Engineering, Activity Handling and Emergency Considerations for a Rotating High Power Target

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1. Target Engineering

The target concept proposed for the German spallation source project (see also ref. /1/) is a disc or wheel-shaped target rotating about a vertical axis. It is mounted on a trolley and has moderators above and below the disc to provide the desired thermal and cold neutrons for extraction through beam holes or neutron guides.

For inspection, maintenance and certain repair operations on the target the trolley can be moved out of the shielding block where is located during operation into an inspection cell.

1.1 The target disc

The material to be used as spallation target is lead, although depleted uranium might be a candidate for a later version if sufficient experience has been accumulated. Four different possibilities for the internal structure of the target have been considered

I Target with evolvent-shaped segmentation of the material
II Target with arrangement of spheres
III Target with cylindrical elements
IV Massive ring target.

The heterogeneous arrangement in versions I to III allows very intense cooling and results in relatively low operating temperatures with the advantage of the material remaining solid and retaining good mechanical rigidity . The proton beam would enter the target through the outer periphery of the wheel, passing through a window which is part of the coolant-containment. The inner surface of this window is directly cooled by the target coolant (water). This, together with the fact that this window is hit by the proton beam only once per revolution, ensures low operating temperatures which are important for mechanical properties as well as radiation damage effects.

For the massive ring target (alternative IV) heat removal would occur only from the outer target surface. The resulting temperatures at the centre plane would be high enough for the lead to melt. While this reliefs many of the thermal stresses, provisions are necessary to ensure proper containment of the material. Therefore the proton beam would hit the inner surface of the ring-shaped target with the outer, solid parts supporting the molten portion. To pass above the opposite part of the ring, the beam would be brought in, pointing slightly downwards. To confine evaporating target material a window with internal cooling was considered necessary.

The concept chosen for the reference proposal is alternative III (cylindrical target elements), with the Pb target cylinders clad in aluminium cans. The reasons are

- Well established manufacturing technique by electron beam welding
- Low temperature level (73K above coolant at hot spot /3/)
- Good thermal contact from target to cladding because of thermal expansion coefficients
- Easy handling of pins for disposal.

Some 9128 pins of 10 cm hight and diameters ranging from 18 to 24 cm are arranged on concentric circles in a close packed structure with 1 mm cooling gaps between neighbouring pins to form a target of 700 mm radial depth (Figs. 1a and b). The pins can expand individually without causing excessive thermal stresses on the support structure.

A static stress is caused on the target wheel structure (aluminium-magnesium alloy) by the pressure of the coolant (3 bars average) which drops by 0.5 bar from the inner to the outer target region. Finite element calculations are in progress to ensure adequate design throughout the structure.

1.2 Coolant supply, bearing and target drive system

The water needed to cool the target has to be brought in from the stationary support to the rotating target. The necessary rotating seals are integrated in a unit which at the same time provides for the support of the rotating wheel and encorporates also the drive system.

For the bearings, three possibilities have been considered

- Standard ball and roller bearing, oil lubricated positioned outside the high radiation field on an extended shaft /2/.
- Magnetic bearings using permanent magnets for the axial support and hydrostatic bearings for the radial guidance or magnets for both /4/.
- Hydrostatic water bearings.

Although the first two concepts are considered feasible and continue being examined, the last one was picked for the reference design because of its low friction torque, its small structural dimensions, its short shaft allowing a small height of the transport trolley and because its spent water could be fed into the cooling circuit quite easily (Fig. 2).

The target disc is driven by a water turbine acting directly on the disc shaft. Nominal speed of 30 rpm is reached within 3 minutes and is measured by a contact free ceramic insulated inductive sensor. No high stability is necessary for the control of the target's rotation. The spent water from the turbine is also fed into the colling circuit.

The coolant flow as determined by the heat transfer coefficient on the pins is 250 $m^3 h^{-1}$, with a pressure of 3.5 bars when entering the target. The coolant flows from the centre of the wheel to the outer window and is returned through a large number of bores in the upper and lower support structure (Fig. 1). The sealing against the vacuum surrounding the wheel is on the low pressure side by a ceramic slide ring working against graphite and surrounded by a separately pumped vacuum space (10^{-1} bar) and an annular labyrinth gland towards the main vacuum (Fig. 2). Water seeping out of the seal can thus be pumped off separately and the conditions of the sealing can be checked via the water leakage. The expected leakages is about 10 g/h under routine conditions.

1.3 The target trolley

To enable the target to be moved into and out-of operating position, it is mounted on a trolley (Fig. 3) which is also part of the target shield during operation. All supplies to the target and the lower moderator are incorporated in this trolley with the connections arranged at the rear end. All feed-throughs on the trolley are arranged to minimize neutron streaming in them. Jumpers which can be placed by remote handling provide the connections to the stationary ducts. One common vacuum hood will cover all the feed-throughs. The total weight of the trolley is about $12 \cdot 10^5$ kg. It is supported by 32 wheels arranged in twin sets and running on two rails.

2. Active handling system

Active handling will have to be provided for (1) the target disc, (2) the bearing, driving and water sealing unit, (3) the target trolley, (4) the lower moderator, (5) the last proton beam deflection magnet, (6) the upper moderator tank and cold source, (7) the beam shutters and, (8) the beam tube windows. Items (1) through (5) which are the most likely ones to need servicing can be handled using the provisions in the inspection cell alone. Servicing or

replacing items 6 and 7 requires temporary use of the crane in the hall above the target block (see ref. /1/) to transport these parts through this hall before lowering them into the inspection cell through a hole which can be opened between them. If one of the beam windows has to be changed, this will be done with suitable equipment through the beam tube.

In order to retrace the target trolley into the inspection cell, part of the proton beam line will be removed and the heavy deflection magnet (see Fig. 4) will be moved to the far end of the cell on rails. After this the vacuum cover over the trolley's connecting pipes will be removed and the jumpers disconnected. For this purpose a heavy duty manipulator will be available which can use tools of up to 50 kg weight or lift parts up to 5000 kg. In addition, the cell will be equipped with a crane of 25000 kg lifting capacity and four directly operated manipulator units.

A special engine will be available to move the deflection magnet or the target trolley on their rails into a position where several non-destructive tests can be carried out such as visual inspection by television, microhardness measurements, collection of irradiated test probes, leak testing and examination and exchange of the transport wheels. The target disc, the support and driving unit and the lower moderator can be dismounted and replaced in this cell.

Parts which have to be put out of service, in particular spent target discs, will be transported to the adjacent hot cell where they are prepared for disposal. Here equipment for machining and cutting will be available to dismantle the target wheels and remove the target pins one by one to be safely packed for shipment.

3. Emergency considerations

The proposed design has been chosen largely to minimize hazards which might result from the target operation. As a primary precaution, the proton beam will be turned off whenever irregularities in the operating parameters are detected. Since the beam can be shut off in lees than one pulse's duration (i.e. in a few tens of microseconds) the emphasis has to be on the detecting systems for any fault that might occur.

3.1 Loss of proton beam

In the case of a loss of the proton beam along the beam transport line, increased radiation levels in the tunnel will lead to a shutdown of the accelerator. This will also be true if the vacuum in the beam line is lost.

These cases do not constitute a hazard to the target's operation.

3.2 Loss of target coolant

Loss of target coolant can occur due to rupture of the supply pipes or due to failure of the operating water pumps. The coolant flow will be monitored by redundant pressure and flow gages in the circuit and by the pumps' electrical data. The temperature of the coolant will also be measured. All joints are equipped with leakage detecting systems and the water vapour content in the vacuum system will be monitored.

If a complete loss of coolant occurs, each proton pulse will heat the most heavily loaded target pin by 70 degrees. Since each pin returns to the proton beam only after 2 seconds, and a temperature rise of 150 degrees is no problem, no specially fast detection systems are needed. It should be noted that it is foreseen to have always two coolant pumps with separated pipe systems and independent electrical supplies operating in parallel and that also the spent water from the turbine and the bearings contribute to the coolant flow. It is therefore extremely unlikely that any sudden complete loss of coolant will happen at all.

3.3 Afterheat

According to calculations /5/ the heat production in the target immediately after shutoff of the beam from full power will be 40 kW and will drop to 25 kW within ten seconds and to 12 kW within one hour. Assuming that all heat is stored in the target with heat exchange occurring only within the target, the target temperature would rise by 150 K within the first hour, which would still be below the melting point of lead. Although being very conservative, this estimate shows that minor cooling for 24 hours (100 ℓ of water per hour) after shutoff is sufficient to keep the target in safe conditions for later use. Even in an emergency case there would be ample time to start safety measures such as sprinkling the target from outside to avoid any damage.

3.4 Failure of target pin cladding

Should the aluminium containment of some of the target pins fail, e.g. due to burnout following a cooling gap closure or due to corrosion effects, this will eventually result in an increase of the coolant activity level. Since the amount of water in the circuit is fairly high, it will be necessary to monitor the water and the filters for specific radioactive nuclides

which can only be produced from the target and not from the structural material. Due to the large number of pins in use, the release of activity will always be small if one or a few of the pins become defective. The target will be put out of service if coolant contamination becomes intolerable.

3.5 Loss of water pressure in the bearings

If the water supply for the turbine is turned off routinely, the friction in the sealing will bring the target wheel to a standstill after two minutes if water lubrication and pressure for the bearings remain normal. Should the water pressure of the bearings and the turbine be lost simultaneously, the time needed for slowing down the wheel would be 35 seconds. Since the change in the wheel's speed of rotation as well as the pressure loss would lead to a shutdown of the proton beam, there is no risk of overheating due to the wheel's slowing down.

References

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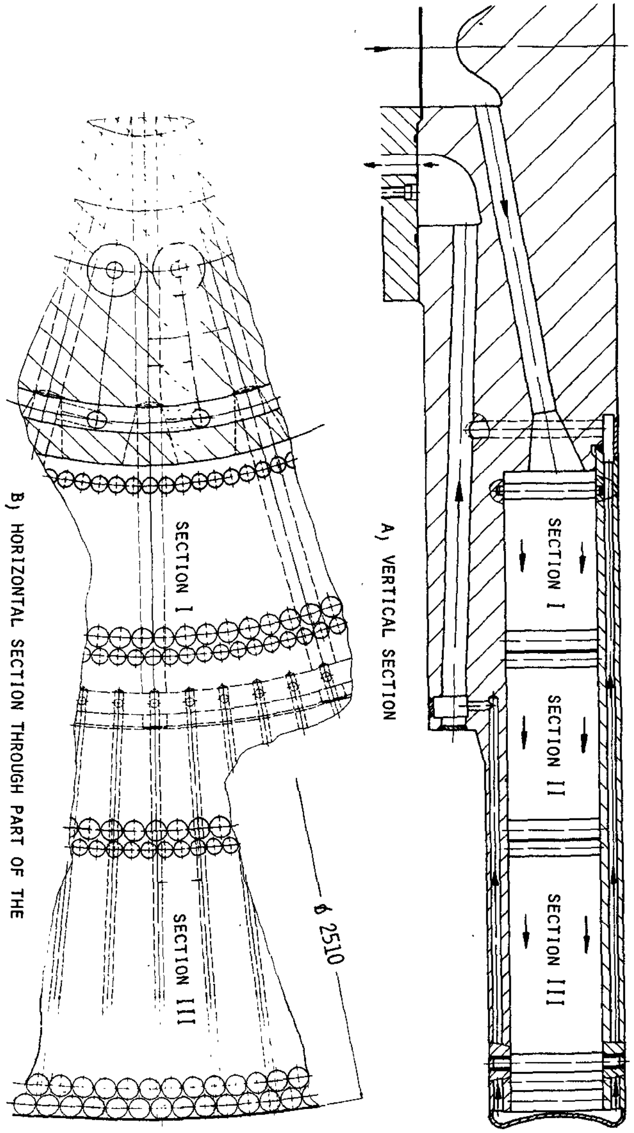

A) VERTICAL SECTION

B) HORIZONTAL SECTION THROUGH PART OF THE TARGET DISC

FIG.1 ARRANGEMENT OF TARGET PINS AND COOLANT CHANNELS IN THE TARGET DISC. CLOSELY PACKED PINS OF DIAMETERS VARYING FROM 24 TO 18 MM ARE ARRANGED IN THREE GROUPS OF CONCENTRIC CIRCLES.

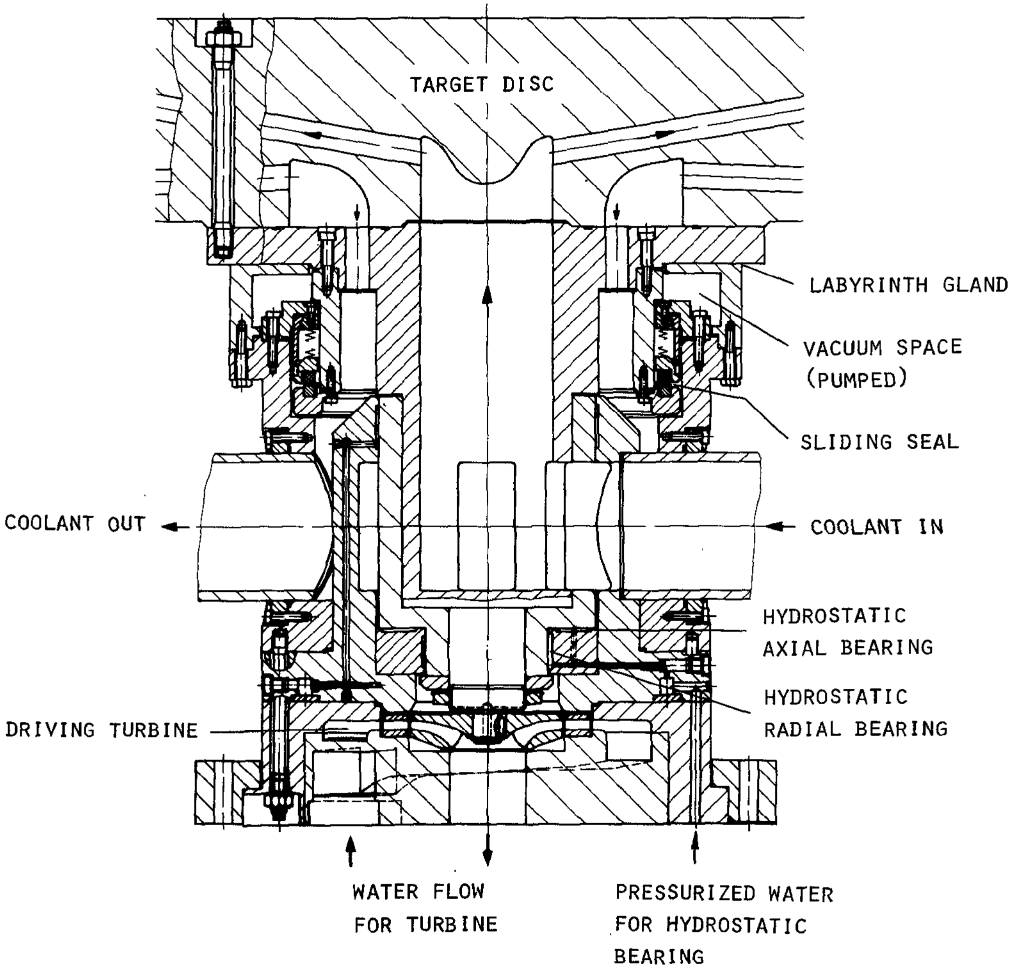

FIG.2 SECTION THROUGH TARGET SUPPORT AND DRIVE UNIT

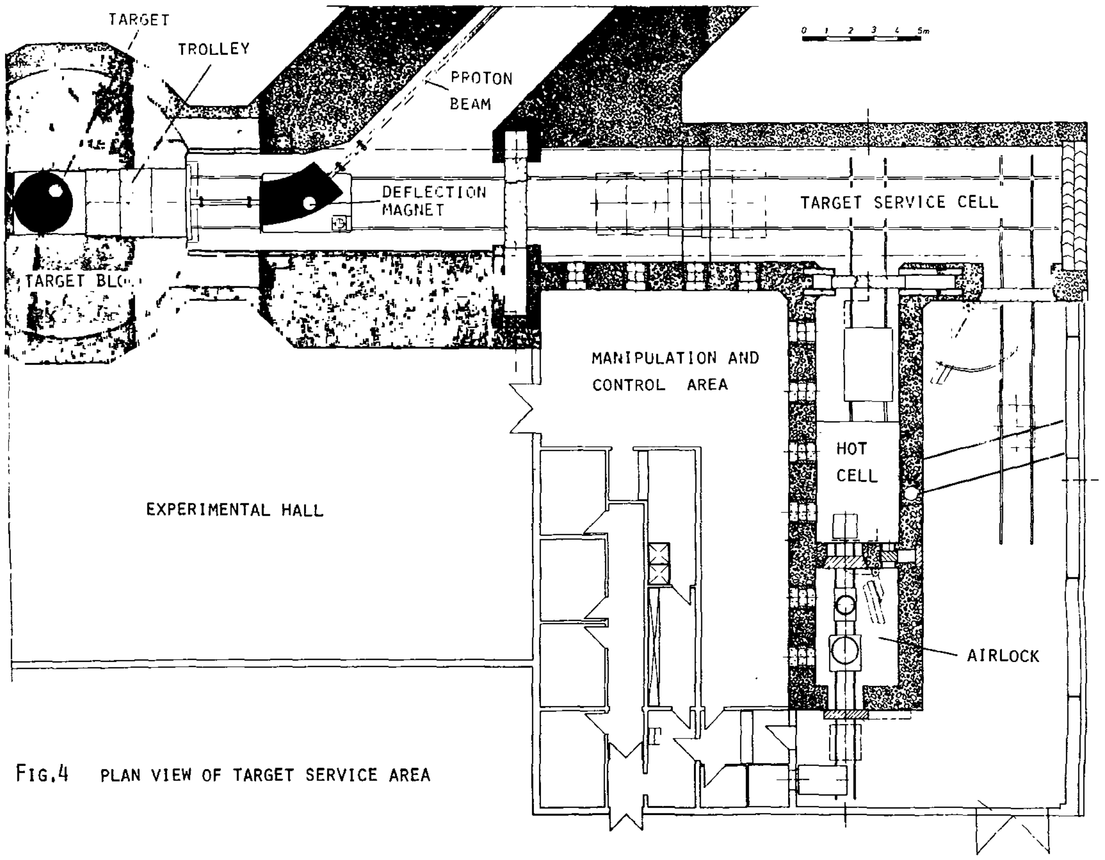

FIG.4 PLAN VIEW OF TARGET SERVICE AREA

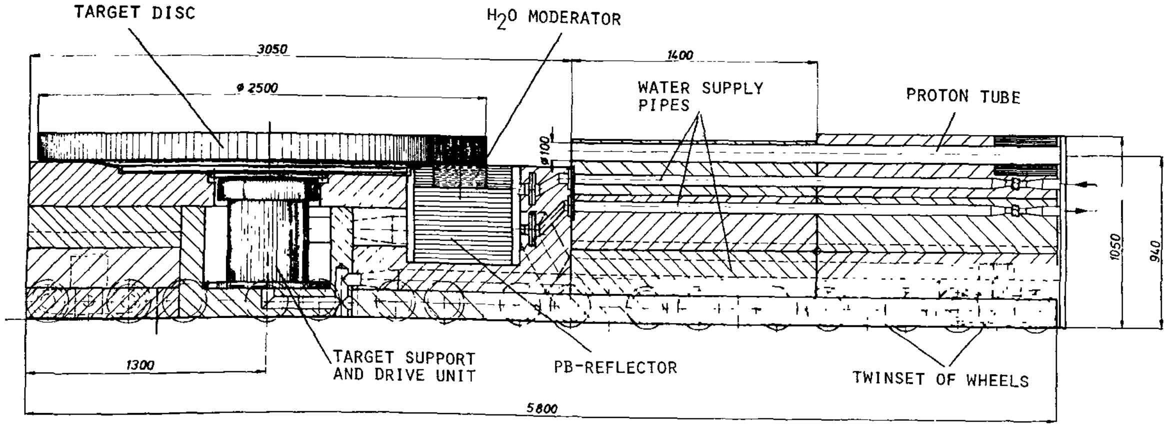

FIG.3 VERTICAL SECTION THROUGH TARGET TROLLEY WITH TARGET WHEEL AND WATER MODERATOR