

1 mA 30 MeV PROTON BEAMS FOR RADIONUCLIDE PRODUCTION

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An on-going program started two years ago to upgrade the output of the 30 MeV cyclotron at the National Medical Cyclotron facility in Sydney, Australia has resulted in a reliable 600 μA proton beam and a record peak value of 860 μA . Over the same period, improvements in the solid target systems have brought their safe working limit to 400 μA at full energy. Two cyclotron subsystems, namely the ion source and the final stage r.f. amplifier still need attention to reach the 1 mA, 30 MeV goal. This combined with the use of dual beam extraction on two identical target stations will soon put the capacity of the NMC at 800 μA on target for SPECT isotopes. Underlying the improvement of performances, the key feature of this program is to increase the reliability and serviceability of the whole system. Some technical aspects of these evolutions are described in the paper.

1. Introduction

The National Medical Cyclotron, Sydney, Australia presently produces PET radiopharmaceuticals (^{18}F FDG, ^{13}N Ammonia and ^{15}O) and bulk SPECT radiochemicals (^{201}Tl , ^{67}Ga and ^{123}I) for use by imaging facilities throughout Australia, using an IBA Cyclone 30 Negative Ion Cyclotron.

From the early stages of SPECT production at the NMC, it was clear that production could only reliably meet the existing demand by improving the production efficiency of the facility. While optimising cyclotron operation and the efficiency of target processing brought significant increases in production output, it was increasingly apparent that the potential for further optimisation of the existing set-up was limited; a production 'ceiling' being met.

A number of development projects were undertaken to increase capacity; doubling target area, increasing the available beam intensity and the devising of a system of beam diagnostics to provide the beam optic data necessary for the safe and accurate delivery of the increased beam powers. Reliability of design was also vital to these improvements' validity in a production environment.

In quantitative terms, the combined goal was set at producing 1 mA of extracted beam, to allow the extraction of dual 400 μA beams irradiating two high power capacity targets.

2. Beam Intensity Improvements

a) Ion Source and Axial Injection Developments

Increasing the beam output of the multicusp negative ion source and its efficiency of transport into the cyclotron

acceleration chamber, by the axial injection system was fundamental to achieving the cyclotron output beam intensity required.

Redesign of the source's filament binding posts eliminated a significant source of outgassing within the ion source and nearly doubled the standard filament life to 350 hours. Outgassing had earlier prevented running at high beam levels without carrying out hours of conditioning.

Another valuable development was the replacement of the source's manual gas flow controller with a motorised unit. Previously, gas flow optimisation required a vault entry, during which time no beam could be accelerated- the motorised valve allows adjustment of flow with 'beam on' and thus easy optimisation of beam output.

The cumulative effect of these improvements was a source capable of delivering a 4.5 mA H⁻ beam.

Injection efficiencies of the order of 25% had already been achieved with the existing axial injection system, but previous tests had shown that injection efficiency dropped off as the source output approached its peak. The axial injection system, therefore, required to be modified to maintain injection efficiency levels at high beam intensities.

A significant part of this work was the development of a new buncher system driven by the 1st and 2nd harmonics of the cyclotron frequency to modulate the ion velocities with a waveform approaching the 'ideal' sawtooth shape. The initial testing of this buncher produced injection efficiencies of around 30%, for an extracted beam of just over 500 μA . This was an improvement of 8% over the performance of the original set-up.

Another major upgrade was the addition of a turbomolecular pump to the axial injection line, since the geometry of the source axial injection vacuum system limited its effective pumping.

The turbomolecular pump improved the line vacuum to 210^{-5} mbar and similarly delivered a 13% improvement in beam output in test.

On the basis of the best performances of the source and injection system, 1.1 mA would have been anticipated as possible in high beam testing. The achievable beam intensity at 21 MeV, was $855 \mu\text{A}$. At the time of testing, the previous source output could not be reproduced, with an output limit of 3.5 mA being met, still yielding an efficiency of over 24%.

b) R.f. Developments

While acceleration of beams approaching 1 mA was possible with beam energies restricted to 21 MeV, a 1 mA proton beam at the full cyclotron energy of 30 MeV requires 30 kW of r.f. power. To meet this requirement the procurement of a 40 kW amplifier was investigated as an upgrade from the existing 25 kW unit, and, as a result a design commissioned from PAC.

Before the final stage amplifier could be installed, however, a replacement would also be required for the system's penultimate amplifier stage. The original 2.0 kW amplifier had been prone to tuning drift and was operating close to its capacity, even with the existing beam intensity requirements. A new amplifier was chosen with a 5 kW rating.

The control system interface of the 5 kW amplifier has been configured in such a way that it mimics that of the 2.5 kW. This means that the 2.5 kW amplifier can be retained as a 'plug in' spare, providing some level of redundancy.

3. Solid Targetry

a) New Solid Target Station

In mid 1993 design commenced on a new solid target station to be installed on the 40 degree port of the beam room switch magnet.

The new solid target station was intended to offer SPECT production redundancy, operating in parallel with the existing station on the switching magnet's 20 degree port. A number of design criteria were fundamental to this work, based on experience with the existing station:

- the use of structural metals with short activation half-lives in construction, as far as practical, to minimise cumulative activation of the station e.g. Aluminium was used extensively
- all construction materials to be stable in the high radiation environment
- easy maintainability through quick and easy removal of

components for repair

- rationalisation of the electrical insulation between target, collimator and ground
- improved beam diagnostics
- provision for the conversion of the station for the irradiation of larger double width targets

The new target station was installed and commissioned in January 1994, within the routine two week maintenance period. At the same time, the transfer system was modified with the addition of a transfer switch to allow the transfer of the solid target to either target station (see Fig. 1).

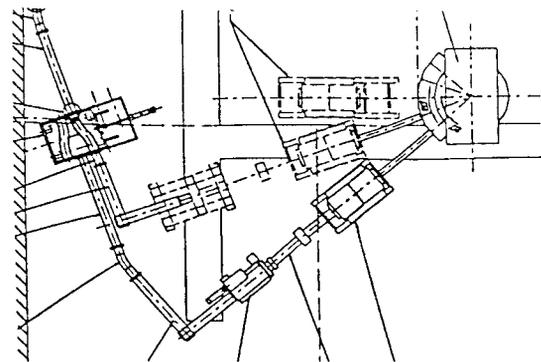


Fig. 1

The solid target station was also fitted with a novel beam diagnostic element, designed to give an accurate representation of beam centring. Sandwiched between the target and its collimator, the unit contains four elements, barely intercepting the beam peripheries along the horizontal and vertical axes. Displaying the beam current from each element on a 'crosshair' of bar leds provides a measure of the roundness and centring of the beam.

The information provided by this element has been valuable in the optimisation of routine irradiation conditions, resulting in reduced set-up times and consistently higher target yields. The information has also allowed beam intensities to be safely increased by nearly 20%, with subsequent similar increases in yield, since uniform irradiation of the target plate can be guaranteed. This was not possible without the new element, target plate melting being a significant problem without the crosshair information.

b) Collimator design

While the new solid target station proved itself quickly as a reliable and efficient SPECT production workhorse, the

sealing of the target beam line vacuum system in the region of the target collimator was being found to be the 'Achilles heel' of the system.

The o-ring sealing between the collimator water jacket and the beam line high vacuum was found to fail after 10-30 mAhr of integrated target beam current (and 2 to 8 mAhr integrated collimator current) with a water to vacuum leak resulting. Besides interrupting production, replacing the o-ring meant working in the high radiation environment of the solid target station, leading to increased personnel exposures and further required an allowance of 36 hrs of decay for exposures to fall to manageable levels.

A number of modifications were implemented to extend the life of the seal:

- increasing cooling water flow to the cooling jacket by reducing cooling path lengths as possible and removing flow restrictive fittings where possible
- improving the flow distribution around the collimator through insertion of manifolds with multiple holes positioned to evenly and accurately distribute flow over the length of the collimator
- through testing different o-ring materials, including those recommended for high temperature applications
- through machining away the outside wall of the o-ring groove to give direct water to o-ring contact

The cumulative result of these changes was to extend the o-ring life to 40 mAhr of integrated target current. This was equivalent to an average production month, still significantly less than the required 6 months life, for planned changes to be made as preventative maintenance basis during each six monthly maintenance period.

On the basis, that the existing collimator and water jacket design offered no further clear scope for improvement, a new collimator and water jacket arrangement was designed in consultation with PAC and Ansto Engineering. The new design was developed such that seals water to vacuum boundaries were eliminated. Following installation of the new design in July 1995, one related vacuum failure has occurred, at 92 mAhr.

Inspection of the o-rings removed in disassembly of the collimator unit, reveal virtually identical deterioration, independent of the expected thermal environment/ beam vulnerability of the particular o-ring. This now indicates cumulative secondary neutron and gamma exposure of the o-ring material as the failure mechanism. It is planned to investigate implementation of more radiation tolerant materials as seals in place of the standard o-ring materials used presently.

In July 1995 a second solid target station of the new design was installed on the beam room switch magnet's 20-

degree port. The original solid target station had become increasingly difficult to maintain and could not be easily modified to adopt the beam diagnostic crosshair technology. It was removed from the beam room to 'hot storage' in March 1995. The new solid target station was manufactured, assembled and commissioned between April and July 1995.

This station has been fitted with a double-width collimator and initial testing has been carried out on high beam irradiation of double width targets. Beams of up to 285 μA have been used in target irradiations with no deterioration of target material recorded. More are planned with irradiation by beams of up to 350 μA to be attempted.

4. Vacuum System Development

The cyclotron vacuum level determines the level of neutral beam the cyclotron suffers, due to negative ions stripping on residual gas as a percentage of the actual beam extracted.

High levels of neutral beam, above 50 μA , have been found in the past to cause deterioration of vulnerable o-ring seals such as those in the stripper port assemblies, with the resulting vacuum deterioration causing restrictions on the levels of extracted beam possible, higher levels of neutrals and a downward spiral of conditions ending in cyclotron shutdown.

Previous tests determined that, to limit percentage neutral beam to less than 5 %, as required to operate stably at the intended high beam levels, a vacuum of less than 110^{-6} mbar would have to be maintained.

With a cyclotron vacuum normally between 1.6 and 1.810^{-6} mbar, when running, producing 15-20% percentage neutral beam (see fig.2), steps clearly had to be taken to improve the level of the cyclotron vacuum.

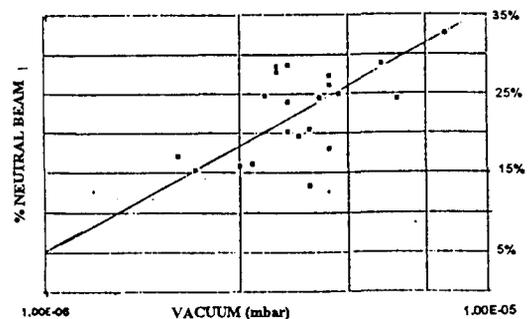


Fig. 2

Leak testing of the cyclotron has consistently failed to indicate real leaks of any magnitude, although traces of water vapour were detected by residual gas analysis. This was found to be due to adsorption to acceleration chamber surfaces.

To reach the required vacuum levels, two development programs are underway. The first of these is to increase the capacity of the pumping system through replacing the two 2000 ls^{-1} diffusion pumps on the cyclotron chamber with two cryopumps, each of 2200 ls^{-1} capacity (the largest capacity that can be accommodated in the spaces previously occupied by the diffusion pumps)

To further improve vacuum levels, two Danielson phototron u-v tubes are to be installed. These will greatly accelerate vapour desorption within the chamber.

Conclusions

The goal of achieving 1 mA of output beam intensity has not yet been fully achieved. This output level will only be reliably achieved, when the source can routinely deliver output levels approaching the optimum 4.5 mA.

A development program is currently underway to overcome the problem, with an option of source redesign being considered. Acceleration of that intensity to 30 MeV will become possible after the commissioning of the new 40 kW final stage amplifier planned for early 1996.

The goal of routine target irradiation at high beam intensities (up to 400 μA) is being approached, with beams in excess of 300 μA soon to be used in test irradiations.

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