ICANS-VI

INTERNATIONAL COLLABORATION ON ADVANCED NEUTRON SOURCES

June 27 - July 2, 1982

CRYOGENIC MODERATOR DESIGN

B R Diplock
Rutherford Appleton Laboratory
Chilton, Didcot, Oxon, United Kingdom

ABSTRACT

This paper describes the present design of the two cold moderators to be built for the Spallation Neutron Source. It discusses the reasons behind a number of the design features and highlights several problem areas requiring solutions before a final design can be constructed.

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1. INTRODUCTION

This paper is intended to be a report on the current position of the two cold moderators being designed for the SNS. It is not meant to indicate how cold moderators should be designed, but rather to indicate the author's present thinking in the hope that it will stimulate discussion.

2. TARGET/MODERATOR ASSEMBLY

The position of the four moderators with respect to the target is shown in Fig 1, two ambient temperature moderators above the target, and two cryogenic moderators below. The physics requirements for the four moderators is shown in Table 1.

The forward lower moderator contains liquid methane (CH_4) at a temperature in the range 95-97K controlled to ± 1K, and the rearword lower moderator contains supercritical hydrogen (H_2) at a temperature of 25 ± 1K.

The methane is at a pressure of 4 atmospheres so that the boiling point (131.4K) is well away from the operating temperature to minimise the formation of bubbles which would give unacceptable density variations.

The hydrogen is at a pressure of 15 atmospheres, ie. above the critical pressure, to again avoid the risk of large variations in density.

3. MODERATOR VESSEL DESIGN (FIGS 2 AND 3)

Since the moderating fluids are at elevated pressures, both vessels need to be designed as pressure vessels, and a compromise needs to be reached between wall flatness and thickness. Ideally, for maximum coupling to the target, the walls should be completely flat and for minimum wall interactions, should have zero thickness.

To a first approximation, the ratio of wall radius of curvature to thickness is constant for a given stress level. It is possible, therefore, to vary one of the parameters, provided the other is varied simultaneously. Thus a flat wall requires to be thick, or alternatively, a thin wall needs a small radius of curvature.

A spherical radius of 250 mm has been chosen for both vessels coupled with a wall thickness of 3 mm for the CH_4 vessel, and 5 mm for the H_2 vessel. The material for both vessels is a 3.5% Mg aluminium alloy, since it has good mechanical properties at cryogenic temperatures and is easily welded.

The hydrogen moderator design has triple containment, the space between the outer wall and the vacuum vessel being filled with pure helium gas at a slight pressure above the outside volume. This latter volume is the target void vessel containing a minimum of 95% helium, the remainder being air. If no triple containment were provided, any leak through the vacuum vessel would allow the 5% air to cryopump on to the cold moderator vessel. Under irradiation ozone and various oxides of nitrogen would be formed which could explode spontaneously possibly causing a major failure of the moderator and target assembly. The pure helium blanket around the vacuum vessel provides a guarantee that air can never reach and cryopump on to the cold vessel.

4. HEAT LOAD

The heat load on the moderators arises from several sources. The vast majority of the energy input is due to nuclear heating within the moderating fluid itself, and this is very large compared with the heat input due to thermal radiation. As a result, there is little penalty in deleting the thermal radiation shield on the hydrogen moderator that is customary for cryogenic vessels that operate at temperatures below 80 K. Deletion of this shield reduces both the complication and also the material in the neutron beam.

A summary of the estimated heat loads from the various sources is shown in Tables 2 and 3 together with the moderator flow rates required to keep the temperature rise to the values stated.

The magnitude of the energy deposition in the moderator due to nuclear heating causes great concern, since the accuracy of the estimate appears to be poor. Under-estimation results in too little refrigeration capacity being available with the result that the operating temperature will not be attained, and over-estimation means that large amounts of money are needlessly used to provide over-size refrigeration.

The estimates that have been made for SNS have been based on information given at ICANS V1) and from SNQ2). This information has been extrapolated in the best possible way to the proton beam power of SNS.

It is very necessary for further experimental and theoretical work to be done to corroborate these estimates.

5. HEAT REMOVAL

Early calculations indicated that it was not possible to remove the heat from a static volume of moderator without unacceptable temperature variations due to the limitations of natural convection and conduction.

It was decided therefore that there remained two alternatives:-

a) Design a local circulation system for the moderator and transfer the heat via a heat exchanger to cold helium gas flowing through a long transfer line from the refrigerator.

b) Circulate the moderator through the long transfer line to the refrigerator.

Option a) reduces to a minimum the areas where hazardous gases are present, but requires a circulation fan to be placed in a high radiation environment, and the extra heat exchanger requires an operating temperature drop that reduces the operating temperature of the refrigerator.

Option b) is a simpler system but has a considerably larger region containing hazardous fluids.

After careful consideration, it was decided to opt for the second alternative, largely to avoid the problem of breakdown of the circulating fan in the high radiation area and its subsequent replacement using remote handling techniques.

6. LAYOUT OF CRYOGENIC SYSTEM

The general layout of the cold moderator system is shown in Fig 4. The target, moderator, transfer lines, refrigerators and shielding plugs are all mounted on a number of trollies making up a train. The whole assembly is designed to move horizontally on rails a distance of about 8 m to place the target assembly in the remote handling cell for maintenance work, target change, etc.

As can be seen, the transfer lines pass through the primary and secondary shielding plugs and have an overall length of about 16 m. As a result, it is very difficult, if not impossible, to design a removable transfer line without dis-assembling the shielding plugs. It is proposed therefore to design the transfer lines that are installed in the shielding plugs to be permanent and of maximum possible reliability. This means that they will have a minimum number of joints which will be fully welded and of high integrity.

To allow changes in moderator design to be accommodated, a demountable joint will be incorporated between the primary shielding plug and the moderator.

Due to the extremely intense radiation in this region, this joint will be designed for breaking and re-making using remote handling techniques, thus posing a major design problem.

As the refrigerators are mounted on a trolley in a restricted area, emphasis will be placed on using a design which is as compact and integrated as possible. It is hoped that an inert working fluid can be used, and that fans for circulating the moderating fluids will be incorporated in the refrigerators. The basic requirements for the refrigerators are shown in Table 4.

7. IRRADIATION EFFECTS ON METHANE

It is expected that a partial breakdown of the methane moderator will occur under irradiation and the products will be hydrogen gas and higher hydrocarbons, such as ethane, propane, etc.

The hydrogen gas can be removed fairly easily by a gas eliminater, but the higher hydrocarbons pose more of a problem. Some of the radiation products may have a freezing point above the operating temperature of 95 K so there is a finite risk of partial or complete blockage of the circuit, particularly in the refrigerator area.

To avoid this it is proposed to continuously remove a small percentage of the fluid, replacing it with fresh methane. It is anticipated that this will maintain the levels of the higher hydrocarbons at a sufficiently low level to avoid the risk of blockage. The amount of fluid to be removed has not yet been established, but it is hoped that it will be considerably less than 1% of the total flow.

A schematic layout of the methane circuit, Fig 5, shows this outgoing methane bleed cooling the make up gas in a regenerative heat exchanger.

8. OUTSTANDING PROBLEMS

As was said in the introduction, this paper is a report on the author's thinking on cold moderator design and it is clear that a number of problems still exist which should be resolved before the two moderators are built and commissioned. These can be summarised as follows:-

a. Temperature Variations in Moderator

The present design has a simple "in and out" flow system. Will this be good enough to maintain the temperature variation within ± 1 K, or must a more sophisticated design of flow channels be incorporated?

b. Temperature Excursions Due to Variations of Proton Beam Intensity (including On/Off transients)

What magnitude of excursions will occur and what time interval is there before temperatures settle down to within the acceptable limits?

c. Design of Remote Handled Transfer Line Joint

How simple, or difficult, will it be to design a reliable leak tight joint using remote handling techniques?

d. Risk of Methane Freezing in the Refrigerator

Is it reasonable to operate the moderator at 95 K (4.5 K above the freezing point) without the risk of local freezing in the refrigerator heat exchanger?

e. Triple Containment for H_2 Moderator

Is the risk of air cryopumping on the hydrogen moderator vessel sufficiently real to warrant incorporating a pure helium atmosphere in a triple containment?

f. Radiation Breakdown of Methane

What is the magnitude of the build-up of higher freezing point radiation products and how can they best be eliminated?

Answers to the above questions are not easy to obtain, but are necessary in order to design and build cold moderators having a high degree of reliability and safety.

9. ACKNOWLEDGEMENTS

The author gratefully acknowledges the help of various members of the SNS Target and Utilisation Group in discussions on cold moderators, and to Rob Hambleton, Graham Toplis and Elaine Wright for producing the illustrations.

10. REFERENCES

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TABLE 1

SNS Moderators

A	B	C	D
H_2O	CH_4	p-H_2	H_2O
316 K ± 1 K	95 - 97 K ± 1 K	25 K ± 1 K	316 K ± 1 K
High Intensity at expense of resolution	High Resolution slowing down spectrum	Long wavelength	(as required)
dimensions of moderator material, mm			
w 120 h 120 $d\ \left.\begin{array}{l}15\\30\end{array}\right\}45$	120 115 45 (at centre)	110 120 80 (at centre)	120 120 $\left.\begin{array}{l}22.5\\22.5\end{array}\right\}45$
Poison: 0.05mm Gd. Clad	Poison: provision for future incorporation	Poison: None	Poison: 0.05 mm Gd. Clad
Decoupler: 6mm boron loaded laminate, 35% natural B_4C	Decoupler: 6mm boron loaded laminate, 35% natural B_4C	Decoupler: None	Decoupler: As 'A'
Void Liner: As for decoupler (shared with 'D')	Void Liner: As decoupler preferred (shared with 'C')	Void Liner: 1mm Cd preferred (shared with 'B')	Void Liner: As for decoupler (shared with 'A')

TABLE 2

25K MODERATOR (PARA-HYDROGEN)

Max. Dimensions: 12 cm H, 11 cm W, 8 cm D,
Volume: ≃ 1 litre

Heat Input:	Nuclear in H_2	454 w*
	Nuclear in Aluminium	30 w†
	Thermal into Moderator	35 w
		519 w
	Transfer line (80K→25K)	6 w
	Circulating Fan	60 w
	TOTAL REFRIGERATION	585 w

Temperature Rise Across Moderator ~ 1.3°C
H_2 flow rate: ~ 33g/sec. (500 cm³/sec)
H_2 pressure: 15 atm abs. (supercritical)

* based on 1.2 mw/cm³ - μA for 500 MeV beam (ref ICANS V)
† based on 2.4 w/g for aluminium and 5mA beam (ref SNQ DATA)

TABLE 3

95K MODERATOR (METHANE)

Max. Dimensions: 11.5 cm H, 12 cm W, 4.5 cm D.
Volume: ≃ 0.6 litres

Heat Input :	Nuclear in CH_4	625 w*
	Nuclear in Aluminium	13 w†
	Thermal into Moderator	26 w
		664 w
	Transfer line	60 w
	Circulating Fan	60 w
	TOTAL REFRIGERATION	784 w

Temperature Rise Across Moderator ~ 2°C
CH_4 flow rate: ~ 98g/sec (220 cm³/sec)
CH_4 pressure: 4 atm abs
Boiling Point: 131.4K

* based on 2.64 mw/cm³ - μA for 500 MeV beam (ref ICANS V)
† based on 2.4 w/g for aluminium and 5 mA beam (ref SNQ DATA)

TABLE 4

REFRIGERATORS

HYDROGEN

~ 600 w at 25K
\+ ~ 150 w at 80K for radiation shield.

Working Fluid:	High Pressure Helium Gas.
Transfer Fluid:	Supercritical Hydrogen.
Flow Rate:	500 cm³/sec. (33g/sec)
Pipe Bore:	15 mm.
Circuit Resistance:	40 m.
Fan Power:	60 w into Transfer Fluid.

METHANE

~ 800 w at 95K

Working Fluid:	High Pressure Helium Gas.
Transfer Fluid:	Liquid Methane.
Flow Rate:	220 cm³/sec. (98 g/sec).
Pipe Bore:	15 mm.
Circuit Resistance:	30 m.
Fan Power:	60 w into Transfer Fluid.

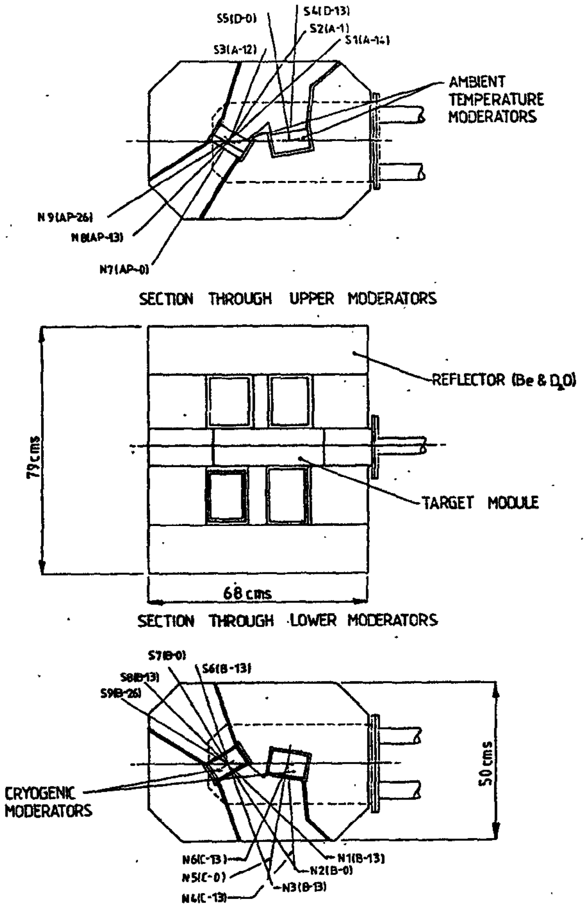

Fig. 1. Target/moderator/ reflector assembly

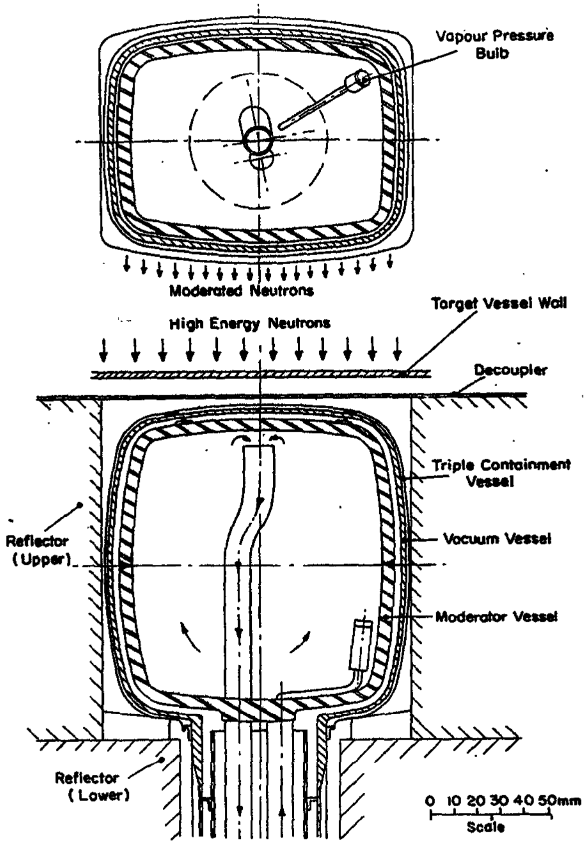

Fig. 2. Hydrogen Moderator (25°K)

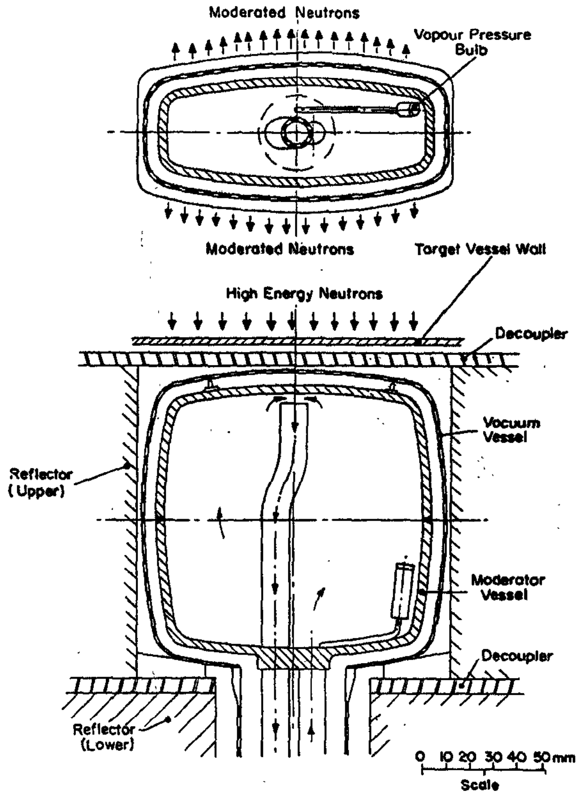

Fig. 3. Methane Moderator (95°K)

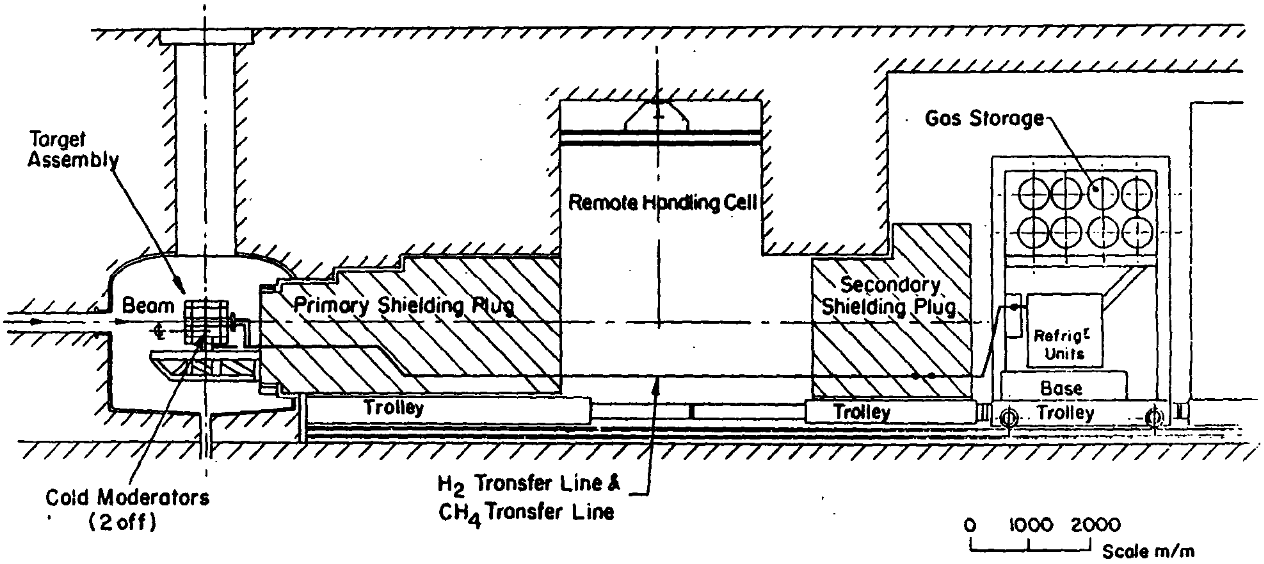

Fig. 4. General layout of cryogenic system

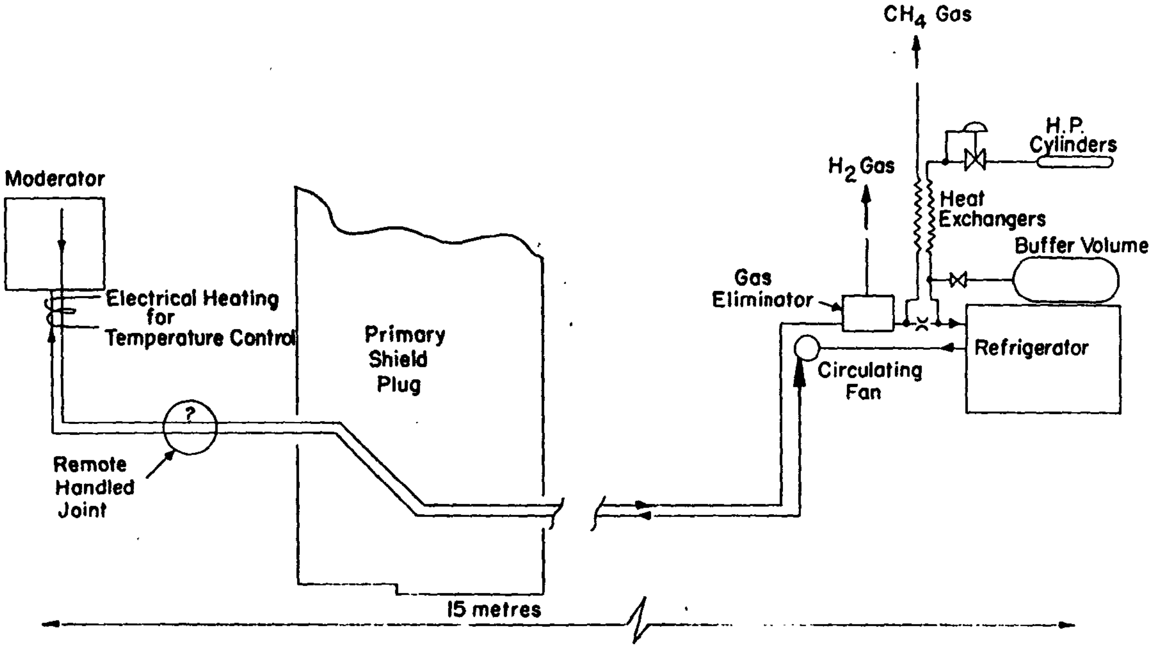

Fig. 5. Schematic layout of methane circuit