NEW IRRADIATION FACILITIES AT THE AUSTRALIAN NATIONAL MEDICAL CYCLOTRON

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Two new irradiation facilities have been developed at the National Medical Cyclotron for radionuclide production. The first relocates PET irradiations from the cyclotron vault to a dedicated PET beam room, to improve accessibility and reduce radiation exposures associated with target maintenance. This new facility consists of a beam line to transport 16-30MeV proton beams from the cyclotron to 1 of 8 PET targets mounted on a target rack. The target rack has increased the number of targets available for production and experimentation.
The second is a completely independent solid target irradiation facility for SPECT. This facility consists of a beam line to transport 26-30 MeV proton beams from the cyclotron to a dedicated beam room containing one solid target station. A new pneumatic target transfer system was also developed to transport the solid target to and from the existing chemistry hot cells.
The beam line and target components are operated under the control of a dedicated PLC with a PC based user interface. The development and some technical aspects of these new irradiation facilities are discussed here.

1. Introduction

The National Medical Cyclotron, A division of ANSTO, Sydney, Australia produces both PET radiopharmaceuticals (^{18}FDG, ^{13}N Ammonia and ^{15}O) and SPECT radiochemicals (^{201}Tl, ^{67}Ga and ^{123}I) for supply to imaging facilities throughout Australia using an IBA Cyclone 30 negative ion cyclotron.

A program commenced in mid 1995 to relocate the targets for PET irradiations from the cyclotron vault to a new 'PET' beam room to improve availability and reduce radiation exposures from target maintenance. A beam line was developed to transport 16-30MeV protons from the cyclotron to 1 of 8 PET targets mounted on a target rack system, for selection of the target to be irradiated. The target rack system contains 8 target locations and allows considerable expansion of the previous PET irradiation facility, giving greater redundancy and a facility for target experimentation.

A second program commenced early in 1996 to develop a second solid target irradiation facility to provide redundancy with the existing facility for SPECT isotope production. The existing facility is comprised of twosolid target irradiation stations [1], [2], located in the original beam room, that use a common beam line and target transfer system. A beam line was developed to transport 26-30 MeV protons from the cyclotron to a solid target irradiation station located in a new 'SPECT' beam room, adjacent to the 'PET' beam room. A dedicated target transfer system was also developed for the new solid target irradiation station, providing two totally independent SPECT irradiation facilities at the NMC.

All the PET and SPECT beam line components and their associated services are operated under the control of a single Siemens S5 PLC linked to the original Cyclotron PLC. Both PLCs are linked to a PC based user interface for operator control of the cyclotron and associated beam lines.

2. PET Beam Line

2.1 Beam Line Design and Development

The PET beam line was required to transport 100% of the proton beam to the target location in the PET beam room, 7 metres from one of the ten cyclotron exit ports. The beam spot size at the collimator, positioned immediately in front of the target, was required to give a 1:1 collimator to target current ratio. This ratio was required over the energy range of 16-30MeV, up to a beam current of 50μA on target.

Given the above requirements, the design proceeded to include the following components

- quadrupole doublet - located in the cyclotron vault
- beam line diagnostic elements – consisting of three sets along the beam line to indicate the beam shape and position
- beam stops - faraday cup type, one located in the cyclotron vault and one in the PET beam room
- steering elements - located in the cyclotron vault
- vacuum systems - rotary and diffusion pump combination, one located in the cyclotron vault and one in the PET beam room

Beam transport calculations were performed using the "OPTIC" code [3] to determine the layout of the PET beam line, the strength and location of the quadrupole doublet, and the set-up for the beam line diagnostics. The considerable focussing of the beam in the horizontal plane, during steering to the cyclotron exit port for the PET beam line, greatly affects the transport and focussing required to achieve the correct spot size at the target/collimator interface. The beam transport was simplified by utilising the target rack system, which physically aligns the selected target with the beam line, eliminating the need for a target selection magnet.

The resulting beam line layout is shown in fig 1. For ease of maintenance no beam line components were located in the 2.0m wall between the cyclotron vault and the PET beam room. The wall penetration for the beam line is just large enough for the pipe to fit through, maintaining maximum shielding between the cyclotron vault into the PET beam room.

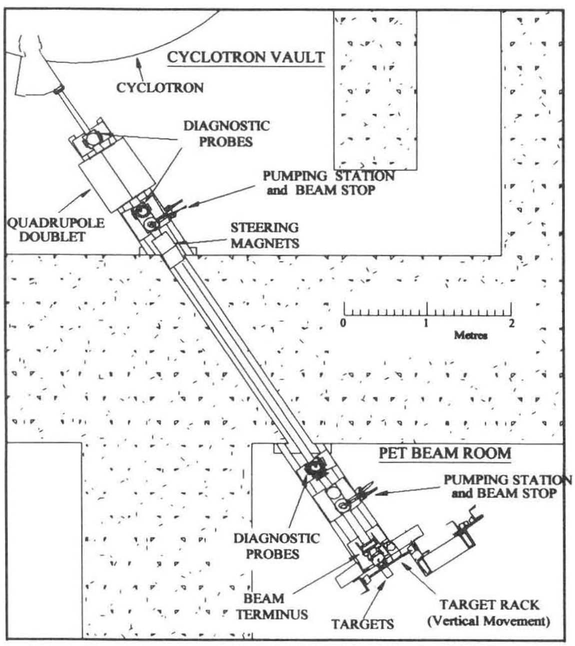

Figure 1: PET Beam Line Layout

The beam line components, with the associated pneumatic, electrical and water cooling services, were manufactured by ANSTO's Engineering section and installed over a 12 month period with no interruption to the production schedule.

2.2 Target Rack System and Beam Terminus

The target rack system developed was based on the system in use at the PET facility, University of Michigan Medical School, Ann Arbor. The target rack consists of an aluminium plate mounted vertically onto a frame by four linear bearings and a ballscrew (fig 2). Eight PET target assemblies are mounted on the rack plate, which is adjusted vertically by rotation of the ballscrew, to align the selected target with the beam line. The rack plate movement is controlled by a PLC driving a stepper motor connected to the ballscrew, giving +/- 10 microns accuracy for vertical positioning. A thin foil at the front end of each target assembly seals the target chambers.

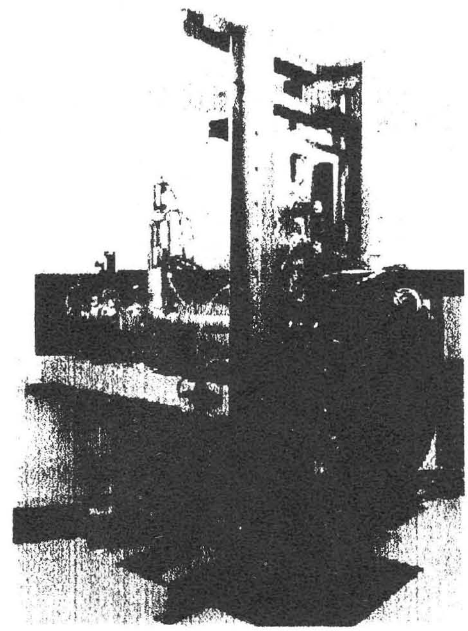

Figure 2: Target Rack

The selected PET target is physically connected to the beam line using a beam terminus, which consists of a collimator, beam diagnostic elements, a helium cooling chamber, and a bellows that allows the terminus to move onto the front of the target assembly.

The beam diagnostics consists of four probes that intercept the beam peripheries to 'measure' the beam shape and position just prior to the target.

Helium flow cools both the thin target foil and a vacuum foil in the beam terminus that seals the beam line vacuum. The helium cooling chamber is split when the beam terminus moves away from the target assembly to select a different target on the target rack. Thus both the beam line vacuum and target chamber are maintained when selecting a new target.

2.3 Testing and Beam Commissioning

All components and services for the beamline, target rack and beam terminus were individually tested after installation and then operationally tested under PLC control. Beam commissioning of the PET beam line was undertaken using a dummy target installed on the target rack. A proton beam was easily transported onto the dummy target with the beam centred down the beam line, indicated by the beam diagnostics. This was confirmed by testing that the quadrupole doublet focussed the beam without introducing steering effects.

The beam transport calculations were confirmed with the quadrupole doublet focussing the proton beam to achieve a 1:1 collimator to target current ratio over the energy range of 16-30MeV, at 50μA incident on the target.

3. SPECT Beam Line

3.1 Beam Line Design and Development

The SPECT beam line was required to transport 100% of the proton beam to a solid target station in the SPECT beam room, 6 metres from one of the ten cyclotron exit ports. The beam spot size at the collimator, positioned immediately in front of the target, was required to give a 1: 10 collimator to target current ratio over the beam energy range of 26 -30MeV.

Given the above requirements, the design proceeded to include the same components as the PET beam line, with the exception of the beam stop and vacuum system located in the beam room. Beam transport calculations were performed to determine the layout of the SPECT beam line, fig 3(a), the strength and location of the quadrupole doublet, and the set-up for the beam line diagnostics.

The considerable focussing of the beam in the horizontal plane, during steering to the cyclotron exit port for the SPECT beam line, greatly affects the transport and focussing required to achieve the correct spot size at the target/collimator interface (as was found in the PET beam line modelling).

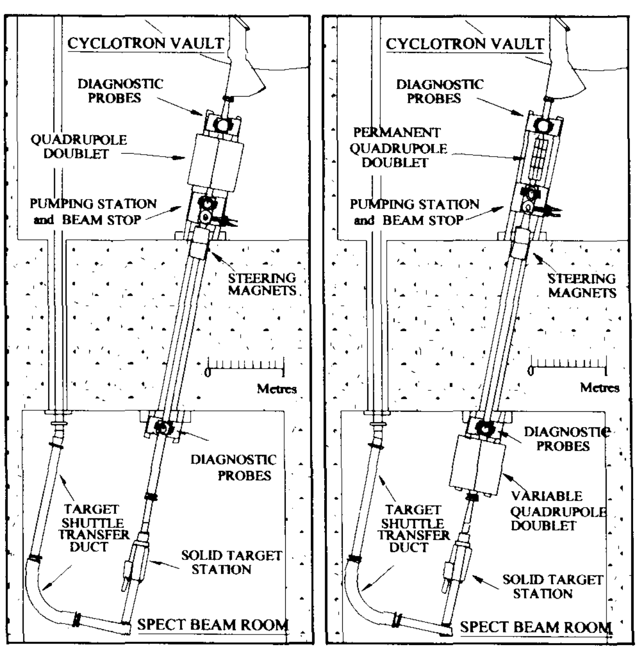

Figure 3: a. Initial SPECT Beam Line Layout
b. Modified SPECT Beam Line Layout

The considerations applied in the layout of the PET beam line were again applied here. No beam line components were located in the wall between the cyclotron vault and the SPECT beam room, and the wall penetration for the beam line is just large enough for the pipe to fit through.

The beam line components with the associated pneumatic, electrical and water cooling services were installed over a 6 month period no interruption to the production schedule.

3.2 Solid Target Station and Transfer System

The solid target station developed for the new SPECT beam room is of the same design as the solid target stations located in the original beam room, developed in collaboration with PAC [1]. The solid target stations consist of a collimator and beam diagnostic element prior to the target location [1],[2]. The target is enclosed in a shuttle to transport the solid target through a transfer duct to and from the processing hot cells using an air turbine. The target remains in the shuttle during irradiation.

The processing hot cells are located in a production laboratory adjacent the original beam room. The transfer duct was directed from the new SPECT beam room through the cyclotron vault and original beam room to the production laboratory (fig 4), a total distance of 35m with a typical transfer time of 25 secs.

A dedicated reception station was developed in the processing hot cells to give the new target station complete redundancy.

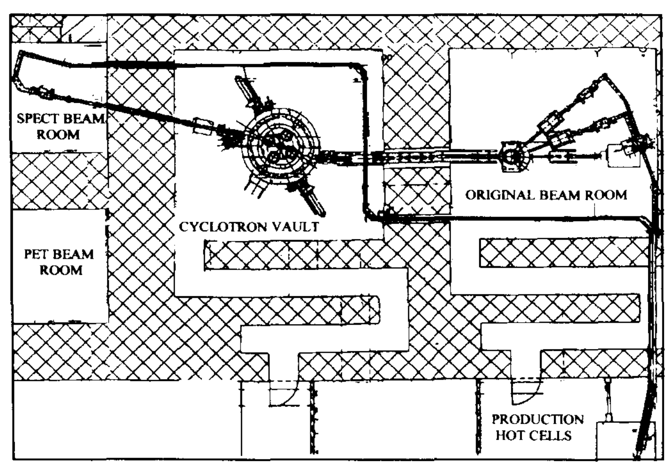

Figure 4: Solid Target Transfer System

3.3 Testing and Initial Beam Commissioning

All components and services for the beam line, solidarget station and transfer system were individually tested after installation, and then operationally tested under PLC control.

Beam commissioning of the SPECT beam line was undertaken using a natural thallium solid target and followed the same procedures as used in the PET beam line commissioning.

The beam could only be focussed to achieve a 1:3 collimator to target current ratio using the quadrupole doublet, short of the required 1:10 current ratio. Extensive beam measurements were performed, using the beam diagnostics, to determine values for the starting conditions of the beam being delivered out of the cyclotron exit port used for the SPECT beam line. The beam starting conditions determined were found to be different from the values used in the initial calculations, obtained from the cyclotron manufacturer.

3.4 Revision and Modification of Beam Line Layout

Further beam transport calculations were performed using the starting conditions determined above. The new beam line layout determined , fig 3(b), required the addition of a second quadrupole doublet, with similar specifications to the first, to achieve the 1:10 collimator to target ratio. This addition was made without changing the location of other beam line components, with exception of the original quadrupole doublet.

The original quadrupole doublet purchased for the SPECT beam line is a standard 4 pole variable field strength unit, requiring two dc power supplies. The addition of a second quadrupole doublet of a similar type would have been a costly modification to the beam line. Although two quadrupole doublets were now required, only one needed to be variable. Therefore, as an alternative, a permanent magnet quadrupole doublet design [4] was implemented, using small NdFeB magnets. The permanent quadrupole design gives the advantage of being a low cost alternative, approximately 20% of the cost of a variable quadrupole doublet, and allowed the component design and manufacture to be performed in house.

Initial beam commissioning tests with the modified SPECT beam line have resulted in a 30MeV proton beam being transported down the SPECT beam line with a 1:10 collimator to target ratio. Further beam tests will be carried out soon to commission the beam line for the required 26-30MeV energy range up to a beam current of 400μA on target.

4. Conclusions

The PET beam line will soon be available for routine production of PET radiopharmaceuticals, once the transfer systems for the targets are commissioned. This will significantly improve the accessibility and reduce radiation exposures involved with PET target maintenance, as well as increase the number of targets available for PET irradiations.

Full beam commissioning of the SPECT beam line will be undertaken soon to give a second solid target irradiation facility for production of SPECT radiochemicals.

The completion of both these irradiation facilities will significantly improve the reliability of the National Medical Cyclotron as a supplier of radiopharmaceuticals and radiochemicals for use in imaging facilities throughout Australia.

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