OPERATIONAL CONSIDERATIONS FOR FUTURE MULTI-USER RIB FACILITIES*

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Abstract

Like other radioactive ion beam facilities, the ISAC facility at TRIUMF is capable of serving only a single RIB user at a time. With the construction of ARIEL, the Advanced Rare-Isotope Laboratory, ISAC will gain a second RIB production front end and the ability to serve multiple users simultaneously. This will introduce significant new complexity to operations and beam delivery at ISAC and place additional constraints on experimental scheduling and personnel requirements. These constraints will have to be taken into consideration when planning the operation of the combined ARIEL and ISAC facilities in order to maximize the benefits associated with having multiple RIB production facilities.

INTRODUCTION

ISAC, the Isotope Separator and Accelerator facility at TRIUMF, is a high-power ISOL-type rare-isotope beam (RIB) facility [1,2]. RIB production is driven by 480—520 MeV protons from TRIUMF's main cyclotron at currents of up to 100 µA. An artist's rendering of the facility is shown in Fig. 1 with the proton beamline visible at lower right. As ISAC has only a single driver and mass separator, only one RIB can be produced at any one time. This limits the amount of RIB that can be delivered to experiments to ~2500—3000 hours/year.

To increase the amount of RIB available to experiments, a new facility, the Advanced Rare Isotope Laboratory (ARIEL) [3], is currently under construction. In its initial phase, ARIEL will comprise a 10-mA, 50-MeV superconducting electron linac, target station(s), mass separators and low-energy beam transport to the existing ISAC experimental beamlines (Fig. 2). The e-linac will serve as a driver for RIB production by photofission and other photon-induced reactions. With ISAC, this will allow the simultaneous delivery of two RIB, doubling the number of hours of RIB available to experiments. Plans for the future expansion of ARIEL include a second high-current proton beamline to complement that already driving RIB production at ISAC and the ability to deliver three RIB simultaneously.

The move from single-user to multi-user operation brings with it a number of challenges. Many of these are technical in nature and beyond the scope of this paper. From an operations and beam delivery standpoint, however, there are still significant challenges to be addressed, in particular because of the impact that multi-user operation will have on both experiment scheduling and personnel requirements.

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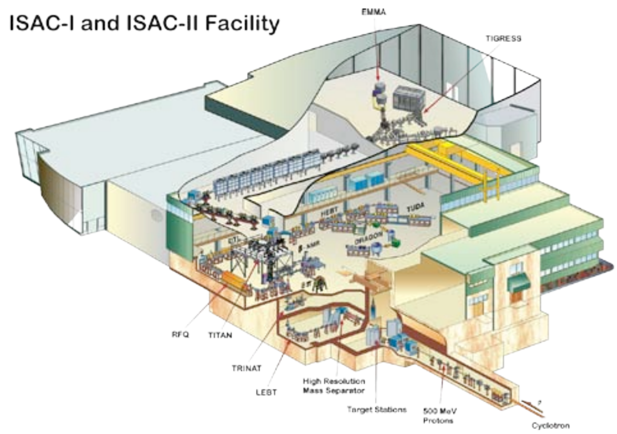

Figure 1: The ISAC facility at TRIUMF.

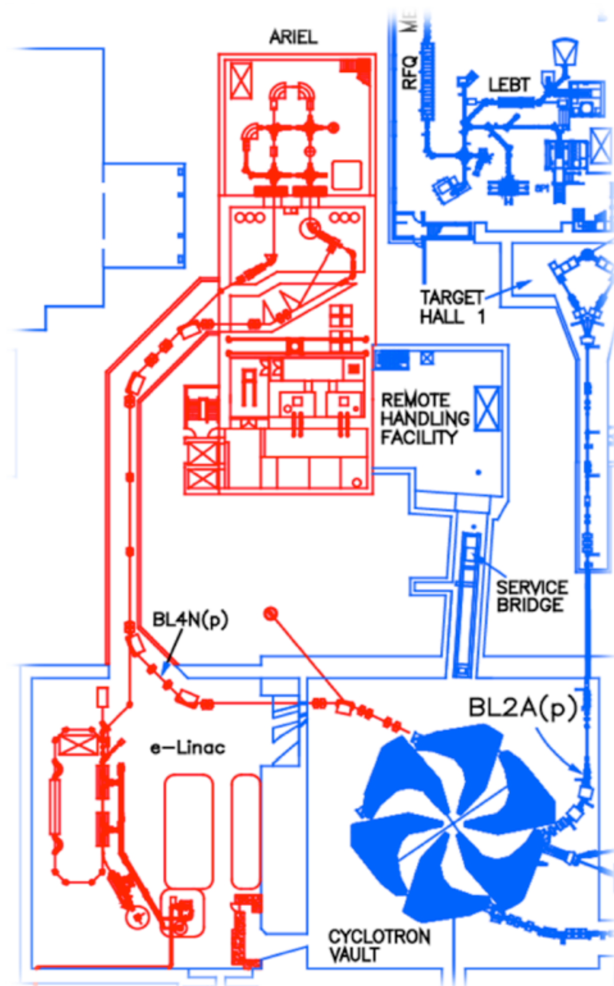

Figure 2: Beamline layout of the Advanced Rare Isotope Laboratory, showing its location relative to existing TRIUMF facilities. ISAC is at top right.

EXPERIMENT SCHEDULING

As shown in Fig. 3, low-energy RIB transport from ARIEL will be coupled into the existing ISAC LEBT so as to allow simultaneous delivery to two low-energy experimental beamlines or to the combined ISAC-I and ISAC-II high energy areas. (Simultaneous delivery to both ISAC-I and ISAC-II will not be possible without the addition of a second low-beta acceleration section parallel to the existing ISAC-I RFQ and DTL.) Additional destinations, such as the TRINAT neutral atom trap, the ISAC yield station and a future ARIEL yield station, will only be accessible from either ISAC or ARIEL; however, they represent special cases that have only a limited impact on the overall beam schedule. For typical operation, the combined ARIEL and ISAC facilities can be thought of as sharing three distinct experimental areas that can be served independently.

The existing ISAC beamline layout dictates where beam can or cannot be delivered simultaneously. Because the two production facilities will share a single set of experimental destinations they will have to be scheduled in concert taking into consideration the fact that changing the destination of RIB being delivered from one of ARIEL or ISAC will have knock-on effects on delivery from the other. Delivering RIB from multiple sources simultaneously will introduce both greater complexity and additional constraints on the experimental schedule.

Figure 4 illustrates four options for scheduling a typical week of operation. In options a) and b), the week begins with ISAC RIB being delivered to one of two low-energy areas (ILE1) and ARIEL RIB being delivered to the combined high-energy area (HEBT). The goal in both cases is to end the week with ISAC beam being delivered to HEBT and ARIEL beam to the other low-energy area (ILE2). The cyclotron maintenance scheduled mid-week serves as an incentive to switch ISAC operation from ILE1 to HEBT at that time. The need for setup time using stable beam from the ISAC offline ion source (OLIS) dictates that ARIEL delivery to HEBT end early on the Tuesday. In option a), ARIEL delivery to HEBT is maintained to that time then switched immediately to ILE2. This creates a "pinch point" in the schedule as beam tuning and RIB setup are then required for both ILE2 and HEBT at the same time, increasing the need for personnel and/or time to complete the setup of both successfully. In option b), ARIEL delivery to HEBT is suspended a day earlier. This eliminates the conflict with the start of OLIS tuning to the HEBT area but represents a loss of high-energy beam time.

In options c) and d) delivery from one of ARIEL or ISAC is maintained to a single experimental area while delivery from the other is changed between areas. In these cases it is sufficient to stagger experiments and setup times in order to eliminate scheduling conflicts. In studying numerous options for scheduling beam delivery it becomes apparent that the most straightforward way to avoid conflicts is to maintain delivery from one RIB

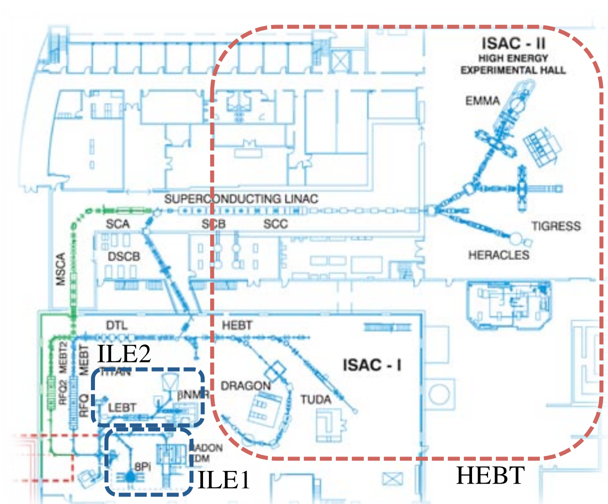

Figure 3: Experimental areas at ISAC.

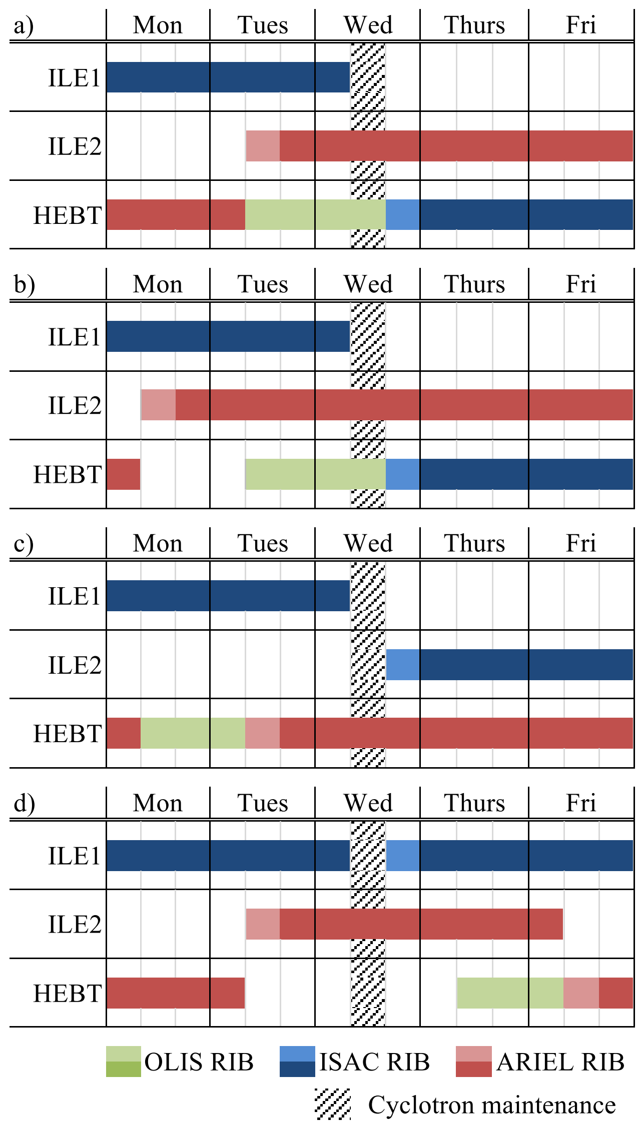

Figure 4: Representative options for scheduling RIB setup and delivery for the combined ARIEL and ISAC facilities. Lighter shades denote tuning and setup time; darker, delivery to experiment. Note the conflicting ILE2 and HEBT setup time (Tuesday, mid-day) in option a).

source to a single area for extended periods of time. This is not unusual at present; as an example, ISAC RIB were scheduled to be delivered solely to high-energy locations from June 1, 2012 to July 14, 2012, a period spanning the operation of two ISAC production targets. The ideal situation would be to deliver beam to a single experimental location with only minimal intervention for several weeks at a time. The specific need for ^{8}Li to serve the materials science program is a good candidate for such a mode of operation; this could be produced via the ^{9}Be(γ,p) reaction using a beryllium target at ARIEL and delivered exclusively to the βNMR location in the ILE2 area while RIB from ISAC are delivered to either ILE1 or HEBT.

Accepting constraints on beam scheduling can help to limit the need for additional personnel or tuning time when setting up RIB delivery to experiments. This does, however, come at the cost of scheduling flexibility and, ultimately, the amount of RIB delivered to experiments. There is a trade-off between personnel requirements and flexibility. With even the most stringent constraints on scheduling, there is some minimal level of staffing needed to maintain operations. Increasing the number of available personnel allows greater freedom to plan beam delivery, accounting for technical or experimental constraints, but only to the point at which scheduling can be carried out without regard to personnel availability; beyond that, additional personnel provide little further benefit. Assuming too much scheduling flexibility for the personnel available will result in an inefficient use of beam time as conflicts arise in beam tuning and setup. Conversely, assuming too little flexibility will introduce unnecessary constraints on the scheduling process and result in an inefficient use of the available personnel. Figure 5 shows in schematic form the relationship between the two quantities; the ideal operating regime will lie in the shaded region near the top of the curve, before it flattens out as the gains from additional hires diminish.

PERSONNEL REQUIREMENTS

TRIUMF presently has a single Operations group comprising both ISAC and Main Control Room (MCR) operators located in separate control rooms. The MCR has a full complement of 15 operators, with three on shift at any given time. There are ten ISAC operators, scheduled two to a shift 24 hours/day when running; during shutdown periods, operators are only on shift 12 hours/day Monday through Friday and pursue other tasks when not on shift. Both e-linac operation and ARIEL RIB delivery will have to be incorporated into TRIUMF Operations once ARIEL comes online.

While ISAC operators are responsible for the safe, efficient delivery of RIB to experiments, they are also responsible for aspects of things such as maintenance coordination, work permits, and site services. From past beam delivery experience, having two fully trained and experienced operators on shift is sufficient to *e.g.* establish RIB delivery to one experimental location while delivering stable beam (from OLIS) to another, though even this assumes some measure of coordination and support from TRIUMF's Beam Delivery group. With fewer experienced operators on shift, or setting up both RIB and stable beam delivery at the same time, additional personnel are generally required.

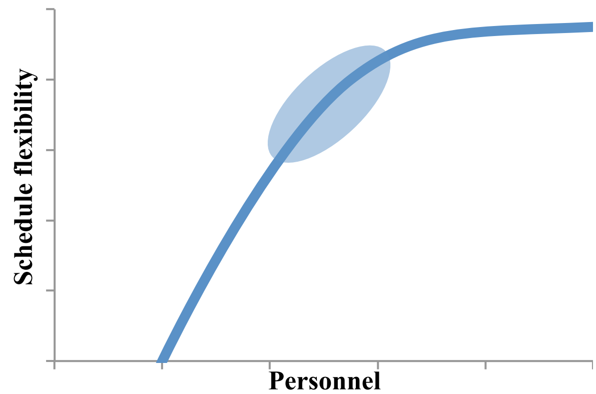

Figure 5: Schematic representation of the relationship between flexibility in beam scheduling and personnel availability. The shaded region represents an operating regime in which a high degree of scheduling flexibility is achieved with a minimum of personnel.

There are several options for addressing the personnel requirements associated with multi-user delivery. It is planned to move both the MCR and ISAC operators into a common control facility. This would allow operators from one group, when not actively tuning beam or otherwise managing delivery at their own facility, to assist with the operation of the other given appropriate cross-training. Furthermore, it may be possible to move things like maintenance coordination, work permits and site services out of the control room, allowing the operators on shift to focus on their core responsibilities of safety, machine protection and beam delivery. (There may be additional efficiencies to be gained with the development and increased use of high-level applications within the ISAC and cyclotron control systems, but that is also beyond the scope of this paper.) Combining control facilities and reducing operators' responsibilities may be sufficient to allow e-linac operation with the existing complement of operators as the machine is not expected to require significant intervention when running and it is not possible to tune drivers and RIB at the same time (as RIB delivery requires stable driver operation), but it is unlikely that this will be sufficient for both e-linac operation and the simultaneous delivery of multiple RIB.

Simply achieving the full desired shift coverage of three operators per shift in the MCR and two per shift at ISAC requires the hiring of additional operators to account for the fact that, with 25 operators, an average of two will be on vacation in any given week. Managing ARIEL RIB delivery on top of existing commitments will likely require an additional person to be available for beam tuning and setup. There are two options for addressing this need: hiring additional operators, or hiring Ph.D.-level physicists (or similar) to provide expert support on an as-needed basis. The main difficulty with hiring additional operators lies in shift scheduling. Adding a single operator position requires hiring five operators in order to maintain that position throughout an entire shift rotation. While that would provide significant flexibility from a beam scheduling standpoint, the cost is large.

Hiring physicists to provide support as needed requires fewer new hires, but their availability will be limited outside of normal working hours. This is an acceptable compromise as setting up RIB for delivery during daylight hours is desirable for other reasons, in particular the lack of availability of technical staff after hours in the event of equipment or controls problems that might arise during setup. Physicists offer the additional advantage of having advanced knowledge of beam delivery systems and procedures and can provide research and development effort when not actively supporting operations. Key to this approach, however, is ensuring that those hired to support beam delivery and operations have a well-defined service role. It should be noted that this role could change with time: a physicist could be hired before ARIEL comes online to pursue his or her own research interests on a part-time basis while working on a particular aspect of the ARIEL project as a service to the lab, then take over an operations support role as the project phase of ARIEL comes to a close. Using this model an additional 40 hours/week of operations support could be provided with one full-time equivalent, or two highly-qualified personnel working half-time in a service role and half-time in research and development.

CONCLUSIONS

With the combined ARIEL and ISAC facilities, TRIUMF will be able to support multiple RIB users simultaneously. The move to multi-user operation will bring additional challenges and introduce a number of operational considerations:

- beam scheduling to avoid tuning conflicts;
- long-term scheduling to limit the number of changes between experimental destinations;
- personnel requirements; and
- the nature of additional personnel that may be needed.

Some lack of scheduling flexibility will have to be accepted as a trade-off against personnel requirements. Even then, it is likely that additional personnel will be needed, including additional operators to ensure full shift coverage. Beyond that, hiring Ph.D.-level physicists (or similar) to provide expert-level support when necessary may provide the greatest benefit to the lab.

ACKNOWLEDGMENT

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