Target and mass separator concept for the RIB facility

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Construction has begun on ISAC, a radioactive ion beam and accelerator facility which utilizes the ISOL production method. The ISAC facility includes: a new building with 5000 m^2 of floor space, a beam line with adequate shielding to transport up to 100 μA of proton at 500 MeV from the H^- TRIUMF cyclotron to two target stations, remote handling facilities for the targets, a high resolution mass separator, a linear accelerator and experimental facilities. A novel approach for the target/ion source station is described. The target/ion source assembly and heavy ion optic components are located in a shield canyon under 2 m of steel shielding plug. A separator is to be coupled with either a low energy experimental area or to a linear accelerator for post-acceleration up to 1.5 A•MeV.

1 INTRODUCTION

The TRIUMF's ISAC uses the isotope separation on line (ISOL) technique to produce radioactive ion beams (RIB). The ISOL system consists of a primary production beam, a target/ion source, a mass separator, and a separated beam transport system. These systems together act as the source of radioactive ion beams to be provided to the accelerator or the low-energy experimental areas. We utilize the 500 MeV - 100μA primary proton beam extracted from the H^- cyclotron. A new beam line has been built to transport this beam to two target stations. The target station contains proton beam monitoring equipment, production target and ion source, a beam dump, and the front end heavy ion beam optics. A strategy has been adopted in which the target station is contained in a heavily shielded building connected directly to a hot cell facility. This approach is based on the successful experience at TRIUMF of vertically servicing and remote handling of modular components embedded in a close-packed radiation shield, coupled with the requirement for quick access to the production target and of containment of any mobile activity. Careful design of both the modular components and the remote-handling systems was carried out to ensure the operational viability of this system.

The effective operation of the ISOL system is crucial to the overall ISAC facility performance. It is therefore essential that we build in as much flexibility as possible. The target/ion source module is the key component. It must be serviced, or modified and exchanged on a regular basis to satisfy the varying demands of the physics program. Its design addresses many difficult aspects, including high voltage services, containment of radioactivity, accommodation of different target/ion source combinations, radiation-hard components, and ease of remote handling.

Existing target designs can accommodate up to 10 μA beam intensities and the available intensities of many radionuclides can be expected to scale with the proton beam currents. But, production targets capable of withstanding proton beam intensities up to 100 μA without compromising the yield of radioactive isotopes will be a future challenge. Several approaches to the dissipation of the power deposited in such targets by the proton beam have been investigated and a realistic solution for the removal of the heat from the target container seems possible. The heat transfer within the target material itself, however, is highly target dependent and it is clear that 100 μA operation will be limited at least initially to only a few target's materials. Some of the problems may have to be addressed near the 10 μA level but, in general, heat has to be supplied to the target system to maintain the prescribed temperature. The development of high power target is the subject of a development program at TRIUMF.

Ion beams from most ion sources contain many unwanted ion species, in many cases, several orders of magnitude more intense than those of interest. A mass separator is essential in order to produce RIB. The quality of mass separation required will depend on the particular experiment and the production target/ion source system. In some cases, high mass resolution will be required to remove contamination from the beam, while, in others, high acceptance will be of more importance. A mass separator with a mass resolving power m/δm of the order of 10,000 is proposed to satisfy most of the experimental program. It is composed of two stages. The first stage is used as a cleaning device to remove most of the contamination in the heavily shielded building. The second stage is at high potential with respect to the first stage. Most of the particles having the same momentum but different mass will be rejected at the second stage. This system will allow a large rejection of cross contamination.

2 TARGET STATION

The ISAC target-handling concept and the ISAC target facility is based on fifteen years of experience at operating meson factories. The meson production target and beam stop areas of these facilities have power dissipation and radiation levels similar to, or greater than, those expected at ISAC. Meson factory experience shows that the correct approach to handle components in high-current and thick-target areas, is to place them in tightly shielded canyons. Access to the components is done vertically and repair and service is made in dedicated hot cells.

Three important factors not encountered in the meson factory targets have to be addressed. These are; the containment of large amounts of mobile radioactivity; the high voltage required for beam extraction; and quick routine replacement of short-lived target systems. In the present design these issues are solved by placing the target in a sealed self-contained module which can be transferred directly to the hot cell facility for maintenance. The main guides lines for radiation protection considerations are described elsewhere at this conference [1].

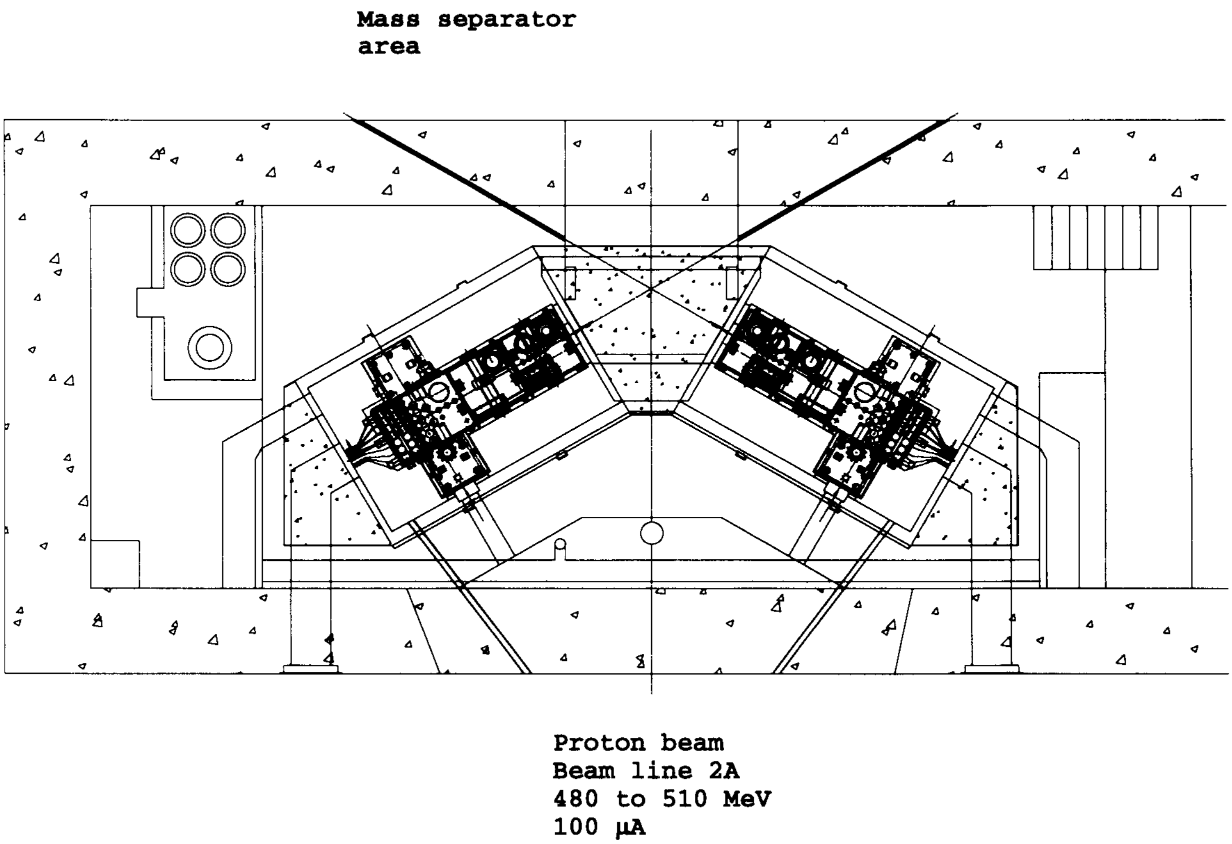

Fig. 1 – Plan view of the ISAC target stations area.

The target stations are located in a sealed building serviced by an overhead crane. The target maintenance facility includes a hot cell, warm cell, decontamination facilities and a radioactive storage area. The target area is sufficiently shielded so that the building is accessible during operation at the maximum proton beam current.

Beam-line elements near the target are installed inside a large T-shaped vacuum chamber surrounded by close-packed iron shield. This general design eliminates the air activation problem associated with high current target areas by removing all the air from the surrounding area. The design breaks naturally into modules; an entrance module containing the primary beam diagnostics, an entrance collimator and a pump port; a beam dump module containing a water cooled copper beam dump; a target module containing the target/ion source, extraction electrodes and first streering component and heavy ion diagnostics; and two exit modules containing the optics and the associated diagnostics for the transport of heavy ion beams. Figure 1 shows a plan view of the target stations area.

The vacuum design seeks to eliminate the need for radiation-hard vacuum connections at beam level by using a single vessel approach. The front-end components, with their integral shields, are inserted vertically into the T shaped

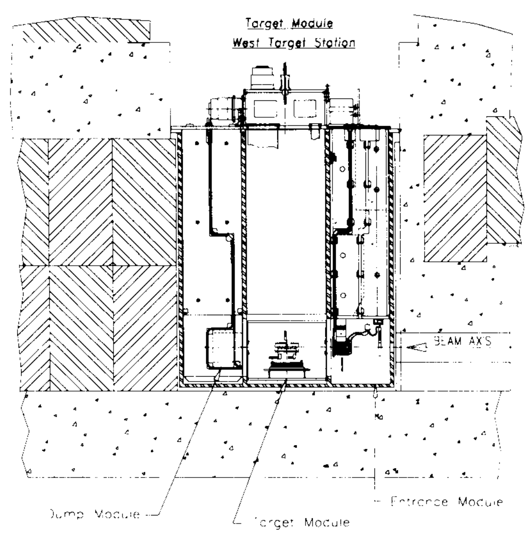

Fig. 2 – Section view of the target station along the primary beam axis.

single large vacuum vessel. Most vacuum connections are situated where elastomer seals may be used. Only two beam-level connections exist; one at the proton beam entrance and one at the heavy ion beam exit.

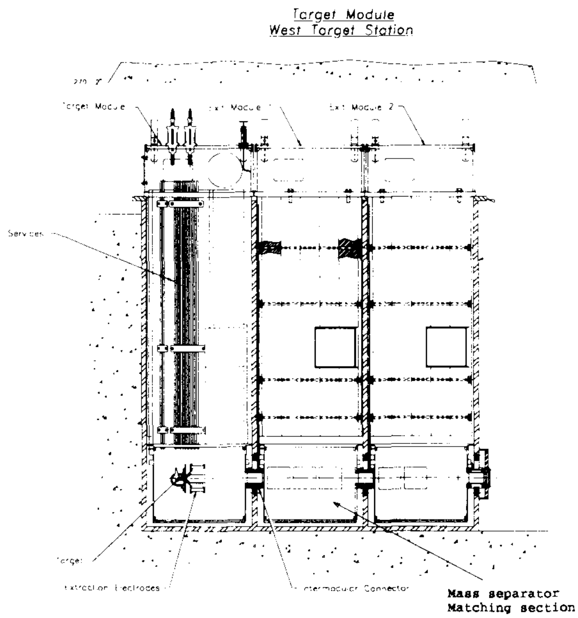

Fig. 3 – Section view of the target station along the heavy ion beam axis.

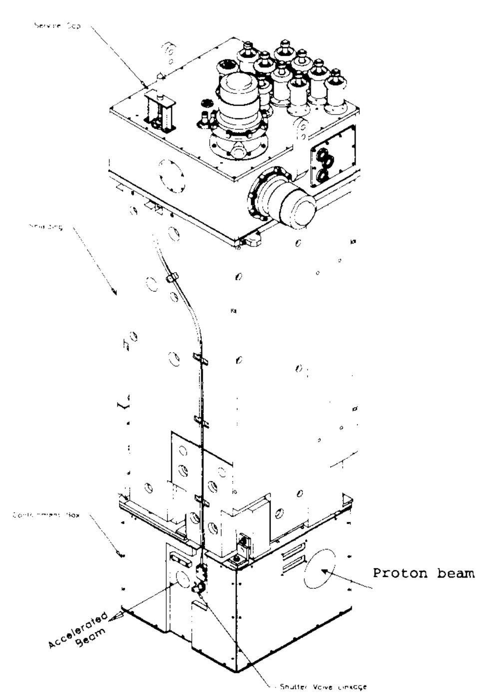

Fig. 4- Three dimensional view of the target module showing the different aspect of the shielding plug concept.

The target stations are shielded by approximately 2 m of steel placed close to the targets, see fig. 2-3 and 4. Outside this steel shielding the operating radiation fields will be sufficiently low so that radiation damage to equipment is not a concern. The steel shielding is surrounded by an additional 2-4 m of concrete, which provides the required personnel protection during operation. To service the targets, shielding above the target station is removed giving access to the services at the top of the steel shielding plugs. Residual radiation fields at this level will be low enough to allow hands-on servicing.

3 Remote handling

An effective remote handling and servicing system will be required to bring about quick and frequent target changes. All modules in the target area will have high levels of residual activity and will be potentially contaminated with mobile activity. Both aspects are considered in the handling design.

Target component maintenance involves disconnecting services and craning the module to the hot cell. Removing aside the concrete blocks covering the target station gives the overhead crane access to the modules. While the target module is pulled out of the canyon personnel are excluded from the area. Target module transfers to the hot cell must therefore be done completely remotely. The connection and disconnection of the target module services can be done manually since the shielding of the module is thick enough to allow hand-on operation.

The mobile contamination produced in the target area is normally contained within the target module. The target module and the two exit modules are equipped with a containment box, which is sealed with pillow-seals to avoid migration of the mobile activity. Nevertheless, contamination of the target building is considered possible. This building must therefore be considered as an extension of the hot cell complex and all entrances must be controlled and provided with appropriate contamination control. The air within the building must be maintained at reduced pressure and HEPA-filtered. The interior surfaces are painted to allow easy decontamination. All fluid drains will go to sump tanks for monitoring before disposal, see Lutz Moritz paper at this conference.

A module storage area is located between the hot cell and the target station. One silo will be provided with the necessary services for the testing and preconditioning of targets before installation for a beam run. This area is fully accessible during beam operation; servicing and testing of modules will therefore be possible during beam production.

The hot cell provides facilities to remotely maintain; replace; decontaminate, or inspect the highly-radioactive components removed from the target area. It is a conventional design with concrete shielding walls, lead glass viewing windows, and sealable roof ports to allow crane access to the hot cell. Personnel access to the top of the cell is possible, if required. The hot cell bay is provided with direct actuated master slave manipulators. The mechanical bay includes remote viewing, service equipment, and an elevating turntable to support and position the component being serviced. The hot cell is kept under negative pressure by its own HEPA-filtered air handling system.

A support annex houses the remote handling control room, offices, personnel change rooms, radiation safety monitoring equipment, and target hall entry air-locks. All the equipment needed to control the remotely-operated crane, viewing systems and other devices is in the control room. Cameras are mounted in strategic locations throughout the building and on the cranes. An air-lock is provided for transfer of equipment into the target hall.

4 Ion Sources

Experience at operational ISOL facility clearly shows that there is not a universal target/ion source combination for the production of all required isotopes for the physics program. Several types of ion sources are foreseen at the ISAC facility. The target module design was done with this idea in mind and flexibility has been provided in the system to allow their successful implementation.

To maximize the yield of a desired species we have to reduce the losses. This means that the ion source has to be closely coupled to the target oven. This fact has enormous implications on ion sources. The hostile environment also dictates that the ion source be both simple and small for sake of economy and to minimize surface area.

The simplest and most efficient of the ISOL ion sources is the surface ionization source. It works well for elements having an ionization potential smaller than 7 eV, such as alkali and some rare earth elements.

For most of the other elements plasma ion source are required. The most common is the arc discharge ion source such as the very successful FEBIAD (Forced Electron Bombardment Arc Discharge) developed at GSI[2] and modified at ISOLDE-CERN[3]. Another type of plasma ion source is the ECR (Electron Cyclotron Resonance) which is very powerful for light gaseous elements and noble gases.

Very recently, optically pumped ionization with LASER ion source has been developed and shows very good ionization efficiency. Combined with a high degree of selectivity this ion source become very attractive for the future development.

4.1 Ion Source Extraction System

The extraction electrodes system is suspended at the bottom of the shielding plug and is pre-aligned to the ion source during installation. The high radiation fields anticipated at the target station preclude the use of electrical components, such as positioning motors, on the extraction electrode.

Mechanical positioning of the extraction electrode through 2 meters of shielding is excluded as impractical and imprecise. This gives rise to, perhaps, the most significant departure from traditional ISOL designs, the use of fixed geometry, multi-electrode extraction systems for all ISAC ion sources. The optimum beam extraction will be accomplished by tuning the voltages of the component electrodes rather than the relative positions of the ion source and extraction electrode. While this approach solves the problem represented by the high radiation field environment, it presents new problems in the need for precise and reproducible alignment and voltage regulation. An ion test stand was built to allow evaluation of various ion source extraction geometries and optics [4].

5 Mass Separator

The front end of the mass separator includes an electrostatic triplet followed by a doublet. The ion optics calculations were performed up to the third order. The mass separator will handle beam from mass 6 to 238 amu, source extraction voltages between 12 and 60 kV. Preliminary mass selection is achieved using a ± 60° pre-separator magnet. The pre-separator is followed by three matching-sections that allow enough flexibility to adapt the beam in order to obtain the same mass dispersion from either target station. The mass separator magnet is the former Chalk River magnet[5], which became available after the laboratory shut down during 1997. The mass separator magnet including the entrance and exit matching sections are on a high voltage platform in order to allow reduction of the cross contamination and ease the magnet tuning.

5.1 Pre-Separator Section

The optic devices following the ion source are also suspended at the bottom of the exit modules shielding plug. The limited space allowed by the size of the shielding module complicated greatly the optics design. Furthermore, the type of ion source foreseen at ISAC will have different sizes, modifying the position of the object point. This problem was solved by using an electrostatic triplet just after the ion source. Downstream an electrostatics doublet prepares a parallel beam for the pre-separator magnet. The role of the pre-separator is to act as a cleaning stage in order to limit the contamination in the rest of the mass separator. The mass dispersion of this stage is about 0.3 m. The magnet is designed in such a way that the yoke steel is used as a shield of the contamination deposited inside the vacuum chamber.

5.2 Matching Sections

The pre-separator is followed by three matching-sections, which permit to adapt the beam from either the East, or the West target stations. We can change the magnification sign M according to the target in use and obtain the same mass dispersion after the second mass analyzer.

5.3 High Resolving Power Separator

The mass separator magnet is the old Chalk river mass separator. We just modified the entrance and exit arms in order to adapt the magnet to our needs. The magnet is equipped with so called α and ß coils. The α coil allows correction of the magnet index and the ß coil allows adjustment of the second order correction provided by the pole face curvature. The magnet is on a high voltage platform that will allow rejecting the cross contamination. Such cross contamination comes from ions of different mass which have the same momentum, for example, due to collision with the residual gas. After acceleration these ions will have different energies and moment. Consequently, a mass separation becomes possible.

After the mass separator selection slits the beam is injected into the low-energy-beam-transport line (LEBT). The ion beam from the mass separator is to be switchable between the Low Energy (LE) experimental area and the accelerator. At the same time, it is desirable to have an off-line source, which is switchable between the same two areas, although its primary purpose is for commissioning the accelerators. A switch-yard has been designed which meets all these goals. At the heart is a cross-over switch which allows the off-line source to supply beam to either the RFQ or the LE, while simultaneously, the mass separator can supply beam to the LE or the RFQ, respectively.

7 TARGET AND MASS SEPARATOR SERVICES

7.1 Vacuum System

The vacuum system of the target station consists of two separated vacuum stages; the primary vacuum which will contain all the exhaust gasses escaping the target/ion source and a secondary vacuum which will surround the target and the extraction and the heavy ion beam transport system installed into the two exit modules. The primary vacuum is expected to be very contaminated by radioactive species produced in the target wile the secondary vacuum is expected to be less contaminated. All the exhaust will be stored into two tanks.

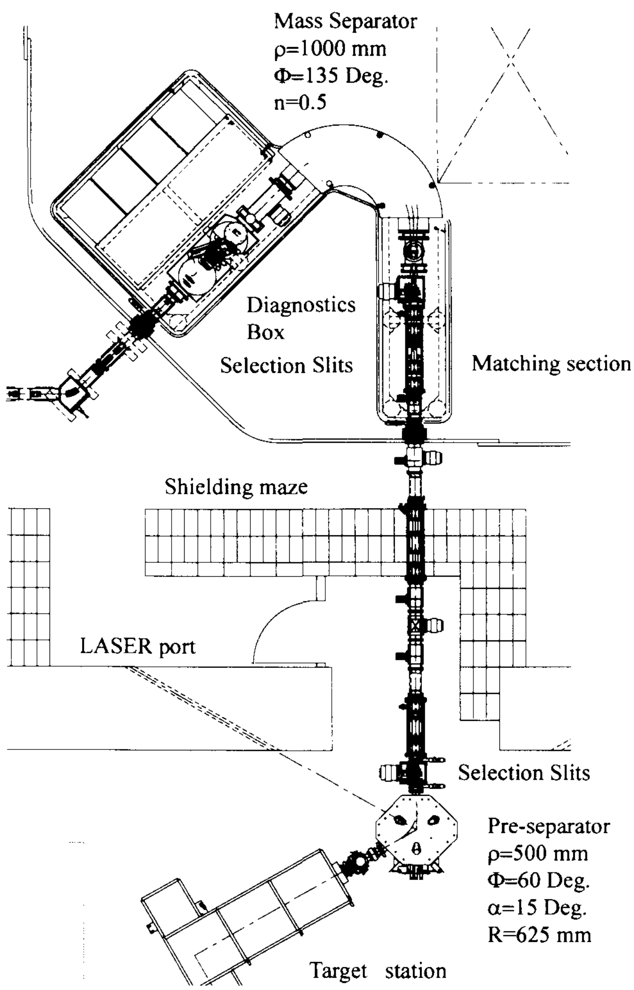

Fig. 5 – Layout of the ISAC mass separator.

7.2 Ventilation

In addition to supplying fresh air and removing stale or contaminated air, the ventilation systems for ISAC building will maintain the prescribed pressure differentials that will prevent the inadvertent leakage of airborne radioactivity. These are the short-lived, hadron spallation products of oxygen and nitrogen in the air around the high power targets.

There are two exhaust systems for the radioactive areas. A small one of 100 m^3/min which is dedicated to maintain a depression in the beam line 2A tunnel.

The other is the main ventilation system for the ISAC building. It is designed to exhaust 660 m^3/min of air from six independently regulated exhaust pick-up points each with a capacity of 110 m^3/min. The air flows through HEPA filtration system.

7.3 Cooling system

The dissipated power in the beam line and target will be dissipated in a raw water evaporator. All the cooling circuits for components will use de-ionized water in closed loop systems that transfer their heat to the raw water through heat-exchangers. This design maintains water purity and prevents the release of any radioactivity that is produced by nuclear reactions in the cooling circuit. There are three de-ionized water systems. They cool equipment as follows;

1) non-active low conductivity water,
2) active low conductivity water,
3) high-active low conductivity water.

The first system cools all component which is considered non-radioactive or where the radioactivity contamination probability is expected to be very low. The system services all water-cooled power supplies and vacuum pumps, mass separator beam line components.

The second system cools all equipment which is radioactive but not in direct contact with the target/ion source vacuum chamber and thus is not exposed to high level of neutron radiation fields. This means that the concentration of tritium radioactivity which cannot be removed by ion exchange will be low. The system services the primary proton beam line, the high-active heat exchanger, the target assembly components outside the vacuum tank, the target module storage area, the pre-separator magnet, and the high voltage lines from the Faraday cage to the target.

The third system cools all components inside the target assembly vacuum tank. As this water is exposed to the intense radiation fields from the target bombardment, it will contain tritium at concentrations similar to those in the existing meson production target cooling systems.

8 Status of the ISAC Project

The ISAC building is now completed. The target East and West vacuum boxes are being aligned. The ventilation system is operational and the vacuum system is being installed. The five shielding modules are on site. The entrance and beam dump modules are completed and have already been successfully installed and used for the beam line 2A commissioning.

The mass separator is being installed and first stable beams for the mass separator commissioning are expected in August. We intend to produce the first radioactive ion beam for the TRIUMF Neutral Atom Trap (TRINAT) experiment in November this year.

9 REFERENCE

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3- M. Dombsky et al. Nucl. Instr. and Meth., B70(1992) 56-61.
4- S. Sundell et al. Nucl. Instr. and Meth., B70(1992) 160-164.
5- H. Schmeing et al. Nucl. Instr. and Meth., 186(1981) 47-59.