

# THE ARIEL RADIOACTIVE ION BEAM TRANSPORT SYSTEM<sup>\*†</sup>

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## Abstract

The Advanced Rare IsotopE Laboratory (ARIEL) is going to triple the radioactive ion beam (RIB) production at TRIUMF. The facility will enable multi-user capability in the Isotope Separation and ACceleration (ISAC) facility by delivering three RIBs simultaneously. Two new independent target stations will generate RIBs using a proton driver beam up to 50 kW from the 500 MeV cyclotron and an electron driver beam for photo-fission from the new superconducting e-linac in addition to the existing ISAC RIB production. The multi-user capability is enabled by a complex radioactive ion beam transport switchyard consisting entirely of electrostatic optics. This system includes two separation stages at medium and high resolution with the latter achieved by a mass separator designed for an operational resolving power of 20000 for a 3  $\mu\text{m}$  transmitted emittance. Part of the system also includes an Electron Beam Ion Source (EBIS) charge breeder fed by a radio frequency cooler that allows the post-acceleration of heavy masses. Beam selection downstream of the EBIS is achieved by means of a Nier type separator. The facility is in a detailed design stage and some tests, procurements and partial installation are foreseen by the end of 2016.

## INTRODUCTION

The ARIEL project [1] at TRIUMF is an extension of the current ISAC facility [2] with two additional independent target stations meant to produce RIB using the isotope separation on line (ISOL) method [3].

One target station is going to receive 500 MeV proton beam up to 100  $\mu\text{A}$  from a fourth extraction line of the TRIUMF cyclotron [4] while the second is going to produce RIB via photofission [5] using the new electron linac [6] designed to deliver 50 MeV electrons up to 10 mA for a maximum beam power on target of 0.5 MW.

The two combined facilities, illustrated in Fig. 1, are going to produce three simultaneous radioactive ion beams to be delivered to the existing fifteen ISAC experimental stations.

The single-charge beam produced and extracted from the ARIEL targets is going to be delivered through the RIB transport system. This is a complex of electrostatic beam lines where the beam can be selected with various degree of separation. A charge breeding option for post acceleration of heavy elements is part of the system . An analyzing station is also present at ground level to measure yield production.

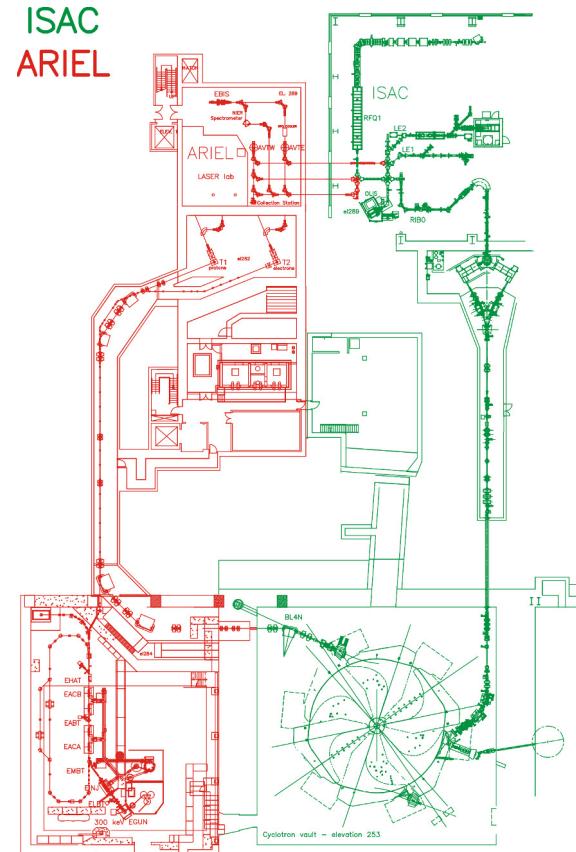


Figure 1: ARIEL (red) and ISAC (green) facilities at TRIUMF.

## RIB TRANSPORT SYSTEM

The RIB transport system extends over three levels on the far north side of the new ARIEL building. The beam line design is based on the proven and well understood ISAC electrostatic optics [8] that consists of few optical sections with matched input and output parameters. These sections are based on a 1 m long period with 90° phase advance. The basic ones are: straight periodic, straight crossing, 90° achromatic bending and order reversing necessary to match two consecutive bending sections in the same plane. Some sections have unique lengths in order for the ARIEL beam lines to properly align to the existing ISAC installation.

The beam lines start in the the target hall just downstream of the target stations as represented in Fig. 2. Each target station has a dedicated pre-separator system for isobaric separation of the produced RIB species The mass resolving power of the pre-separator magnetic stage is 300. The dipole magnet is coupled with a 90° toroidal electrostatic bender to compensate dispersion due to energy spread. This selection

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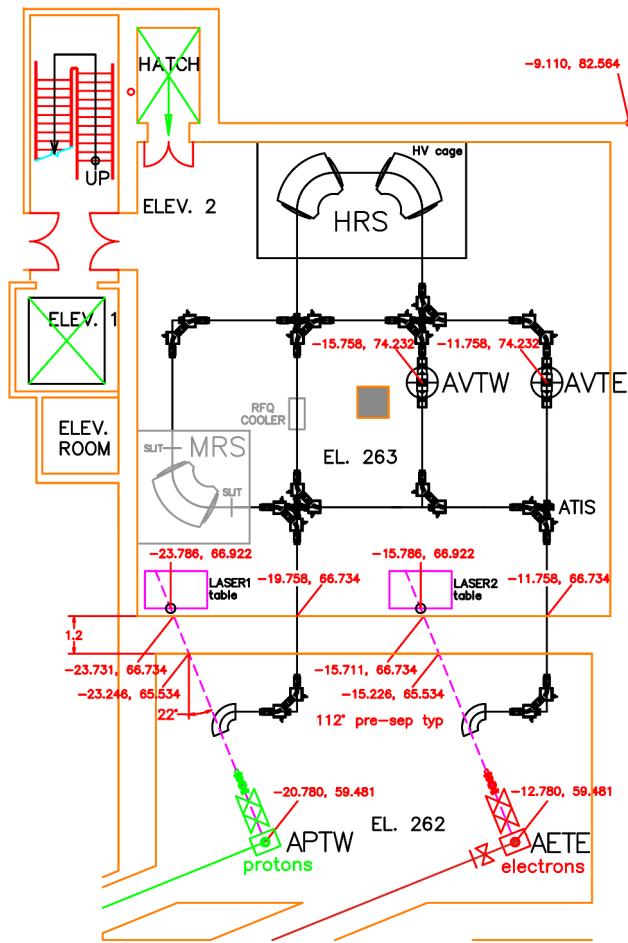


Figure 2: Target hall and B2 level layout of the RIB transport system

stage reduces the amount of radioactivity transported outside the shielded target hall.

Outside the target hall the beam is transported at the same elevation into the second basement (B2) level (see Fig. 2). At this level isobaric separation can be performed by means of a medium or a high resolution mass separator. The medium resolution separator (MRS) is not part of the present funding scenario and it is considered a future upgrade. The high resolution separator (HRS) is instead fully funded under the CANREB project. The HRS [7] design resolving power is 20000 for a  $3\text{ }\mu\text{m}$  transmitted transverse emittance.

The transport system at B2 includes also a by-pass mode where the only selection stage is achieved by the pre-separator. This option simplifies beam delivery for light ions like  $^{11}\text{Li}$ .

The beams selected at B2 are then directed to ground (G) level via two vertical sections: Ariel Vertical Transport East and West, respectively AVTE and AVTW, as represented in Fig. 2. The B2 level switchyard allows to transport two RIB's simultaneously from either target station to either vertical line.

The beam lines layout at ground level is represented in Fig. 3. Here the beam can be directed to the low energy (up

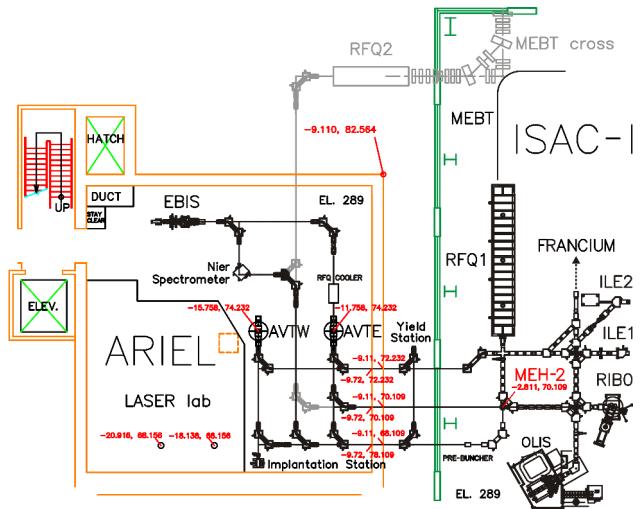


Figure 3: Ground (G) level layout of the RIB transport system that connects to the ISAC facility. Beam line sections in grey represent future upgrade.

to 60 keV) experimental area or sent for post acceleration [9] to be delivered to the medium (up to 1.5 MeV/u) or high energy (up to 20 MeV/u) experiments.

Due to the post-accelerators acceptance, masses heavier than 30 need to be multi-charged. The charge breeding in ARIEL is going to be performed by an electron beam ion source (EBIS). This is an alternative option to the existing ISAC electron cyclotron resonance [10] (ECR) charge breeder. The beam injected into the EBIS is bunched by a radio frequency quadrupole (RFQ) cooler. The charge state bred out of the EBIS is going to be selected by a Nier type separator with a resolving power greater than 200.

An updated version of the existing ISAC yield station [11] is also located at ground level before entering the ISAC building (see Fig. 3).

## VACUUM ENVELOPE

The major upgrade with respect to the existing beam lines is the vacuum envelope. The vacuum level requirements is  $1 \cdot 10^{-8}$  Torr, one order of magnitude lower than the present operating pressure. This is in order to maintain the beam losses due to electron capture [12] to less than 5% over the full length of the transport system. This is particularly critical for the section downstream of the charge breeder due to the high charge state.

Inside the target hall the vacuum envelope for each target station consists of five modules. Each module has a built-in shielding plug and remote handling connections that allow its removal and transportation to the hot cell.

Outside the target hall, the vacuum envelope is composed of custom vacuum boxes with CF flanges and metal seals, manufactured with tight tolerances for alignment purposes. Optical elements such as electrostatic quadrupoles, benders and correctors are contained inside the vacuum envelope.

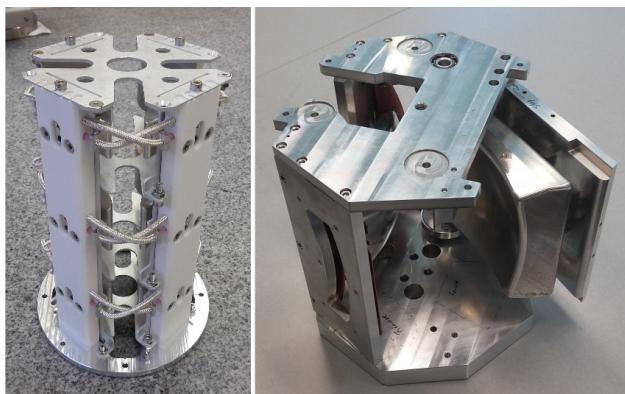


Figure 4: ARIEL RIB transport system quadrupole triplet (left) and spherical bender (right) assemblies.

## PROTOTYPE

A prototype section is being assembled in order to validate the new vacuum envelope design. The prototype is a fifteen meters long subsection of the entire system. The mechanical design is going to be tested for vacuum performance and alignment procedure.

The prototype is being installed in the B2 level and it is meant to be part of the final installation. The installation includes all the optics elements in order to have the correct conductance for the vacuum test. Diagnostic devices are also part of the installation.

Optical elements are tested for high voltage or mechanical design prior to assembly into the vacuum boxes.

### *Electrostatic Quadrupoles*

The electrostatic quadrupole assembly is completely redesigned with respect to the existing. Four ceramic insulators (Macor<sup>®</sup>) acts as a backbone to support the electrodes. The four insulators are then assembled on a mounting ring in order to guarantee a tolerance of  $50\text{ }\mu\text{m}$  on the 50 mm quadrupole aperture. Opposite electrodes are connected with an internal ground shielded wire while the required voltage is fed directly to one of the two electrodes from the outside. The macor components are also shielded from the beam via a ground plates. The left picture of figure 4 represents the quadrupole triplet prototype assembly.

Because of the new design, the triplet has been tested from a high voltage point of view. A megger test has been conducted to assess the insulation that has been measured greater than  $200\text{ M}\Omega$  at 5 kV. The triplet has then been successfully tested up to 11kV corresponding to a value 25% higher than the maximum operational voltage.

### *Spherical Benders*

The optics uses  $45^\circ$  degrees spherical benders that focus the beam in the direction perpendicular to the bending plane. A single  $90^\circ$  achromatic bending section includes two spherical benders.

A spherical bender prototype (see fig. 4, right picture) has also been assembled to check the mechanical design. In

## 2 Proton and Ion Accelerators and Applications

### 2G Other Proton/Ion

this case only the external support frame has been modified while the electrodes are mounted in the same way as the existing bender, therefore a dedicated high voltage test is not planned.

### Diagnostics

The diagnostic for the RIB transport system is also redesigned to meet the vacuum requirement. Four prototype devices are being assembled for the prototype section to test for mechanical interferences: high intensity (Faraday cup) and low intensity (Channeltron<sup>®</sup>) monitor, profile monitor (wire scanner) and linear profile monitor (slit scanner).

## CONCLUSION

The RIB transport system of the ARIEL facility is in an advanced stage of detailed design. The new mechanical design will be tested in the prototype section installation. Procurement of the prototype vacuum envelope components is completed. Optics and diagnostics components are expected to be delivered in the coming weeks while installation and testing are foreseen to be completed by the end of November 2016.

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