The reaction products were guided through a sextupole ion guide (SPIG) [3], accelerated to an energy of $30 \times q$ keV and directed to a separator magnet, where a rough mass separation was performed with a mass resolving power of $M/\Delta M \sim 500$. Following that the ions were guided into a radio-frequency quadrupole cooler/buncher (RFQ) [4], where the ions were cooled in collisions with buffer gas atoms, before injecting them into the first Penning trap of the JYFLTRAP.

The JYFLTRAP setup consists of two Penning traps inside the same 7 T superconducting solenoid. In the first trap, called purification trap, a buffer-gas cooling technique [5] is used to purify the beam. With this technique, a mass resolving power $R = m/\Delta m = \text{few} \times 10^5$ can be achieved, which is enough to separate individual isobars on mass number A. Purified bunches of radioactive ions are injected either into the second Penning trap or sent forward to the spectroscopic setup for subsequent low-background spectroscopic studies [6].

The second Penning trap, called precision trap, is used for high-precision mass measurements of atoms. For this purpose a true cyclotron frequency $\nu_{\mathrm{c}} = qB/2\pi m$ of the ion-of-interest has been measured by using the time-of-flight ion-cyclotron resonance (TOF-ICR) technique [7,8]. In this technique, an increase of the radial kinetic energy resulting from the quadrupole excitation causes a reduction of the time-of-flight to the MCP-detector located after the trap. Recently, also a separation of two isomeric states in same nucleus have been performed [9] by using a Ramsey cleaning method [10].

After the isobaric purification performed by the JYFLTRAP, the bunched beam can be sent to the decay spectroscopy setup located after the trap. A typical spectroscopy setup consists of a scintillation detector for detecting beta particles and Ge-detectors for detecting gamma rays and X-rays. A radioactive sample is sent to the movable tape, which is moved periodically to get rid of the daughter activities. A layout of the IGISOL-facility is presented in Fig 1.

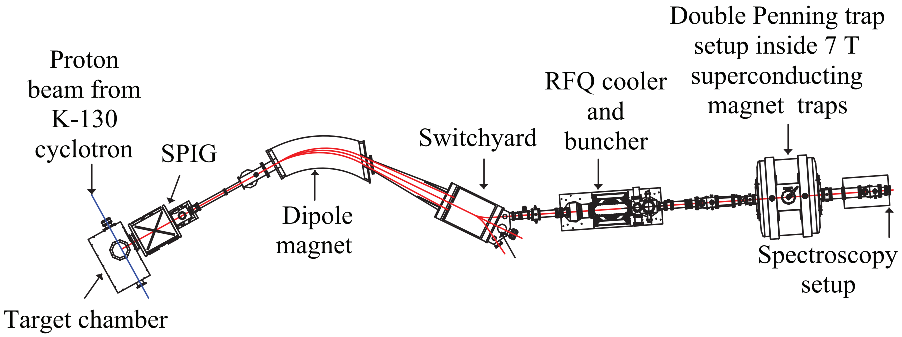

Fig. 1. (Color online) A schematic layout of the IGISOL-facility before June 2010.

3. Discussion

The atomic masses measured at JYFLTRAP before June 2010 are presented in Fig. 2. The measurements motivated by nuclear structure have focused mostly on three areas of interest: (1) $N = 50$ region, (2) isotopes with proton number $37 \leq Z \leq 46$ and (3) isotopes near ^{132}Sn. In the first area of nuclide chart (1), the $N = 50$ shell gap has been studied by observing the systematic behavior of two neutron separation energies (S_{2n}), which were

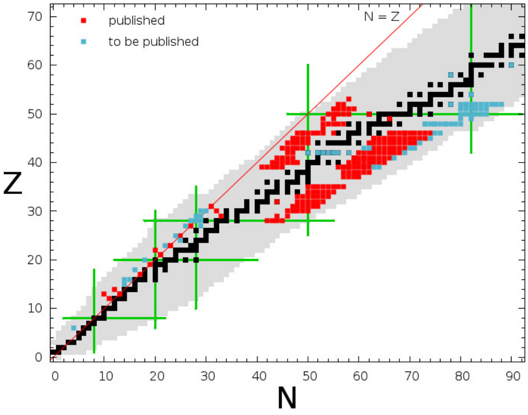

Fig. 2. (Color online) A chart of measured masses at JYFLTRAP before June 2010 [16].

calculated from the measured atomic masses [11]. In the second area (2), the results of the atomic mass measurements show clearly an effect of the strong quadrupole deformation on atomic masses around Zr ($Z = 40$) [12, 13]. In the third case (3), masses of the nuclei around doubly-magic ^{132}Sn have been measured and the results are to be published.

The spectroscopic studies performed with an isobarically purified radioactive samples have been concentrated on $A \approx 110$ region. These studies have been motivated by changing nuclear deformations and the astrophysical r-process. For example, the beta decay of very neutron-rich refractory element ^{114}Tc has been studied. A strong beta feeding from ^{114}Tc to the 0^+ ground state of ^{114}Ru as well as significant beta feedings to the states with spins greater than 3^+ in ^{114}Ru suggest the existence of two beta-decaying states in ^{114}Tc [14]. This is the first observation of beta-decaying isomer in Tc isotopic chain, although recently gamma-decaying isomers have been found to exist in ^{112,113}Tc [15].

This work has been supported by the Academy of Finland under the Finnish Centre of Excellence Programme 2006–2011 (Nuclear and Accelerator Based Physics Programme at JYFL).

REFERENCES

[1] J. Äystö, *Nucl. Phys.* **A693**, 477 (2001).
[2] H. Penttilä *et al.*, *Eur. Phys. J.* **A25**, 745 (2005).
[3] P. Karvonen *et al.*, *Nucl. Instrum. Methods Phys. Res.* **B266**, 4794 (2008).
[4] A. Nieminen *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A469**, 244 (2001).
[5] G. Savard *et al.*, *Phys. Lett.* **A158**, 247 (1991).
[6] S. Rinta-Antila *et al.*, *Eur. Phys. J.* **A31**, 1 (2007).
[7] G. Gräff, H. Kalinowsky, J. Traut, *Z. Phys.* **A297**, 35 (1980).
[8] M. König *et al.*, *Int. J. Mass Spectrom. Ion Processes* **142**, 95 (1995).
[9] K. Peräjärvi *et al.*, *Applied Radiation and Isotopes* **68**, 450 (2010).
[10] T. Eronen *et al.*, *Nucl. Instrum. Methods Phys. Res.* **B266**, 4527 (2008).
[11] J. Hakala *et al.*, *Phys. Rev. Lett.* **101**, 052502 (2008).
[12] U. Hager *et al.*, *Phys. Rev. Lett.* **96**, 042504 (2006).
[13] U. Hager *et al.*, *Nucl. Phys.* **A793**, 20 (2007).
[14] J. Rissanen *et al.*, *Phys. Rev.* **C83**, 011301(R) (2011).
[15] A.M. Bruce *et al.*, *Phys. Rev.* **C82**, 044312 (2010).
[16] JYFLTRAP mass database,
`http://research.jyu.fi/igisol/JYFLTRAP_masses/`