STATUS AND PLANS FOR THE TRIUMF ISAC FACILITY

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Abstract

The TRIUMF 500 MeV cyclotron provides up to 100 μA of protons for the production of exotic beams, primarily via spallation in a thick target, at ISAC. The cyclotron is being upgraded and refurbished to meet the ISAC requirements for reliability and stability. The ISAC (Isotope Separator and Accelerator) at TRIUMF uses the ISOL (On Line Isotope Separator) technique to provide mass-separated isotopes at energies up to 60 keV for low-energy experiments. For higher energies, the ion beam is transported at 2 keV/u, injected into a room temperature RFQ Linac and then into a five-tank drift tube linac that provides variable-energy accelerated exotic-beams from 0.15 to 1.8 MeV/u for nuclear astrophysics experiments. The first stage of a Linac using super conducting rf cavities has been recently commissioned to increase the energy to 4.0 MeV/u for A/q = 7. In January, 2007 a $_{11}$Li beam was accelerated to an energy of 3.6 MeV/u for the first experiment in the ISAC II experimental hall. Additional super conducting rf cavities will be added to the linac chain to permit a further increase in the maximum energy of the exotic beams to 6.6 MeV/u by 2010. An ECR-based charge state booster is also being added in front of the RFQ to increase the available mass range of the accelerated isotopes from 30 to about 150. A second proton beam line and new target station for target and ion source development have been proposed for ISAC. In the future this new target station could be used as an independent simultaneous source of exotic beams for the experimental program.

INTRODUCTION

There are two main techniques for creating these exotic beams, namely, the fragmentation method and the ISOL method. At TRIUMF the ISOL approach is used. ISOL type facilities typically use a light-ion driver-accelerator to produce a variety of isotopes in a target. At TRIUMF the driver is an H-, 500 MeV, cyclotron that has been shown to have the capability of accelerating over 400 μA to 500 MeV. The TRIUMF cyclotron can simultaneously extract multiple independent proton beams into different locations. The transport beamline from the cyclotron to the target area in ISAC is shielded for a maximum current of 100 μA of 500 MeV protons on a thick target where the exotic isotopes are created & ionized.

The extracted beam is transported through a beamline with electrostatic focusing and steering elements. The electrostatic approach allows isotopes with adequate intensities to be used for tuning purposes and then, to adjust only the mass selecting system to the low flux isotopes. These fluxes cannot be, in general, observed on the normal beam diagnostic elements. However, with the electrostatic focusing elements, the beamline tune is not sensitive to the mass, only to the beam energy and that is kept constant. Therefore the low intensity isotope can be transported through the line without needing to readjust the beam optics elements and requires only a minimum of low intensity diagnostics for optimizing the transport efficiency to the experimental target. An off line ion source (OLIS) is used to provide stable beams for commissioning beamlines, accelerators, setting up tunes and experimental calibrations. The required beam quality, the beam intensity, the beam energy and the momentum spread of the accelerated exotics depend on the particular experiment. For ISAC I the user input led to a continuously variable energy from 0.15 to 1.5 MeV/u for isotopes having an A/q ≤ 30. Recently ISAC II was added with super conducting linac to increase the energy of the isotopes. The accelerator layout is shown in figure 1.

The production of exotic isotopes in an ISOL target depends on a number of variables such as driver beam-current & energy, nuclear cross-section for production, target material and target thickness. The observed yield of a particular exotic isotope also depends on the half-life of the isotope, the time that it takes the isotope to leave the target and reach the ion source, and the efficiency for ionization in the ion source. The time required to reach the ion source following production depends on material properties that are temperature dependent. The observed exotic flux from an ISOL target varies non-linearly with the proton beam current because of changes in the target temperature and factors such as radiation induced diffusion. Enhanced variations of the exotic beam flux compared to the proton beam current variations, introduce difficulties for both the experimenter and the accelerator operator. To minimize these problems it is necessary to require beam size, beam position, beam profile and beam current stability tolerances on the proton beam from the driver accelerator. In addition each accelerator event that causes an interruption in beam delivery results in an even longer interruption to the delivery of exotic ions. The target temperature at high beam powers is primarily determined by the driver beam power. The time to restore the equilibrium operating temperature in the target when the beam is restored to the operating level exceeds the time for the temperature to drop to unusable levels when a short beam interruption occurs. Consequently it has become important to monitor, analyze, and take actions to reduce the mechanisms causing the beam interruptions and beam instabilities.

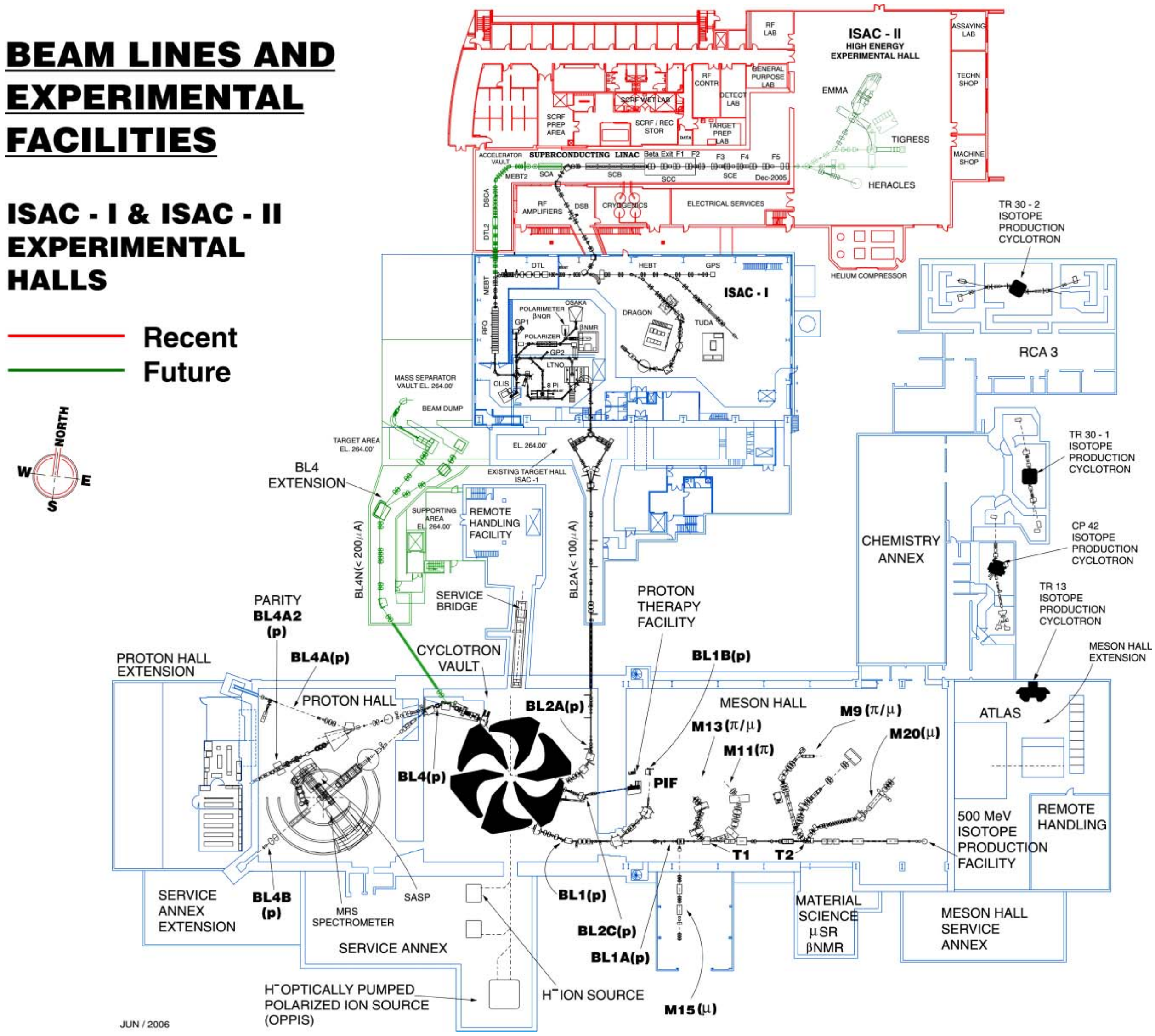

Figure 1: A schematic layout of the TRIUMF facility. The red lines indicate the building envelop for the ISAC II civil construction. The green lines labeled as BL4 extension, indicate the proposed building envelop for the proposed new high power target test facility. The ISAC II high beta cryomodules have been omitted in the schematic. Instead the HEBT beamline to the experimental hall is shown after completion of medium beta cryomodule installation in 2006.

CYCLOTRON DRIVER

A cyclotron refurbishment program was initiated to replace selected unreliable cyclotron components & to allow higher current operation. The cyclotron vacuum is being improved to reduce activation from stripping by residual gas molecules in the cyclotron vacuum chamber. Beam dynamics studies have focused on understanding the sources of the beam instabilities and on increasing the 'head-room' for the current of the circulating beam in the cyclotron. Diagnostics and feedback have been added to monitor and improve the beam stability on the ISAC targets. The cyclotron current extracted for the ISAC target is stabilized, though feedback from a non-intercepting current monitor, by varying the duty cycle with a 1 kHz pulser. Collimators & halo monitors are being used to ensure the beam size is maintained throughout the operation.

ISAC TARGETS & ION SOURCES

The exotic isotopes created in the target material are transferred by effusion and diffusion processes to an adjacent ion source where the isotopes are ionized, extracted and formed into an ion beam. The isotope production target material is located in a tube (2 cm diameter and up to 20 cm long) and the material composition varies depending on the particular isotopes that are being optimized. The target and ion source can be biased up to a voltage of 60 keV. Target configurations have been developed that allow extended operation at the full 50 kW beam power.

Isotopes are ionized at ISAC by three different types of ion sources; a thermal (surface) ion source, a resonant laser ion source and a FEBIAD (forced electron beam induced arc discharge) ion source. Each of these ion sources is capable of operating for many weeks with high power targets. An ECRIS (electron cyclotron resonance ion source), based on a 2.45 GHz design from GANIL, has been modified for operation at 6 GHz and is being tested on a test stand.

Two ion sources are being presently used to provide stable beams from an off line ion source (OLIS). There is a need to add a more universal ion source to meet these needs and super-nanogan ECRIS has been acquired for this purpose. Proposals have suggested that OLIS might even be useful for longer lived isotopes that were produced by one of the other four cyclotrons on site and delivered to the OLIS ion source in gas bottles after chemical separation.

ISAC I

Although the ISAC I accelerators were initially designed for a maximum energy of 1.5 Mev/u for beams having a $A/q \leq 30$ ratio, isotopes have been accelerated from the injection energy of 2 keV/u up to a maximum energy of 1.8 MeV/u. The accelerating system consists of a multi-harmonic pre-buncher, a cw RFQ, a medium energy beam transport (MEBT) section, an electron stripper, a re-buncher and a cw drift tube linac. The pre-buncher provides a pseudo saw tooth velocity profile at a fundamental frequency of 11.8 MHz, thereby providing approximately 86 nS between beam buckets. Bunched beam from the pre-buncher fills every third bucket of the 35 MHz, cw, 8 m long, split-ring, RFQ. The singly-charged beam out of the RFQ, at energy 0.15 Mev/u, is focused (transversely and longitudinally) and stripped to a higher charge state in the medium energy beam transport line (MEBT). The MEBT has a 106 MHz bunch rotator to provide a time focused beam at the stripper and a dual frequency rf chopper to select cleanly separated rf bunches separated by either 85 or 107 ns. The stripped beam is magnetically bent through 90 by two 45 dipoles where silts are used to select only those isotopes having a chosen A/q ($3 \leq A/q \leq 6$) and re-bunched prior to injection into the first tank of the DTL. The DTL provides a beam that can be continuously varied in energy from 0.15 to 1.8 MeV/u. The DTL is a separated-function structure with five DTL tanks, each operating at 0° synchronous phase, with magnetic triplets located between each tank and three split-ring, three-gap bunchers located between tanks 2,3, and 4. As the DTL system operates cw at 106 MHz, only 1 in 9 rf buckets are nominally filled (beam bursts are at the pre-buncher fundamental frequency). Two additional bunchers are located in the high-energy beam transport (HEBT) beam line prior to the experimental stations to optimize the longitudinal timing at the experiments. For bunching the lower beta beams an 11.8 MHz triple-gap structure is used and a 35.4 MHz spiral buncher is used for bunching the higher beta beams. This accelerator has provided a wide range of isotopes over the full energy range to the experimental stations for the past six years.

ISAC II

The ISAC I facility has been accelerating radioactive ions (with q = 1 and m = 30) up to 1.8 MeV/u. ISAC II will increase both the possible mass to at least m = 150 and the energy to 6.5 MeV/u.

The ISAC II LINAC has been described at previous conferences[1,2]. Briefly the completed system will include a cw DTL to increase the energy of the beam from the RFQ to 400 keV/u before stripping to a higher charge state. A superconducting linac with cavities designed for $\beta_o = 4.2\%$ (8 low beta cavities at 70.7 MHz), 5.7% (8 medium beta cavities at 106 MHz), 7.1% (12 medium beta cavities at 106MHz) and 10.4% (20 high beta cavities at 141 MHz). The design fields for these cavities are specified to achieve the ISAC II design energy (6.5 MeV/u) for A/q = 6. Solenoids are located between groups of cavities for transverse focusing and to enhance multi-charge acceleration when strippers are used. The medium beta section of the superconducting linac is composed of five cryomodules with each cryomodule consisting of four bulk niobium quarter wave cavities for accleleration and one superconducting solenoid for periodic transverse focusing. The cavities each produce about 1 MV of accelerating voltage. The top assembly of an ISAC II cryomodule is shown in Figure 2.

Although heavier masses are being produced in the targets and extracted from the ion sources, the high-pressure conditions near the ion sources permit only singly ionized ions to be extracted at reasonable intensities. These heavier masses could be accelerated if their charge state was increased to within the required A/q. In order for experimenters to reach the Coulomb barrier for masses up to A = 150, it is necessary to increase both the length of the ISAC accelerating system and the maximum mass that can be accelerated. To increase the maximum mass of ions accelerated by the RFQ, a 1+ to n+ charge state booster (CSB) is required. The installation of an ECR-based charge-state-booster in ISAC, in 2008, will allow the acceleration of all masses to 0.15 MeV/u.

A plan to achieve the ISAC II specifications in a phased approach is being followed in a way that allows experiments to begin prior to completion of the full accelerator capability. In the first phase, at the end of 2006, the accelerator has 20 medium-beta superconducting cavities that bring the beam to 4.0 MeV/u for A/q = 7 and, of course, somewhat higher for isotopes that can be charge-boosted to a lower A/q (9 MeV/u for A/q = 2). At this energy a number of experimenters have approved experimental proposals and are waiting to begin data taking. By the end of 2009, on completion of the second phase, 20 more cavities (high-beta) will be added to bring the final energy up to 6.6 MeV/u (for A/q = 7). The accelerator layout is shown in figure 3.

In a later addition, ISAC I would be extended from the RFQ to a new DTL in ISAC II, that would allow acceleration of the beams from the RFQ to 0.4 keV/u. This would provide an alternative for accelerating elements that are not efficiently charge-boosted and require additional stripping before acceleration in the superconducting ISAC II linac. A short superconducting low beta section would be added to bring the energy up to the 1.5 MeV/u required for injection into the medium beta superconducting linac.

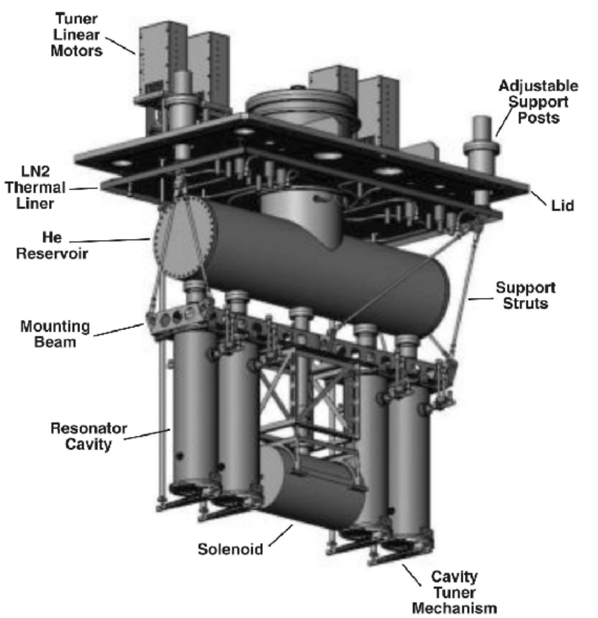

Figure 2: Component layout for each of the five medium beta cryomodules installed and operating in the ISAC II accelerator.

The first stable beam acceleration through all 20 cavities occurred on April 08, 2006 when 12C3+ was accelerated to 6.3 MeV/u within the accelerator vault during the accelerator commissioning. Subsequently a variety of other stable beams with different A/q values have been commissioned. The measured average gradient is 7.2 MeV/u resulting in final energies of 10.8 MeV/u (4He2+), 6.8 MeV/u (4He1+, 12C3+, 20Ne5+, 40Ca10+) and 5.5 MeV/u (22Ne4+) with transmissions exceeding 90%.[3]

CSB (CHARGE STATE BOOSTER)

The CSB for ISAC is a Phoenix based ECRIS. TRIUMF has collaborated with ISN, Grenoble on its further development. The ECRIS has been assembled on an extension of an existing ion source test stand where its performance is being measured and optimized. The CSB booster will be installed in the mass separator pit at the target level, downstream of the mass separator, in the January 2008. The low energy beam transport structure to allow the beam to go through the CSB is being installed this year (2007).

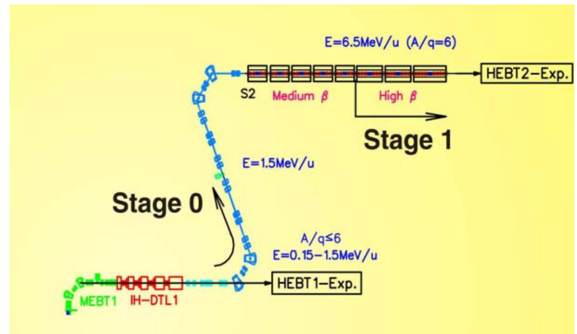

Figure 3: The accelerator layout at ISAC II. Stage 0 which includes the medium beta superconducting section is operational. Stage 1 which adds 20 high beta cavities is scheduled to be completed in 2009.

ISAC II OPERATION

A major milestone at TRIUMF was achieved on January 5, 2007 when an accelerated radioactive beam, 11Li was delivered from the ISAC II accelerator to the first experiment in the ISAC II experimental hall. The beam was transported to the MAYA experimental setup and within two hours data taking commenced. The MAYA equipment was brought to TRIUMF from the GANIL laboratory in France to study the outer skin structure of the exotic nucleus 11Li. The medium beta cryomodules in the ISAC II accelerator adds 20 million volts of accelerating voltage to the existing ISAC accelerator chain. For the MAYA experiment, only 11 of the 20 available cavities were needed to accelerate the beam to the required experimental energy of 39.6 MeV.

FUTURE PLANS

High power target development and the experimental program compete for the same beam time from ISAC. Target development scheduling requires a substantial overhead and is inconsistent with the beam reliability demanded by the user community. Experience has shown that high power target development must be done on line with proton beam. Therefore to maintain a viable experimental program, TRIUMF has decided that it is necessary to build a dedicated target development facility. A rarely used (recently) extraction port could be upgraded for high current operation and a beam line constructed to a new target hall in ISAC, capable of operating at the nominal 100 kW. The facility would include the ISAC style target station modules, a mass separator and yield station. The facility would make use of the existing remote-handling capability, the existing nuclear exhaust system and the existing hot cells. It would operate independently of the other cyclotron beam lines and therefore target development could be carried out simultaneously with the ISAC experimental program. The expansion would be done in a manner that in the future when the target development facility is not being used for target development a second RIB beam could be transported to any of the ISAC experimental stations. This would permit the facility to operate multiple RIB experiments simultaneously. A potential layout for this new facility is shown in figure 4.

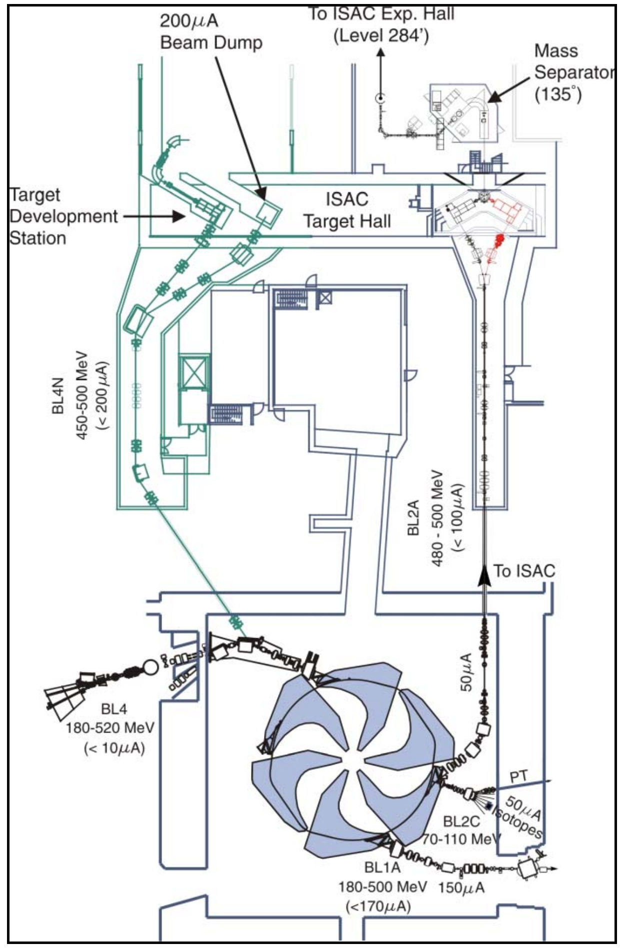

Figure 4: The BL4 cyclotron extraction port will be used to provide beams for high target development in an underground expansion of the ISAC target hall (shown in green).

SUMMARY

The accomplishments described in this paper were realized by a team effort. Without presenting the many names individually, I must nevertheless acknowledge them for these achievements.

The success of a facility is ultimately measured by its science output. The nuclear physics experimental facility has attracted experimental groups internationally because of its unique capabilities. Experimental groups are acquiring and setting up the apparatus needed for the ISAC II science program. The three major facilities will include TIGRESS (a high efficiency gamma array), HERACLES, EMMA (a recoil mass spectrometer) and a general purpose station which presently accommodates the MAYA detector.

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