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THE TRIUMF 500 MeV, 100 μA ISOTOPE PRODUCTION FACILITY

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Abstract

A facility for isotope production has been built to be installed in the TRIUMF 500 MeV proton beam. A plywood and acrylic model was built to study cooling water flow characteristics, target drive system and human engineering features with respect to target transfer into a lead container. Target and window heat transfer tests were done prior to final construction. The actual target drive system and its control system have been assembled and tested, and are ready for installation in the beam line.

Introduction

The subject facility has been built to take advantage of the abundant radioisotope production capabilities of the 100 μA beam at TRIUMF, via the 500 MeV proton-induced spallation reaction. There will also be isotope production at 70 MeV and at 11-42 MeV, as discussed in the previous paper.[1]

The 500 MeV radioisotope production facility is being installed in the main, 100 μA beam line, just ahead of the beam stop to minimize the effect on experimental targets. The beam stop is optimized for thermal neutron production and is the core of the thermal neutron facility (TNF).[2] The distance between the facility and the TNF target is only 70 cm so that both facilities share the same shielding. Figure 1 shows the location of the facility within the TNF.

The facility allows radioisotope targets to be irradiated, completely submerged in cooling water, which also acts as shielding. This feature it has in common with the Brookhaven linac isotope producer (BLIP).[3] However, it takes up considerably less space and differs in many other aspects.

Design Criteria

The facility was built to the following criteria:

- Irradiation of up to 6 thick or 12 thin targets in the available space: a vertical vacuum tank in the TNF section of the beam line with an internal diameter of 318 mm.
- Irradiation should be at atmospheric pressure, so as not to require a complicated vacuum lock.
- Insertion and removal of the targets should be possible without disturbing normal operation of the beam line.
- Target activities of up to 1 kCi are required to be handled safely after irradiation.
- The facility should not degrade the proton beam in excess of 200 MeV. This sets the maximum heat dissipation at 20 kW.
- The thin targets should be designed to dissipate up to 2 kW each, the thick targets up to 4 kW each.

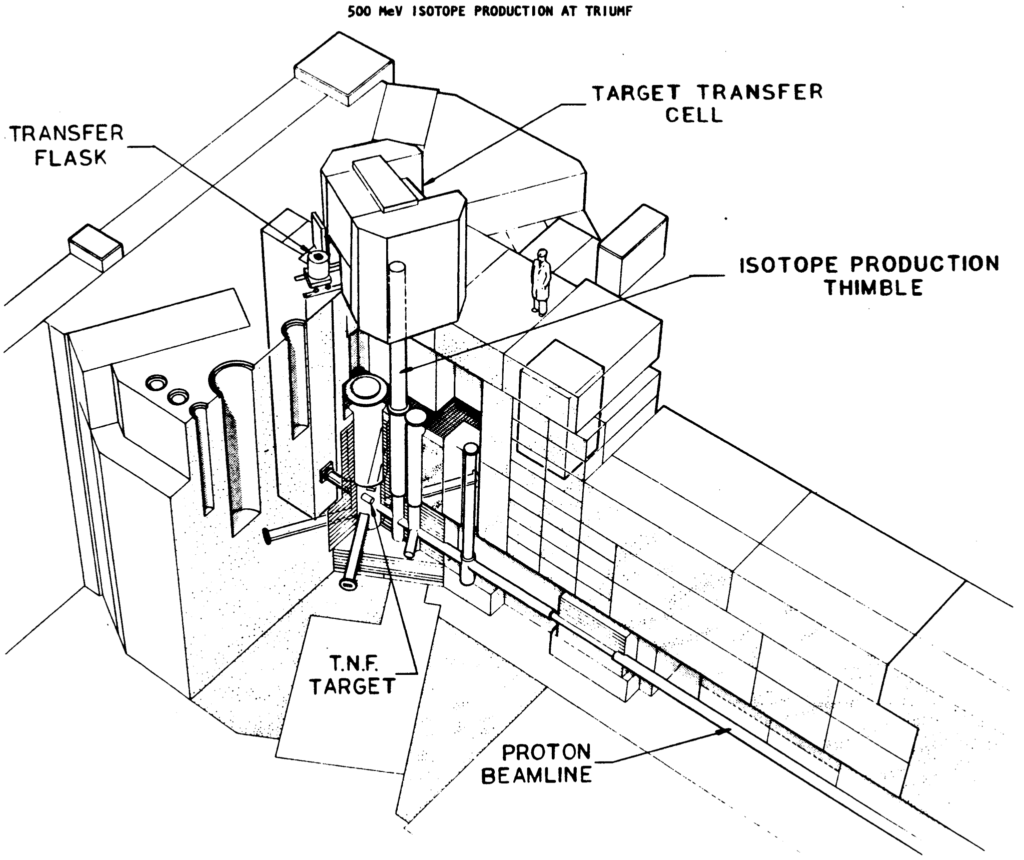

Fig. 1. Cutaway view of the thermal neutron facility, showing the location of the isotope production facility.

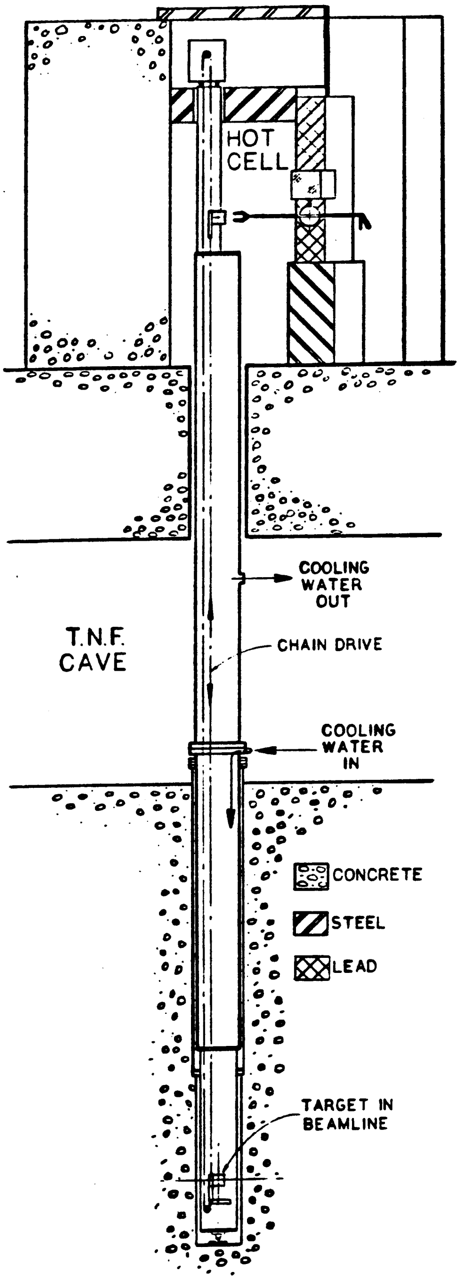

Fig. 2. The isotope production facility: vertical cross-section normal to beam line.

Irradiation Thimble

The above criteria have been met by accommodating the targets inside an 8.63 m long thimble, which is to be placed inside the vertical TNF vacuum tank (Fig. 2). The proton beam passes through the thimble via two 3 mm thick windows (Fig. 3). Six target holders, each of which can accommodate one thick or two thin targets, can be placed between the two windows. The thimble is filled with water, which serves as shielding as well as cooling for the targets and the windows.

The target holders can be moved from the irradiation position to the target transfer hot cell above the TNF shielding by means of stainless steel chain drives. The lower part of the drive system has been kept as simple as possible for maximum reliability. Its residual radiation field may become as high as 3 rad/h at 1 m after a cooling time of three days, and any repairs would have to be done in a hot cell. The only part subject to wear is the idler sprocket for the chain return.

Water is pumped into each target holder from the bottom. It is forced to run between the target faces and the 0.75 mm thick target holder walls and leaves through a hole in the top. When a holder is moved out of the beam its water connection is severed automatically as the entrance tube withdraws from the water manifold. The length of this tube is such that cooling is maintained until the holder is completely out of the beam. Separate tubes supply water to the thimble windows.

In case of failure of the thimble it can be raised out of the beam by 60 cm in a few hours, with minimal disruption of beam line operation. It can then later be moved to a hot cell at a convenient time.

Hot Cell for Target Transfer

A single-purpose hot cell is used to transfer the targets to a lead container for transportation to the radiochemistry hot cells (Fig. 4). The upper front wall facing the operator is made of 20 cm thick lead. The radiation field at the location of the operator will be ~10 mrem/h under worst conditions. Average daily occupancy of that location is expected not to exceed 15 min. The lower front wall and the roof are made of steel, and the side and rear walls are made of concrete of equivalent shielding quality, but at substantial cost savings. There is a 20 × 25 cm viewing window and a conventional ball-mounted manipulator in the front wall. The cell has a stainless steel liner and a suction fan in the roof to maintain a negative pressure inside.

As the cell is located above the shielding over the TNF cave, it is made demountable for crane access to the cave and to the TNF target.

The roof of the cell contains the drive mechanism consisting of one worm gear drive motor, a slip clutch, gearing to six electrical clutches and six chain tensioning gear sets. The drive mechanism is attached to the thimble and stays with it when the cell is disassembled.

When a target holder has been irradiated to a pre-set dose, it is automatically moved out of the beam to a parking position above it. The operator then brings it up into the cell. Next he uses the manipulator to remove the target from the holder and place it either in a storage rack or in a magazine that fits inside the lead container. The manipulator is fitted with a special attachment that screws into the target to hold it firmly without chance of being dropped. The magazine is attached to the underside of the lead container plug. Subsequently, the plug with the magazine, containing one or more targets, is lowered through a hole in the bottom of the cell and into the lead container. A steel shielding door behind the container can then be unlocked and opened. The 1000 kg container, which has wheels running on rails, can be moved out from under the cell to where it can be picked up with the building crane.

To prevent targets or other objects from being dropped into the thimble or the exit port, there are covers that have to be closed during manipulation. The cell also has a dosimeter with a 1-10,000 R/h range.

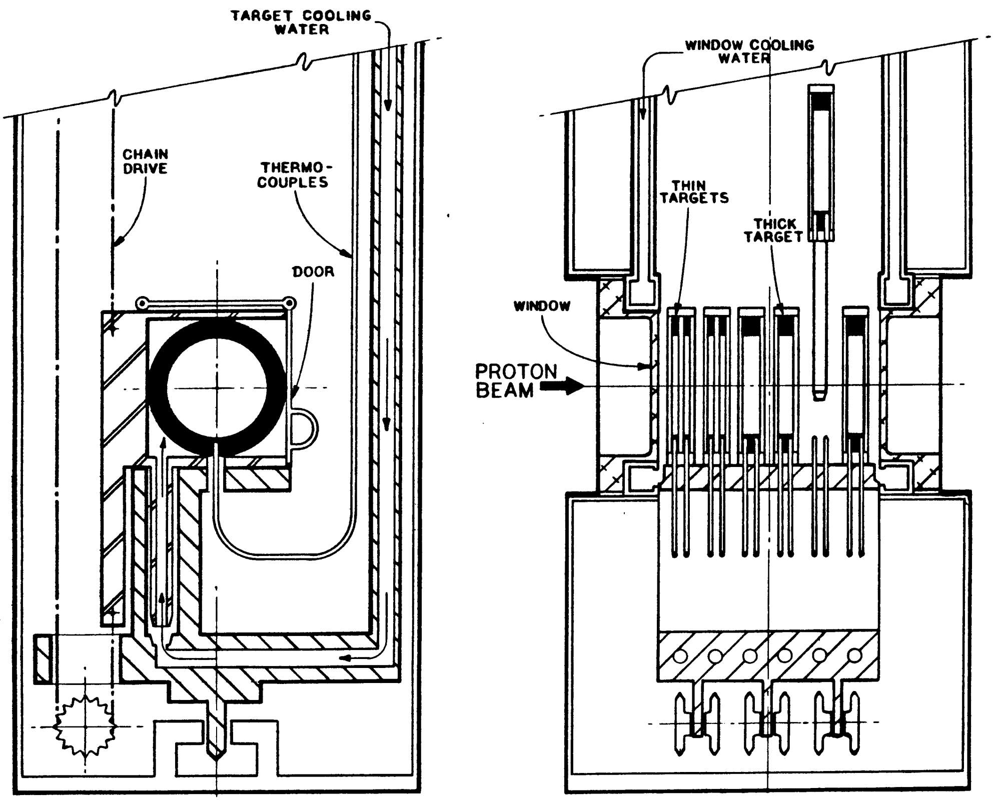

Fig. 3. The "in-beam" section of the isotope production thimble. Cross-section normal to proton beam (left) and parallel to proton beam (right).

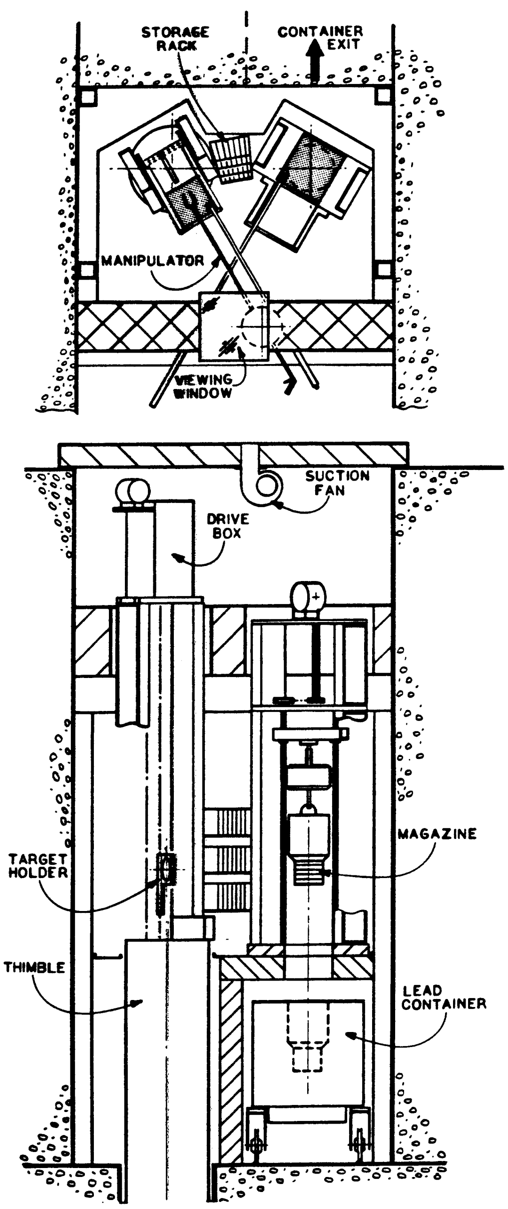

Fig. 4. The target transfer cell. Vertical cross-section (top) and horizontal cross-section (bottom).

Cooling System

Target and window cooling is provided by a closed water circulation system that is completely contained within the thimble and the shielded TNF cave. The total flow in the system is 114 ℓ/min, which is shared equally by eight circuits: six for the target holders and two for the thimble windows. The eight 3.80 m long parallel tubes that form the cooling manifold ensure that when a target holder is removed from the beam position, the flow in the remaining circuits is not unduly affected. A heat exchanger transfers the 20 kW maximum heat load to an external cooling circuit.

The proton beam passes through 19 to 25 layers of cooling water with a total maximum thickness of almost 50 mm. Radioactivity produced in this water at 100 µA, at saturation, is expected to be as follows:

Species	Half-life	Saturated activity (Ci)
^{3}H	12.3 yr	85
^{7}Be	53.0 d	28
^{11}C	20.5 min	33
^{13}N	10.0 min	17
^{15}O	124.0 sec	42
^{16}N	7.35 sec	25

None of these activities can give rise to unacceptable exposures to personnel as the whole water system is shielded. There could be some release of short-lived gaseous activity into the hot cell via the water surface in the thimble, which has only a loose-fitting cover. A continuously running suction fan will maintain a negative pressure inside the cell and dispose of any activity through an exhaust stack. The stack is monitored continuously and the beam would be turned off in case of any release above the Maximum Permissible Concentration. ^{7}B and ^{11}C will be trapped in a demineralizer (nuclear grade mixed bed resin, 15,000 grains) through which some of the water is continuously circulated. Tritium can be disposed of at the rate it is produced, ~0.3 mCi/h at an all-time average beam current of 50 µA. The proposed system would bleed off a small trickle of irradiated water and dilute it with the building sub-surface run-off (~23 ℓ/min), thus releasing it below the Maximum Permissible Concentration for the general public. A long, shielded release tube would delay the release by a few hours to allow the short-lived species to decay to a safe level. Radioactive particulate matter, produced from wear in some of the moving parts, will be trapped in an absolute filter.

Targets

The disc-shaped targets have an outside diameter of 102 mm. They are made in two thicknesses, 18.8 mm and 8.6 mm. They may either be made of a solid metal or the shells may be hollow to contain powders. The powder targets are made of Inconel or stainless steel and have an inside diameter of 76 mm. The electron beam welded windows are 127 µm thick.

There are some holes in the periphery of each target: one hole which is threaded to permit secure attachment to the manipulator in the hot cell, and a 3.57 mm diam × 11.7 mm deep hole to provide for temperature monitoring. (The thick targets have two such holes.) When the targets are in the in-beam position, the holes fit over the 3.18 diam mineral-insulated thermocouples mounted on the cooling manifold.

Dummy targets are used to fill unoccupied slots in the target holders. This is to minimize the amount of water exposed to the beam, so as to limit water activation and unnecessary degrading of the beam. The dummy targets are filled with 2 kg/cm^2 helium. At this pressure the windows will be flat, when in the beam position, where the water pressure is also 2 kg/cm^2.

Control System

The control system uses a microprocessor to monitor the irradiation dose and temperature for each target as well as the safety interlock status. Operation of the facility is semi-automatic and practically foolproof. The facility is normally left unattended until targets have to be changed, or a fault condition occurs.

The safety interlock system controls the thimble cover, exit port cover, exit port plug, lead container position and hot cell door. As an irradiated target moving through the TNF cave would expose a person present in the cave, opening the cave door not only disables the cyclotron beam, but also the target drive mechanism.

All target temperatures are continuously recorded on a multi-channel strip chart recorder. A temperature rise beyond the present limit causes the target holder to be moved out of the beam and a signal to be activated.

Model Tests

During the early design stage several tests were performed to ensure proper performance of the facility. A model was built from plywood and acrylic that included the hot cell and the thimble with one target holder. The model was built at full scale, except that the thimble was shortened to a suitable length.

The model was used to determine the required water flow through the target holder to avoid air pockets and to do a series of corrosion tests. Materials in the thimble and the cooling system are limited to stainless steel and aluminum alloys. Appreciable corrosion was apparent when untreated city water was used. This was eliminated after a demineralizer was installed, which kept the resistivity of the water above 5 MΩ cm.

The idler sprockets at the beam position have aluminum bearings on a #316 stainless steel shaft. Accelerated wear tests indicated that the bearings will still be operational after 25 years at one target change per day for each target holder. The water, in which the whole assembly is submerged, appears to act as an effective lubricant: bearings seized up several times, but only when run dry.

Adequate cooling of the thimble windows had been verified previously with some heat transfer tests done for the TNF, which has a similar window.[4] The adequacy of this design has also been proven under actual beam conditions. Some more heat transfer tests were done to study the effect of a thinner cooling path, 1.5 mm, as exists between targets and holder walls, as well as a much widened cooling path, 26 mm, which exists when a holder is removed next to a thimble window. The required heat flux densities for a 5 cm^2 beam spot are 400 W/cm^2 for the double targets and 58 W/cm^2 for the thimble windows. The tests showed that these heat loads could be handled with a reasonable safety margin. Also tested was the target well-thermocouple response, as the thermocouple makes rather poor thermal contact with the target. The following wells were tested:

#1 3.97 mm diam × 6.35 mm deep
#2 3.97 mm diam × 11.68 mm deep
#3 3.57 diam × 11.68 mm deep
#4 a spring-loaded brass electrical connector

Well #3 produced the best response: ~80% of the actual metal temperature at the well location.

The temperatures as measured by the thermocouples under actual irradiation conditions will show only a small fraction of the temperature of the target material at the centre of the target. Further tests with targets exposed to the beam would be required to determine the relationship between these temperatures.

Assembly

The irradiation thimble is now completely assembled and ready for installation in the beam line (Fig. 5). Some problems with the extremely long chains could only be studied at this stage and have been solved satisfactorily.

All chains have been run in, under tension, for several days prior to installation to eliminate most of the stretching that would otherwise take place during operation. Each target holder was also run up and down 500 times to verify proper operation of all drives.

Figure 6 shows the lower end of the drive mechanism with cooling manifold and thermocouples. Figure 7 shows the top end that will be located inside the hot cell.

Acknowledgements

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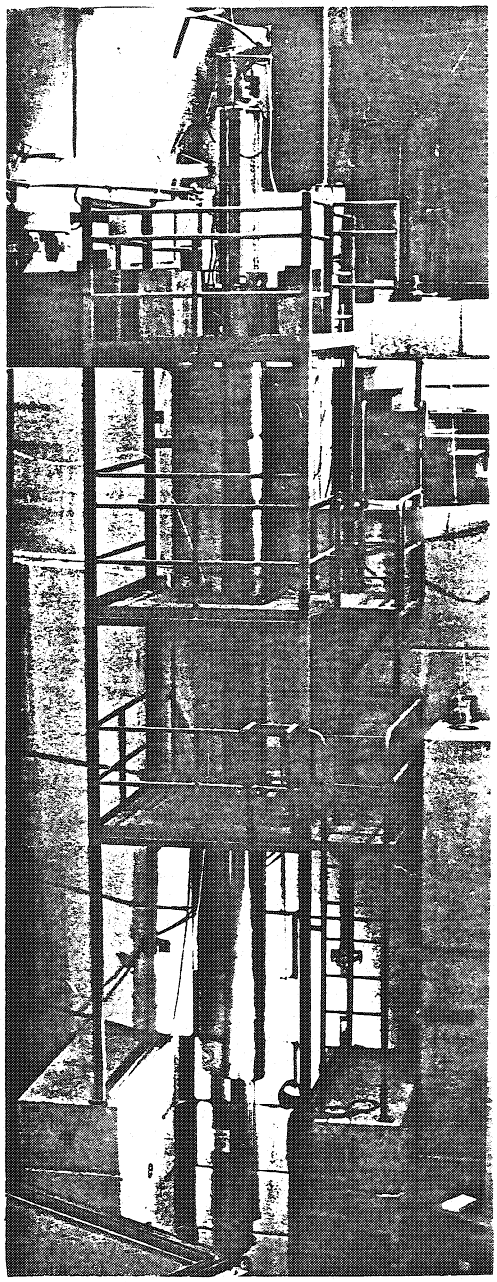

Fig. 5. Isotope production thimble, ready for installation.

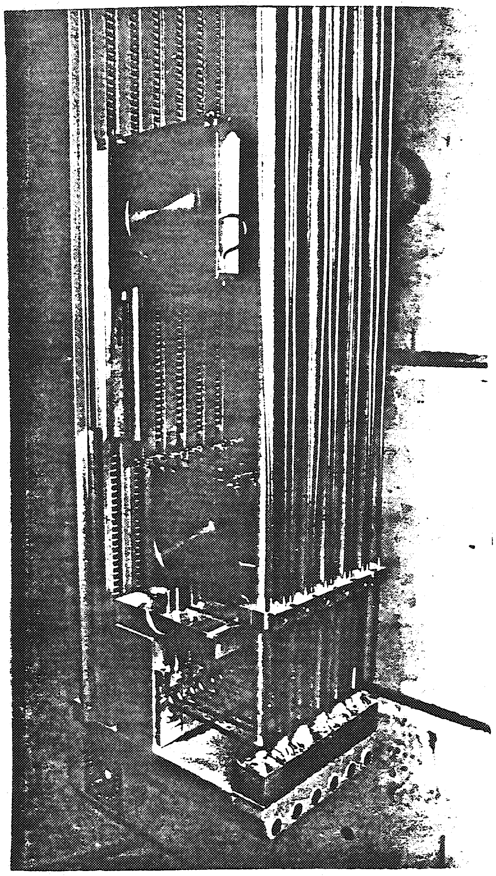

Fig. 6. Target holders in "in-beam" position, with cooling manifold, thermocouples and chain drive.

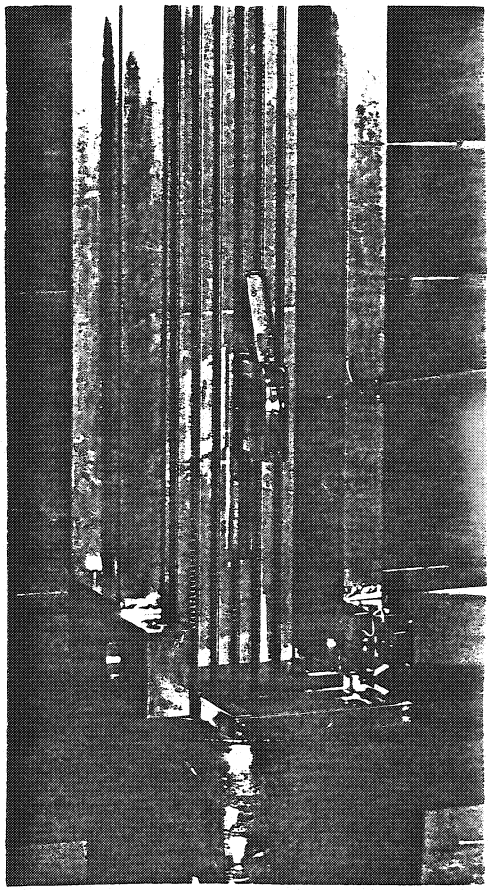

Fig. 7. Target holders in transfer cell position. The door is open to show the targets.