A MULTI-PURPOSE TARGET STATION FOR RADIOISOTOPE PRODUCTION AT MEDIUM ENERGIES

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ABSTRACT: A remotely-controlled target station for radioisotope production at the National Accelerator Centre is described. The facility consists of three rotary magazines behind one another, each of which can hold up to five target holders, and provides for different combinations of a variety of targets to be irradiated in tandem. The targets are irradiated outside the beam-line vacuum, from which they are isolated by a double-foil beam window system. Cooling water to the targets is supplied through a pneumatic pusher arm. Electrical connections and gas or liquid lines to the target holders are automatically coupled when a target holder is inserted in its slot. The target magazines are locally shielded to protect sensitive components inside the irradiation vault against excessive radiation damage and reduce neutron activation of the vault and its contents. Target holder transfer between the magazines and an electric-rail transport system is effected by means of a remotely-controlled pneumatic robot arm.

1. INTRODUCTION

For the maintenance of a routine cyclotron radioisotope production programme it is essential to have at one's disposal at least one dedicated target station, specifically designed for this purpose. In planning and designing such a station, the following important general considerations should be taken into account:

- Each station should be as versatile, and therefore as cost-effective, as possible, by providing for as large a variety of targets as is practical. This, of course, also implies standardized targetry, as far as possible.
- Medium or high-energy beams permit the simultaneous production of a number of radioisotopes for which the production energy windows do not overlap, via the irradiation of targets in tandem. In this way available beam time can be utilized more efficiently, resulting in reduced production costs of the specific radioisotopes.
- Target handling has to be by remote control, in order to avoid exposure of personnel to radiation from the highly-active irradiated targets and/or residual neutron-induced radioactivity inside the irradiation vault during the target loading and unloading procedures. Remote control also eliminates possible long, uneconomical waiting times between irradiations, during which the radiation dose rate inside the vault has to decrease to an acceptable level before target changes can be performed manually.
- Target stations must not only be located in special irradiation vaults, enabling the safe bombardment of production targets with high-intensity beams, but should also be locally shielded in order to protect sensitive components inside the vault against excessive radiation damage and reduce the neutron activation of the vault and its contents.

This paper describes a target station designed and built along the above-mentioned lines, and in routine use at the National Accelerator Centre (NAC) since November 1988. Although a total of four beam lines are available for the NAC's radioisotope production programme (three horizontal beam lines in one vault, plus one vertical beam line in another), it is envisaged that, in view of its versatility, this target station will be the sole irradiation facility required for routine production purposes in the foreseeable future. The NAC's routine radioisotope production programme is based on a 66 MeV proton beam, regularly available for neutron therapy, at beam currents of up to 100 µA.

2. BASIC DESIGN FEATURES

Overall views of the target station are shown in Figs. 1 and 2. Basically it consists of three remotely-controlled rotary target-holder magazines behind one another (see Fig. 3 for more

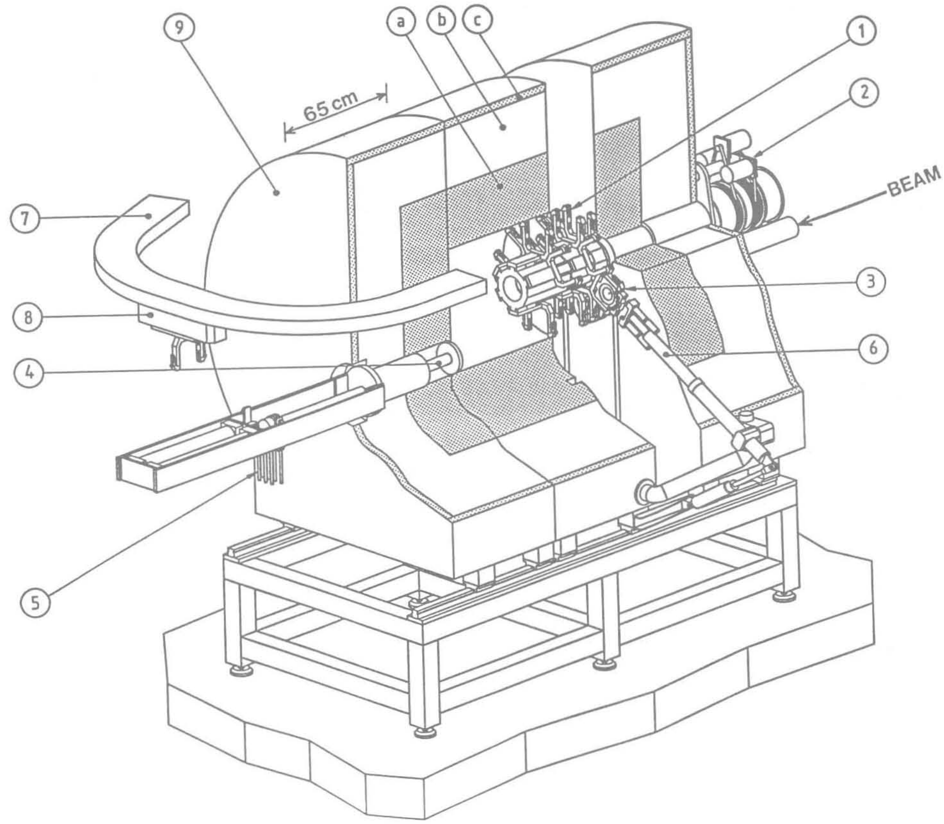

Fig.1 Perspective view of the target station, showing the rotary target magazines (1) and their motor drives (2), target in load/unload position (3), target pusher arm (4) with cooling water lines (5), target transfer robot arm (6), electric-rail target transport system (7) with trolley (8) and neutron attenuation shield (9), composed of iron (a), paraffin wax containing 2.5% boron-carbide (b) and lead (c). Also see photo in Fig. 2.

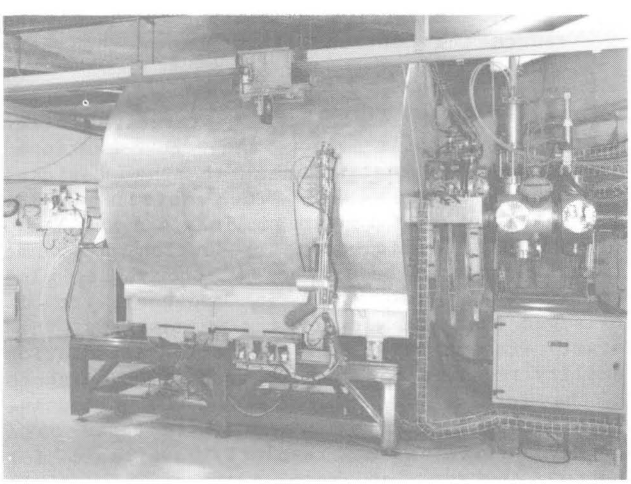

Fig.2 Overall view of the target station, with the neutron attenuation shield closed and a target transport trolley, with target, in position for target transfer to one of the magazines. Note the beam diagnostics chambers immediately upstream (i.e. to the right) of the target station. See Fig. 1 for further details.

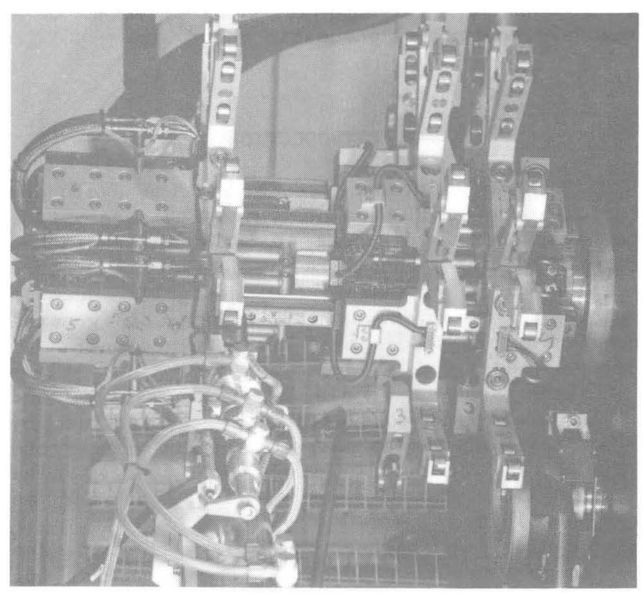

Fig.3 Close-up of the rotary target magazines, also showing the beam window assembly (lower right-hand corner) and the target transfer robot arm (left foreground).

detail) inside a cylindrical neutron attenuation shield (see Sect. 3). The targets are irradiated outside the beam-line vacuum, from which they are isolated by a double-foil beam window, cooled by helium gas (Fig. 3). Target holder transfer between the magazines and an electric-rail transport system, which links the irradiation vaults with a hot-cell complex, is effected by means of a remotely-controlled pneumatic robot arm mounted against the side of the neutron shielding (Figs. 1 and 2). In order to obtain access to the magazines, the shielding is remotely driven open by means of a stepper motor, which also automatically positions the robot arm opposite the appropriate rotary magazine.

Each magazine can hold up to five standardized target holders, while an open segment in each provides for the case that no target is to be irradiated in that specific magazine. Selected target holders are rotated to the irradiation position or the load/unload position under stepper motor control. Once these target holders (numbering one, two or three) are lined up in front of the beam line, a remotely-controlled pneumatic pusher arm, pushing from the rear, secures them in the irradiation position, at the same time also establishing cooling water connections to, as well as between, the target holders. Three parallel cooling lines allow for independent pressure and flow control of each individual target holder,[1] the cooling water

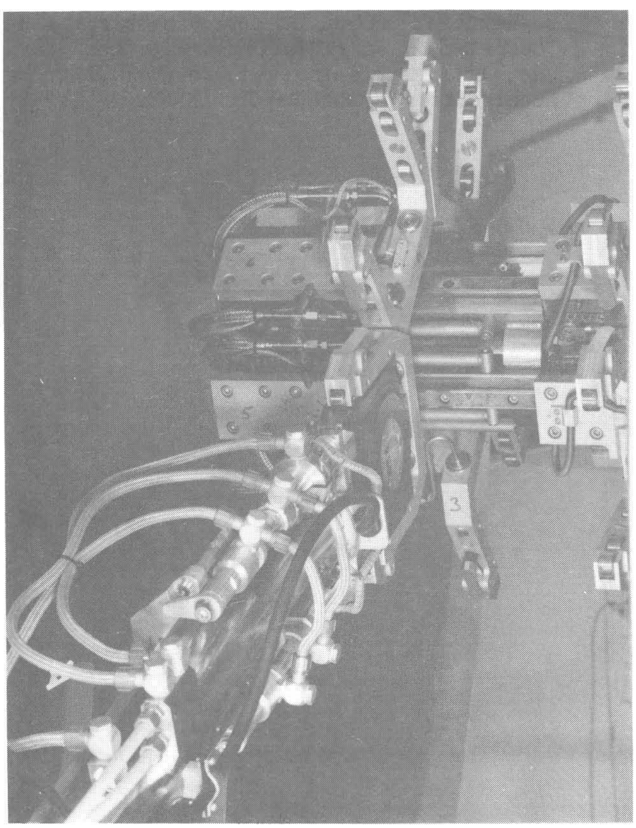

Fig.4 A target holder being loaded into the rear rotary magazine by the remotely-controlled pneumatic robot arm.

to each being channeled through those behind it (if any). Electrical connections, as well as gas or liquid lines to some target holders, are channeled through the driving shafts of the rotary magazines and are automatically coupled when a target holder is pushed into its slot (Fig. 4). Within certain dimensional and other restrictions, specific to each magazine, target holders of widely different design - for solid, liquid or gas targets - can thus be handled.

The facility therefore not only allows up to three target holders to be irradiated in tandem, but also provides for different combinations of a large variety of target holders loaded into the magazines to be irradiated without having to transport and transfer them to and/or from the magazines each time. This is a very useful feature in the case of semi-permanent targets, such as on-line targets, or targets which have to be repeatedly irradiated over a relatively long period in order for sufficient (long-lived) activity to be produced.

3. NEUTRON SHIELDING

The cylindrical neutron attenuation shield around the target magazines is composed of three layers in both the radial and axial directions (Fig. 1): an inner layer of 300 mm iron with a low manganese content (0.11%), followed by a 300 mm layer of paraffin wax containing 2.5% boron-carbide (B_4C), followed by a 40 mm lead outer layer. These dimensions were decided upon on the basis of radiation transport calculations performed with a discrete ordinates computer code.[2] The inner layer effectively slows down most fast neutrons to intermediate energies via non-elastic interactions in the iron. Neutrons at energies below about 4 MeV are then moderated to thermal energies in the second layer by elastic scattering on the hydrogen nuclei in the wax, while the boron in the boron-carbide serves to absorb the thermalized neutrons, utilizing the high thermal neutron capture cross-section of boron. The outer lead layer is an attenuation shield for gamma-radiation, especially for the 2.2 MeV gamma rays emitted in the capture of thermal neutrons by hydrogen.

The neutron attenuation shield forms an integral part of the remote control of the target station, which would otherwise not have been a practical proposition. A 66 MeV proton beam of 100 μA produces of the order of 10^{13} - 10^{14} neutrons per second when stopped in a thick target,[3] depending on its atomic number. Without any shielding the dose rates during irradiation would be of the order of 100 Gy/h at the locations of the pneumatics, stepper motors, valves, etc. employed in the remote control of the target station. Sensitive components used in this instrumentation, such as rubber or polymer parts, typically have radiation resistances of 10^5 - 10^6 Gy.[4] The shielding, however, has a dose transmission of ~0.1%, thereby extending the expected "safe" operational lifetimes of these components from several weeks to many years.

The local neutron shielding also effectively reduces neutron activation of the irradiation vault and its contents, specifically the production of ^{24}Na($t_{\frac{1}{2}}$ = 14.96 h) in the concrete walls of the vault,[2] which is the main contributor to the residual dose rate after 1 h after the end of the irradiation. Radioactivity induced in the shielding material, of which ^{56}Mn ($t_{\frac{1}{2}}$ = 2.58 h) is the most troublesome, is to a large extent shielded by the shielding itself. This, as well as the favourable ratio of $t_{\frac{1}{2}}(^{56}Mn)/t_{\frac{1}{2}}(^{24}Na)$, considerably reduces the waiting time after an irradiation before the vault can safely be entered. A low manganese content of the iron is, however, essential in order to prevent excessive production of ^{56}Mn via thermal neutron capture, which is known to be a problem in thick iron shielding.

Finally, although not primarily intended for this purpose, the iron and lead layers of the composite shield of course also act as effective gamma-ray shielding of the highly-activated target station and beam line components, and in some cases even the irradiated targets, during maintenance, repair or development work inside the irradiation vault.

4. OPERATION AND MAINTENANCE

The target station is remotely controlled by means of a personal-computer-based system, located in the radioisotope production control room. A versatile control program provides for single action control, as well as for the control of automatic sequences, such as the loading or unloading of a target holder. Status information on all moveable mechanical parts and on all target holders stored in the rotary magazines is displayed on a video screen. Software and hardware interlocks provide for internal movement interlocking, as well as for interlocking with other systems, such as the beam diagnostics, the target cooling water system and the helium cooling system for the double-foil beam window.

The entire target station is insulated from earth in order to monitor the beam current on target during irradiations. Immediately upstream of the double-foil window a graphite beam collimator, consisting of four individually insulated sectors, assists in focussing and centring the beam on target. Further upstream a diagnostics chamber provides the standard NAC beam profile and current measurement capabilities at low and high intensities (harp, scanner, Faraday cup and non-destructive capacitive current measurement device).

The whole design of the target station strives to eliminate maintenance and repairs to components inside the shielding. All pneumatics, electrical motors, service connections, etc. are mounted outside the shielding, and only extremely radiation-resistant materials (metals as far as possible) were used inside. In view of its lower neutron activation, preference was given to aluminium above stainless steel, where practical. Stainless steel bellows were used for the flexible parts of the gas and liquid lines. The electrical connectors provided for the target holders on the magazines were machined from ceramic material, and kapton-insulated wiring was used throughout. All target coupling seals for cooling water, gas or liquid lines are located on the target holders, and can therefore easily be replaced every time a target holder is being prepared for loading. The double-foil beam window system is coupled to the beam line by means of a quick-release chain coupling and can be replaced as a complete assembly.

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