Solid Targetry Systems: A Brief History

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In the last twenty years we have witnessed a dramatic increase in the demand for accelerator-produced radioisotopes and a corresponding increase in the beam capabilities of the new generations of commercial production cyclotrons. This paper will attempt to trace the changes in the design of external solid target systems for radioisotope production and discuss the many new challenges imposed by pushing the extracted beam currents to one milliampere and beyond, especially as applied in the "MDS Nordion" facility at TRIUMF.

Introduction

The solid production target system is the backbone of the radioisotope industry. As such, it is expected to perform continuously with minimum failure time and maintenance. Those expectations, indeed demands, pose a considerable engineering challenge. By the very nature of their use, the irradiated target and its systems work in a harsh environment of high radiation fields, limited access, high vacuum integrity and fully remote and (in most cases) automatic operation.

Internal Targets

Solid radioisotopes targets can be of the internal (to the accelerator) or external type. Internal targets were in the past a necessary compromise for the positive ion machines that were dominant at the time.

While the production of positive ions is much simpler than negative (simple internal PIG system ion source can deliver several milliamperes of ion beam) their extraction is tricky. Electrostatic deflectors limit the practical extraction currents to much lower values as beam losses and the associated activation of the deflector become unacceptablely high.

Placing the target directly in the cyclotron vacuum tank to intercept the internal beam dispenses with the extraction, but at a considerable cost:

- Immediate exposure to cyclotron vacuum does not provide the comfort of separation and an independent pumping system
- Design restricted by cyclotron limiting the access and space.
- Most serious problem: cyclotron activation and contamination due to high neutron fields produced during the target bombardment. In fact the radiation damage to the components, combined with the long lived activity produced in those parts, can make the cyclotron almost a consumable item under regular production schedule.

While the design of the target itself and its transfer system can be similar to the external concept (because of the serious drawbacks of the internal target design), it is not practical in modern practice, especially in view of the advances in negative ion machines.

External Targets

In the last decade, improvements in negative ion sources (usually H^-) combined with efficient extraction made a high current external target, which is placed in the extracted beam some distance from the cyclotron, a practical reality. (The new generation of external targets at TRIUMF can, in fact, handle more power than internal targets).

The slightly higher initial cost of the beamline and its components is, in a short time, offset by the savings in maintenance, higher production rate, and lower operating personal dose. Multiple extraction from different sides of the cyclotron allows one cyclotron to serve more than one beamline and several targets simultaneously if needed. Best of all, target irradiation stations can be placed in independent vaults allowing service without disrupting cyclotron operation.

The first production facility layout of TRIUMF (featuring a 42MeV, 200μA negative ion cyclotron), however, placed the two target stations in the same vault, just a short distance from the cyclotron (Fig.1). This was due, in part, because a budget restrictions and part lack of practical operating experience. Local shielding "igloos" around the target stations, intended to protect the cyclotron and other vault equipment were designed but, luckily, not constructed! Those would not only have limited the service access but would have forced the service personal very close to the active station.

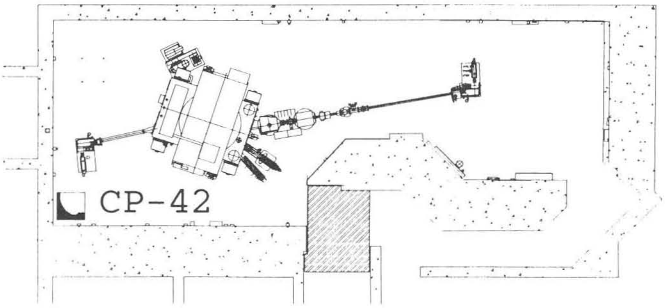

Figure 1: Old configuration of CP-42 Cyclotron and Target Stations

The introduction of a second cyclotron (30MeV 1mA negative ion, TR-30) allowed changing the original layout and moving target stations to separate vaults (Fig. 2). By providing "beam blockers" (moving neutron stopping plugs in the beamlines) each target vault can be completely separated from the cyclotron and each other, allowing full access even during irradiation of the other targets in different vaults.

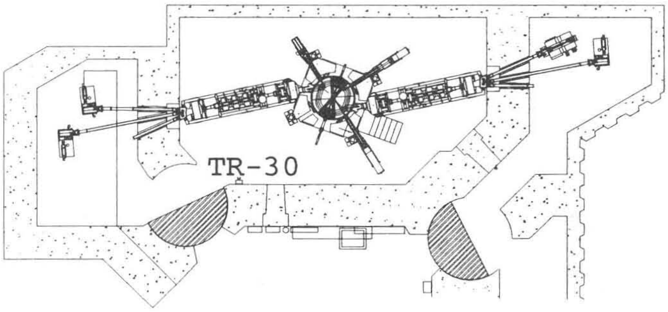

Figure 2: Configuration of TR-30 Cyclotron and Target Stations

Transfer System

There is more than one way to "skin a cat", or move active targets from the irradiation point to the processing area. Those vary in sophistication, starting from a stick, a bucket, and a fast runner!

Some facilities use various forms of mechanical moving tracks and miniature trains or chains. These, while slow, perform well. At TRIUMF, we used a 3" diameter pneumatic transfer system, similar to the pneumatic mail systems installed in offices and factories. This system is fast and reliable but has to be properly designed to avoid the venting of contaminated air to the clean areas. In the current arrangement the targets are "sucked" from the irradiation facility to the landing terminal in the processing cell, and blown the other way.

The original mechanical transfer sensing switches are being replace with electric sensor activated by a small permanent magnet in the travelling target shuttle. A reversible commercial blower supplies the air.

The reliability of the system was recently improved by installing a positive locking mechanism on the target in its transfer shuttle ("rabbit").

Target Irradiation Station

Slowly improving on earlier versions we are now at our 3rd generation of target stations. The many improvements and changes can be categorized in three main areas:

a) *Changes in the concept of target placing.* The first design was awkward. The target (see next section) was pulled into the beam making an internal cooling water connection inside the vacuum chamber. The dispersing of the beam along the target face was done by providing an integral 7° tilt to the target face. The newer design departed completely from this arrangement. The problematic water connection were made outside the vacuum chamber, the target being pushed into the beam path. To simplify the target design the chamber itself was placed at 7° thus allowing the target to remain flat [1,2].

b) *Target manipulation.* Further improvements followed. After the transfer, the target (in its rabbit) is oriented the proper way, removed from the rabbit, and placed in the vacuum chamber while making the cooling water connections. By eliminating some parts the whole process became more reliable. The orientation, for example is achieved by permanent magnets (using the same transfer sensor magnet in the rabbit) completely eliminating mechanical components. The mechanical manipulator was simplified to provide a firm grip on the target while allowing positive locking of the target in the rabbit. The landing brake (the target transfers at about 3 m/s) was completely removed and by sealing the landing terminal the rabbit comes naturally to a gentle stop. This is a perfect example of improving the performance and reliability by removing components and simplifying the design.

c) *Improvements in radiation hardness.* With the increase in beam currents and irradiation times, many target station parts fail as a result of radiation damage. Plastics and elastomers are most vulnerable, but pumps, electric motors, pneumatic piston etc. fail as well. Some consideration should be given to the activation of target station parts and in some cases, we do not find both qualities in the same material [3].

The latest generation of TRIUMF's solid targets solved many of these problems (Fig.3). Metal seals and metal tubes replaced the elastomers. Air cylinders were custom built using graphite seals. Pumps, valves and other parts that could not be physically separated from the station (many, like water and air solenoid valves were simply placed outside the vault) were mounted farther away from the beam impact point. For electrical insulating purposes we found polyimide and polyurethane can withstand high radiation doses without suffering much damage. To reduce activation and long term residual activity, many components are made from pure aluminum rather its common alloys [6].

Target

Higher beam currents, lower cost, and longer target life have resulted from three generations of targets at TRIUMF. As mentioned earlier, the first target (made out of copper) included an integral 7° slant for beam dispersion. The one piece construction included machined seals in the target itself. This was soon replaced by a two part silver face target designed to stop a 6kW beam with a 150°C temperature rise. Since the 7° tilt was built into the chamber target, manufacture was much simplified. By providing a bolt-on aluminum adapter the seals were separated from the target body and this reduced the cost further. In the current design the target was enlarged to accommodate higher beam powers up to 20kW and more. The single piece design features a silver face soldered to an aluminum body. Despite being bigger, the target is lighter and less expensive than the smaller target.

A major consideration in the target design is the surface temperature, especially in the case of low melting-point target materials. The design objective was to keep it below 150°C allowing a safe margin when using thallium (the powers and beam currents quoted are for this surface temperature). Higher current are, of courses, possible for different materials. Two water cooling schemes are used. In the first, water is forced thorough thin parallel groves in the target face plate. Larger targets have more grooves and require higher water flow. Special attention must be given during the target construction to mechanical strength as the 6 bar water pressure (combined with vacuum on the other side) can deform the target face [4].

A simpler cooling arrangement was implemented in the encapsulated style targets. Concentric water flow using a central nuzzle simplifies considerably the target manufacturing and provide a mechanically strong circular geometry, while providing a cooling pattern optimized for the beam profile. The thermal performance of the target has been analyzed using finite element analysis and experimentally verified [7].

Embedded and surface-plated thermocouples were used to measure the surface temperature showing a good correlation with the calculations. A special germanium window was constructed to measure the thermal profile using an infrared camera, but difficulties in setting it up combined with the reluctance to activate the (very expensive) camera prevented us from obtaining conclusive results [5].

Controls

Following modern automation practice the irradiation system is controlled by a programmable logic controller (PLC). This approach allows maximum flexibility in the system operation and allows full monitoring of the large number of parameters such as water flows, beam currents and vacuum.

The control system can be only as good as the sensors so these were steadily improved as well. Radiation hard ceramic limit switches are used now in radiation areas and, as pointed earlier, some were replaced by passive pickup coils and magnetic switches. These have to be radiation hard, eliminating the choice of using electronic devices. In its present configuration the control allows varying degree of operator intervention from fully automatic target placing and retrieval to step-by-step sequencing. The last mode is especially useful in case of problems.

Future Developments

To expand the versatility of the targetry system a new design, representing a major departure in the target construction, was tested at TRIUMF (Fig. 4).

The encapsulated target system is for use with horizontally oriented encapsulated targets, which are carefully designed so that the target material and its irradiated product are completely isolated from the rest of the system. The target station, while still based on the existing high current solid target system, incorporates several custom designed modular subassemblies.

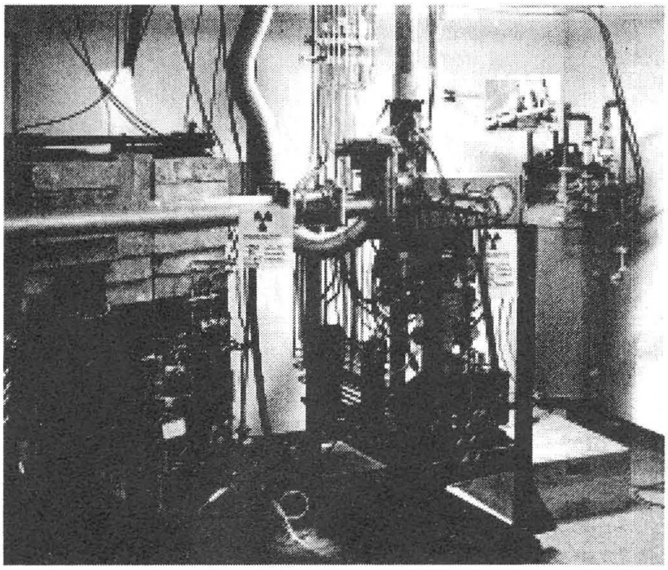

Figure 3: Solid Target Station in Cyclotron Vault

Additional reduction in target fabricating cost was achieved by adopting a circular geometry for the target, and water cooling channels are now part of the manipulator leaving the target itself as a simple thin cup about 60 millimeters in diameter.

The encapsulated target is a bimetallic assembly that comprises a copper or silver central disc and a stainless steel ring. These two parts are silver soldered together to form one assembly. The target material is placed in a shallow recess of the central disc and a thin foil is electron beam welded to the periphery of the target. The encapsulated target is concentrically water-cooled and can withstand up to 240µA 30 MeV proton beam bombardment at a 12.5° angle. The horizontal beam dispersion is provided by the bending magnet [7].

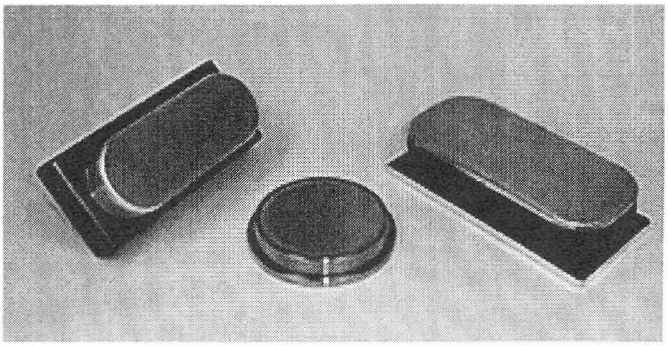

Figure 4: Three Generations of targets at TRIUMF: 6kW target (left), encapsulated, and 15kW target

Conclusion

Starting with the first beam at TRIUMF's radioisotope production facility in 1982, we have seen a steady increase in the production level, mostly on the solid targets. The gradual improvements in targetry systems not only allowed us to achieve that production growth but, combined with a well designed maintenance program, considerably reduced the crew indication dose, despite the aging of the facility (Fig. 5).

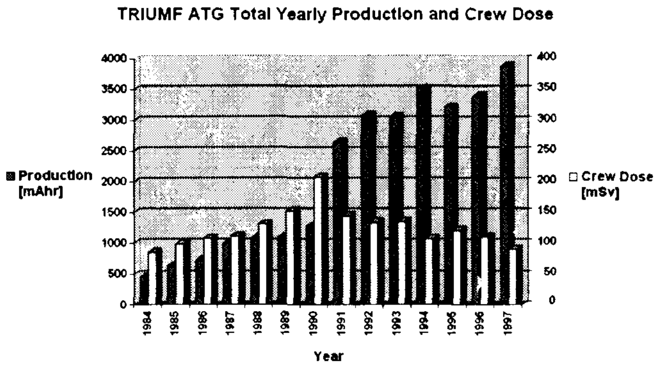

Figure 5: Crew Dose Decline Despite Increasing Production

Acknowledgments

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