High Power ISOL Radioactive Target Remote Handling at TRIUMF

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Abstract

TRIUMF, Canada's national laboratory for particle and nuclear physics, currently maintains a high power ISOL (Isotope Separation On-Line) target station facility called ISAC (Isotope Separator and ACcelerator), commissioned with first beam in 2001. At ISAC, refractory metal and actinide compound targets are bombarded with 5-50 kW of 480 MeV protons from TRIUMF's cyclotron accelerator to produce rare isotope species for a variety of experimental applications, including nuclear astrophysics and fundamental nuclear structure. The ISAC proton beam targets expire, and must be exchanged on an operating cycle that produces about 10 waste target units per year. About 1 week after removal from service, these waste targets have a residual gamma radiation field producing a dose rate of up to 1 Sv/h at 1 m, and must be stored on site for decay for several years, prior to shipment in flasks to a national disposal facility. TRIUMF has remote handling infrastructure in place for servicing the ISAC target facility, which includes hot cells and a remotely operated bridge crane. TRIUMF is currently designing a next-generation ISOL facility called ARIEL (Advanced Rare IsotopE Laboratory), with improved remote handling infrastructure. ARIEL will apply modern technology and lessons learned from ISAC.

1. Introduction to ISAC

TRIUMF, Canada's national laboratory for particle and nuclear physics, currently maintains a high power ISOL (Isotope Separation On-Line) target station facility called ISAC (Isotope Separator and ACcelerator), commissioned with first beam in 2001. The primary components of the ISAC facility are identified in Figure 1. 480 MeV proton beam from the TRIUMF cyclotron accelerator is directed towards either the East or West target station. The targets at the target station sit on a high voltage platform at 10 – 60 kV.

Collision of the proton beam with the target materials at a power of 5 to 50 kW produces isotopes via spallation, fragmentation, and fission reactions [1, 2]. The isotopes are extracted from the target material via diffusion and effusion, ionized, and then accelerated from the high voltage platform through a ground electrode towards a high-resolution mass separator magnet. As the ISAC ion sources produce singly charged ions, the mass separator magnet is able to select specific isotopes based on their mass. This process of ionizing the isotope products at high voltage and then accelerating them away from the target through a mass separation system defines the ISOL technique.

Once the desired isotopes are selected via the mass separator, they are further accelerated via low, medium, and high energy beam transport systems, to a maximum of 16 MeV/u, and directed to a variety of experimental detector stations in the ISAC I and ISAC II experimental halls. At these stations, study is done in a variety of experimental fields, including nuclear astrophysics and fundamental nuclear structure, as well as material and life sciences.
2. The ISAC Target Assembly Design

The ISAC target assembly is the interchangeable unit that is exchanged with each target operating cycle of typically 3-5 weeks in the ISAC facility. The target assembly consists of the following fundamental components: (1) a target material oven, which is typically made of tantalum and filled with a target material ranging from light oxides and refractory metals to fissile actinide compounds, such as UC₂ (2) an ionizer tube / ionization device, (3) heating terminals, and (4) a water cooled copper heat shield. These items are described in Figure 2, Figure 3, and Figure 4 below [1].

When the target is in service on-line, the 480 MeV proton beam from the cyclotron is incident on the target oven, as shown in Figure 2. Isotope species are generated in the target material, and diffuse into the ionizer tube. The isotopes are ionized in the ionizer tube and then accelerated through the extraction electrode as rare isotope beam (RIB), see Figure 4.

In order for the isotope generation process to occur most efficiently, the target oven and target material must be heated to approximately 2000°C either by active ohmic heating or by the high-power proton beam itself, hence the use of refractory metals. For efficient ionization, the ionizer tube must also be heated, so the target material oven and ionizer tube have separate heating terminals. Heat from the target oven is transferred by radiation to the water-cooled copper heat shield.
Figure 2. The ISAC target assembly with heat shield cover removed.

Figure 3. The ISAC target assembly, with the heat shield cover shown.

Figure 4. The ISAC target assembly, section view through the target oven centre plane.
3. The ISAC Target Hall

The ISAC target hall layout is presented schematically in Figure 5 (plan view) and Figure 6 (section view), and photographically in Figure 7 and Figure 8. The target assembly is transported between the East or West target station and the hot cells for maintenance, using the target module (Figure 6). The target module is carried by the remote handling crane (Figure 6). In the hot cell, an expired target assembly is removed from the target module and a fresh target assembly is installed. The target module with the fresh target is then carried by the remote handling crane to the conditioning station, where off-line tests are performed and the high voltage is conditioned to operational levels. Once the target is tested and ready, it is transported by the remote handling crane in the target module from the conditioning station to the East or West target station, where it receives proton beam [3].

![Figure 5. The ISAC Target Hall layout, in plan view (layout drawing by M. Gallop, 1997).](image)

![Figure 6. The ISAC Target Hall layout, in section view (layout drawing by M. Gallop, 1997).](image)
Figure 7. ISAC Target Hall, looking in the West direction.

Figure 8. ISAC Target Hall, looking in the East direction.
4. The ISAC Target Modules and Remote Handling Crane

The ISAC target module, which carries the irradiated target assembly, is transported using the target hall remote handling crane, see Figure 9 and Figure 10 [4]. The target module weight is approximately 10,000 kg due to the steel shield plug, see Figure 9.

![Figure 9](image1.png)

**Figure 9.** The ISAC target module being transported by the ISAC Target Hall remote crane.

![Figure 10](image2.png)

**Figure 10.** ISAC target module being delivered to the West target.
The target hall crane has redundancy built into the bridge and trolley drive systems, brakes, and hoists. These redundancies allow the crane operator to continue to transport and lower the target module remotely with the radioactive target during a drive system or hoist single-point failure scenario, so that the radioactive load can be disconnected from the hoist.

The load block on the crane has a gear and pinion rotation stage, which allows the operator to rotate the target module and align it with the target station (see Figure 5 showing the target station angle). The rotation stage on the crane load block has no redundancy. A rotation failure is currently addressed by a turntable device installed at the South hot cell or a dedicated safe landing structure, currently under construction, discussed in sections 5 and 7.

The remote handling crane is controlled using a remote console from a separate room outside of the ISAC target hall, see Figure 11. The crane operators in this room are protected from the target radiation by the concrete shielding walls of the target hall. Alignment of the crane and target module with the target stations, conditioning station, and hot cells is aided by using camera views [3]. The crane PLC control racks are kept in this remote control room, so that they are not exposed to radiation from the target inside the target hall, and so that they may be serviced without personnel access to the radiation environment in case of failure.

The ISAC target hall remote crane was not originally installed with any position feedback system for the bridge, trolley, and hoist. Initially, rulers were added to the walls and bridge with camera views, which allow the human operators to view the approximate position of the bridge and trolley. Later, bridge and trolley laser position sensors were added. Currently, load positions are manually recorded in a log book for each module move.

![Figure 11. The ISAC remote handling crane control console.](image)

In order to lift the target module with the remote crane, a below-the-hook lifting device must be attached to the top of the target module, see Figure 12. The rotation gear on the load block is also visible in Figure 12. Due to the tight clearance between the top of the target module and the underside of the removable shielding blocks (see Figure 6), the lifting device must be removed once the target module is installed in the target station.

Once the target module is landed in the target station, multiple service connections for heating power, diagnostic signal, vacuum pumping and cooling water must be connected to the top of
the target module service cap, see Figure 13. This is currently done manually. There are currently four target modules in ISAC, and many different target assembly configurations. There are approximately 40 service connections made at the top of the module, but the number depends on the type of target and the module in service.

Currently, these service connections are made manually by a technician. It takes the technician approximately 30 to 60 minutes to make the connections. The residual radiation fields in the target station during this service connection are typically 100 to 400 µSv/h at half a metre. The technician will typically receive between 0.1 and 0.3 mSv of dose during this operation. This is the highest routine dose operation performed in ISAC.

Figure 12. Lifting device being connected to the ISAC target module in the target station.

Figure 13. The heating power, diagnostic signal, and cooling water services for the target assembly being connected to the top of the ISAC target module.
5. The ISAC Hot Cell and Target Exchange Process

The ISAC South hot cell has a motorized turntable-lift device with a flange that accepts the target module, see Figure 14 and Figure 15. The turntable is rotated by a chain and sprocket, and lifted and lowered using screw jacks. The turntable can be controlled from the hot cell or the crane control room, and currently provides the redundancy for the crane rotation stage.

![Figure 14. The ISAC South hot cell turntable and lift system.](image)

When the target module is installed at the hot cell, the turntable lift system is used to position the containment box of the target module (see Figure 9) in front of the hot cell window, see Figure 16. The hot cell operator can then open the containment box and access the target assembly inside and perform the target exchange, see Figure 17. The target exchange process at the hot cell involves opening the containment box, removing the expired target, installing the fresh target, and performing a series of checks before closing the containment box. This takes about one full shift (7 hours). Other repairs are sometimes required to the target module, which require the hot cell operator to use the turntable to rotate the target module into different positions.

![Figure 15. The ISAC South hot cell turntable and lift system, with target module installed.](image)
Figure 16. The ISAC South hot cell, operator side.

Figure 17. The ISAC target exchange inside the South hot cell.

- Target module shield plug
- Target module containment box (open to expose target assembly)
- New target assembly installed on target module
- Telemanipulators
- Expired target assembly removed
6. The ISAC Waste Target Disposal Process

To dispose of the expired (waste) target assembly, a modified US 5-gallon pail covered in plastic is brought into the hot cell using the target hall remote crane with an open hook attachment, see Figure 18. The pail is covered in plastic to protect it from contamination on the surfaces of the hot cell.

The waste target assembly is placed into the pail using the telemanipulators, see Figure 19. Then the clean pail lid, with a steel lifting yoke device is lowered into the hot cell, see Figure 20. The lid is attached to the pail in the hot cell with a snap ring using the telemanipulators. The hot cell operator has a procedure for doing this that prevents contamination from spreading to the lid of the pail. The snap ring has some small tack-welded tabs attached to it, which help the hot cell operator support the snap ring over the pail. These tabs are broken off using the telemanipulators after the snap ring is locked to the pail.

![Figure 18. Empty 5-gallon pail wrapped in plastic, being craned remotely into the South hot cell for loading with waste target before disposal.](image)

Once the lid is secured, the plastic is removed from the outside of the pail while the pail is lifted out of the hot cell. The plastic stays in the hot cell. The pail is then transported by the remote handling crane to the decay storage vault, see Figure 21 and Figure 22.

The decay storage vault can hold 24 pails. It has manually actuated latch features on the outside of the vault to select individual drawers, visible in Figure 21. The spent targets stay in the decay storage vault for about two to three years. The dose rates of the targets in the vault are measured periodically to determine if their residual radiation fields are low enough to permit shipping of the waste to a disposal facility.
Figure 19. Waste target being inserted into 5-gallon pail with telemanipulators.

Figure 20. Pail lid, with steel lifting yoke and snap ring being placed on the pail.
After the decay period, the waste targets are removed from the decay storage vault, and manually loaded into a Nordion F-308 shipment flask, see Figure 23. The shipment flask has a removable bottom, and a removable cap with a steel cable system that attaches to the lid of the waste target pail. This cable system allows the pail to be lowered through the bottom of the flask into a below-ground receptacle at the disposal facility. TRIUMF currently makes two shipments of five targets per year in F-308 flasks by truck, from Vancouver, BC, to the disposal site in Chalk River, Ontario, a distance of about 4,000 km.
7. Current and Future Remote Handling Developments in ISAC

TRIUMF currently has two parallel development projects underway for improving ISAC remote handling infrastructure: (1) the ISAC North hot cell and (2) a redundant backup system for the crane rotation called “Safe Module Parking”.

The North hot cell (see Figure 5 and Figure 7) is currently undergoing interior and exterior assembly, finishing, and ventilation upgrades. Once commissioned, the North hot cell will allow TRIUMF to perform routine target exchanges in parallel with development and repair activities on target modules in the South hot cell. Some features of the North hot cell are shown in Figure 24, Figure 25, and Figure 26. The North hot cell features 3-piece telemanipulators, and an access hatch for removing the slaves for maintenance.

The ISAC “Safe Module Parking” concept is presented in Figure 27. This system provides remote rotation backup for the ISAC target hall crane, using a chain and sprocket system for rotating a shielded target module receptacle. It will be installed in the module storage silo area, identified in Figure 5. This system allows target modules to be transported in the target hall without requiring that the South hot cell turntable is vacant (see Figure 14). This provides greatly improved schedule flexibility in ISAC.
Figure 24. Telemanipulator installation into ISAC North hot cell.

Figure 25. Target module landing flange with alignment cameras for ISAC North hot cell.

Figure 26. Removal of telemanipulator slave through access hatch in ISAC North hot cell.
In the longer term, TRIUMF has the following goals for improving ISAC Remote Handling:

- Improve and/or automate the connections to the ISAC target module so that a manual process for making the connections is not required (see Figure 13). This will greatly reduce the time and dose to personnel required for a target exchange in ISAC, and increase operational schedule flexibility.

- Design and implement a remote rigging solution for the target modules that does not require a technician to manually connect the lifting device (see Figure 12).

- Design a remote system to load the waste targets into the F-308 flasks. This process is currently done hands-on (see Figure 23).

8. The ARIEL Project and Next-Generation ISOL Target Remote Handling Facilities

TRIUMF is currently designing a next-generation ISOL target facility called ARIEL (Advanced Rare IsotopE Laboratory). This facility will provide two additional target stations for production of rare isotopes at TRIUMF, and will approximately triple the scientific output of the TRIUMF RIB (Rare Isotope Beam) program.

The ARIEL target hall layout is presented in Figure 28. ARIEL will make use of two driver beamlines: (1) a proton beamline from the existing TRIUMF cyclotron accelerator, and (2) an electron beamline from the new electron linear accelerator, built and commissioned with first beam in 2014 [5]. These two independent driver beamlines will allow simultaneous operation of the two target stations in the ARIEL target hall.

In comparison to the manual process followed in ISAC (see Figure 13), ARIEL will feature improved service connections to the targets and target modules. These service connections will eliminate the need for routine personnel access to the target stations. This will greatly improve operational flexibility and reduce routine radiation dose exposure to personnel.
The ARIEL target hall features a 20 metric tonne capacity remote handling crane, with drive system and hoist redundancies like the ISAC crane, but also with improved position and load feedback and controls technology. The ARIEL target hall crane was installed and load tested in 2015, see Figure 29 and Figure 30.

**Figure 28.** ARIEL target hall layout.

**Figure 29.** ARIEL target hall crane load test and commissioning, August 2015.
ARIEL will also feature a new hot cell facility, see Figure 31. This facility will feature two hot cells, Cell 1 and Cell 2 in Figure 31. Cell 1 will be equipped with two pairs of telemanipulators, two viewing windows, and two motorized turntable lift systems for supporting target station modules, similar to the ISAC South hot cell (see Figure 14). Cell 2 will be used for PIE (post irradiation examination), waste packaging, and material processing.
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