# THE INJECTOR CRYOMODULE FOR E-LINAC AT TRIUMF

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*Abstract*

The e-Linac project at TRIUMF, now funded, is specified to accelerate 10mA of electrons to 50MeV using 1.3GHz multi-cell superconducting cavities. The linac consists of three cryomodules; an injector cryomodule with one cavity and two accelerating modules with two cavities each. The injector module is being designed and constructed in collaboration with VECC in Kolkata. The design utilizes a unique box cryomodule with a top-loading cold mass. A 4K phase separator, 4K/2K heat exchanger and Joule-Thompson valve are installed within each module to produce 2K liquid. The design and status of the development are presented.

## INTRODUCTION

TRIUMF is developing the first stage of a 50 MeV, 0.5 MW super-conducting electron linac photo-fission driver (Fig. 1) to support its expanding RIB program. This will be an independent and complimentary primary accelerator to the present 500 MeV, 100 μA proton cyclotron that has driven the ISAC-I and ISAC-II programs. The linac will be the centerpiece for a new centre called the Advanced Rare IsotopE Laboratory (ARIEL)[1]. At VECC an ISOL type RIB facility is being built around the existing K130 cyclotron as driver[2]. VECC also plans to develop a 30 MeV, 100 kW superconducting electron linac fission driver for the RIB facility. Owing to VECC and TRIUMF's converging goals, the two institutes are collaborating on the SC e-Linac. In the first phase, a 10MeV, 3mA injector will be built and tested at TRIUMF.

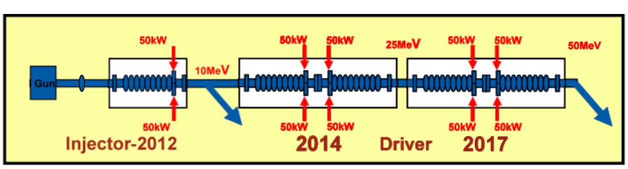


Figure 1: Conceptual layout of the TRIUMF e-Linac.

Due to heavy beam loading five nine-cell cavities at 100kW per cavity are required to reach the 0.5MW beam power. Each cavity is equipped with two 50kW cw couplers. An injector cryomodule (ICM) with a single cavity is required to reach an energy compatible with eventual ERL application (5-10MeV). The accelerator cryomodules (ACM) house two cavities per cryomodule. The two other obvious variants of one cavity per module and four cavities per module were abandoned due to inefficiency of cryogenics on one hand and maintaining a comfortable assembly unit size on the other. The project will proceed in a staged way as manpower and resources

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allow. An initial goal is the beam test of one ICM in ISAC-II as part of the TRIUMF/VECC collaboration to 30kW in 2012 and installation of the 25MeV/100kW linac section in the e-Hall in 2014. The final linac goal of 50MeV/10mA is expected in 2017.

A test area has been identified in a vacant space in the ISAC-II superconducting linac vault. The area is in close proximity to the ISAC-II cryogenics system and will enable cryomodule tests well in advance of when the e-Linac cryogenic system will be installed. The test area is presently being outfitted with a 100kV thermionic e-gun and LEBT to allow initial beam dynamics studies of the gun and LEBT. A 300kV gun now in design[3] will be installed early next year to allow acceleration tests up to 10mA with the ICM.

## SYNERGY WITH ISAC-II DESIGN

Modern cryomodule technology for elliptical cavities has centered on designs with a round vacuum chamber and end loaded cold mass assemblies. In applications such as X-FEL involving long linac structures the gas return pipe in the cryomodule acts as both the support strongback for the cold mass and the helium cold return distribution line for the overall cryogenic system. Operation is at 2K with the 2K produced either in a central 2K cold box or in a JT expansion valve close to the cryomodule that transforms a typically 3Bar stream from a 4K cold box to He-II. Heavy ion linacs operate at 4K due to typically lower rf frequencies and lower BCS resistance and are typically designed as box cryomodules with cold mass loaded from above due to the large transverse size of the low frequency low beta cavities.

TRIUMF began superconducting activities in 2000 in support of the installation of a heavy ion accelerator as part of the ISAC-II upgrade of the ISAC RIB facility[4]. Presently 40MV of quarter wave structures are installed operating near 100MHz and at a temperature of ~4.4K. The bulk niobium cavities are housed in box-like cryomodules with four, six or eight cavities per cryomodule variants. The cavities are mounted on a strong back 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. (Fig. 2).

The cryogenic distribution in ISAC-II 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. A liquid helium reservoir in each cryomodule acts like a phase separator and the cavities are fed LHe by gravity. Cold gas returns in parallel back to a common return trunk and is delivered back to the cold box and represents a refrigerator load.

Figure 2: ISAC-II top loading cryomodule.

Although non-standard a top-loading box design has some advantages for the e-Linac over an end-loading round variant. Firstly the modular and staged testing/installation sequence of the e-Linac suggests that each cryomodule be self-reliant to convert 4K atmospheric LHe into 2K He-II. To this end the box cryomodule design has sufficient head room that makes possible the addition of a dedicated 4K/2K cryo-insert on each module. Secondly, incorporating features of the ISAC-II design reduces the engineering design load within TRIUMF and takes best advantage of the existing infrastructure. This finds important savings in both the cryomodule design and the cryogenic system design.

The basic concept of the e-Linac cryogenic system[5] replicates the ISAC-II delivery (Fig. 3). A 4K cold box produces 4K liquid at 1.3Bar to a supply dewar that feeds LHe to a common delivery trunk with parallel 4K feed to each cryomodule. A 4K reservoir on board each cryomodule acts as phase separator and the 4K return vapour is sent back to the cold box with distribution identical to ISAC-II. The 2K liquid is produced in each cryomodule by passing the 4K liquid through a heat exchanger in counterflow with the returning exhaust gas from the 2K phase separator and expanding the gas to 30mTorr through a JT expansion valve. The two-phase header pipe above the cavity string acts as a 2K phase separator and delivers cold gas back through the 4K/2K heat exchanger to the sub-atmospheric pumping system as

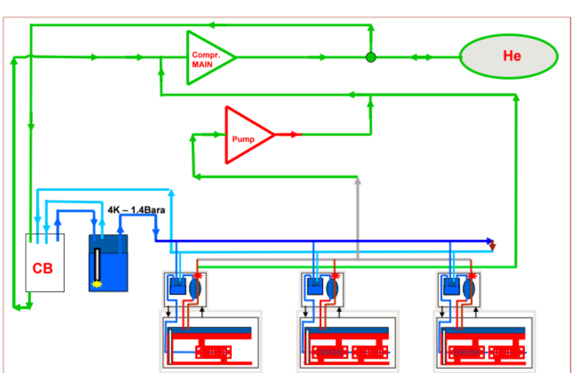


Figure 3: Schematic layout of the 4K and 2K systems.

a liquid load. The cryogenic connections in the e-Linac cryomodules are shown schematically in Fig. 4. A siphon circuit from the 4K reservoir is used to cool the 4K temperature intercepts with vapour return back to the reservoir.

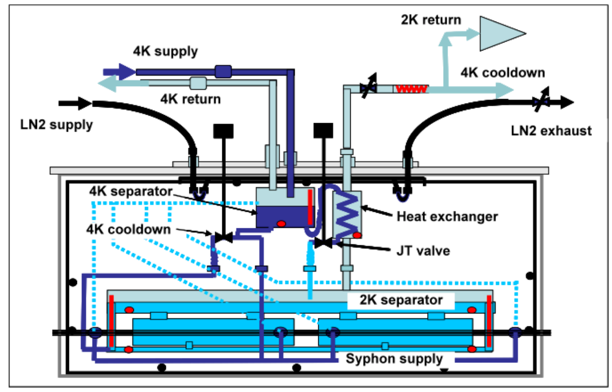


Figure 4: Cryomodule cryogenic circuit showing cold mass, 4K phase separator, 4K cooldown circuit, JT valve and heat exchanger. The dashed line indicates the siphon return circuits from 4K intercepts.

## E-LINAC CRYOMODULE DESIGN

The ICM is shown in a cutaway view in Fig. 5.

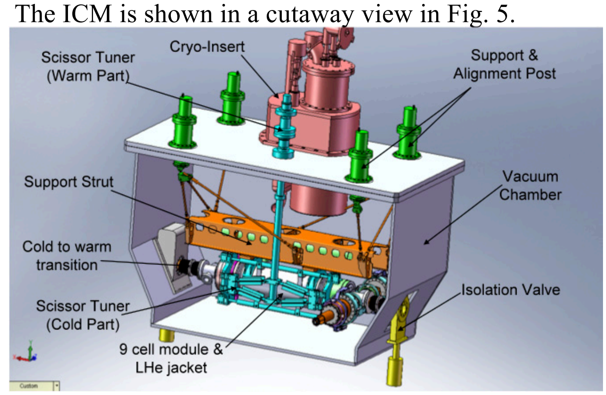


Figure 5: The injector cryomodule for e-Linac.

### *Vacuum Vessel*

The vacuum vessel is a stainless steel vessel in a rectangular box shape with additional ribs welded on to strengthen against the vacuum load. A warm layer of mu-metal is placed in the vacuum space anchored to the vacuum vessel. The entrance and exit beam tube regions are angled to allow the installation of the cold mass as a hermetically sealed unit with warm isolation valves at either end. This angled structure was first introduced at ATLAS with the energy upgrade cryomodule for heavy ions[6]. The cold mass is supported from the top plate with a few minor exceptions. The beam pipe is connected at the warm isolation valve to the end flange. In addition each cavity is fed rf power through two couplers mounted horizontally and symmetrically opposed at the `coupler end' of the cavity. The cold part of the coupler is assembled with the cavity as part of the hermetically sealed unit. After the top assembly has been inserted into the cryomodule the warm end is assembled to the cold end through cutouts in the side of the cryomodule. Two Cornell/CPI 50 kW couplers will be used to feed rf power to each of the 9-cell cavities. On the ICM the power couplers are on the downstream end to reduce coupler kicks and on the ACM the power couplers are in the center of the cryomodule. There are also flanges adjacent to the beam tubes for off-axis wire position monitors (WPM) for alignment purposes. The top plate has a cut out opening to allow independent installation and removal of the cryo insert (see below). In addition a side panel cut-out allows access to the cryo-insert VCR connections to allow removal of the cryo-insert without pulling the cold mass.

### *Strong-Back and Cold Mass*

The strong-back supports the cold-mass and forms a rigid assembly unit. The cold-mass includes the niobium cavities, two-phase helium gas return pipe (HGRP), lower cooldown supply pipe, tuners, coupler cold-part, bellows with HOM damping capability, isolation gate valves and ancillary components.

**Strong-back:** The strong-back is supported from the top flange of the cryostat through struts. The support struts are equipped with spherical rod ends to avoid any mechanical stresses that may develop during thermal cycling. The strong back and struts will thermally contract during cooldown though the reduced length of the module limits this to <4mm for stainless steel or <2mm for titanium; the choice is being analyzed. The vertical contraction does not affect the alignment since this can be compensated for during the initial set-up using the WPM and optical measurements and is repeatable.

**Power coupler and mock-up test:** The longitudinal contraction does impact the warm-cold power coupler connection and this is being studied in a mock-up test stand. The coupler has sufficient flexibility through transition bellows and a coupler exoskeleton gymbal has been designed to allow the warm and cold end of the coupler to move with respect to each other while maintaining the concentricity of the inner to outer conductor and keep stresses from the coupler windows.

**Cavity unit:** The e-Linac will be using TTF type 9-cell elliptical niobium cavities with modified end cells and asymmetric beam pipes (96mm diameter on the coupler side and 78mm diameter on the tuner side) to push certain potentially trapped HOMs to the tuner side. Present thinking is to use damping material in the warm-cold transition at the tuner ends of the cavities to reduce $Q_L$ of any dangerous dipole modes. The cavity tuner is a CEBAF style scissor tuner with room temperature motor sitting on the top flange of the module. The cavity is first assembled with power couplers, WPM outrigger target holders indexed to the beam center and beamline isolation valves in a clean room then assembled with a cold Cryo-perm layer and the cold tuner mechanism before being installed on the strongback that hangs from the top assembly. The estimated cryogenic static heat load for the ICM for the 2K, 4K and 77K circuits are 5W, 6W and 250W respectively plus a 10W 2K active load considering 10MV/m acceleration gradient and $Q_0$=1e10. Two chimneys (ID=90mm) connect the multi-cell cavity to the 150mm ID HGRP to take care of the heat load – the sizing compatible with a doubling of the gradient and allowing a heat removal of 0.5W/cm$^2$ .

### *4K/2K Cryo-Insert*

The 4K/2K cryo-insert is to be built and tested as a separate package. The size of the cryogenic unit is chosen to be compatible with pre-testing in an existing cryostat at least in the prototyping phase. The insert includes a 4K phase separator, 4K/2K heat exchanger, JT expansion valve, 4K cooldown valve plus siphon circuit for intercept cooling. The prototype heat exchanger will be manufactured by DATE with an estimated capacity of 2.5gm/sec. All components are being procured for an initial cold test.

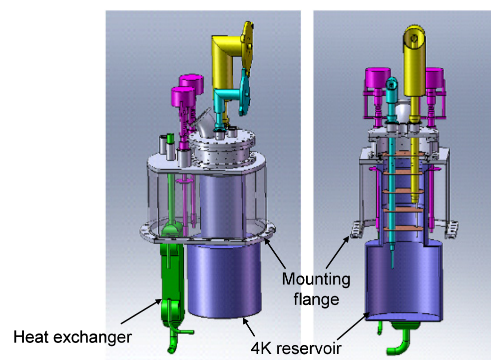


Figure 6: The 4K/2K cryo-insert for the ICM and ACM.

### *ICM test Schedule*

The construction and beam tests of the injector at the ISAC-II site are scheduled to be completed by the end of the year 2012. The aim is to test all the engineering and beam acceleration related issues before starting the ACM construction. Two ICMs will be built – one each for VECC and TRIUMF. After the beam tests, one ICM will be shipped to VECC.

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