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Shielding and Handling of Targets for a High Intensity Radioactive Ion Beam Facility

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TRIUMF

There has been a steadily growing worldwide interest in generating accelerated beams of unstable nuclei for use in a variety of applications such as nuclear physics, nuclear astrophysics, atomic and condensed matter physics, and medicine. A number of facilities, either planned or under construction, will couple an intense production source of unstable elements to an efficient accelerator in order to produce accelerated ion beams of a wide range of nuclei far from stability. We describe here the production targets and their shielding as designed and constructed for ISAC, the high-intensity accelerated radioactive ion beam facility at TRIUMF.

The shielding for the targets is integrated into each target module so that all services and radiation-sensitive connections are made outside the shielding and the vacuum enclosure. This allows the use of, for example, elastomer seals for the vacuum connections. Including the weight of the steel shielding, each target module weighs approximately 15 tonnes. For servicing, the target modules are removed vertically by a remotely operated crane. The modules may then be transported either to one of two hot cells for maintenance or to a storage silo. The remotely controlled transport takes place in the Target Maintenance Hall. This is a shielded, ventilated building that allows the target modules to be transported without shielding for the induced radioactivity.

We also present some observations of experience during the initial commissioning at low and medium proton beam intensities.

KEYWORDS: RIB, Radioactive ion beams, targets, shielding, remote handling

I. Introduction

The new radioactive ion beam facility at TRIUMF is of the ISOL type. This means that the ion beam is produced by bombarding a thick target with energetic (495 MeV) protons. The target is heated to high temperature and the atoms liberated in this way are transported by diffusion or effusion to an ion source contiguous with the target. The beam of mostly radioactive ions is separated by a magnetic spectrometer and a selected species of ions is transported to experiments or to be further accelerated. A wide variety of radioactive ions may be produced through judicious choice of the target material. There is some incentive to use high mass targets such as ThC or UC_2 to serve as general purpose generators of a wide spectrum of ions.

The goal at ISAC (Isotope Separator and Accelerator) is to eventually bombard targets with up to 100 μA of approximately 500 MeV protons, i.e. with a beam power of 50 kW. For a typical high-Z target, 50 g cm^{-2} thick, this would lead to a saturated source strength of approximately 5×10^2 TBq and a residual γ-radiation field of up to 10 Gy h^{-1} at 1 m. It is clear that such targets require remote handling.

A second radiological issue is the possibility of high levels of contamination which might be generated by operating such targets, especially those high-Z targets that might produce α-emitting radioisotopes. The requirement of the experiments to efficiently extract the greatest possible quantity of radioactivity from the targets is at odds with the requirement to minimize the spread of radioactive material.

II. Design of targets

At ISAC there are two production target stations for generating radioactive ion beams. The proton beam may be directed to either one or the other and the ion beams generated in these targets are directed into the same ion beam separator and transport system. This allows one target station to be operational while the other is being serviced.

The design of the target assemblies for ISAC is based on the experience at the existing meson factories at PSI (Switzerland) and LAMPF (USA), as well as TRIUMF. The targets are mounted at the bottom of approximately 2 m long steel shielding columns suspended in an evacuated tank. This vacuum tank contains several such columns holding the front-end radioactive ion beam transport elements as well as the proton beam diagnostics and the proton beam dump. The shielding columns have been made sufficient thick so that any service and vacuum connections made outside the shielding will not be subject to significant radiation damage during the operational life of the facility. The shielding also assures that residual radiation fields will be sufficiently low at the point where these service connections are made to allow hands-on manipulation.

The service space above the target modules is accessible from above after the removal of the overhead

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shielding and the target assemblies, including the shielding columns, may be withdrawn from the vacuum enclosure and the surrounding shielding by an overhead crane. The targets are closely coupled to a variety of ion sources which require numerous services. The resultant target module, including the approximately 2 m high steel shielding column, weighs some 15 tonnes and is too heavy to further enclose in a shielded flask for transport. It was therefore decided to transport the targets to the service hot cells without shielding using a remotely driven crane. The arrangement is shown in **Fig. 1**.

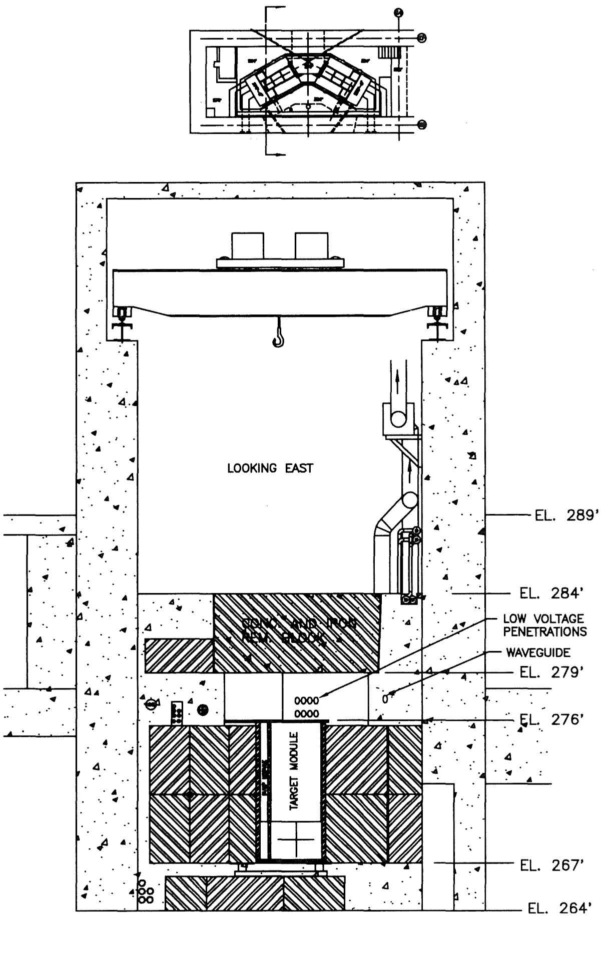

Fig. 1 Cross section through the heavily shielded ISAC Target Maintenance Hall showing the remotely driven crane used to transport radioactive components of the target/ion source. The small inset at the top of the figure is a plan view of the arrangement of the two targets.

The transport takes place within the Target Maintenance Hall, which also contains two hot cells for servicing the targets and a storage area for used targets. This hall is shielded on all sides by approximately 1.2 m of concrete and is kept at a negative pressure with respect to the outside. Before a remote transfer of targets can take place the hall must be searched and cleared of all personnel. An Access Control System enforces this search and is interlocked to the remote crane control system.

The requirement to operate highly efficient target/ion sources and the need to contain all loose radioactivity are contradictory objectives. Typically targets consist of an 'oven' made of a refractory material such as tantalum, filled with the target material which may be heated to temperatures up to 2000^o C during bombardment. Optimizing such a target/ion source to yield the maximum ion beam intensity for a particular elemental species will also optimize it for chemically and physically similar species. The neutral refractory atoms will plate out on the nearest cool surface but the volatile neutral atoms will be pumped away by the vacuum system. The most severe problems will be encountered for targets of high atomic number such as Th and U because they are capable of producing the greatest variety of radioactivity (including α-emitters).

To address the need to contain any possible contamination during removal and transport of the target modules, the target (and each of the front-end ion beam transport modules) is enclosed in an aluminum 'containment box' that completely surrounds the target. The inside of this box constitutes the 'primary' stage of a two-stage vacuum system. The vacuum outside of the box constitutes the second stage. Both the exhaust from the primary stage and that from the second stage is pumped into shielded hold-up tanks to allow the radioactivity to decay. The target containment box has water cooled entrance and exit windows for the proton beam and a shutter for the ion beam that is closed during transport. An exploded view of the target assembly is shown in **Fig. 2**. The steel shielding which surrounds the vacuum exhaust chase is not shown in this drawing.

III. Shielding Calculations

The calculations for the shielding of this facility were done using a modified version of the Moyer Model wherever the geometry was simple. This method is described elsewhere in these proceedings [(1)]. For complex geometries the multipurpose Monte Carlo code FLUKA [(2)] was used. An example of a calculation for complex geometry is that for the shielding above the target service space. Account has to be taken here of the vacuum exhaust chases through the target assembly steel shielding. The shielding above the service space was optimized using a mixture of steel punchings and ordinary concrete in a ratio of 1:1 by volume. The result of a typical FLUKA run is illustrated in **Fig. 3**. **Fig. 4** shows the attenuation of the neutron dose equivalent through the composite top shield. The top 30 cm are composed of standard concrete. The upper two lines show results for slightly different geometries of the vacuum exhaust chase and the lower line indicates the attenuation if there is no chase.

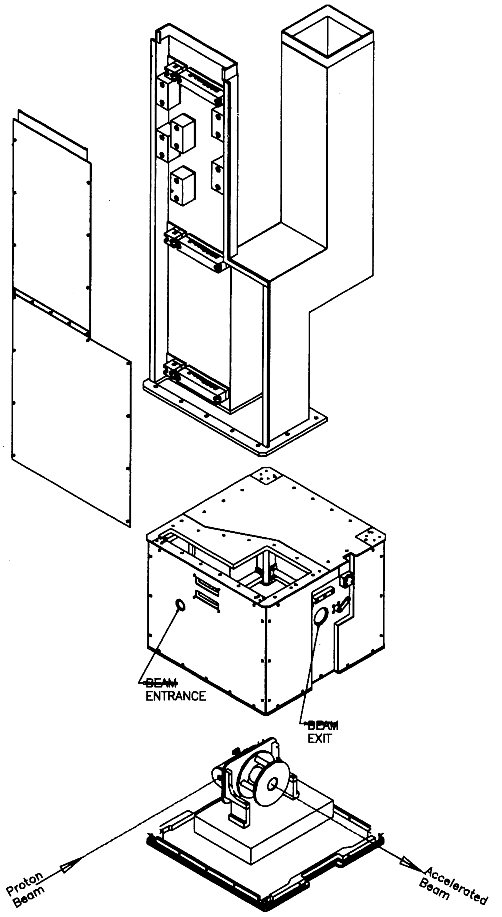

Fig. 2 An exploded view of the target/ion source module, showing the containment box below with the target/ion source on its alignment plate. At the top is the vacuum exhaust chase and the service duct. The space surrounding these is filled with steel shielding.

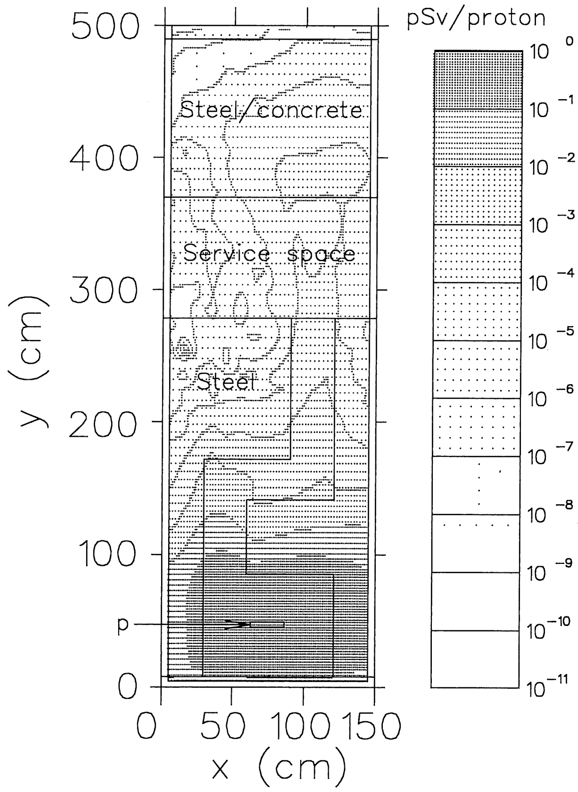

Fig. 3 Vertical section through the ISAC target assembly showing streaming through vacuum exhaust chase. The proton beam enters from the lower left at $y = 50$cm. Shown are neutron ambient dose equivalent calculated using the Monte Carlo code FLUKA.

IV. Calculation of target radioactivity inventories

Both in order to make estimates of the radiation fields from the irradiated targets and in order to evaluate the possible consequence of releases of radioactive volatiles, detailed calculations were performed of the radioactive inventories. These were mainly based on the Silberberg and Tsao semi-empirical cross section formulae (3) (4), although for critical radioisotopes such as the radio-iodines, experimental data were used wherever possible. Very little data is available for the radioisotope production by the bombardment of U and Th with 500 MeV protons and the Silberberg and Tsao formalism is suspect in this mass region. We therefore also used the Monte Carlo code FLUKA and the LAHET code system (LCS) (5) to estimate cross sections for U and Th. **Fig. 5** shows a comparison between the Silberberg and Tsao estimates and calculations using LCS. The agreement is poor for low mass products because the LAHET code does not have a good model for fragmentation reactions. There is also poor agreement in the spallation region near mass 180 although other considerations seem to indicate that the LCS calculations are more reliable here (6). Unfortunately this is the region of the production of Po isotopes which are mobile α-emitters. We are presently refining our estimates and hope to do measurements to improve our understanding of the radioisotope production from these targets.

V. Experience so far

As of this writing there have been only two runs at low intensity (< 1 μA proton beam) on a low mass target (CaO) each lasting for a few days. As far as it was possible to make measurements with such low proton beam currents, the shielding estimates seem to be in agreement with the calculations to within better than a factor of two. Several transfers of an irradiated target were performed and basically no contamination was detected outside of the target containment box. At the present time commissioning is proceeding with a medium mass target (Nb) at proton beam intensities up to 10 μA.

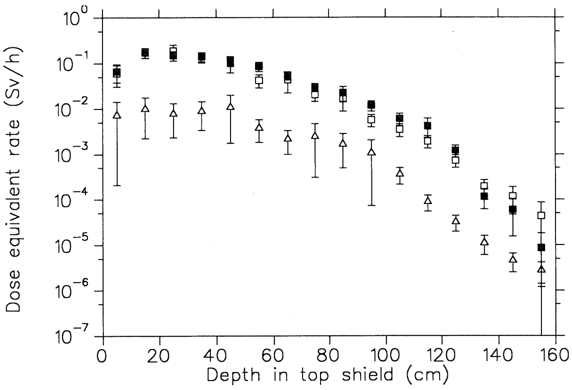

Fig. 4 Attenuation of the neutron dose equivalent in the shielding above the target service space. The shielding consists of a mixture of steel and standard concrete in the ratio 1:1 by volume except for the last 30 cm. The calculations were done using FLUKA for two slightly different geometries for the vacuum exhaust chase (upper curves) and for no vacuum exhaust chase (lower curve).

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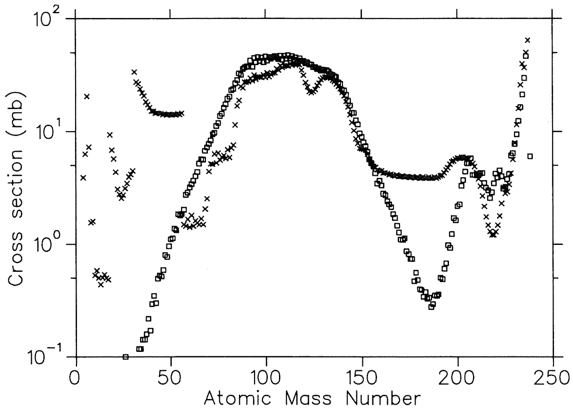

Fig. 5 Radioisotope production cross sections summed over Z as a function of atomic mass number A for 500 MeV protons bombarding a U target. Open squares are calculated using LCS, crosses using the semi-empirical formulae of Silberberg and Tsao.

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