Review of SNS Target Station

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1. Introduction

Aspects of the SNS Target Station have been described in the reports of the previous ICANS meetings; particularly of the ICANS III meeting at LASL, USA, in March 1979(1), also of an informal meeting on Targets for Spallation Sources held at Jülich, West Germany, June 1979(2). It is the purpose of this review to report progress and modifications over the last 12-18 months.

Figure 1 shows the SNS Target Station and its relation to the rest of the SNS facility. The Target Station consists broadly of four parts: Target, Target Assembly, Bulk Shield and Shutter System, and Remote Handling Facility. These will be described in the following sections.

2. Target

2.1 Target Physics

The target will consist of a number of parallel plates of uranium clad in Zircaloy-2 and cooled by D_2O, the whole being contained in an Inconel pressure vessel. Plate thickness of the uranium varies according to the energy deposition and is limited by metallurgical requirements; plate diameter has been determined to be 90 mm to maximise the epithermal neutron current from the moderator, as can be seen in Figure 2. Detailed computational studies have been made of the target and target assembly and some of the results are contained in Table 1. For the expected 200 μA, 800 MeV proton beam incident on the target the total thermal load is 230 kW; 209 kW is due to the uranium itself, of which fission contributes about 110 kW. There are 24.7 sub-15 MeV neutrons escaping from the effective surface of the cylinder containing the plates. The growth and decay of target activity are shown in Figures 3 and 4. Some 1200 nuclides contribute to the total of 0.86 MCi (corresponding decay heating 8.7 kW) after 6 months' continuous irradiation. Activity due to the Zircaloy-2 cladding is 9.5kCi. After storage to allow a one year cooling period, the total activity and decay power in the target are 3.2 kCi and 14W respectively; in particular the α-activity is 54 Ci. Short-lived nuclides in the coolant will give a saturation activity of 6.3 Ci/l and will result in a total of 500 Ci in the "external" cooling circuits. Some short-lived neutron emitters will be present. Long-lived nuclides are ^3H (0.06 Ci/l after 2 years' irradiation), from oxygen spallation, and ^7Be (0.1 Ci/l); contributions from ^{14}C and ^{10}Be being negligible.

2.2 Target Engineering

The development of bonding between the uranium and the Zircaloy-2 cladding has concentrated on two techniques readily available in the UK. The first technique, liquid phase bonding, has the attraction of obviating the β-quench. Tests were done using tin and lead sputter coatings on the uranium and Zircaloy-2, and metallic interlayers. No successful bonds were obtained. The second technique, hot diffusion bonding, relies on direct pressure, 7 N/mm^2 at 800°C for 1 hour, on the pure materials. Three target plates were produced with satisfactory bonds, which failed during subsequent processing (β-quenching, forming) due to differential contraction. Though the second method has possible solutions, a new program of work is being initiated using the most economic and promising process, hot isostatic pressure bonding.

The cooling mechanism for the target is nucleate boiling. Figure 5 shows the flow/pressure drop characteristics for cooling gaps ranging from the initial 1.75 mm to 1.0 mm. The coolant operational parameters will be velocity 5.5 m/sec, pressure 2.75 bars, T_{sat} 131°C and T_{bulk} 38°C. Figure 6 shows a plan of the actual target, including data on plates and cooling. The maximum power density in the uranium is 0.77kW/cm^3 with a corresponding centre line temperature of 348°C. The chosen maximum allowable temperature of 400°C gives a safety margin of 30% on power or 15% on beam width. The peak heat transfer rate required is 250 W/cm^2; for the given coolant parameters this is 1/3 of the experimentally measured burn-out. It can be seen from Figure 6 that there will be 3 inlet and 3 outlet channels and that the plate cooling channels are in groups of three. This method reduces the total quantity of coolant required (537 litres including the external cooling system), yet allows adequate monitoring of the cooling parameters. Individual gap closures of 0.25 mm can be detected by the pressure and flow monitors. Flow diagrams of the overall cooling system have been completed.

3. Target Assembly

The Target Assembly contains 4 moderators: 2 above the target and 2 below, in wing geometry. Each moderator is surrounded on all but its exit faces by decoupler and the whole array is contained within a beryllium and heavy water reflector. Neutron beam ports through the reflector are also lined with decoupler. The disposition of the moderators is shown in the isometric view of the target assembly, Figure 7, and a total of 18 neutron beams can be served by these moderators. The dimensions, material, and temperature of each moderator have been chosen to match the requirements of the instruments. The actual moderators and their characteristics are shown in Table 2. The coupling factors quoted are for the so-called "reference design" dimensions of all the moderators of 100 x 100 x 50 mm^3. Moderators built to the maximum dimensions indicated will allow increases in flux by factors of approximately 1.4 Type A, 1.2 Type B, 1.3 Type C and 1.3 Type D respectively. The flux calculations have assumed a decoupler energy of about 36 eV for the A, B, D moderators. The final optimisation of dimensions and decoupler energies has still to be done, and Figure 8 indicates some of the scope. For the high resolution, Type B, moderator material and temperature are also very important. This moderator ideally extends the slowing down region to the longest possible wavelength, has low frequency modes and large hydrogen density. Recent studies have concluded that metal hydrides (eg TiH_2) are not suitable. The favoured material at the present is cooled and poisoned methane. For the Type C moderator with the longest possible wavelengths (4Å-10Å range) a para-hydrogen moderator at 20K will be used, with a cadmium decoupler of about $\frac{1}{2}$ eV decoupling energy. The relaxation of decoupler strength and dimensions has allowed a doubling of moderator flux compared to the reference design.

Table 2 also indicates the expected total thermal loads in the moderators due to all effects. The values for the Type B (methane, 20 or 77K) and Type C (p-H_2, 20K) represent formidable technical, safety and cost problems.

The "reference" decoupling energy of 36 eV corresponds to a ^{10}B density of 0.01 atoms/$Å^3$ and is obtained by a 10 mm thick layer of natural B_4C powder of density 1.1 g/cm^3. The total power deposited in the decoupler is about 9 kW, with a peak power density of 4W/cm^3. This is due mainly to the $^{10}B\,(n,\alpha)^7\,Li$ reaction; this also liberates 13 litres of He per year. Total activity due to short lived products in the decoupler is 530 Ci.

The reflector is constructed to give 80% by volume beryllium, the rest being filled with D_2O to act as both reflector and coolant. The overall dimensions, 680 x 500 x 790 mm^3, have been chosen to allow at least 250 mm of effective reflector material around each moderator. Total power deposited in the reflector is 7.2 kW, 60% of this being due to high energy particles from the target. Tritium production in the D_2O in the reflector will result in an activity of 0.3 Ci/l after 2 years' operation.

Detailed flow measurements on the ambient water moderator have been made to ensure the temperature stability of ± 0.3% can be obtained. Proper location of the inlet and outlet pipes has ensured that there are no unswept regions. Measurements have shown that at the operating pressure of 1.68 bars the neutron exit face of the moderator, 3 mm thick aluminium, will deflect about 0.18 mm, which is acceptable. No detailed work has been done on the cryogenic moderators.

Layout design of the whole assembly has been done. Design of the reflector is almost complete and it will be built in 5 basic layers using 27 mm diameter rods. The beryllium has been obtained, but machining is not due to be done till 1982.

4. Bulk Shield and Shutter System

The target station bulk shield can be seen in Figure 9 and consists of 4 parts: 1) target void, 2) shutter vessel, 3) outer shield, and 4) plinth. Items 2 and 3 constitute the bulk biological shield whose function is to reduce the radiation level at the outer surface to less than 0.1 mrem/hr. Through the shield are 18 neutron beam lines, each of which can be closed by an independently operated shutter.

4.1 Target Void

The target void vessel is cylindrical, 1.6 m radius by 3.8 m high, and provides a contained helium atmosphere around the target. The helium will flow in a closed cooling circuit at about 0.4 m^3/sec to remove the 5kW of heat deposited in the vessel walls. For containment the helium will be at reduced pressure (- 5.5 mbar). Modern codes of practice require the vessel, including its windows, to be a vacuum vessel so it will have walls of mild steel clad on the inside face with stainless steel, overall thickness about 12 mm. The windows will be mounted in frames which can be oriented to view an upper or lower moderator and will be maintained by remote handling techniques from the inside. Each window will, in practice, be a double window of thickness 2 x 0.5 mm aluminium, of cross-section 190 x 190 mm^2, to allow complete viewing of a moderator by an inclined neutron beam line of 10 cm aperture.

The target void vessel floor is of stainless steel of conical shape, connected at its centre with a double walled stainless steel drain-pipe leading to external emergency dump tanks. The radiation levels at the middle of the empty target void vessel due to induced activity in the walls will rise to about 130 rem/hr.

4.2 Shutter Vessel

On either side of the target void vessel is a shutter vessel, each containing 9 shutters on nominal 13° centres. The shutters, when closed, reduce the radiation level in the beam at 10 m to 2.5 mrem/hr and so allow access when the proton beam is on. The shutters are made of iron and concrete and have dimensions 4.5 m x 2 m x 0.28 m, weighing about 22 tonnes each. Because of crane limitations in the experimental hall each shutter is in 3 sections, the centre one of which has a 200 x 200 m^2 hole in which the beam collimator is mounted, with its own helium or vacuum, atmosphere. A 250 mm vertical movement of the shutters is provided by mechanical jacks. Vertical Location is expected to be better than 1 mm and stability $\sim$ 0.2 mm. Between the shutters is wedge shaped steel shielding, with removable iron and concrete shielding above.

The shutter vessels themselves have only the inner face of steel (the target void vessel), the other faces being concrete. Energy deposition is about 6.5 kW in each vessel and this will be removed by flowing air, rather than by closed circuit helium proposed earlier. These last features lead to a considerable simplification and saving in cost, but also bring problems of their own. Vertical stability of the shutters is now twice the previously reported value of 0.1 mm but is still acceptable. Cooling by air, at a rate of 5 volume changes per minute, results in a specific activity of 83 μCi/l. Present plans are to feed this air along the extracted beam line enclosure, to be diluted with the air in the magnet hall prior to venting.

4.3 Outer Shield

The outer shield extends from the shutter vessel to a radius of 5.9 m. This gives a total shield thickness of 4.4 m of iron and concrete. On the outer surface of the shield the radiation level will be less than 0.1 mrem/hr, except in those sections containing the neutron beams when the radiation levels may reach 6 mrem/hr and will be increased further close to the neutron beam lines. In these regions the shielding will be supplemented by loose blocks. The outer 0.25 m of the bulk shield will be concrete loaded with 1% boron.

As reported previously, a feature of the outer shields is the use of inserts to allow local reconfiguration of the beam lines. These shielding inserts are ready to go out for manufacture.

4.4 Plinth

The plinth forms the foundation for the target station and the remote handling cell. Overall dimensions are 17 m x 12 m x 3 m. On either side are caverns, one of which will contain the emergency dump tanks for the target void vessel. The plinth consists of a reinforced concrete tank 0.75 m thick (containing a water seal), filled with iron and concrete. The iron used was mainly magnet sectors of the former NIMROD accelerator, 3 layers deep. A rigid pillar is incorporated into the plinth to form the basic datum from which the target station and experimental area survey grid are set out. Figure 10 shows the plinth and the embedded magnet sectors can be clearly seen. The next stage in this construction is to add a reinforced concrete raft on which will lie the machined base plates for the shutter system.

5. Remote Handling Facility

Immediately downstream of the bulk shield is the remote handling cell. The target assembly is mounted on a cantilever frame from a movable iron and concrete shielding door about 5.5 m thick. Beyond the shielding door are trolleys carrying the pipework and services. When it is necessary to remove the target assembly the whole system of door and trolleys rolls back on rails until the target assembly is located in the remote handling cell. Work on the components of the target assembly is done using conventional master-slave-manipulators; viewed directly through zinc bromide windows with exit faces 550 x 550 mm^2 and supplemented by TV cameras.

The major source of activity in the remote handling cell will be the target itself. Assuming it takes 1 hour to withdraw the target, the dose rate at 1 m is then about 10^6 mrem/hr. The walls of the remote handling cell will be 1.6 m of ordinary concrete. The zinc bromide windows will also be 1.6 m thick. The dose rate will be less than 1 mrem/hr at the outside face of the windows allowing prolonged use of the manipulators. Irradiated targets will be stored in a tank within the remote handling cell for periods up to about 12 months. As many as 3 targets can be stored at any one time. A target will be removed for disposal via a well into an existing service tunnel under the experimental hall. Ventilation for these systems is being designed in accordance with the United Kingdom codes of practice.

The base of the remote handling cell and the disposal well have been built as part of the construction of the target station foundation. A full scale mock remote handling cell has been recently completed to study in detail the problems of handling the components of the target assembly. As a design philosophy all components intended for the target assembly will be proven in this mock-up cell. Prototypes, including a target and its coupling flanges, for testing in this cell are now being assembled.

6. Timescale

The rate of design and construction of the target station (indeed the whole of the SNS) are determined by program manpower and financial profiles. Within the overall project are 6 "milestones" the last two of

which are of special importance to the target station: early 1984, 600 MeV protons at low intensity to provide the first neutrons; late 1984, 800 MeV protons at low intensity. Full intensity operation with 800 MeV protons is expected by about 1986. We look forward to these dates with no little eagerness!

7. Acknowledgements

This review summarises the work of members of the SNS Target Station Group, particularly Francis Atchison, Tim Broome, Dave Clarke, John Hogston, Mike Holding, Bernard Poulten, Ken Roberts, and Ron Wimblett; also Andrew Taylor of Neutron Division. It is a pleasure to record their continued efforts and enthusiasm.

8. REFERENCES

1. ICANS III, LASL, USA, March 1979. Papers by A D Taylor, R W Wimblett and A Carne.

2. Meeting on "Targets for Neutron Beam Spallation Sources" Jülich, West Germany, June 1979. Papers by F Atchison, T A Broome, A D Taylor and A Carne.

TABLE 1

Input Beam Protons, 800 MeV, 2.5×10^{13} ppp, 50 Hz, I mean = 200 μA

Beam diameter 70 mm, $I = I_o(1-(r/r_o)^2)$

1. **TARGET**

a. Power:

Prompt in Uranium	200	kW
Nuclide decay	8.7	
Zircaloy-2 cladding	6.4	
Coolant	5.2	
Inconel Vessel	7.0	
Total (rounded)	230	kW

b. Activity:

Irradiation		Post Irradiation			
t_i	Total(MCi)	t_c	P(kW)	α-act^y(kCi)	Total(MCi)
1 day	0.65	1 min	4	1	0.65
1 month	0.82	1 hour	1.4	0.6	0.4
6 months	0.86	1 day	0.5	0.47	0.2
		1 month	0.2	0.22	0.03
		1 year	0.014	0.54	0.003

c. Coolant Activity:

Short lived products in external circuit	500Ci
tritium	35Ci (2 years)
^{7}Be	60Ci

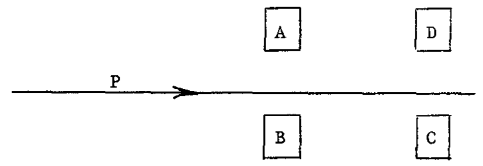
2	**REFLECTOR**	Power	7.2 kW
3.	**MODERATORS**	Power total	1 kW
4.	**DECOUPLERS**	Power total	8.9 kW

5. **ESCAPE PARTICLES**

Low Energy Neutrons (≲15 MeV)	1.3×10^{16}/sec	1.4 kW
High Energy Neutrons (15-800MeV)	1.0×10^{15}/sec	14 kW
Protons	2.8×10^{13}/sec	0.6 kW
Mesons	2.5×10^{12}/sec	0.018 kW
Total energy carried away		16 kW

TABLE 2

Moderators



	A	B	C	D
	H_2O	CH_4 ?	p-H_2	H_2O ?
	300K	20 - 77K	20K	300K
	High intensity at at expense of resolution	High resolution slowing down spectrum	Long wavelength 4-10A	(as required)
w	12	11.5	11	11
h	12	11.5	12	12
d	6	5	8	6
Est total power	368 W	283	240	250
design for	440 W	380	330	290
Decoupler	B_4C(∿1eV)	B_4C (1eV)	Cd(∿½eV)	B_4C(∿1eV)
Coupling factor x 10^{-4} n/eV/sr/100cm^2/n_f	2.2	1.8	2.0	1.3
Neutrons per SNS pulse at 1eV/sr/100cm^2	1.4×10^{11}	1.1×10^{11}	1.3×10^{11}	0.8×10^{11}

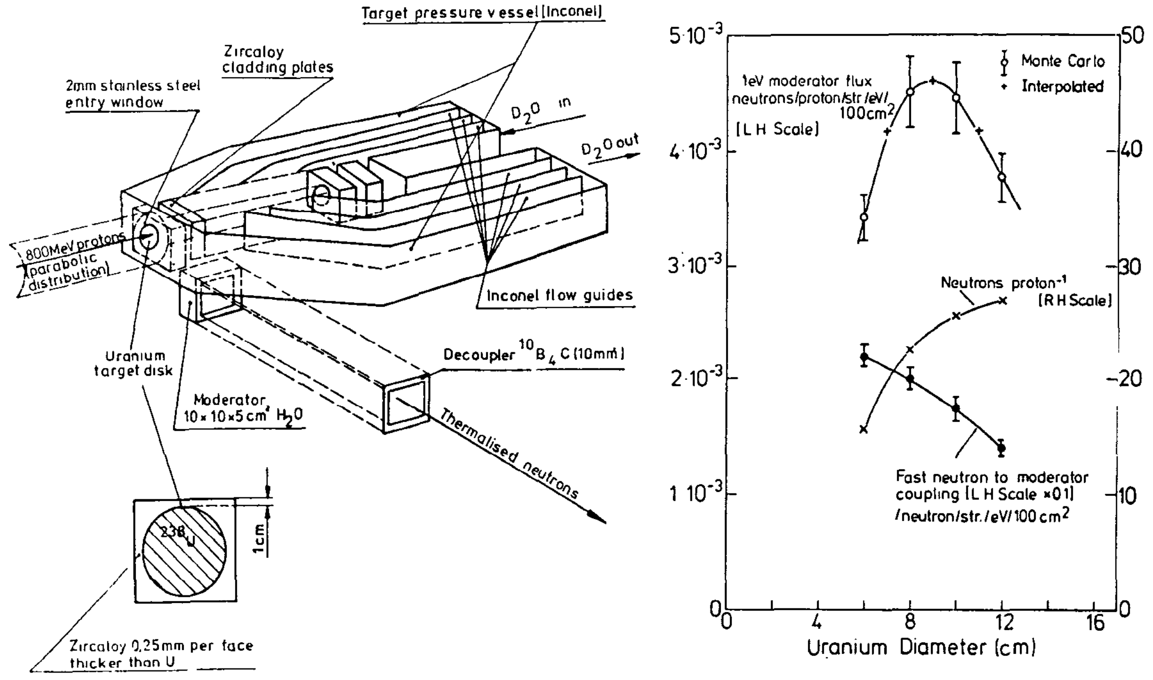


Fig. 2. OPTIMISATION OF TRANSVERSE DIMENSIONS OF SNS TARGET.

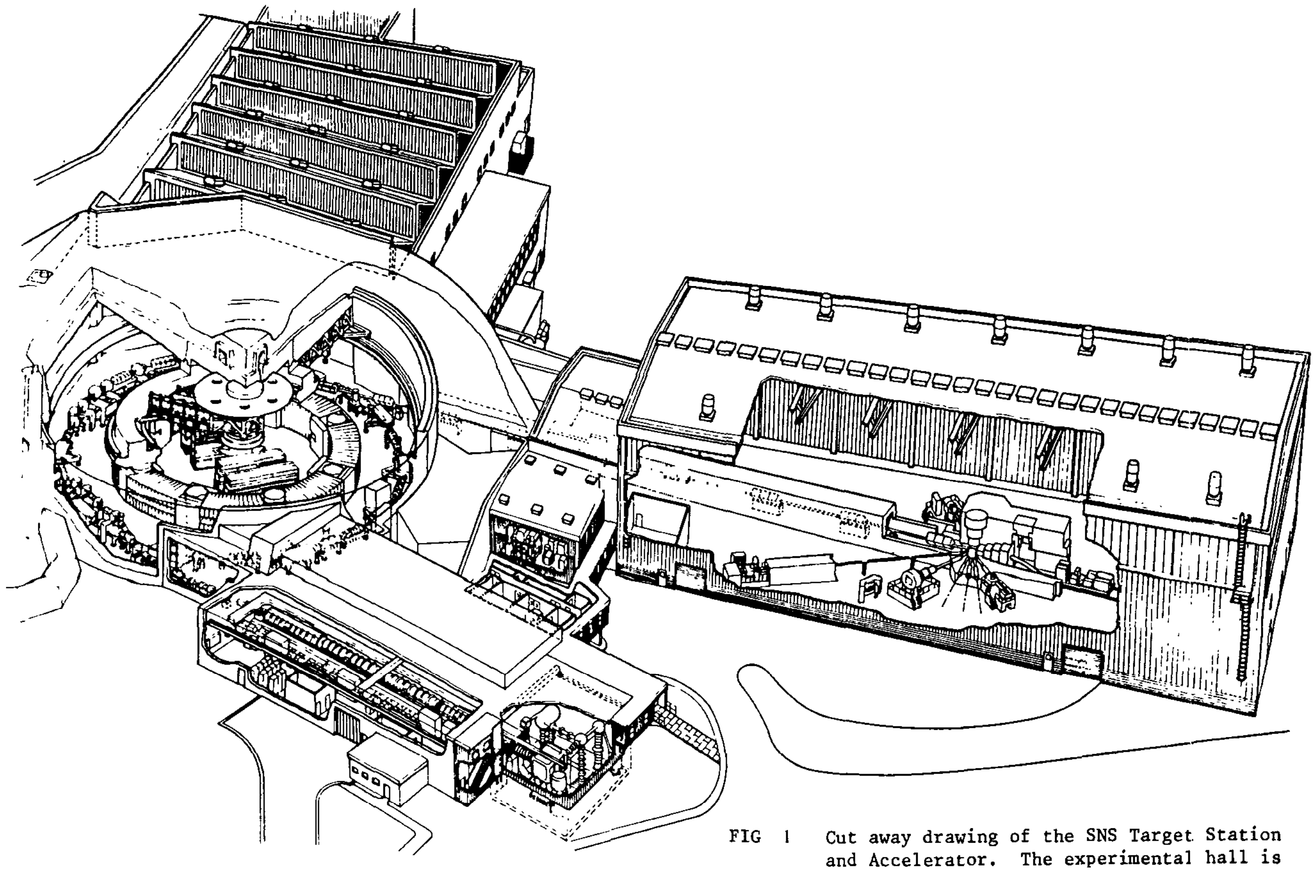
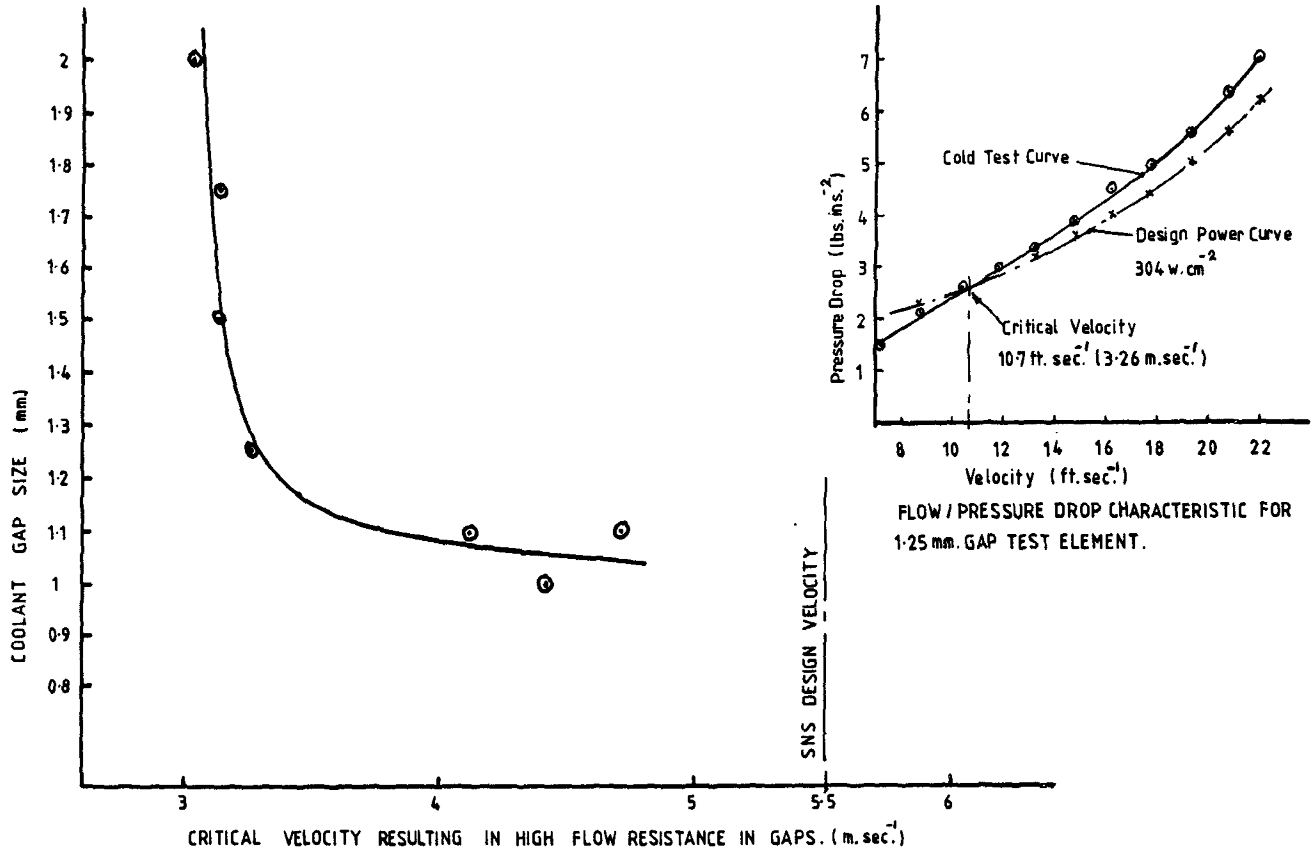


FIG 1 Cut away drawing of the SNS Target Station and Accelerator. The experimental hall is approximately 110 m long by 45 m wide



FLOW / PRESSURE DROP CHARACTERISTIC FOR 1·25 mm. GAP TEST ELEMENT.

Fig. 5. FLOW CHARACTERISTICS AND CRITICAL VELOCITY OF SNS TARGET COOLING CHANNEL.

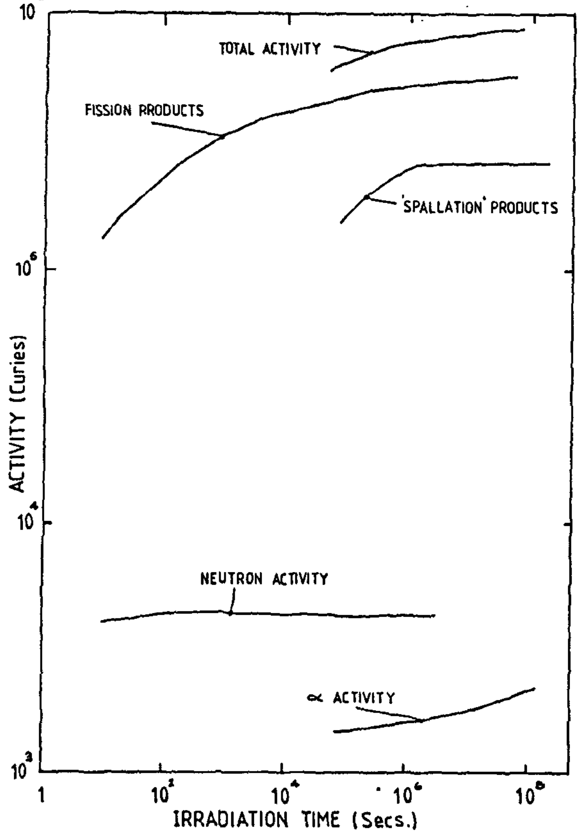


Fig. 3. GROWTH OF ACTIVITY IN SNS TARGET.

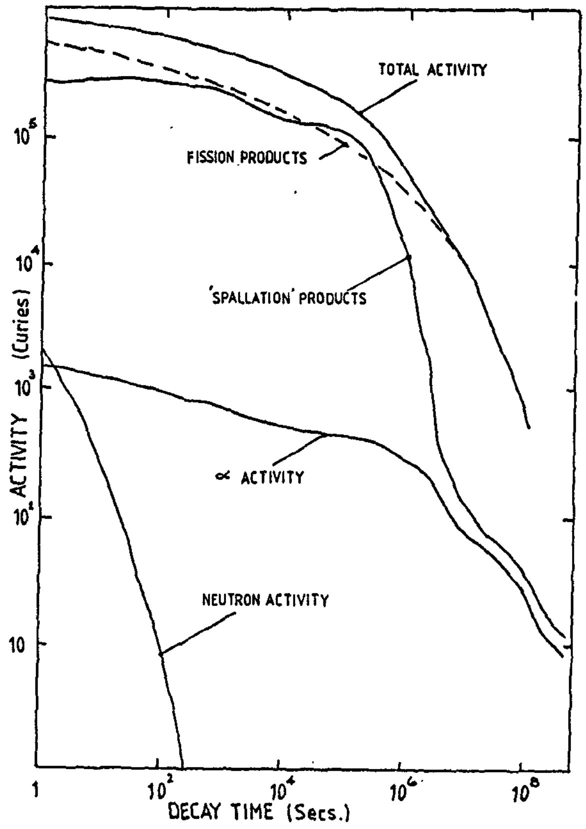


Fig. 4. DECAY OF ACTIVITY IN SNS TARGET.

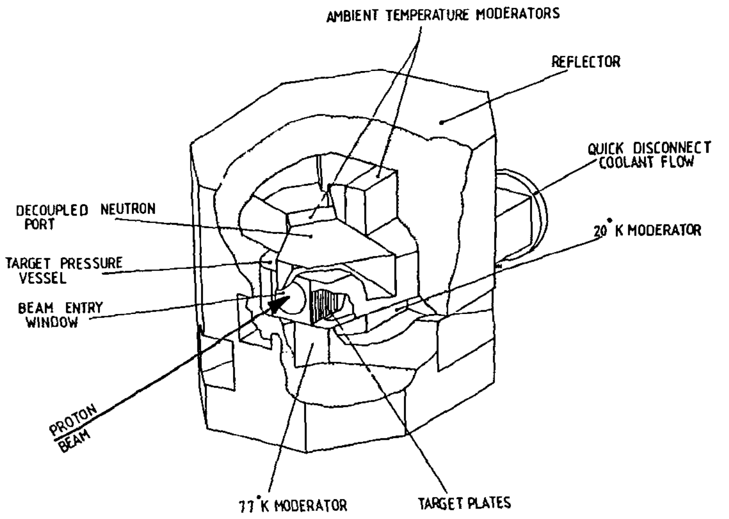


FIG. 7 PROPOSED TARGET ASSEMBLY WITH FOUR WING MODERATORS

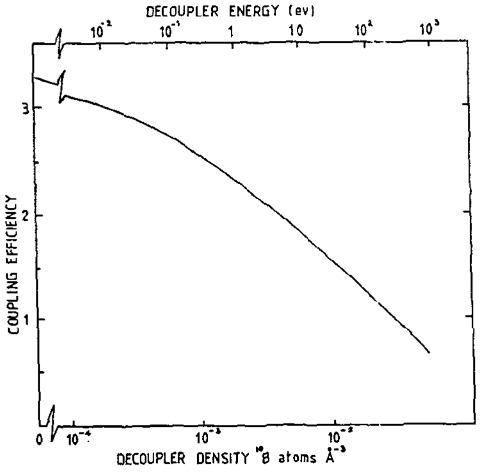


Fig. 8 MODERATOR COUPLING EFFICIENCY AND DECOUPLER DENSITY.

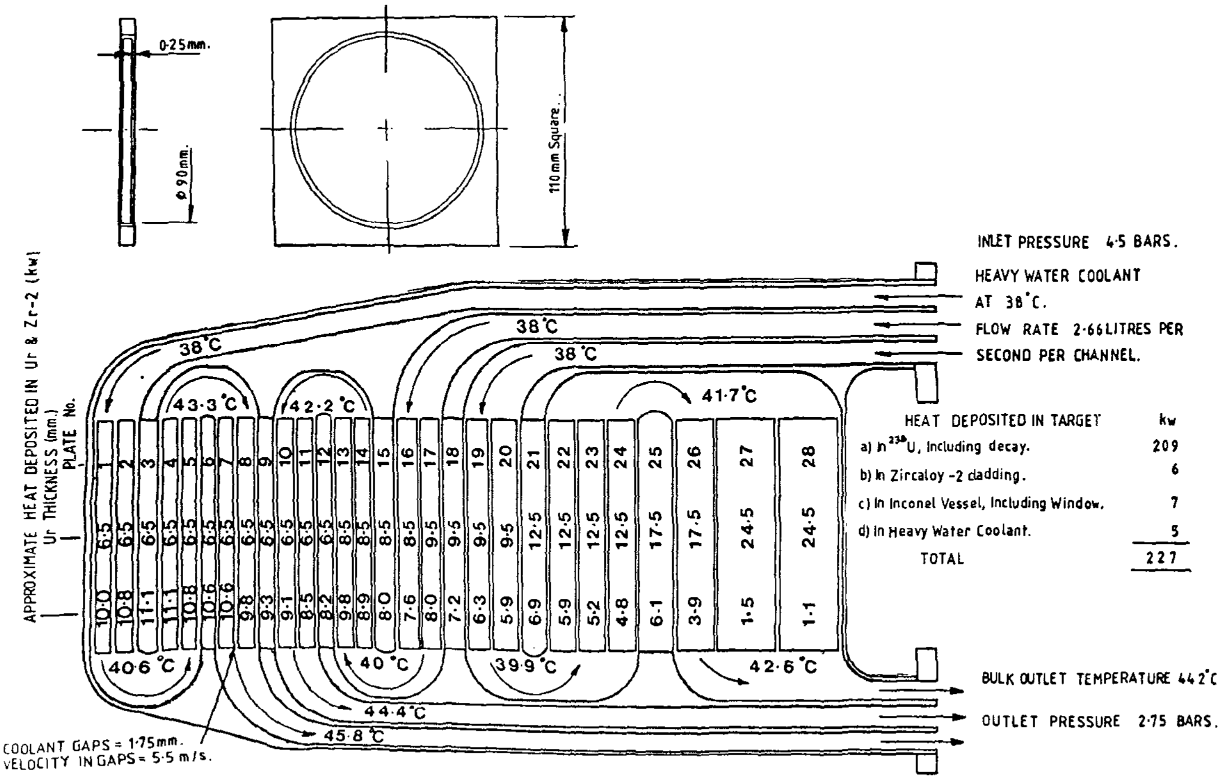
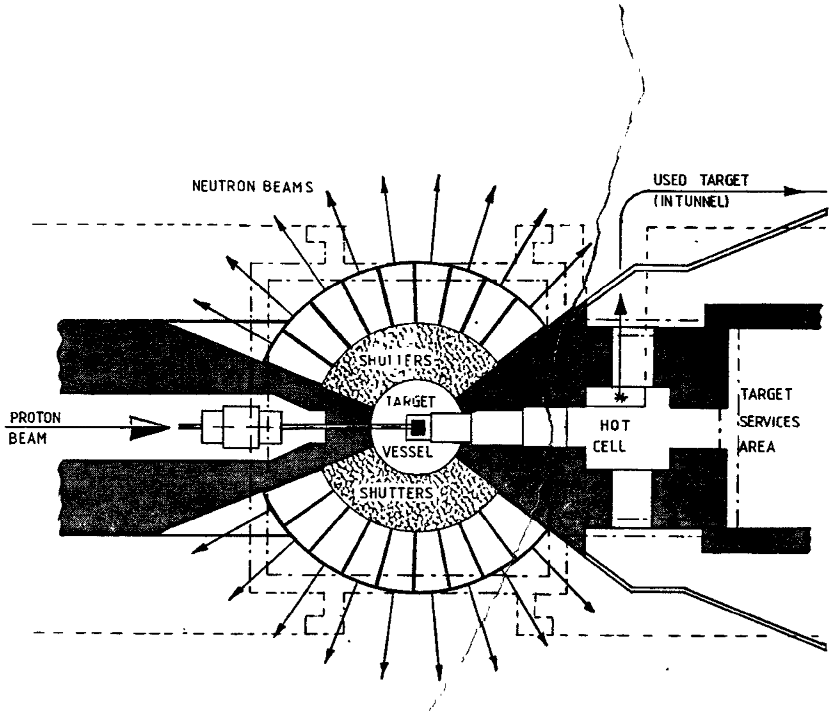


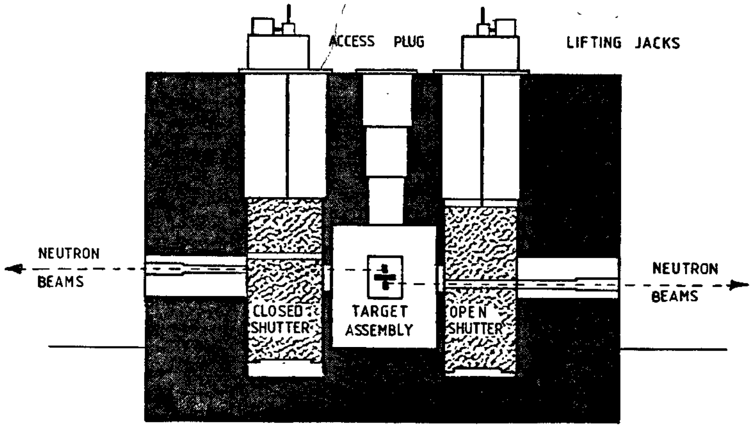
PLATE No.	Ur THICKNESS (mm.)	APPROXIMATE HEAT DEPOSITED IN Ur & Zr-2 (kw)
1	6·5	10·0
2	6·5	10·8
3	6·5	11·1
4	6·5	11·1
5	6·5	10·8
6	6·5	10·6
7	6·5	10·6
8	6·5	9·8
9	6·5	9·3
10	6·5	9·1
11	6·5	8·5
12	6·5	8·2
13	8·5	9·8
14	8·5	8·9
15	8·5	8·0
16	8·5	7·6
17	9·5	8·0
18	9·5	7·2
19	9·5	6·3
20	9·5	5·9
21	12·5	6·9
22	12·5	5·9
23	12·5	5·2
24	12·5	4·8
25	17·5	6·1
26	17·5	3·9
27	24·5	1·5
28	24·5	1·1

HEAT DEPOSITED IN TARGET	kw
a) In ^{238}U, Including decay.	209
b) In Zircaloy -2 cladding.	6
c) In Inconel Vessel, Including Window.	7
d) In Heavy Water Coolant.	5
TOTAL	227

Fig. 6. TARGET COOLING PARAMETERS AND TEMPERATURE DISTRIBUTION.



a) PLAN VIEW



b) VERTICAL SECTION

Fig. 9 TARGET STATION BULK SHIELD SCHEMATICS.

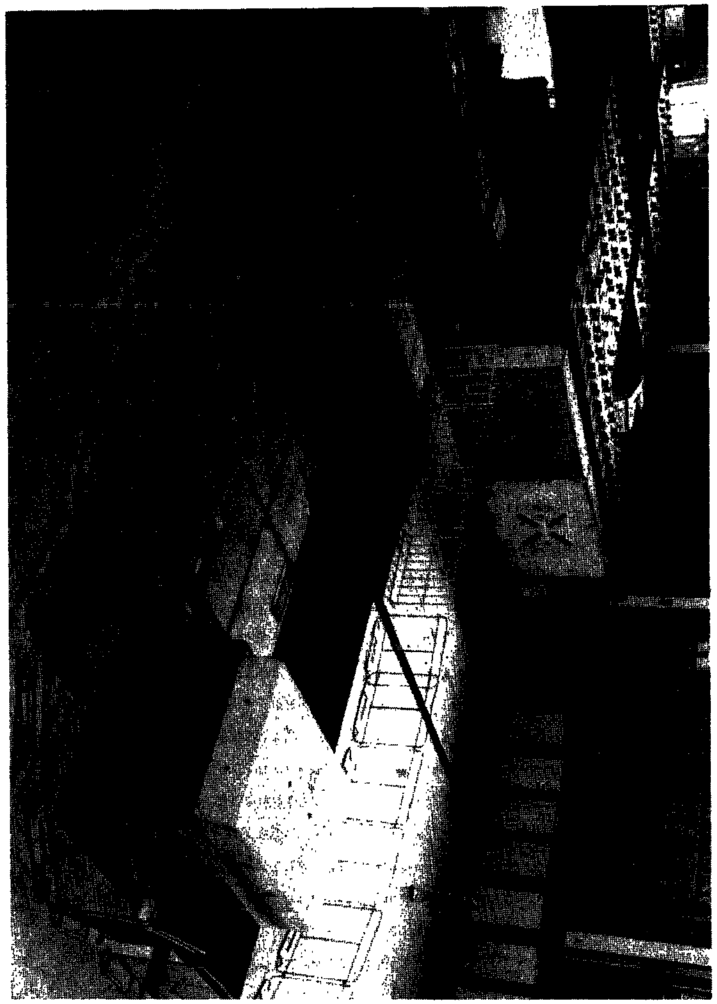


Fig. 10 TARGET STATION PLINTH