ARIEL: TRIUMF'S ADVANCED RARE ISOTOPE LABORATORY*

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Abstract

TRIUMF has recently embarked on the construction of ARIEL, the Advanced Rare Isotope Laboratory, with the goal to significantly expand the Rare Isotope Beam (RIB) program for Nuclear Physics and Astrophysics, Nuclear Medicine and Materials Science. ARIEL will use proton-induced spallation and electron-driven photo-fission of ISOL targets for the production of short-lived rare isotopes that are delivered to experiments at the existing ISAC facility. Combined with ISAC, ARIEL will support delivery of three simultaneous RIBs, up to two accelerated, new beam species and increased beam development capabilities. The ARIEL complex comprises a new Superconducting RF (SRF) 50 MeV 10 mA cw electron linac photo-fission driver and beamline to the targets; one new proton beamline from the 500 MeV cyclotron to the targets; two new high power target stations; mass separators and ion transport to the ISAC-I and ISAC-II accelerator complexes; a new building and a tunnel for the proton and electron beamlines. This report include an overview of ARIEL, its technical challenges, and status of design activities.

ARIEL OVERVIEW

The main motivation for ARIEL is to substantially expand the RIB program at TRIUMF with up to three simultaneous beams, increased number of hours delivered to users per year, new beam species and expanded beam development capabilities. Combined with ISAC, ARIEL shall support delivery of three simultaneous ISOL RIBs to experiments, including up to two simultaneous accelerated RIBs. To fulfill its primary scientific mission, the ARIEL facility comprises five major elements:

- Superconducting 50 MeV, 10 mA cw linear electron accelerator and a beamline to transport high current electron beam to target stations.
- A new proton beamline capable of transporting up to 100 μA from the cyclotron to the target stations.
- Two new high-power ISOL target stations.
- Mass separators and ion transport to the existing ISAC-I and ISAC-II accelerator complexes.
- A new building to house the two target stations, remote handling infrastructure, chemistry labs, mass separators and front-end (Fig. 1); a tunnel for the proton and electron beamlines; renovations to the existing proton hall for its conversion to the electron hall; associated services.

Figure 2 is a schematic representation of the ARIEL facility. An extension in a future phase of the electron linac to an energy recovery linac (ERL) driver of a 4^{th} generation light source is also envisioned. In this scenario a high brightness electron beam is interleaved with the single-pass RIB beam and accelerated in the same linac. This beam could be used to drive an IR or THz free electron laser (FEL) or a Compton back-scattering X-ray source in the back leg of the recirculation loop. After recirculation the beam is decelerated in the linac and dumped [1]. Conceptual layout of the electron linac with recirculation loop is depicted in Figure 2.

Funded up to now are the 25 MeV, 100kW electron linac and civil construction to encompass the objectives of the entire ARIEL program.

Figure 1. Architects' rendition of the ARIEL building.

THE ELECTRON LINAC

The goal of the ARIEL electron linac (e-linac) is to deliver 50-75 MeV, 10 mA cw electron beam as a driver for photo-fission of actinide targets to produce rare isotope beams (RIB) for nuclear physics, and $^{9}Be(\gamma,p)Li^{8}$ for materials science research. The e-linac parameters were chosen to reach rates up to 10^{14} fissions per sec. Beam must be continous to avoid thermal cycling on the target.

The electron beam is generated in a 300 kV DC thermionic gun, bunched in a room temperature 1.3 GHz buncher cavity, and accelerated by five 1.3 GHz superconducting cavities. One of these cavities is housed in the injector cryomodule (ICM) whose energy gain is 10 MV, and the others are housed in two accelerator cryomodules (ACM), with two cavities each and energy gain of 20 MV. The final electron beam energy is 50-75 MeV before going to the target stations. The recirculation arc could be tuned either for energy recovery (ERL) operation or for energy doubling (RLA). When tuned as an RLA, it transports the beam through the linac for a second pass, thus reaching RIB energy up to 75 MeV with a single ACM installed.

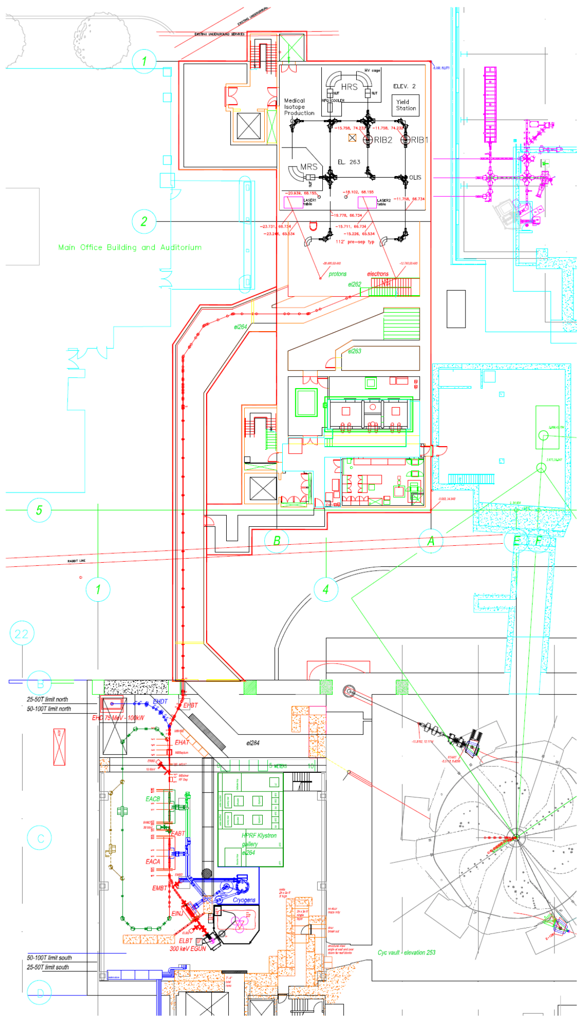

Figure 2: Schematic of the ARIEL facility

Electron Source

The electron source is based on a thermionic gridded cathode assembly that is modulated at 650 MHz. The RF amplitude and the grid bias are adjusted to provide ±16° (at 650 MHz) for 16 pC per bunch. To minimize field emission within the source, the design has an inverted electrode profile compared to the classical electron gun design. This reduces the surface area of the high voltage electrode, reducing the likelihood of field emission. To reduce the required length of the ceramic, the gun vessel will be mounted in a vessel of pressurised SF_6 insulating gas.

For the purposes of emittance characterization and the implementation of a 650 MHz modulation scheme, a 100 keV DC gun was acquired from Jefferson Laboratory. Evaluation of the cathode on this electron gun test stand has been crucial in developing the rf requirements for the gun and has provided necessary confidence in the simulations.

Major long-lead items, including the high voltage power supply, cathodes, and ceramic have been ordered or have arrived on site. An engineering review was recently conducted and gun component fabrication is imminent.

Superconducting RF Development and Cryomodule Design

The e-linac accelerating cavities are TTF-type 9-cell niobium cavities with modified end cells and asymmetric beam pipes to ensure adequate damping of Higher Order Modes [2]. The nominal operating gradient is 10 MV/m at $Q_0=1\text{x}10^{10}$. HOM cavity studies in the range of 1.5-3.25 GHz have been completed and it was determined that damping of dipole modes with rf absorber material yields loaded shunt impedance at least 2 times below the BBU threshold, in energy recovery mode. RF design of HOM dampers has started.

The cavity design is complete and cavity fabrication has started. A copper 7-cell cavity model nears completion, and the 9-cell Nb cavity fabrication will commence in September 2011.

To reach the ultimate 0.5 MW of beam power, each cavity must provide 100 kW, and is equipped with two Cornell/CPI 50 kW cw couplers. The cavity tuner is a CEBAF style scissor tuner with room temperature motor.

The injector and main linac cryomodules borrow heavily from the ISAC-II heavy ion linac top-loading cryomodule design. The cryomodule vacuum vessel is a stainless steel vessel in a rectangular box shape. The cavities are mounted on a strongback slung from the top assembly from struts. All components are installed and supported from the top plate and the top assembly is loaded into the cryomodule from above [see Figure 3].

The e-linac cryogenic system distribution replicates the ISAC-II system, which is based on a parallel feed of atmospheric LHe from a main trunk line to each of the cryomodules. The LHe is drawn from a main supply dewar supplied from a 4K cold box. The 2K liquid is produced in each cryomodule [3].

The construction and beam test of the ICM is the subject of collaboration between TRIUMF and the Variable Energy Cyclotron Centre (VECC) in Kolkata, with the initial goal of 10 MeV and 30 kW in 2012.

High Power RF

The high power rf concept [4] has the injector cryomodule to be fed by up to two 30 kW cw Inductive Output Tubes (IOT), while the accelerator to be powered by two cw klystrons. For the first stage the 30 kW output power of the IOT will be split into two to provide rf power for two couplers in the ICM. A second 30 kW IOT will be added in the second phase of installation. Installation and full rated output power tests of the IOT on a 50 ohms load have been carried out. A power coupler conditioning station utilizes the same IOT.

The first accelerator cryomodule (ACM) consisting of two 9-cell cavities will require four power couplers operating at 50 kW cw. A 300 kW klystron will be adequate to provide this power. 3 dB hybrids and phase shifters will be used to divide power equally and maintain required phase of the rf voltage in the accelerating cavities with respect to the beam.

In a joint venture with Helmholtz Zentrum Berlin, an order has been placed with CPI, USA, for the 300 kW cw klystron for the first accelerator cryomodule. This klystron is designed to deliver RF output power to at least 270 kW (rated for 290 kW) with the incremental gain to be equal or larger than 0.5 dB/dB. This klystron has a specified perveance of 0.55 $\mu A/V^{1.5}$ and beam voltage of 65 kV; efficiency is expected to be minimum 52%.

Beam Physics Challenges

A 0.5 MW electron beam requires careful control of losses (few Watts per meter; even less in superconducting cavities). Too high density on target means developing a failsafe rastering scheme (>~1 kHz). Need non-intercepting diagnostics and a pulsing scheme to safely raise beam power without de-stabilizing the rf. Electron gun with clean 650 MHz-modulated grid. Control of beam alignment in spite of large (3 Gauss) stray ambient magnetic field.

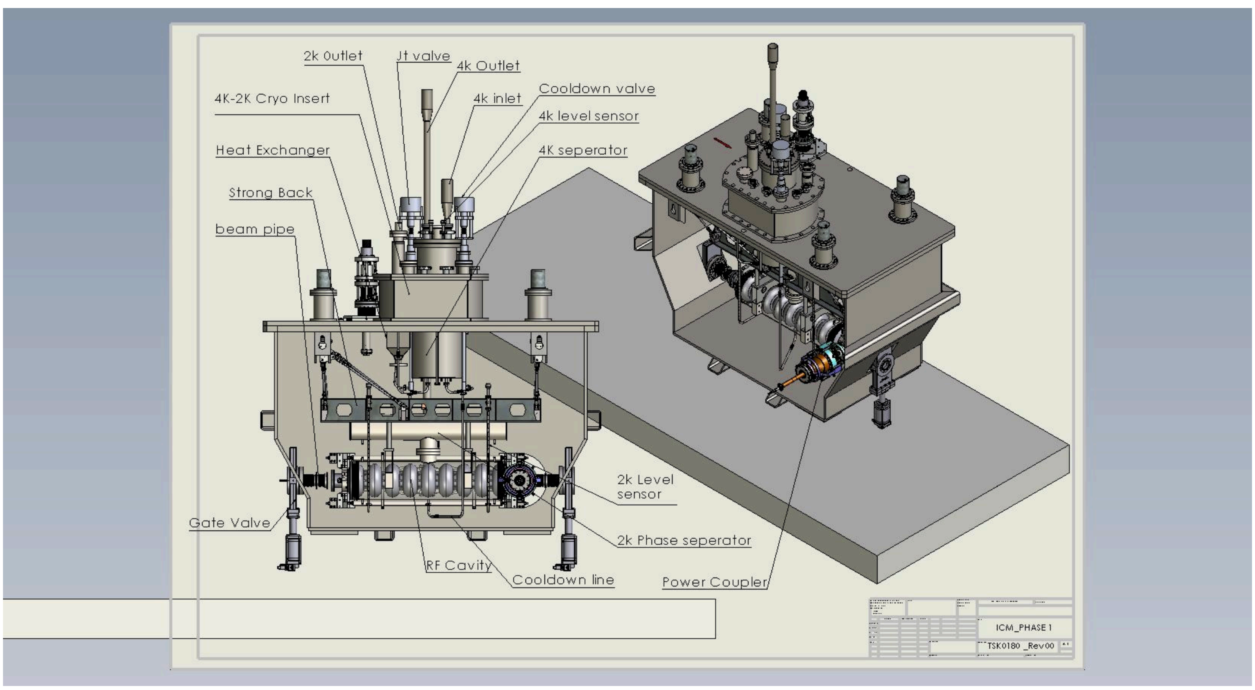

Figure 3: Electron linac injector cryomodule.

E-linac: A "green" accelerator

A partnership between the University of British Columbia, and TRIUMF, has recently been established and is focused on exploiting up to 3MW of waste heat from the e-linac and up to 10 MW from the entire TRIUMF site.

UBC and TRIUMF believe that there is a technically and economically viable opportunity to use the waste heat from the TRIUMF accelerators to heat the surrounding residential neighbourhoods. And in doing so, reduce associated Greenhouse Gas emissions, from building operation, by 50% and reduce TRIUMF's operational costs. A first stage of feasibility study is presently carried out the results of which will define the next steps in this partnership.

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