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Production of beams of neutron-rich nuclei between Ca and Ni using the ion-guide technique

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Abstract. It was shown for the first time that quasi- and deep-inelastic reactions can be successfully incorporated into the conventional Ion-Guide Isotope Separator On-Line (IGISOL) technique. Yields of radioactive projectile-like species such as ^{62,63}Co are about 0.8 ions/s/pnA corresponding to a total IGISOL efficiency of about 0.06%.

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1 Introduction

Since several elements between $Z = 20$–28 are refractory by their nature, their neutron-rich isotopes are rarely available as low-energy Radioactive Ion Beams (RIB) in ordinary Isotope Separator On-Line facilities [1,2,3,4]. These low-energy RIBs would be especially interesting to have available under conditions which allow high-resolution beta-decay spectroscopy, ion-trapping and laser-spectroscopy. As an example, availability of these beams would open a way for research which could produce interesting and important data on neutron-rich nuclei in the vicinity of the doubly magic ^{78}Ni.

One way to overcome the intrinsic difficulty of producing these beams is to rely on the chemically unselective Ion-Guide Isotope Separator On-Line (IGISOL) technique [5]. Quasi- and deep-inelastic reactions, such as ^{197}Au(^{65}Cu$, X)Y$, could be used to produce these nuclei in existing IGISOL facilities, but before they can be successfully incorporated into the IGISOL concept their kinematics must be well understood. Therefore the reaction kinematics part of this study was first performed at the Lawrence Berkeley National Laboratory using its 88-Inch cyclotron and, based on those results, a specialized target chamber was built, see fig. 1 [6]. This chamber was then moved to the Jyväskylä IGISOL facility for on- and off-line tests. In addition to the spectroscopy station, the Jyväskylä IGISOL facility is coupled to a double Penning trap ($m/\Delta m = 10^7$–10^8) and a laser spectroscopy installation. We wish to report here the first results from the studies done at Jyväskylä.

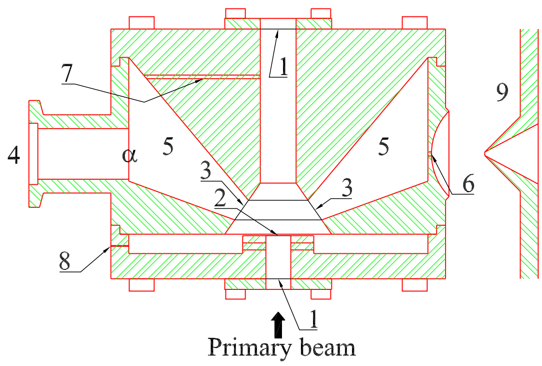

Fig. 1. Target chamber designed for use with quasi- and deep-inelastic reactions. The parts of the chamber are: 1) Havar-windows (1.8 mg/cm^2), 2) Au-target (3.0 mg/cm^2, diameter = 7 mm), 3) conical Ni-window (9.0 mg/cm^2, angular acceptance from 40 to 70 degrees), 4) He-inlet, 5) stopping volume, 6) exit-hole ($d = 1.2$ mm), 7) connecting channel ($d = 1$ mm), 8) second exit-hole ($d = 0.3$ mm), 9) skimmer electrode, α) see text.

2 Experimental

The ^{197}Au(^{65}Cu$, X)Y$ reaction was used in the on-line experiment at Jyväskylä. The Au target used had a thickness of about 3 mg/cm^2 and the maximum beam intensity of the 443 MeV ^{65}Cu^{15+} beam is typically about 20 pnA

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at Jyväskylä. A small fraction of the projectile-like reaction products recoiling out from the Au target could be converted to a low-energy +1 ion beam using the target chamber shown in fig. 1 (see also next section). The +1 ion beam was separated from the neutral gas, accelerated up to 40 keV kinetic energy, mass-separated and transported into the experimental area using the existing IGISOL installations [7]. Mass-separated RIBs were implanted into a movable tape viewed by a coaxial HPGe detector (70% relative efficiency) and two ion implanted Si-detectors (thickness 500 μm). The master trigger of the VME based data acquisition system was a logical OR of all the detectors.

In addition to the above on-line setup, for off-line tests a ^{223}Ra alpha-recoil source (collected onto the tip of a needle) was placed at position α in fig. 1 between the He-inlet channel and the stopping volume (at the opposite side of the stopping volume compared to the exit hole). Emitted ^{219}Rn alpha-recoils were then used for transport efficiency studies. The resulting mass-separated 40 keV ^{219}Rn ion beam was implanted into a thin C-foil viewed by a single ion implanted Si-detector (thickness 500 μm). The data generated by this Si-detector was collected using a separate multi-channel analyzer system.

3 Results

The yields of mass-separated radioactive projectile-like species such as ^{62,63}Co are about 0.8 ions/s/pnA, corresponding to about 0.06% of the total IGISOL efficiency for the products that hit the Ni-window, see fig. 1. (These yields were measured using a ^{65}Cu beam intensity of about 4 pnA.) For the efficiency calculation see [6]. This total IGISOL efficiency is a product of two coupled loss factors, namely inadequate thermalization and the intrinsic IGISOL efficiency. In our now tested chamber, about 9% of the Co recoils are thermalized in the flowing He gas ($p_{\mathrm{He}} = 300$ mbar) and about 0.7% of them are converted into the mass-separated ion beams. This intrinsic IGISOL efficiency is comparable to the one reported in [8] for the Heavy Ion-Guide Isotope Separator On-Line system (0.5%). Figure 2 shows a part of the beta-gated gamma spectrum of $A = 63$. The 87 keV gamma-transition belonging to the beta-decay of ^{63}Co is clearly seen.

The calibrated ^{223}Ra alpha-recoil source was used to further investigate the intrinsic IGISOL efficiency. Absolute intrinsic efficiencies of about 1.3% for the ^{219}Rn alpha-recoils from the source position through the whole system (without the cyclotron beam) were measured ($p_{\mathrm{He}} = 200$ mbar). These efficiencies are comparable to the ones published in [9] for a long cylindrically symmetric gas cell which suggests that there must be a relatively "direct" and fast flow channel between the source position and the exit hole. This claim was verified with He-flow simulations [6]. These simulations also suggest a relatively smooth overall evacuation of the chamber. When the 2.7 pnA ^{65}Cu beam was switched on, the transport efficiency dropped by a factor of five.

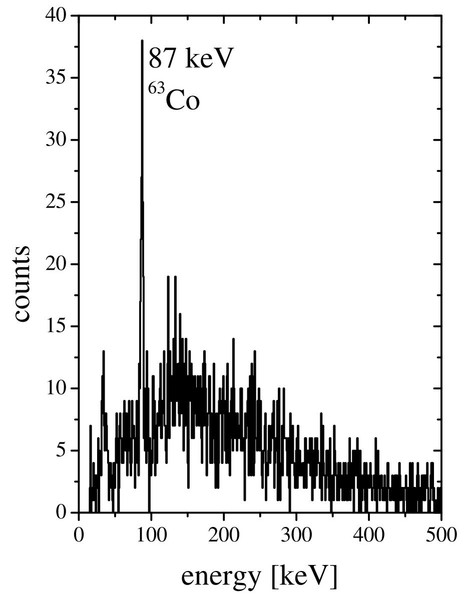

Fig. 2. Part of the beta-gated gamma spectrum of $A = 63$.

4 Conclusions

It has been shown for the first time that quasi- and deep-inelastic reactions can be successfully incorporated into the conventional IGISOL technique. In the future, both of the discussed physical/chemical loss mechanisms (thermalization and intrinsic IGISOL efficiency) can be suppressed by introducing Ar as a buffer gas and by relying on selective laser re-ionization. This combination will produce isobarically pure beams and it will increase the existing yields by about a factor of 100, making this overall approach to the study of neutron-rich nuclei really attractive. See also [10] for an operational gas catcher laser ion source.

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