TRIUMF'S ARIEL PROJECT

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Abstract

The Advanced Rare Isotope Laboratory (ARIEL) will expand TRIUMF's capabilities in rare-isotope beam physics by doubling the size of the current ISAC facility. Two simultaneous radioactive beams will be available in addition to the present ISAC beam. ARIEL will consist of a 50 MeV, 10 mA CW superconducting electron linear accelerator (e-Linac), an additional proton beam-line from the 520MeV cyclotron, two new target stations, a beam-line connecting to the existing ISAC superconducting linac, and a beam-line to the ISAC low-energy experimental facility. Construction will begin in 2012 with commissioning to start in 2014. The ARIEL Control System will be implemented using EPICS allowing seamless integration with the EPICS based ISAC Control System. The ARIEL control system conceptual design and initial results from a prototype injector control system will be discussed

INTRODUCTION

Commencing in 2012, with staged installations, the TRIUMF ARIEL project will triple TRIUMF's Rare Isotope Beam (RIB) program by providing two new radioactive beam sources. Combined with the existing beam from ISAC, TRIUMF will have three simultaneous radioactive beams available for experiments or beam development. The ARIEL project consists of a superconducting electron linac, a new proton beam line from the TRIUMF cyclotron, 2 new target stations, 2 new mass separators and a low-energy beam line switchyard feeding into the existing ISAC accelerators (Figure 1). The project implementation will extend over 10 years.

ARIEL Phase I, to be completed by 2015, consists of the construction of a RIB Factory comprised of a new RIB driver, an electron beam line, and a temporary production target. The driver, a CW superconducting electron linac with 250 kW beam power operating at 2 K will use a demonstration dump. ARIEL Phase II will complete that factory with RIB production targets, a linac energy upgrade, and the addition of a proton-driven RIB production line.

The Phase 1 electron linear accelerator (e-linac) will be comprised of a 300 keV Thermionic gun (e-gun), an injector cryo-module with a single 9-cell cavity and one accelerator cryo-module with two 9-cell cavities. The injector provides a 5-10MeV beam current of 10 mA, i.e a beam power of up to 100kW. The accelerator cryo-module will boost beam energy to 25 MeV. The division into injector and main linac accelerator allows a possible future expansion for energy recovery or energy doubling.

The ARIEL project is aided by collaboration between TRIUMF and VECC of Kolkata, India, which is planning a RIB facility with an e-linac similar to ARIEL. The injector cryo-modules are being jointly developed and one module each will be built for VECC and ARIEL. A beam test for the VECC module is scheduled at TRIUMF in 2012. This presents an opportunity to prototype many elements of the ARIEL control system.

Figure 1 shows the layout of TRIUMF's RIB facility indicating the additions by the ARIEL project.

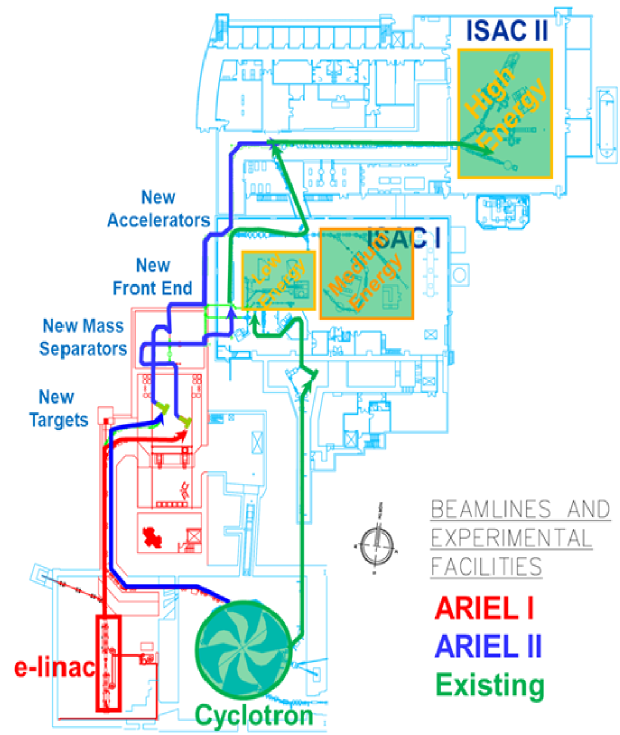

Figure 1: TRIUMF's ARIEL Project.

CONTROL SYSTEM: CONCEPTUAL DESIGN

The ARIEL Control System (ACS) will be implemented using the EPICS toolkit relying on established technologies and productivity tools of the ISAC Control System [1] wherever possible:

- The IOC software will be designed using the tdct [2] EPICS database configuration tool using the "object-like" device and component hierarchy developed for ISAC
- The ISAC device relational database web tools [3] will be used to:

- capture device information and interlock specifications
- instantiate devices in tdct schematics.
- validate interlock implementation in PLCs against the specification.
- auto-generate device control panels with interlock visualization [4],[5]

Evolution of the ISAC standards will be driven by the fact that high power beams are controlled and the need to further optimize resource usage in the control group.

In order to reduce the knowledge base to be maintained within the controls group, Linux will be used as the sole operating system on all IOC target architectures, servers and operator interface stations [6].

Integrated operation of the Cyclotron, ARIEL and ISAC control systems is not needed until after 2015 – when the proton beam line 4North comes on line. For this, a relocation of the Cyclotron and ISAC control rooms together with the ARIEL controls into one operations centre is being considered.

Machine Protection System

With a Phase 2 capability of 500 kW C.W. of beam power, the e-linac has been referred to as an electron blow torch. Therefore – in addition to the ISAC model - a fast machine protection system (MPS) will be required which is intended to prevent the high power beam from damaging the ARIEL accelerator and electron beam line. The MPS conceptual design is based on the JLAB implementation and intends to use JLAB–designed hardware that interface with photomultiplier tubes and ionization chambers [7]. The MPS will consist of a reactive fast shutdown system, a beam loss monitor system in support of the fast shutdown, and a preventive status monitoring and veto system. The MPS has unrestricted control of the e-gun grid modulation and HVPS with reaction time < 10 μsec in event of a full point loss. The MPS independently monitors devices deemed critical to the MPS function.

The MPS will use a modal view of facility operation. An e-linac Operating Mode is a configuration of beam characteristics (current, energy) and machine destination modes that permit such beam (low energy beam dump, high energy beam dump, etc). The desired operating mode is selected by the operator, but may be "downgraded" by the MPS based on events or operating conditions. The MPS will inform the control system of the actual Operating Mode which will form part of the control system interlocks for critical devices. Once a valid beam mode is established, the MPS system will automatically configure itself to monitor only those inputs which are required for beam operation to the designated beam dump.

An MPS trip will result in a hardware distributed event signalling the control system to acquire a time-stamped, beam-mode relevant, device snapshot. This will allow MPS trip post mortem analysis.

Operator interface to the MPS will be through the EPICS control system. Operator screens will be used to select machine configuration, monitor system status and reset trips. Additional screens may be used to set up beam loss monitors, initiate built in self-tests of fast abort components, and analyse trip data sets.

RF

EPICS will communicate with HPRF systems for control and to obtain device status, diagnostic values and interlock status. Interlocks for the HPRF systems will be directly supplied by the control system PLCs. The power supply for the 30 kW Inductive Output Tube that feeds the injector cryo-module will be controlled using the unit's RS232 interface and Streamdevice.

The 1.3 GHz, 300 kW klystron needed for the accelerator cryo-module has now been ordered from CPI. Tendering for all hardware and software to control the operation of the five required HV power supplies is underway. The contract stipulates PLC control for voltage regulation and protection of both the supplies and the klystron. The control module will present a Man-Machine Interface (MMI), a state machine for implementing the sequences required for proper operation of the power supplies for the klystron, and a latching interlock system that provides time-stamped fault logging. An interface layer for EPICS command and readback is stipulated since remote control of the HPRF sources via the control system is required.

Integration of the klystron power supply system and the klystron RF system is included in the scope of work as an option of the tender. If not provided by the vendor, this integration which encompasses interlocks, control, and monitoring of the complete RF system will be implemented in-house. The RF system includes the klystron, circulator with waveguide directional couplers, high power dummy loads with associated cooling and temperature monitoring systems, and a window arc detector. The operating parameters of the klystron for achieving 300 kW CW RF power at the dummy load are yet to be established. The response time of the interlock system must ensure protection of the klystron and other system components under any fault condition. Interlock trips must be time-stamped at a resolution of 1 ms or better. This precludes the use of a slow PLC scan. The status of all signals at the time of fault must be readable via MMIs and EPICS interface.

Figure 2 shows the e-linac RF components as they will exist for Phase 1 in 2014.

Low level RF is controlled by a dedicated RF control system [8] running on PCs running Windows. This local control subsystem is integrated into the EPICS control system using a shared memory interface with a "soft" IOC [9].

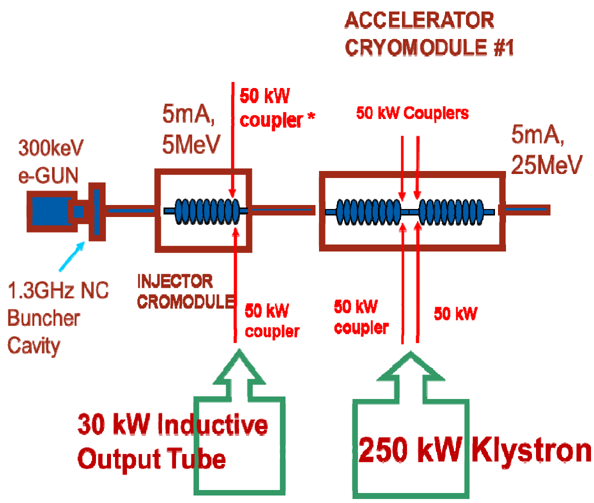

Figure 2: E-linac RF – Phase 1.

Beam Diagnostics

The E-Linac Diagnostic design has already been the subject of an International Review. Expected prompt radiation effects near the beam line would require all electronics to be rad-hard. No electronics will be installed in the E-linac hall, except in select shielded areas. This imposes restrictions on the type of instruments and bus lengths used since a 50 meter cabling path will be required.

The majority of e-linac diagnostic devices are slated to use VME for analog control and read back using 16 bits precision. The response time requirement of the control system is 10 Hz with a 5 Hz rate for updates on the operator consoles. Diagnostics that have data acquisition rates faster than 10 Hz will be handled by specialized hardware which will provide a first order processing. Data communication to the control system may then follow shared memory methods established in the ISAC control system for "soft" IOC data acquisition [9].

Diagnostic elements include button-type beam position monitors (BPM), ring capacitive pickups, DC current transformers, camera screen devices and wire scanners. The control of screen devices is being provided by the University of Victoria, a joint partner in the E-Linac project.

Device actuation into the beam line will be interlocked by the MPS subject to a proper facility operation mode (beam energy, beam intensity) for the device. Device trips, under conditions in which the device should be protected from the beam power, must be dealt with using "upstream" protection since the diagnostic devices cannot move fast enough to protect themselves. Device radiation dosage history will affect the performance of some units. Hence records must be kept by the control system and alerts issued when designated thresholds are reached.

Beam Optics

In ISAC, the supplies powering electrostatic or magnetic beam optics devices were controlled by individual TRIUMF-developed microcontroller cards and supervised from the IOCs via CAN field-bus [10]. This solution, while cost-effective and low maintenance at ISAC, may not be propagated to the electron beam optics control because of a different cost situation and concerns over reliability in the high power beam environment. At present, different approaches for low current and high current power supplies are being evaluated.

For optics devices requiring no more than 10V/5A, the Matsusada R4K-80L is a strong candidate for its cost effectiveness (150+ units are required). A control solution where small R4K-80L clusters are controlled from an EPICS IOC using ASYN/Streamdevice via RS232, with interlocking and external polarity switching provided by PCI digital I/O cards, will be evaluated during the VECC test phase using x-86 IOC targets. [6].

For optics devices requiring more powerful controllers, three possible methods of control are being considered: RS232, CANbus, or PLC. The criteria for instrumentation bus selection includes how fast the PS can be controlled, reliability of power supply shut off, and cost. In each of the following control scenarios, PLC interlocks on magnet temperature switches will cut power to the device. For an RS232 controlled supply, it is estimated that a polling rate of 10 Hz could be maintained from a Linux IOC. If the unit failed to respond, a method to remotely turn off the supply could be implemented using PCI digital I/O driving a relay which removes the power. The design of existing TRIUMF CAN-bus microcontrollers provides for a maximum update rate of 10 Hz and uses a beacon to determine communication health, resulting in a power supply being shut off on beacon loss. PLC control of direct analog/digital supplies is already a feature of the ISAC control system for units at elevated potential. The PLC response rate, reliability, and precision are satisfactory – however price factors may limit this choice.

Source E-GUN

Tests using a 100 keV electron gun have already been performed on a prototype using the standard ISAC Controls model: PLC, VME, and CANbus. Additional tests will be conducted using this source before it is replaced with a 300keV e-gun for VECC injector cryo-module tests.

Vacuum System

As in ISAC, control and interlocking for vacuum devices will be implemented using PLCs and the interlock implementation will be automatically verified against the specification [4]. Schneider/Modicon PLCs of the Quantum and M340 series are currently being commissioned in the VECC injector beam line test. The PLCs are supervised by EPICS using a TRIUMF developed Ethernet driver with the Modbus over IP protocol.

A major departure from the ISAC vacuum system design is the use of movable pumping stations for the ARIEL vacuum system. This translates into large cost savings as turbo and scroll pumps are mounted on carts and connected to sequential vacuum volumes as required. Ion pumps maintain the attained vacuum in the beam line when the pumping cart is detached.

Cryogenics

The cryogenic plant for the e-Linac is currently in the tendering process. The Helium cryogenic system has three components: 4K liquid He in a closed re-liquefaction – refrigeration loop, 2K liquid He produced within the cryo-module by sub-atmospheric pumping, and room temperature gaseous He. A 77K liquid Nitrogen system provides for pre-cooling of He gas. The design places strong emphasis on monitoring and maintaining the helium purity. The scope of work mandates a PLC implementation with a documented TCP/IP interface to EPICS. The existing cryogenic system in ISAC has EPICS controls implemented in-house [11].

High Level Applications

E-linac tuning will require Control System High Level Applications (HLA) based on physics models. The XAL [11] framework, which integrates with the EPICS control system and provides for accelerator models, was chosen as a platform for HLA development, testing, and execution. XAL uses XML descriptions of the beam transport model that include specific optic and beam monitor control system process variables. TRIUMF XAL developments have thus far focused on low energy beam transport models. An empirical model has been created which has been proven to perform correctly at 300 keV [13].

HVAC

The buildings that house the ARIEL project will have a commercial building control system supporting the BACnet standard. In many situations the need to monitor such parameters as room temperature or air flow for correlations with beam or machine behaviour is required. BACnet/Ethernet is the physical and datalink layer that is proposed for the ARIEL facility. The building controls data can be accessed using BACnet support for EPICS [14].

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