THE TRIUMF/VECC COLLABORATION ON A 10 MeV/30 kW ELECTRON INJECTOR

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Abstract

TRIUMF (Canada) and VECC (India) are planning to each build a 1.3 GHz 50 MeV/500 kW superconducting electron linac as a driver for producing radioactive ion beams through photo-fission. The two institutes have launched a collaboration with the initial goal to design, build and test a 5–10 MeV superconducting injector cryomodule capable of accelerating up to 10 mA. A testing area is being set-up at TRIUMF to house the electron gun, rf buncher, injector cryomodule, diagnostic station and beamdump for beam studies. The project will test all critical elements of the final linac; beam halo generation, HOM excitation, LLRF and rf beam loading and cavity and cryomodule design/performance. The scope and status of the project will be described.

INTRODUCTION

The idea of using photo-fission of actinide targets for producing Radioactive Ion Beams (RIB) has existed for many years [1,2]. Photo-fission being a cold process creates higher yields for neutron-rich nuclei as compared to light-ion induced fission. Yields of around 10^{11} f/s have been experimentally measured using 25MeV, 20μA electron beam on uranium target [3]. It is expected that exotic beams such as ^{92}Kr, ^{132}Sn, that are of interest to super-heavy element research and r-process nucleo-synthesis, may be produced with significantly higher intensity using this method. In-target fission rates of 10^{13} f/s are estimated with 30MeV, 100kW electron beams [2].

TRIUMF e-Linac and VECC RIB Project

TRIUMF plans to add a 50 MeV, 0.5 MW super-conducting electron linac photo-fission driver 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) (Fig.1) [4]. In the first phase of the project 30 MeV, 100kW beams will be accelerated by the end of year 2013.

At VECC an ISOL type RIB facility (Fig. 2) is being built around the existing K130 cyclotron with the aim to accelerate 1.3 MeV/u beams [5]. Presently 289 keV/u stable isotope beams are available from the facility. 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 have recently signed an MOU for collaboration on SC e-Linac development. In the first phase, a 10MeV, 3mA injector will be built and tested.

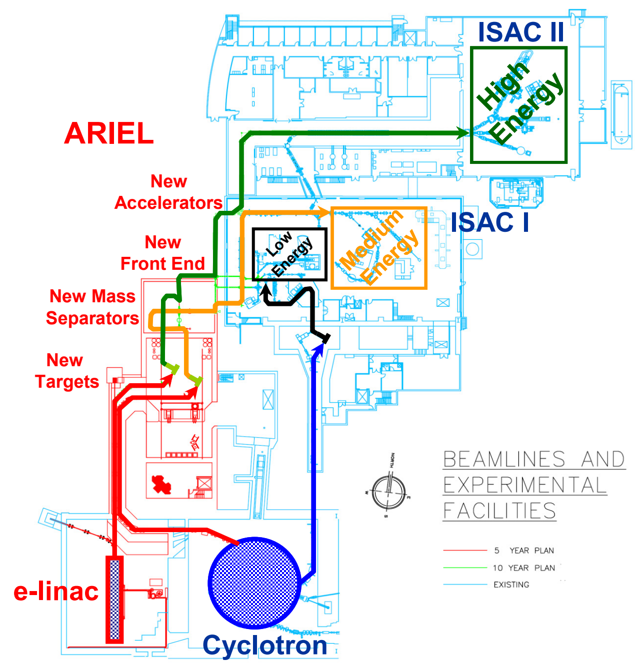

Figure 1: ARIEL project (red highlights) on the TRIUMF site. The present TRIUMF 500MeV cyclotron is driver to one of two production targets in ISAC. A new electron linac will add a complimentary driver to a new target facility while a second beamline from the cyclotron adds a drive beam to a third target allowing simultaneous RIB delivery to the three main experimental areas in ISAC-I and II.

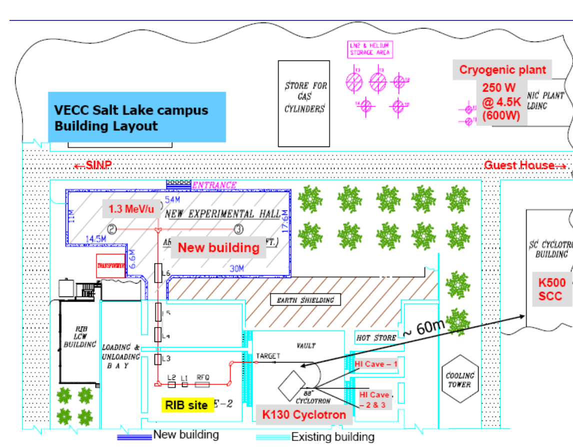

Figure 2: ISOL type RIB facility on the VECC site.

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PROJECT SCOPE

The TRIUMF e-linac[4], is specified to accelerate 10mA of electrons to 50MeV. The cavities operate in cw mode at 1.3GHz and 2.0K. The linac consists of three cryomodules; the first, called the injector cryomodule (ICM), accelerates the beam from 100kV gun potential to 10MeV with two β=0.7 single cell capture cavities and one β=1 multi-cell cavity, while the second and third are identical and hold two multi-cell β=1 cavities each. A schematic of the e-Linac is shown in Fig. 3. The injector and accelerator are spatially separated to allow the possibility of a future multi-pass upgrade either in energy recovery mode for a 4th generation light source, or energy doubler mode for photo-fission using bremmstrahlung with much smaller angular divergence.

The project will proceed in a staged way as manpower and resources allow. An initial goal is the beam test of one ICM in ISAC-II to 30kW by late 2011 and installation of the 25MeV/100kW linac section in the e-Hall by the end of 2013. The final energy/intensity goal of 50MeV/10mA is expected in 2017.

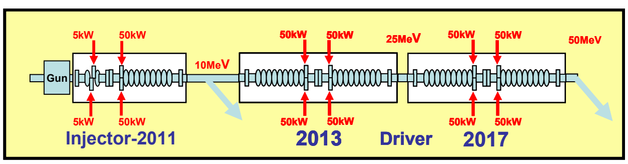

Figure 3: Schematic of e-Linac.

The scope of the VECC/TRIUMF collaboration agreement is to build and test two ICM units one for TRIUMF and one for VECC. A test area at TRIUMF has been identified in the ISAC-II complex that will allow the installation of a complete e-Linac front end complete with 100kV e-gun, low energy beam transport (LEBT) including a 1.3GHz room temperature buncher, the ICM and low and high energy analyzing stations. The front end schematic is shown in Fig. 4.

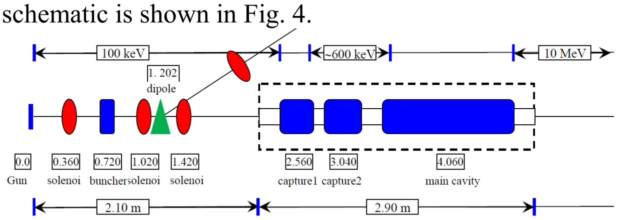

Figure 4: The 10MeV front end of the e-Linac.

The test area in ISAC-II provides a shielded vault and is in close proximity to the ISAC-II cryogenic system. The area offers a test environment well in advance of the readiness of the e-Linac vault and cryogenic system. A 30kW 1.3GHz IOT has been purchased to drive the multi-cell cavity. Solid state 1.3GHz amplifiers will drive the capture cavities and buncher. A new cryoline will be installed from the ISAC-II Phase I plant to the test area. The plant has an excess power of 350W equivalent at 4K. The facility will allow us to test high intensity beams to 3mA and 30kW by 2011 giving valuable early information on beam quality including beam halo formation, the beam interaction with cavities and LLRF, HOM excitation, and power coupler operation to 30kW. After the tests the e-Linac front end will move to the completed electron hall of ARIEL and the second ICM will be sent to VECC.

DETAILS OF THE INJECTOR

The Electron Gun

The electron gun is similar to the one operating at the FELIX facility [6] and was sourced from J-Lab. The 100 kV DC Thermionic Gun with grid delivers 100 keV, 170 ps (±20°@650MHz), up to 10 mA electron beam at 650 MHz pulse repetition rate. It is chosen because of simplicity, low cost and ease of maintenance. It has been equipped with a gridded cathode and is being tested in stand alone mode at a test stand. The electron gun set-up will be moved to the ISAC-II hall and installed in the Injector beam line for LEBT and ICM tests.

Beam Dynamics Simulation

The main parameters of the e-Linac are listed in Table 1. For the fission driver a low brightness beam (100 keV, 16 pC charge per bunch) is considered. The beam dynamics studies however have also been done for a high brightness beam (300 keV, 100 pC per bunch) in order to accommodate a future ERL upgrade at TRIUMF.

Table 1: Summary of e-Linac Parameters

Parameter	**Value**
Energy from gun; low(high) brightness	100 (300) keV
Energy after ICM	10 MeV
Energy (final)	50 MeV
Charge per bunch; low(high) brightness	16 (100) pC
Electron gun modulation frequency	650 MHz
Initial transverse emittance (4rms)	30 π mm mrad
Initial energy width	±1 keV
Initial phase width @650MHz	±20 degree
Buncher frequency	1.3 GHz
ICM and ACM frequency	1.3 GHz
Length of 50 MeV e-Linac (approx)	15 m

The beam dynamics simulation is done and cross-checked using the codes ASTRA [7], PARMELA [8] and TRACK [9]. Space charge effects have been included in the calculations. The 100 keV, ±20^0 beam from the gun is further bunched in a normal conducting 1.3 GHz buncher and injected into the ICM. The two single cell cold capture section and one 9-cell cavity in the ICM ensure that the low beta beam is smoothly accelerated and matched to the subsequent beta=1 acceleration section. The capture cavities each have beta=0.7 to transition the beta=0.55 beam to beta=1. The first capture cavity primarily accelerates the beam while the second capture cavity bunches the beam. The optimal energy after the first capture is 500keV based on an emittance minimization routine.

For the high brightness case, the parameters are more stringent. Further, the initial energy from the gun is required to be higher, and suggests a 300 keV photo-cathode gun. This may provide an opportunity to eliminate the cold capture section entirely and directly inject the beam into a 9-cell cavity. This would significantly simplify the ICM and reduce the overall length of the beam-line. Further, if the gridded thermionic gun is operated at 300 keV instead of 100 keV, simultaneous fission and light source operation with two independent injectors and common ICM+ACM may become possible.

Injector Cryomodule Engineering Design

The ICM engineering design is guided by the following considerations – (a) high average beam power (b) limited number of cavities (c) design and fabrication experience at TRIUMF with ISAC-II heavy ion cryomodules. Based on these parameters, a design incorporating a rectangular cryostat with top-loading cold-mass and integrated 2K converter insert has been adopted. The 2K insert includes a 4K phase separator with 4K LHe supply line to a JT expansion valve that is pre-cooled in a heat exchanger cooled by return flow from the 2K two-phase pipe.

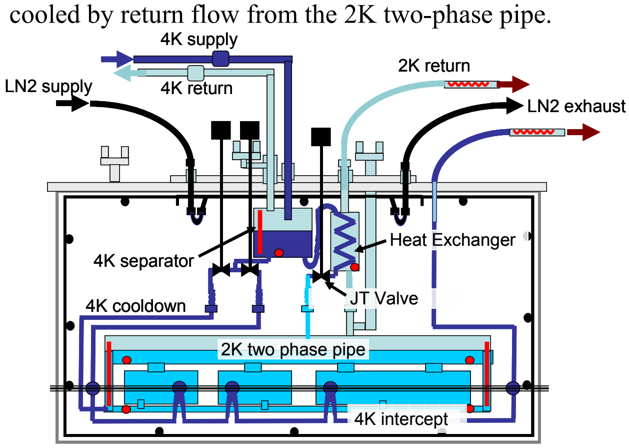

Fig. 5: Cryomodule cryogenic circuit showing cold mass, 4K phase separator, JT valve and heat exchanger.

The rectangular vacuum vessel will be made of stainless steel. 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), supply pipe, tuners, coupler cold-part, bellows, isolation gate valves and ancillary components. The strong-back is supported from the top flange of the cryostat through support struts. The top flange also supports the 2K insert. Two Cornell/ CPI 60 kW couplers will be used to feed rf power to the 9-cell cavity whereas the independently phased capture cavities will be fed via two TTF-3 type 5 kW couplers. The multi-cell tuner is CEBAF scissor-type tuner with room temperature motor. The capture cavity tuner will also be a scissor tuner with altered dimensions for the shorter cavity length.

The estimated cryogenic static heat load for the ICM for the 2K, 4K and 77K circuits are 5W, 6W and 250W respectively plus a 12W 2K active load considering 10 MV/m acceleration gradient and Q_0=1e10. CW operation is expected to result in high dynamic loads on the input couplers and the niobium cavities. Two 90 mm inner diameter chimneys connect the multi-cell cavity to the HGRP to take care of the heat load. A 4K imtercept circuit picks up thermal loads in various locations. LN2 will be used to cool the thermal shield. A conceptual layout of the cryogenic cooling circuit of the ICM is shown in Fig. 5.

1.3 GHz Cavity Fabrication

The e-Linac will be using TTF type single-cell and 9-cell elliptical niobium cavities with modified end cells and larger diameter beam pipe. A 1.3 GHz SRF programme has been started at TRIUMF with the goal to produce and characterize the niobium cavities. The cavities will be fabricated at PAVAC Industries, a Vancouver based machining and electron-beam welding industry. The existing clean-room and SRF test facilities of ISAC-II will be used and necessary upgrades will be put in place. Copper single cells are now being formed prior to niobium forming.

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 2011. The idea 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. The electron gun, buncher and LEBT line will be constructed at Kolkata separately for the VECC e-Linac program.

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