BEAM DELIVERY AND FUTURE INITIATIVES AT THE ISAC RADIOACTIVE ION BEAM FACILITY*

M. Trinczek, F. Ames, R. Baartman, P.G. Bricault, M. Dombsky, K. Jayamanna, J. Lassen, R.E. Laxdal, M. Marchetto, L. Merminga, A.C. Morton, V.A. Verzilov, F. Yan,
TRIUMF, Vancouver, BC V6T 2A3, Canada

Abstract

The ISAC facility, located at TRIUMF, first began delivering radioactive ion beams (RIBs) in 1998, added post-accelerated beam capability in 2001, and is regarded as one of the premiere RIB facilities in the world. The existing constraints on RIBs of Z<83 and accelerated beams of A/q≤30 with energies limited to 5 MeV/u are being addressed. A charge-state booster for RIBs has been commissioned to alleviate the A/q≤30 restriction and has successfully delivered multi-charge beams through the ISAC accelerators. The 5 MeV/u license limit will be removed once an on-line beam monitor is commissioned, allowing beams of up to 11 MeV/u to be delivered presently, and increased to over 20 MeV/u when the next accelerator phase is installed. In 2008, an actinide target was used to produce RIBs of Z>82; this successful test was performed on a uranium target with yields measured and radiation safety monitored. A new Beam Delivery group has been formed to integrate all aspects of RIB production, which has led to improved efficiency and greater experimental results. These new capabilities will be presented, showing how 2009 promises to be both an exciting and productive year at ISAC.

CURRENT STATUS

At ISAC, RIBs are produced using the ISOL technique [1]. The TRIUMF main cyclotron is used as a driver to send up to 100 µA of 500 MeV protons onto a thick target. The target is heated to allow the reaction products to pass through a heated tube to an attached ion source and ions are extracted at a source potential of up to 60 kV. The ion beam then passes through a two-stage separator system to select the radioisotope of interest before being directed on to an experiment.

RIBs can be delivered to any one of 20 experimental locations in three different energy areas (Figure 1). Beams of up to 60 keV (the ion source potential) are available for low-energy experiments. Beams with energies of up to 1.8 MeV/u are available at ISAC-I; an RFQ is used to accelerate beams with A/q≤30 from 2.04 to 150 keV/u which are then stripped in a foil to increase the charge state for A/q≤6 acceptance into a five-tank room-temperature DTL. These beams can then be further accelerated to energies up to 5 MeV/u using the superconducting LINAC at ISAC-II [2].

ISAC has enjoyed tremendous success in its short lifetime. With its ISOL-based system, high intensities of RIBs coupled to state-of-the-art experimental facilities enable previously impossible measurements to be done. As an example, numerous groups have studied the very exotic halo nucleus ^{11}Li at ISAC. The MAYA collaboration used the first high-energy accelerated beam at ISAC-II to study the two-halo neutron transfer reaction of p(^{11}Li,^{9}Li)t at 3 MeV/u, using an experimental setup developed at (and transported to TRIUMF from) GANIL in Caen, France [3]. Also using ^{11}Li, the TITAN collaboration has made the first ever Penning-trap mass measurement of this short-lived (8.8 ms) nuclide, allowing its two-neutron separation energy to be calculated with a precision seven times greater than that previously reported [4]. In nuclear astrophysics, the DRAGON collaboration recently measured the ^{23}Mg(p,γ)^{24}Al reaction rate using a high-intensity, high-quality, laser-ionized beam of ^{23}Mg from ISAC [5]. This is the first direct measurement of this key reaction and is important for understanding radioisotope production in classical nova scenarios, building upon DRAGON's previous measurement of ^{26g}Al at ISAC [6].

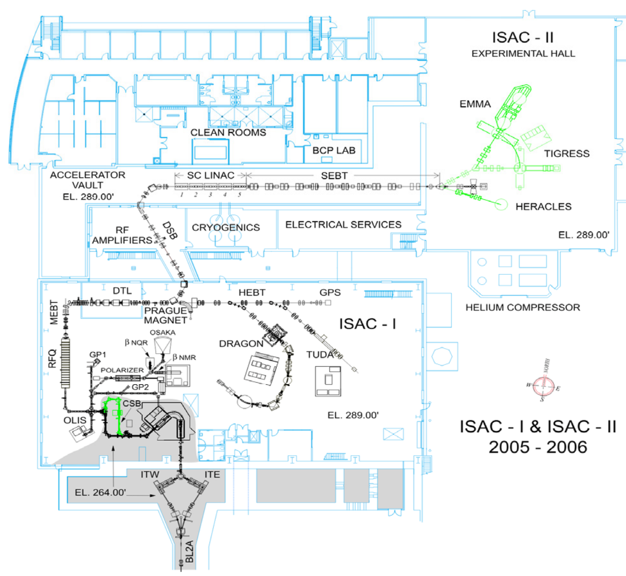

Figure 1: Plan view of the ISAC experimental halls. Protons strike one of two targets on the lower level (gray area). RIBs are mass separated before coming upstairs into the low-energy area; the RFQ and DTL accelerators serve the ISAC-I medium energy area; and the superconducting LINAC leads to the high-energy area of ISAC-II.

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ONGOING IMPROVEMENTS

Despite the success of the scientific programme the current availability of RIBs at ISAC has several constraints, all of which are being addressed to allow a greater variety of isotopes to be produced and delivered to experiments with higher maximum energies. These improvements can be divided into three categories: the production of higher-mass RIBs, the infrastructure to accelerate higher-mass beams, and the ability to accelerate beams to higher energies.

Production of Higher Masses

From its inception, ISAC has been limited by license to target materials, and therefore RIBs, with Z<83. Over the past several years, a push has been made to upgrade the existing target-handling and radiation-monitoring infrastructure and obtain the necessary regulatory permission to allow actinide targets to be used for on-line beam production. Actinide targets are important to TRIUMF's scientific programme as they extend both the range of available nuclei to higher masses and the neutron/proton ratio to higher values, enabling production of more exotic nuclei.

In 2008, ISAC dedicated three weeks to perform a two-stage test with a uranium oxide target. The first stage involved simply putting protons on the target and monitoring the beamline and target infrastructure for migration of radioactive nuclei. The second stage saw RIB extracted from the target and delivered to the ISAC Yield Station while continuing to monitor for migration. The goal of this second stage was not to generate experimental-worthy production rates, but to characterize the output of the alkali isotopes from the target and to compare these results with simulations of isotope production within the target.

The results of this test have been analyzed and there were no surprises found. A report has been finalized for the licensing agency and it is planned to have a second actinide target, better optimized for RIB production, in place for continued development and production at low currents in Fall 2009.

Acceleration of Higher Masses

Another constraint on RIBs at ISAC has been that all post-accelerated beams must have $A/q \leq 30$ due to the acceptance of the RFQ at the beginning of the ISAC accelerator chain. Typically, RIB production sources produce singly charged species; ECR (or similar) sources for high-charge-state production are difficult to use on-line given the highly radioactive environment near the production target. To accelerate beams with A>30, the RIB charge state therefore has to be increased after production, ideally to a charge state that is high enough to remove the need for a stripping foil between the RFQ and DTL accelerators, thus ensuring the highest possible delivered intensity.

For the production of high-charge-state RIBs, an ECR-based charge-state booster (CSB) using a modified 14.5 GHz Phoenix source from PANTECHNIK has been installed and characterized at an off-line test stand [7]. In 2008, the final installation was done at ISAC and the first on-line measurements were made. The charge-breeding efficiency is at the level of a few percent and $^{80}Rb^{14+}$ was successfully delivered through the first stage of the ISAC accelerators [8].

The ISAC accelerators are tuned using a stable ion beam with the same A/q as the intended RIB from a dedicated off-line ion source. With the addition of the CSB, this off-line source also had to be upgraded to be multi-charge capable to provide pilot beams when running in CSB mode. To achieve this, a 14.5 GHz Supernanogan ECR ion source, also from PANTECHNIK, has been installed. In addition to providing the necessary highly charged pilot beams for tuning, it can be used alone as a source for heavy stable-beam experiments. The Supernanogan source is now in final commissioning and its performance has been demonstrated by accelerating $^{40}Ar^{7+}$ through the RFQ [9].

Acceleration to Higher Energies

The present ISAC-II superconducting LINAC produces 20 MV of accelerating voltage and energies of up to 11 MeV/u are possible for very light ions; however, there exists a fixed 5 MeV/u license limit due to the present inability to monitor beam intensities on-line. Efforts are underway to install and commission an on-line current monitor to compliment the existing non-intercepting monitors that measure the total beam current into the ISAC-II experimental area.

The monitoring system consists of two monitor types: a completely non-intercepting capacitive pickup [10] and a partially intercepting RF device that serves as a chopper [11]. This chopper monitor takes ~3% of the beam after the RFQ, which is lost anyhow during normal operation, and sends it to a biased, isolated slit for current readback. The two devices will be incorporated into a current-monitoring utility with the maximum intensity specified by the delivered ion beam and energy and a trip point defined by the associated radiological hazard. This utility will allow beams above 5 MeV/u to be delivered in Summer 2009.

Even higher energies will be available after the ISAC-II superconducting LINAC is upgraded with high-β cavities, beginning Fall 2009 [12]. The installation will see the addition of 20 quarter-wave cavities to add a further 20 MV of accelerating potential. The existing LINAC is composed of five cryomodules, each housing four superconducting cavities and one superconducting solenoid. The new upgrade will be installed downstream of the existing LINAC section and will have three cryomodules. The first two will each contain six superconducting cavities and a superconducting solenoid. The third module will have eight superconducting cavities and one superconducting solenoid. Once complete, beams greater than 20 MeV/u will be available for experiments at ISAC-II – sufficiently high to be above the Coulomb barrier for all masses.

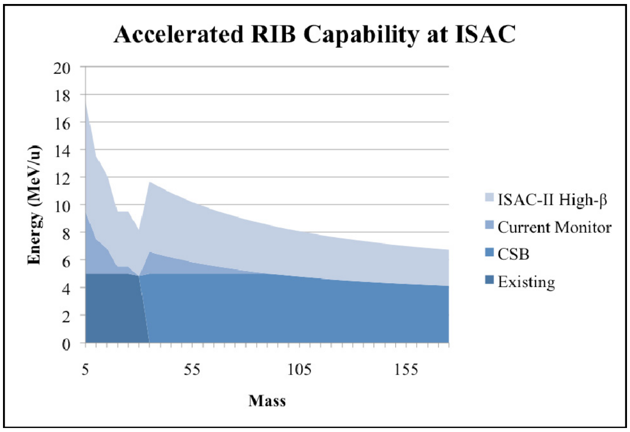

Figure 2: Progression of accelerated beams at ISAC as a function of mass. As each infrastructure improvement is implemented, higher energies become available.

Figure 2 illustrates the above-described progression of increased accelerated RIB capability at ISAC. In the future, once actinide targets become available for experiments, the availability of low-energy RIBs will extend to masses greater than 200.

BEAM DELIVERY

To meet the ever-increasing demands for experimental beamtime, a formal Beam Delivery group has been created to integrate all aspects of beam delivery. This group is composed of target, ion source, accelerator, detector, and beam dynamic experts and, through a liaison, manages the day-to-day interaction between accelerator operation and scientific users.

The Beam Delivery group's goal is to increase the efficiency of delivery and hence maximize both the beam intensities and the beamtime available to experiments. Having recognized that RIB delivery at ISAC is TRIUMF's highest priority, concerted efforts have been made to better schedule the laboratory's maintenance activities and to identify previously overlooked sources of downtime. In addition, face-to-face planning sessions with users in advance of experimental beamtime has helped identify crucial points in the overall delivery chain as well as decrease operational overhead.

Two explicit metrics are used by the Beam Delivery group to track these efforts. The first metric is a measure of the actual time over which beam of sufficient intensity was delivered to the experiment compared to that expected (i.e. scheduled time less overhead). The second metric is a measure of the integrated counts delivered to the experiment compared to the total expected counts, based on the expected time and a mutually agreed-upon minimum beam intensity needed to produce a publishable scientific result. These metrics provide a quantitative measure of beam delivery performance at ISAC, allowing the Beam Delivery group to identify potential shortcomings and improve the overall efficiency of the facility.

CONCLUSION

ISAC is one of the world's premiere RIB facilities and has been delivering RIBs to experiments since 1998. Ongoing initiatives will allow ISAC to expand its scientific programme to include isotopes at higher masses and at greater energies. These initiatives, coupled with the formation of a Beam Delivery group to manage the delivery of RIB to experiments, are allowing the facility to maximize experimental and research output within the existing infrastructure. Despite this, ISAC is still a single-user facility. Future gains in RIB availability and beamtime will require the construction of additional target stations and driver beamlines to allow RIBs to be delivered to multiple users simultaneously. TRIUMF's next five-year-plan [13] addresses this with plans for a second proton beamline and a new electron LINAC driving RIB production at ISAC. This will allow for a dramatic increase in beamtime for experiments within the next 5—6 years, allowing the lab to better serve a growing user community.

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