# Rare Isotope Accelerator Remote Maintenance Concepts

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**Abstract** – *The Rare Isotope Accelerator (RIA) will be a basic science user facility to generate high-energy, high-quality particle beams of rare isotopes for nuclear physics studies. The RIA facility will require remote maintenance capabilities in its target gallery and other associated process areas. This paper outlines the conceptual design for the state-of-the-art remote handling capabilities to support the science mission of RIA. Multiple target stations are used to maximize the availability of the experimental facility. The design philosophy is to produce a system capable of performing a target change-out on one beamline while an adjacent beam remains active. This procedure effectively minimizes the downtime of the facility. The facility must be designed for the possibility of removing and replacing all target gallery components. Consequently, all components must be equipped with lift points and remote couplings compatible with the remote handling system. Remote maintenance will be particularly difficult due to the hardware systems involved and therefore will require careful attention to design-for-remote philosophies.*

## I. INTRODUCTION

The Rare Isotope Accelerator (RIA) [1] is intended to provide an intense source of rare isotopes for experimental research. [2] The DOE/NSF Nuclear Science Advisory Committee has recommended RIA as one of its highest priorities for new construction in its 2002 Long-Range Plan. The development of RIA has a number of technical challenges, which are being addressed by research and development efforts at several U.S. institutions. The primary accelerator is projected to be a continuous wave accelerator capable of accelerating all ions including uranium. Beam energies of up to 1 GeV for protons and 400 MeV/u for uranium are expected, with beam powers up to 400 kW. The overall facility will include the accelerator, the target building, and both a high-energy and a low-energy experimental area. The total footprint of the site is expected to be about 100,000 $m^2$. The optimization of targets, calculations of the prompt radiation and activated inventories, and the development of remote maintenance capabilities are all interrelated activities being considered simultaneously. Many of the remote maintenance strategies and equipment selected in the RIA development are base on the experience gained during the design and construction of the Spallation Neutron Source (SNS).

The target building will include the target gallery and all of the required infrastructure and utilities needed to service it. Along with target bays, the gallery must include a waste disposal area and a "clean" transfer cell. Above the target gallery will be a high-resolution crane and a high-bay crane for assembling and replacing the large components in the area. Two bridge-mounted servo-manipulators will be required to minimize downtime during maintenance operations and waste disposal. Also, it is desired to have human access into the target gallery after a required radioactive "cool-down" period. One important issue is preventing contamination in these human-accessible areas. The RIA facility contains two types of high-energy targets: beam fragmentation and isotope separation on line (ISOL).

### *I.A. Fragmentation Target Station*

The fragmentation-in-flight method involves accelerating a heavy ion into a low-Z target material. The fragmented particles from the reaction pass through a set of magnets which are "tuned" to direct the isotope of interest farther down the beamline while remaining fragments enter a beam dump. For the fragmentation target, the beam diagnostics module and the target module are designed to independently insert into a common vacuum vessel (Figure 1). This vessel interfaces with the flight tube from the particle accelerator on the entrance side and a large quadrapole magnet on the exit side. Directly downstream of the quadrapole is a dipole magnet which "bends" the isotope streams in the desired path to pass through or intersect a beam dump. A beam window which isolates this portion of the beamline from the experimental region follows closely after the beam dump. Another set of quadrapole magnets carries the particles into a "wedge" which deflects the specific isotopes in the experimental region. The components described here make up the section of the fragmentation-in-flight beamline which is located inside the target gallery and available for remote maintenance.

exchanging contaminated and clean equipment, respectively, into the gallery (Figure 3). The target gallery also must be equipped with manipulator stations for maintenance activities and storage facilities for radioactive components, spare modules, and tooling. Specific, well-shielded cells within the target gallery will be referenced as "hot cells." These stations will be used to work on highly activated components. The baseline target layout will include two ISOL targets and two fragmentation targets. Possible ways to expand the facility will be explored and given for future consideration.

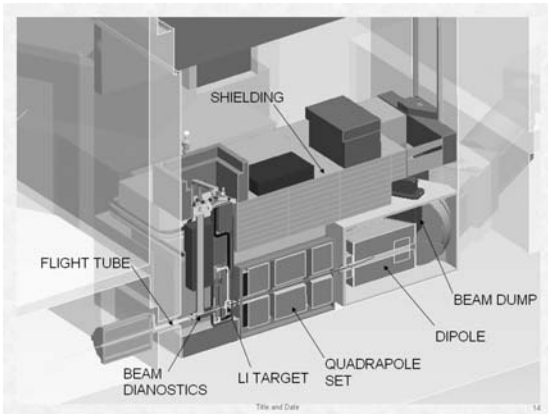


Fig. 1. Fragmentation target station.

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### I.B. ISOL Target Station

Two types of ISOL targets are under consideration. The one-step target involves using a high-density target material such as tungsten or tantalum. The target is bombarded with a proton, deuteron, or a $He^3$ beam. This target is allowed to reach high temperatures (>2000°C) such that the isotopes produced can diffuse from the material. The particles then reach a high-potential ion source which ionizes them so that they can be accelerated through optics and magnet sets into the experimental region. The one-step ISOL concept for RIA is similar to that at the TRIUMF facility. [3] A two-step target is also being developed in which the beam interacts with a primary target to produce energized neutrons which then enter the ion-producing secondary target. The core target can be a mercury loop or solid, water-cooled tungsten. As before, the secondary target is allowed to reach a very high temperature.

The target system employs a large vacuum tank providing a secondary vacuum of about $10^{-5}$ torr and a modular target system. The modules comprising the target system are the beam diagnostics, the target, the beam dump, ion optics, and the dipole/switchyard (Figure 2). Each module seals to the vacuum tank, and some provide additional primary vacuum up to $\leq 10^{-5}$ torr. The target module itself must be isolated at a potential of 60 kV and requires multiple high-power circuits for heating. This requirement alone makes the utility connection design very challenging.

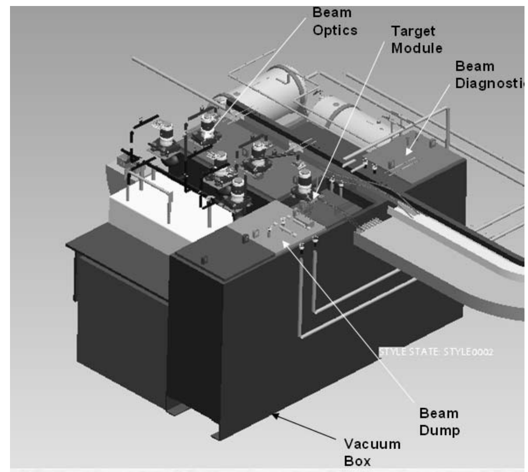


Fig. 2. ISOL target station.

The design philosophy is to maintain the ability to do a target changeout on one beamline while the adjacent beam remains active. This procedure effectively minimizes facility downtime. Also, it is desired to have human access into the target gallery with the beam off after a "cool-down" period. An important issue is preventing contamination in these human-accessible areas.

## II. REMOTE MAINTENANCE REQUIREMENTS

### II.A. General

Along with target stations, the RIA target gallery will also require a waste disposal area and a transfer cell for

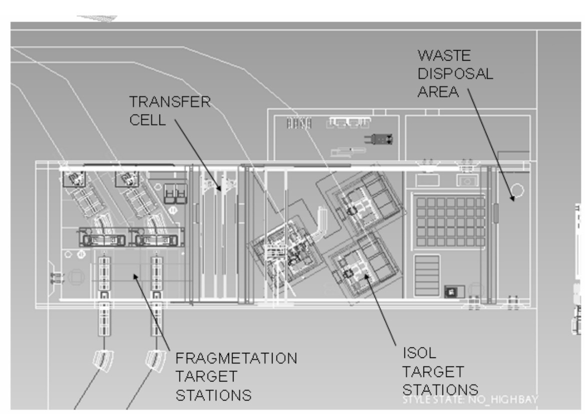


Fig. 3. Target gallery layout.

The facility must be designed for the possibility of removing and replacing all target gallery components including components rated for the life of the facility. Consequently, all components must be equipped with lift points compatible with the remote maintenance system. Access hatches should be sized for the largest component possible to be removed.

The facility will require a target gallery crane and a high-bay crane above the target gallery for assembling and replacing the large components in the area. Two bridge-mounted servo-manipulators will be required to minimize downtime during maintenance operations and waste disposal. This equipment will be similar to that being implemented at the SNS target building, as shown in Figure 4.

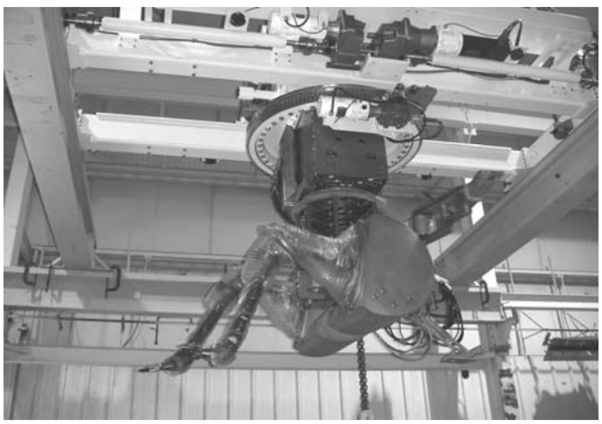

Fig. 4. SNS bridge-mounted servomanipulator.

*II.B. Shielding*

Radiation transport simulations are an integral part of determining many of the remote handling needs of the RIA target gallery. The radiation fields calculated aid in determining component lifetime, construction materials, and size of bulk shielding sections. The thickness of shielding required for personnel and equipment protection ultimately determines the size of the target cell. From this information, cranes and lifting equipment can be sized. The component lifetime determined by radiation damage calculations is a major factor in the development of schedule and downtime planning. The acceptable dose rate for personnel outside the target cell is 0.25 mrem/h. [4] Background dose rates inside the cell are limited only by equipment lifetime issues. For example, the SNS target service bay had a design goal of 250 rem/h in order to maximize component lifetimes and consequent downtime of the facility. RIA will use a similar specification as a design criterion.

*II.C. Fragmentation Target Station*

The first system requirement and remote maintenance obstacle for all targets and beamlines is the vacuum atmosphere required. The fragmentation beamline has a beam diagnostics module adjacent to the target module which is inserted into a common vacuum enclosure (Figure 1). The interfaces must be vacuum-tight couplings which can be released remotely. The enclosure must also be coupled to the adjacent components with a vacuum-tight seal. The coupling hardware must allow for vertical removal of any or all of the units. In addition to the vacuum seal that must be broken, the target has multiple utility connections including coolant, power, and instrumentation. The quadrapole and dipole vacuum enclosures also require vacuum-tight couplings with the same constraints as for the target vacuum vessel.

The beam dump modules will experience high levels of radiation damage from the heavy ions. Consequently, they will require frequent removal and service. The beam dump shares a common vacuum chamber with the dipole magnet because of the close coupling required between the two. The chamber must be designed for a reasonably quick break of the vacuum seal with the beam dump module and must also allow for the removal of dipole magnet components, which may experience failures over the long term. Utility requirements for the beam dump mainly consist of water coolant, but instrumentation may also be necessary.

A beam window is used downstream of the beam dump to separate the target and experiment regions. The window must be constructed of a low-density material to allow the particles to penetrate without significant energy loss. The window will need vacuum seals on both sides and must be designed for vertical removal and replacement. The “wedge” system requires changes during the experimentation and may be somewhat frequent. Therefore, an automated, dedicated changeout mechanism is required for this function.

*II.D. ISOL Target Station*

For the ISOL target station, vacuum containment of the ISOL system is again a primary requirement for remote maintenance. Individual modules as well as the vacuum tank have independent turbo-pumps. These pumps are exhausted to mechanical pumps and then to a storage tank. All of the vacuum pumps will have heavy use and thus relatively short lifetimes. Therefore, the replacement of the pumps will be critical to minimize downtime.

Each module of the ISOL target system will have several utility connections including coolant, power, gases, instrumentation, and vacuum. Remote connection of all these utilities will be a major factor in minimizing maintenance downtimes. Therefore, careful attention to remote maintenance design is required for all of these components.

A beam window is required on the inlet to the vacuum tank and must be remotely replaceable. The tank itself must be replaceable, but because its failure is an off-normal event, the time involved may be extensive.

Another critical requirement for this area is to minimize the spread of airborne contamination. The heavy metal targets could conceivably be used until the material is practically destroyed, leaving contamination free inside the module. Extreme care must be taken to prevent the spread of this contamination during target changeouts or the target gallery will not remain accessible as intended. Figure 5 shows the servomanipulator approaching the ISOL target station pit for service.

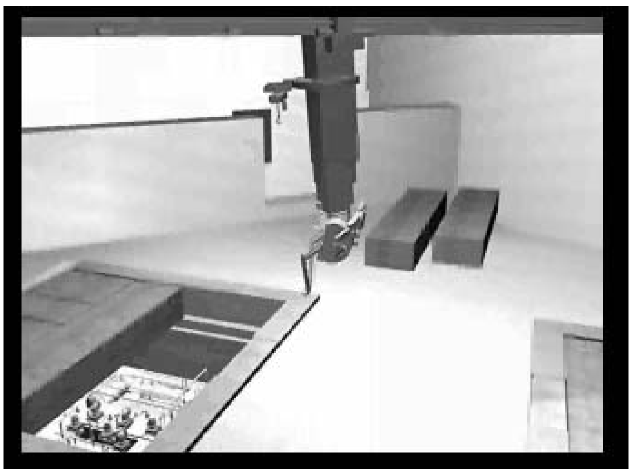

Fig. 5. ISOL station servicing.

## III. REMOTE MAINTENANCE CONCEPTS

Several steps and iterations are required to develop a complete remote maintenance scheme for a given facility. As the design develops and the number and type of components become known, one of the first steps is to classify the components. Classification determines the areas which need the most attention as far as remote handling is concerned. The expected lifetime of components is another important factor which will determine schedule, downtime, and the waste stream of the facility. The RIA classification of components is shown in Table 1

### *III.A Classification of Components*

All components are classified according to their remote handling (RH) requirements by the scheme described below. Classification is based on the need for scheduled or unscheduled maintenance or modification, the likelihood of maintenance, and the impact of the maintenance procedure on RIA operations and availability. Once a component's classification has been determined, the type of RH equipment required, the guidelines for component design, and the program to assure RH compatibility are established. Components that obstruct access are given at least the same classification as the component to which the access is blocked, provided they require RH.

Class 1

The first category applies to those components that require many RH replacement or maintenance operations during the life of RIA (e.g., target modules, Frag beam dump). The component designs and the associated RH equipment and service procedures are optimized to ensure task completion within a specified time. All RH equipment for Class 1 components will be designed in detail during the design phase of the project. The feasibility of Class 1 maintenance tasks is to be verified during the design phase, or prior to final fabrication, and may involve the use of mock-ups. Further demonstration using real components during initial assembly is highly desirable.

Class 2

The second category of components contains those that do not require scheduled maintenance but are likely to require a few to several unscheduled maintenance or removal operations (e.g., target module vacuum enclosure box). These components are designed for full remote repair or replacement, but minimization of repair and replacement time is subordinate to consideration of the component's design, such as nuclear performance and operational reliability. RH equipment for Class 2 components will be designed in detail during the design phase of the project. The feasibility of Class 2 maintenance tasks will be verified where deemed practical and necessary and may involve the use of mock-ups. Demonstration using actual components during initial assembly of the facility is very desirable.

Class 3

The third category of components includes those not expected to require maintenance, such as the ISOL target coolant water delay tank. These components are expected to last through the operating phase, and major maintenance or upgrading is not anticipated. If major maintenance operations should be needed, they will require substantial system disassembly, and the projected maintenance time may be long. Although these components must be designed to make disassembly and replacement feasible by RH means, their design emphasizes reliability and performance optimization. The procedures for maintenance of critical Class 3 components will be defined during the design phase.

TABLE 1. RIA Component Classification

| Frag component | RH class | Expected frequency (years) | Refurb or waste? | Spare | Maintenance/ changeout time* (days) |
|---|---|---|---|---|---|
| Flight tube / magnet | 3 | >10 | W | N | >60 |
| Beam diagnostic module | 1 | 0.5 | R | Y | 2 |
| Target module | 1 | 1 –8 weeks | R | Y | 2 |
| Target vacuum box | 2 | 10 | W | N | 30 |
| Triplet 1 | 2 | >10 | W | N | >60 |
| D1 field probe | 1 | 0.5 | W | Y | 5 |
| D1 liner or winding | 2 | 10 | W | N | 60 |
| D1 vacuum box | 2 | >10 | W | N | >60 |
| Beam dump | 1 | 0.5 | R | Y | 2 |
| Multipole | 2 | >10 | W | N | 60 |
| Beam window | 1 | 1 | W | Y | 5 |
| Triplet 2 | 2 | >10 | W | N | >60 |
| Wedge | 1 | Weekly | Stored | N | <1 |
| Wedge box | 2 | 10 | W | N | 30 |
| Vacuum pumps | 1 | 2 | R | Y | 5 |
| **ISOL component** | **RH class** | **Expected frequency (years)** | **Refurb or waste?** | **Spare** | **Maintenance/ changeout time* (days)** |
| Beam window | 1 | 5 | W | Y | 5 |
| Entrance module | 1 | 2 | R | Y | 2 |
| Target module | 1 | 2–4 weeks | R | Y | 2 |
| Beam dump module | 1 | 5 | W | N | 2 |
| Beam optics module | 1 | 2 | R | Y | 2 |
| Bellows seals | 2 | 10 | W | N | 5 |
| Vacuum tank | 2 | >10 | W | N | >60 |
| Pre-separator | 3 | >10 | W | N | 30 |
| Laser optics insert | 1 | 2–4 weeks | Adjust | Y | 2 |
| Switchyard | 1 | 2 | R | N | 5 |
| Exit beamline | 2 | 5 | W | N | 30 |
| Vacuum pump (turbo) | 1 | 1 | R | Y | 2 |
| Vacuum pump (mech) | 1 | 1 | R | Y | 2 |
| Vacuum valves | 1 | 5 | W | Y | 2 |
| Exhaust storage tank | 3 | >10 | W | N | >60 |
| Exhaust filters | 1 | 1 | W | Y | 1 |
| Water delay tank | 3 | >10 | W | N | >60 |

*All changeout times represent only the RH time required and assume that a replacement component is ready to exchange.

Class 4

The fourth category of components encompasses those that do not require remote maintenance or are non-essential to continued operation of RIA. Class 4 includes components that

1. are hands-on accessible and maintained;
2. are non-essential to facility operation and considered expendable in the event of failure; or
3. have negligible risk of failure.

Examples of Class 4 components include the isotope beamline components that are located within the target station cells and are maintained hands-on.

### *III.B. Component Lifetime Estimates*

The expected functional lifetime of targets and other components, including components which are expected to last for the lifetime of the facility, is important information when trying to determine the equipment and utilities needed to accomplish tasks within the desired time frames. In most cases, the radiation fields determine the lifetime and shielding requirements of individual components. New and developing technologies for radiation-tolerant materials and systems make it difficult to estimate lifetimes for many items. By the time construction begins, the technology for particular components may have changed. Preliminary estimates must be completed in order to give RH design priority to important items with shorter lifetimes.

### *III.C. Waste Handling*

The RIA facility will require a dedicated area in the target gallery for waste handling. The spent targets and other damaged equipment will require disposal and shipping in compliance with the latest DOE requirements. The waste handling area will become the most contaminated and inaccessible part of the facility. From the information provided on lifetime estimates and target stations, one can estimate the amount of the waste stream. The number and size of storage/shipping casks and the frequency of shipments will be determined by the waste stream. Table 2 shows an example of the radioactive waste estimate for the SNS for the entire lifetime of the project. RIA will produce much more waste than SNS.

### *III.D. Remote Maintenance Equipment*

Remote Handling

Given the size of the magnets and the current multi-target layout of the facility, the minimum RH equipment needed for the target gallery is the following:

- Target gallery crane: 50-ton capacity, with auxiliary hoist
- High bay Crane: 100-Ton capacity
- Two bridge-mounted servomanipulators with a vertical range of 7.6 m
- Master-slave manipulator stations
    - two in target gallery
    - two in hot cells
    - one in transfer cell (optional)

Cameras

As with any remote application, visual feedback is an important part of every operation. For the master-slave manipulators this is accomplished by use of a lead-glass-shielded window that allows the operator to see into the work area. Cameras must be used for any other visualization into the target gallery. Radiation-hardened cameras with good reliability and a relatively long life in such an application are now available. An area as large as the RIA target gallery will require many such cameras along with adequate lighting to perform the remote maintenance task. The cameras will be mounted on the crane and servo bridges, allowing for movement into additional viewing areas. The camera's disadvantages are limited depth perception for the operators, black and white images, and dose limits.

Remote Handling Interfaces

The design of remotely maintained equipment must include interfaces that are more easily handled with manipulators and special tooling. Accessibility and ruggedness are important factors, especially for frequently decoupled connections. Pipe couplings that can easily adapt for remote operations—specifically Hiltap and Grayloc types—can be used for frequent and relatively quick decoupling (Figure 6). Figure 7 shows this type of coupling used to seal turbo vacuum pumps on the ISOL target station. Swagelok type connectors can be used for less frequently accessed tube or flexible hose connections. For electrical and instrumentation, connectors that minimize turning of threaded plugs should be used. Special radiation-resistant insulators should be used wherever possible to maximize the lifetime of cables and connectors.

All bolted connections of frequently opened interfaces such as vacuum flanges should employ captured and possibly spring-loaded bolts. This will eliminate any chance of dropping fasteners and expedite their removal. Another important interface for components in a remote area is the lift point. Everything is removed vertically and therefore must be fitted with lifting slings, hoist rings, or lifting features designed for use with specific lifting fixtures.

TABLE 2. SNS Lifetime Rad Waste Estimates

| | | Component | MTBF (yrs) | Total in 40 yrs | Size (in.) | | | Weight (lb) | Residual heat (W) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Hgt | Lgth | Wdth | | |
| **1** | **0** | **Originating in high bay** | | | | | | | |
| | 1 | Small shutter insert | NA | 60 | 16 | 85 | 13 | 1,000 | <100 |
| | 2 | Large shutter insert | NA | 12 | 35 | 85 | 26 | 4,000 | <100 |
| | 3 | Large shutter gate segment | NA | 12 | | | | 20,000 | <100 |
| | 4 | Small vessel insert | NA | 60 | 22 | 60 | 9 | 600 | <100 |
| | 5 | Large vessel insert | NA | 12 | 30 | 60 | 16 | 2,000 | <100 |
| | 6 | Proton beam window | 0.5 | 80 | 33 | 63 | 34 | 5,400 | <100 |
| | 7 | Inner plug, lower module | 2 | 20 | | | | 11,500 | TBD |
| | 8 | Middle plug | 40 | 0 | | | | 20,000 | NA |
| **2** | **0** | **Originating in hot cell** | | | | | | | |
| | 1 | Target modules | 0.25 | 160 | 22 | 80 | 22 | 2,000 | <100 |
| | 2 | Heat exchanger | 40 | 0 | 28 | 132 | 30 | >9000 | <100 |
| | 3 | Pump module | 10 | 4 | 127 | 52 | 52 | >6000 | <100 |
| | 4 | Plug pipe assembly | 10 | 4 | 31 | 280 | 22 | >4000 | <100 |
| | 5 | Cable track | 20 | 2 | | | | >1000 | 0 |
| | | **Total** | | **426** | | | | | |
| | | **Large components/yr** | | **10.65** | | | | | |

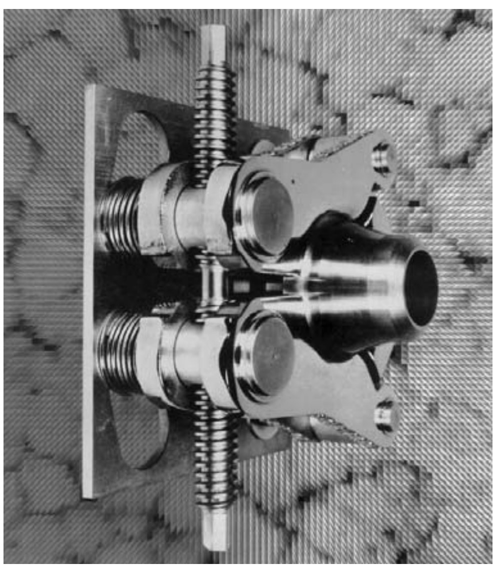

Fig. 6. Grayloc remote maintenance pipe coupling.

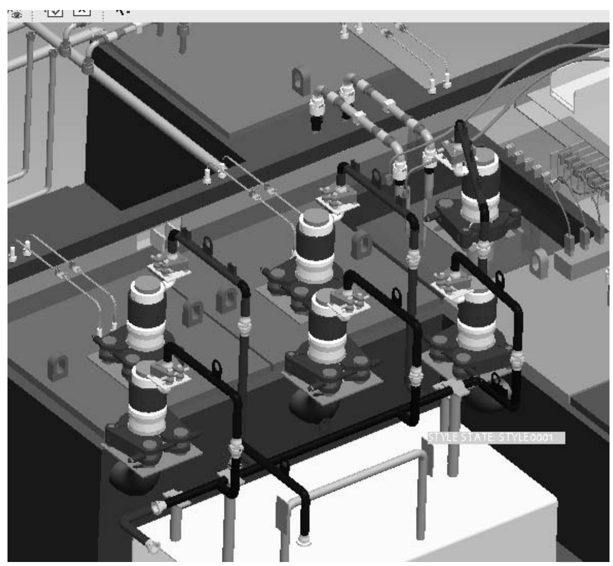

Fig. 7. Application of remote maintenance coupling on ISOL station turbo pumps.

Remote Tooling

The remote tooling required for RIA will include many of the torque and impact wrenches already adapted for other remote maintenance applications. These tools are standard industrial tools that have been adapted with special lifting and handling features. The interface fasteners throughout the cell will be standardized to only a few sizes to minimize the number of tools required for fasteners. Industrial cutting tools will also be adapted for remote demolition and waste reduction inside the target gallery. The tools used can be electric, hydraulic, pneumatic, or manual depending on the application. Other important tooling will be the lifting fixtures. Not only must the tool be designed for loading, but it must also hold the load in the desired orientation. Many fixtures must be self-supporting so that they can be easily picked up by the cranes.

## IV. TARGET MODULE DESIGN

The actual target modules, both the ISOL and fragmentation in flight, are the most frequently changed components in the facility. Targets are not only changed or replaced due to failure, but are also changed because of the experimental requirement for a specific period. Spent target components are also extremely radioactive. Because of the frequency of changes and radioactivity, the target modules must be designed for completely remote maintenance and replacement in a hot cell environment. Included in the facility layout for RIA are specific areas for maintenance on the extremely radioactive target modules (Figure 8). The target module design requires extensive development to reduce the time and complexity of changing target components. Easily decoupled power and coolant connections must be employed wherever possible. Fasteners must be designed and located for maximum accessibility and manipulation. Features should also be included to self-align and support components as they are removed and replaced. Simplified models of the ISOL (Figure 9) and fragmentation target modules have been initiated with some of the features mentioned included. More development will follow as the target design evolves.

## V. CONCLUSIONS

The RIA will be the most versatile experimental nuclear physics facility in the world. Due to the radioactivity produced in the target gallery, the facility will required extensive remote maintenance capabilities. Development efforts at several institutions are aimed at optimizing the facility layout and shielding to maximize production and availability. The design of the target facility and modules themselves will require careful attention to remote handling and maintenance.


Fig.8. Target maintenance “hot cell” station.

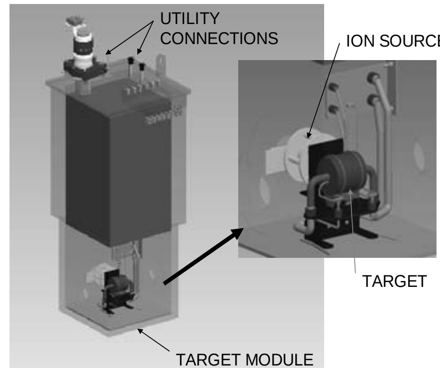


Fig. 9. ISOL target module.

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