THE HIGH INTENSITY RADIOACTIVE BEAM FACILITY AT TRIUMF

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Abstract

Construction has begun on ISAC, a radioactive ion beam and accelerator facility which utilizes the ISOL production method. A five year budget for this new radioactive beam facility at TRIUMF was approved in June 1995. ISAC includes: a new building with 5000 m^2 of floor space, a proton beam-line with adequate shielding to transport up to 100 μA at 500 MeV from the TRIUMF cyclotron to two target/ion-source stations, remote handling facilities for the targets, a high-resolution mass-separator, linear accelerators and experimental facilities. The ISAC design for the target/ion source station permits the production of nuclei far from stability over a large isotopic range with high luminosity. The accelerator system includes an RFQ and a DTL yielding final energies variable from $0.15-1.5$ MeV/u. The buildings are now complete and the installation and commissioning of the injection beam-line, target facility and the RFQ are underway. This paper outlines the ISAC project status.

1 INTRODUCTION

A radioactive ion beam facility with on-line source and linear post-accelerator is being built at TRIUMF. [1] In brief, the facility includes a proton beam (I$\leq 100\,\mu$A) from the TRIUMF cyclotron impinging on a thick target, an on-line source to ionize the radioactive products, a mass-separator for mass selection, an accelerator complex and experimental areas. Beams of $E \leq 60$ keV and $A \leq 238$ will be delivered to the low energy experimental area. The accelerator chain includes a 35 MHz RFQ to accelerate beams of $q/A \geq 1/30$ from 2 keV/u to 150 keV/u and a post stripper, 105 MHz variable energy drift tube linac (DTL) to accelerate ions of $1/3 \geq q/A \geq 1/6$ to a final energy between 0.15 MeV/u to 1.5 MeV/u. Both linacs are required to operate *cw* to preserve beam intensity. A layout of the ISAC project is shown in Fig. 1.

2 INJECTION LINE - BL2A

Protons of 480-500 MeV are extracted from the H$^-$ cyclotron by stripping. Initial experiments will be done with 1-10μA but the target hall design, shielding installation, remote handling capability, and target and source development all assume an eventual maximum beam current of 100μA. A 50 m long underground beam-line transports the protons north towards the ISAC building. A 15° switching dipole steers the beam to either one of two heavily shielded target stations. The beamline has been commissioned to the west target in April 1998. Beam profiles are in good agreement with calculations.

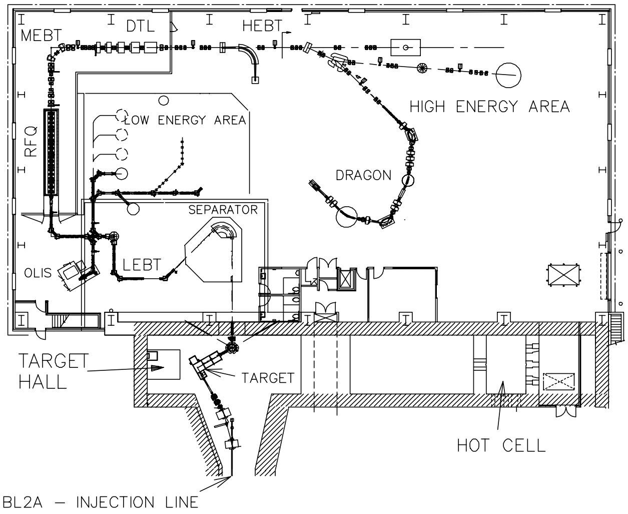

Figure 1: The ISAC Project.

3 TARGET, SOURCE AND SEPARATOR

The design of the target area addresses the following concerns; the containment of large amounts of mobile radioactivity; the high voltage required for beam extraction and quick routine replacement of short-lived target systems. These issues are solved by placing the target in a sealed self-contained module which can be transferred to the hot cell facility for maintenance. Access to the components is done vertically with an overhead crane; repair and service is carried out in dedicated hot cells.

Beam line elements near the target are installed inside a large T-shaped vacuum chamber (see Fig. 2) surrounded by close packed iron shielding. The design is modular with all beam level devices suspended at the bottom of the 2 m long modules. The top of the T handles the driver beam; the entrance module, target/source and beam dump modules. The base of the T contains two exit modules to transport the heavy ion products.

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[1] http://www.triumf.ca/isac/lothar/isac.html

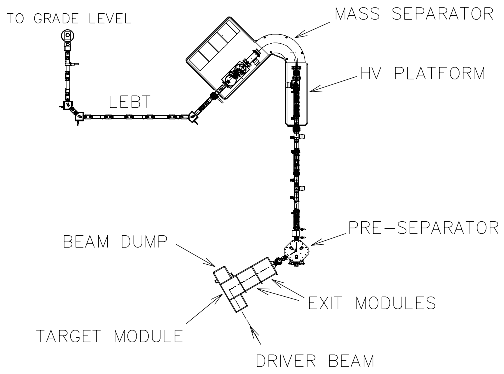

Figure 2: The target and mass-separator areas.

3.1 Mass Separator

Preliminary mass selection is achieved using a $\pm 60^\circ$ pre-separator magnet. The mass separator magnet was obtained from Chalk River. The magnet plus entrance and exit matching sections are on a high voltage platform in order to allow reduction of cross contamination and ease the magnet tuning. The mass separator will handle beams from mass 6 to 238 amu and source extraction voltages up to 60 kV.

The ion beam from the mass-separator is transported vertically to the experimental hall via an electrostatic beamline (LEBT). A beam switchyard selects transportation to either the low energy experimental area or to the accelerator chain and high energy area. There is also the possibility of simultaneously sending stable beam through the same switchyard from an off line ion source (OLIS) to the area not receiving radioactive beam.

4 POST-ACCELERATOR

4.1 RF Quadrupole and MEBT

The 8 m long, 1m×1m ISAC RFQ tank (Fig. 3) houses 19 split ring structures each feeding 40 cm lengths of modulated electrode. Both rings and electrodes are water cooled to dissipate the expected 100 kW of rf power[1].

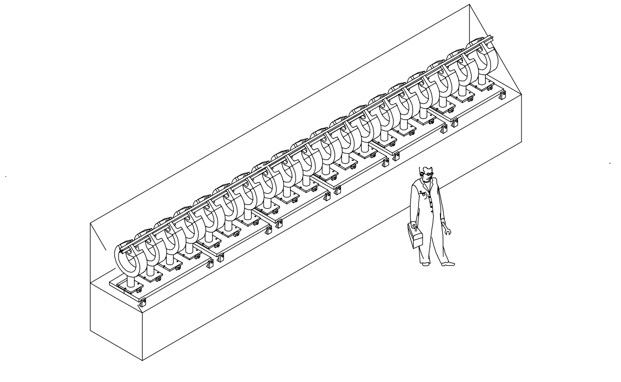

Figure 3: The ISAC 35 MHz RFQ.

The buncher and shaper sections of the RFQ have been completely eliminated from the design in favour of a four-harmonic sawtooth pre-buncher located 5 m upstream[2]. This not only has the benefit of shortening the structure but also reduces the output longitudinal emittance. These gains are made at the expense of a slightly lower beam capture. We expect 81% of the beam will be accelerated in bunches with a time spread of 86 nsec (11.7 MHz).

The beam is stripped in the medium energy beam transport (MEBT) with a thin carbon foil ($3\ \mu$gm/cm^2) to boost the charge state before acceleration in the DTL. A chopper, also located in the MEBT, eliminates the small quantity of beam (3%) accelerated in the two 35 MHz buckets neighbouring the main pulse.

4.2 Drift Tube Linac

The drift tube linac is required to accelerate, in cw mode, ions with a charge to mass ratio $\geq$1/6 from an injection energy of 0.15 MeV/nucleon to a final energy variable from 0.15 to 1.5 MeV/nucleon. A *separated function* DTL concept has been adopted[3]. Five independently phased IH (Interdigital H-mode) tanks operating at $\phi_s = 0^\circ$ provide the main acceleration. Longitudinal focussing is provided by independently phased triple gap spiral resonator structures positioned before the second, third and fourth IH tanks. Quadrupole triplets placed after each IH tank maintain transverse focussing. A schematic drawing of the DTL is shown in Fig. 4.

To achieve a reduced final energy the higher energy IH tanks are turned off and the voltage and phase in the last operating tank are varied. The spiral resonator cavities are adjusted to maintain longitudinal bunching. In this way the whole energy range can be covered with 100% transmission and no longitudinal emittance growth.

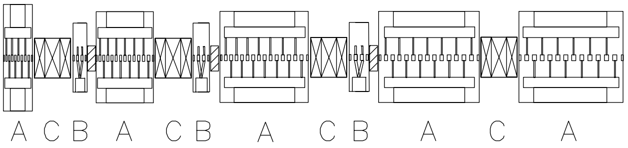

Figure 4: Schematic drawing of the ISAC variable energy DTL. Five IH tanks (A) provide acceleration at 0° synchronous phase, three triple gap spiral resonators (B) provide longitudinal focus ($\phi_s \sim -60^\circ$) and quadrupole triplets (C) provide transverse focus.

5 STATUS

The ISAC building is now complete. The first target vacuum box is being aligned. The entrance and beam dump modules are completed and have been successfully installed and used for the BL2A commissioning in May 98. The mass separator is being installed and first stable beams for the mass separator commissioning are expected in August. We intend to produce the first radioactive ion beam for the TRIUMF Neutral Atom Trap experiment in November of this year.

Installation of the off-line ion source (OLIS) began in July with first beam extracted in November 97. Commissioning of the low-energy transport line (LEBT) from OLIS to the RFQ followed soon after. The saw-tooth prebuncher was installed and commissioned with three harmonics in Febuary 98. The fourth harmonic will be added following an upgrade to the wide band amplifier. The commissioning results are summarized in Fig. 5. The emittance was measured just downstream of the source analyzing magnet with an Allison type scanner. The bunched beam time structure was measured with a cone-type fast Faraday cup.

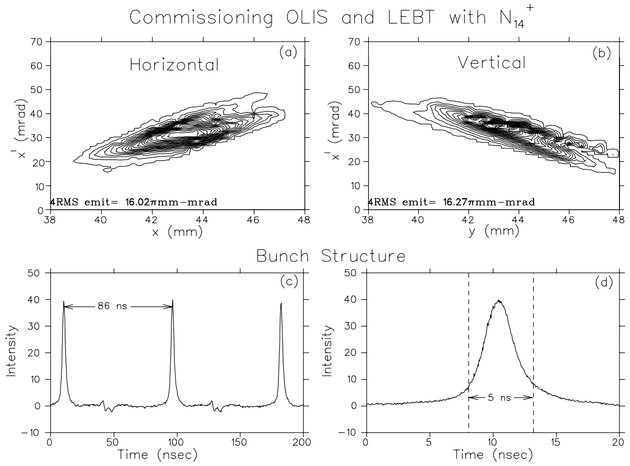

Figure 5: Commissioning results from OLIS/LEBT; the horizontal and vertical emittance of the N_{14}^{+} beam and the bunch structure at the end of LEBT.

The initial seven ring segment of the RFQ has been installed for an interim beam test [4]. The beam is accelerated to 53 keV/u and then eight electrostatic quadrupoles transport the beam to a diagnostic station located at the exit of the RFQ. A copper wall is located just downstream of the seven ring section to isolate the rf fields. RF signal level measurements have been completed with favourable results. An initial acceleration test with unbunched beam confirmed predictions of beam performance with 25% capture efficiency and good beam quality. The tests will continue through the summer. The remainder of the rings will then be installed with the commissioning of the full RFQ in the summer of 1999.

Fabrication of the first IH tank and the first DTL buncher are proceeding well in advance of the bulk of the DTL in order to get experience with the fabrication techniques. The copper stems and ridges of the first tank have been received. The completed tank is being leak tested prior to copper plating. Signal and power level tests of tank 1 are scheduled for summer 98.

The first DTL buncher has been designed and is being fabricated at INR Troitsk. The buncher is scheduled to arrive at TRIUMF in July 98 for testing. The fabrication of the remainder of the components will proceed after the acceptance tests are complete. Commissioning of the DTL is expected in the first half of 2000.

6 FUTURE PLANS - ISAC2

TRIUMF is currently preparing a new five year plan requesting additional funding from the Canadian Government for the period begining in April 2000. A major element of this plan includes an upgrade of the ISAC facility[2](called ISAC2) to permit acceleration of radio-active ion beams up to energies of at least 6.5 MeV/u for masses up to 150. The proposed acceleration scheme would use the existing RFQ with the addition of an ECR charge state booster to achieve the required charge to mass ratio ($q/A \geq 1/30$) for masses up to 150. A new drift tube linac would accelerate the beam from the RFQ to 400 keV/u where the beam could be more efficiently stripped to give a charge to mass ratio greater than 1/7 for the full mass range. This beam would then be accelerated by a linac consisting of many short superconducting cavities. The flexibility inherent in the superconducting option means that lighter ions with higher q/A are accelerated to energies beyond 6.5 MeV/u. To achieve higher energies two years in advance of the final configuration some superconducting cavities will be initially placed directly after the existing 1.5 MeV/u DTL. An additional stripper would be positioned between the DTL and the first superconducting cavity. This would allow an energy up to $\sim$5 MeV/u for masses up to 60 as early as 2003 within the existing building, albeit with reduced ion beam intensity compared to the completed ISAC2 facility shown in Fig. 6.

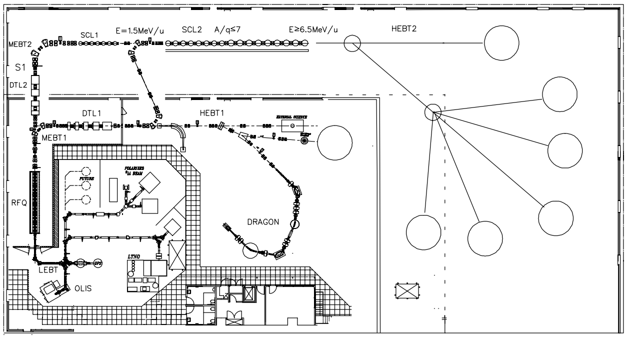

Figure 6: Layout of the proposed ISAC2 facility.

7 REFERENCES

[1] R. Poirier, *et al*, “Construction Criteria and Prototyping for the ISAC RFQ Accelerator atTRIUMF”, Proceedings of the 1997 Part. Acc. Conf., Vancouver, 1997.

[2] S. Koscielniak, *et al*, “Beam Dynamics Studies on the ISAC RFQ at TRIUMF”, Proceedings of the 1997 Part. Acc. Conf., Vancouver, 1997.

[3] R. Laxdal, *et al*, “A Separated Function Drift Tube Linac for the ISAC Project at TRIUMF”, Proceedings of the 1997 Part. Acc. Conf., Vancouver, 1997.

[4] R. Laxdal, *et al*, “Testing the ISAC LEBT and 35 MHz RFQ in an Intermediate Configuration”, these proceedings.

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[2] http://decu10.triumf.ca:8080/ht/ISAC/#future