

## Cold moderators for spallation sources

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**ABSTRACT:** Moderators using both liquid and solid methane and liquid hydrogen are currently in use at major spallation neutron sources. Los Alamos Neutron Scattering Center (LANSCE) is planning the use of liquid methane as part of a major update program planned in about three years time. This report presents an overview of some of these devices and outlines the general engineering design of the proposed LANSCE moderator, including some suggested solutions to the radiation damage problems of methane. Also included is a brief overview of a possible combined  $H_2/CH_4$  moderator for high-intensity proton beams, which is covered in more detail in a separate paper.

### General overview

- Argonne National Laboratory has two liquid moderators and one of solid methane. The solid moderator is a foam-filled vessel of aluminum with a one-sixteenth-in. wall thickness at the viewed face. Cooling is provided by a heat exchanger coil carrying cold helium gas from a Koch model 1400 refrigerator.

The two liquid moderators operate in a closed loop using a room-temperature-positive-displacement pump. All the methane is warmed up to room temperature in a heat exchanger, which subsequently re-cools the fluid on its return to the main loop on each pass. A liquid-nitrogen-cooled helium loop, used to cool a reflector, also supplies a secondary loop on its return leg, which in turn cools the methane heat exchangers. Supercooled liquid methane fed to the moderators is temperature-controlled by varying the flow rate of cold helium gas through the helium/methane heat exchanger. The methane is maintained at a pressure of 2 bar absolute (see Fig. 1).

- KENS also has a solid-methane moderator that is directly cooled by a helium circuit, including a refrigerator. The moderator is an aluminum canister containing four plates, about 10 mm apart, that are in contact with the cooled sides of the vessel to assist heat transfer from the methane (see Fig. 2).
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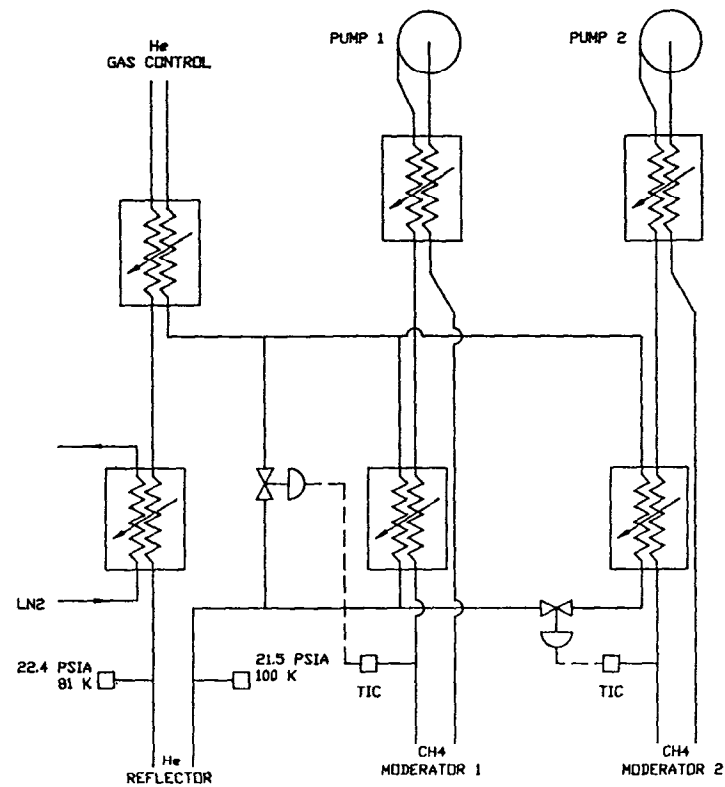


Fig. 1 Argonne National Laboratory CH<sub>4</sub> moderator flow schematic.

- ISIS has a liquid-hydrogen and a liquid-methane moderator, which function as completely independent systems. The hydrogen system was designed to operate in the supercritical region at 25 K and 15 bar absolute pressure. However, the current operating pressure is about 8 bar absolute since no boiling problems have been observed. The refrigerator is built by Sulzer and uses an oil-free reciprocating compressor and two-series-connected high-speed turbines. Temperature control is provided by an electrical heater in the helium refrigerant circuit powered in response to a germanium diode sensor in the hydrogen loop and powered through a three-term controller. The hydrogen pressure is controlled within  $\pm\frac{1}{2}$  bar of its setpoint by a pressure control system, and the hydrogen is circulated by a high-speed centrifugal pump in the return leg of the circuit.

The liquid-methane system is cooled by a Philips-Stirling cycle machine capable of about 1000 W at 100 K. The methane pressure is controlled at 4 bar absolute to raise its boiling temperature to 130 K. Circulation is provided by a high-speed centrifugal pump in the flow side of the circuit. Two 50-micron filters are built into the circuit return leg, and temperature control is provided by

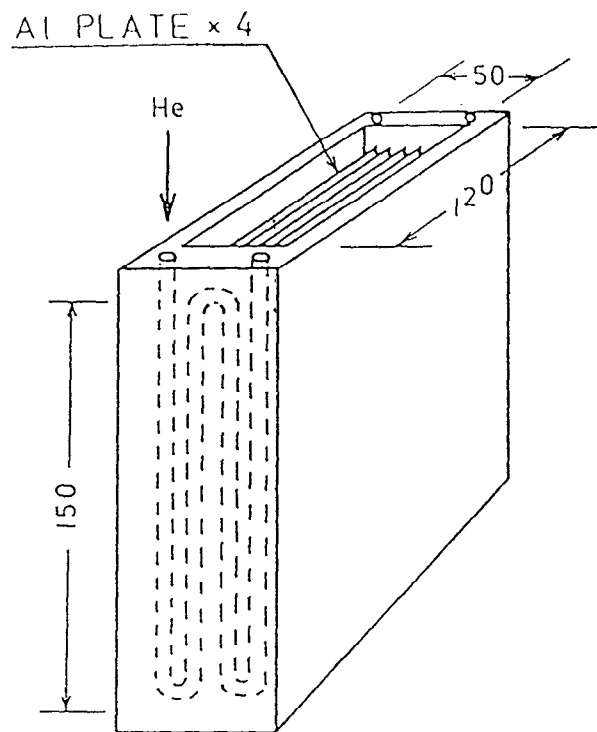


Fig. 2 KENS solid CH<sub>4</sub> moderator.

an electrical heater driven through a three-term controller in response to a platinum thermometer sensor.

Both systems incorporate a spare circulator that can be valved into line by remotely operated valves. A faulty unit can then be isolated, purged, and subsequently removed without shutting down the system. The same applies to the filters in the methane system (see Figs. 3 and 4).

- LANSCE has a single liquid-hydrogen moderator operating at 20 K and a pressure of about 6 bar absolute. The refrigerator is a CTI unit, modified for the purpose, which uses two compressors with oil separators and two reciprocating expansion engines. Hydrogen is circulated by a 3000 RPM centrifugal pump, which is in the outlet line of the system. Temperature control is provided by an electrical heater powered through a three-term controller in response to a germanium-diode temperature sensor. Temperature measurement at the moderator itself is measured by a hydrogen-vapor pressure bulb. The cold box containing the heat exchanger, which interfaces the hydrogen loop with the helium refrigerant, together with the control heater and temperature sensors, is sited within the service cell above the target top plate. Although radiation levels of 1-10 m Rads/hr exist, even at the present energy

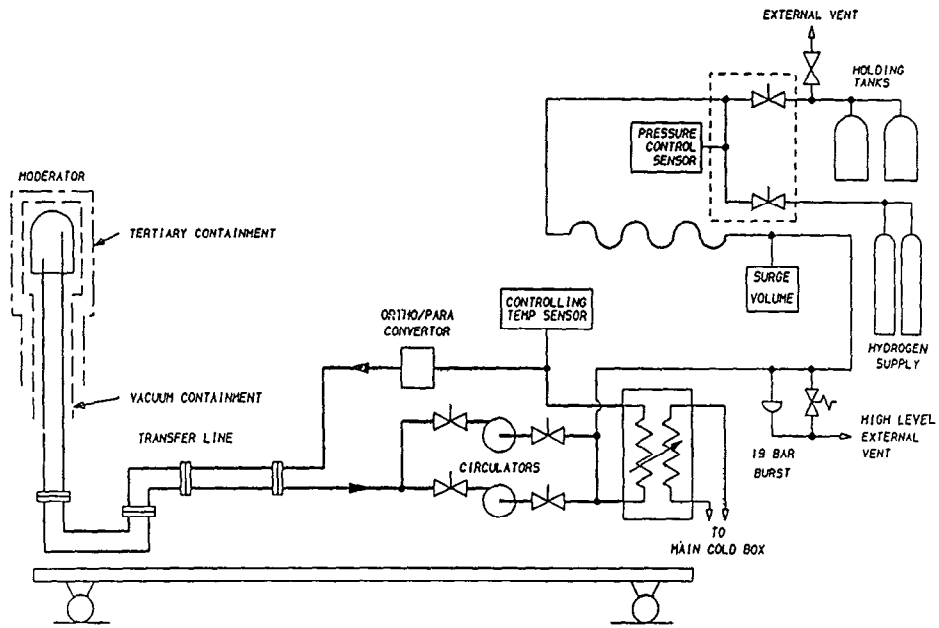


Fig. 3 ISIS H<sub>2</sub> moderator flow schematic.

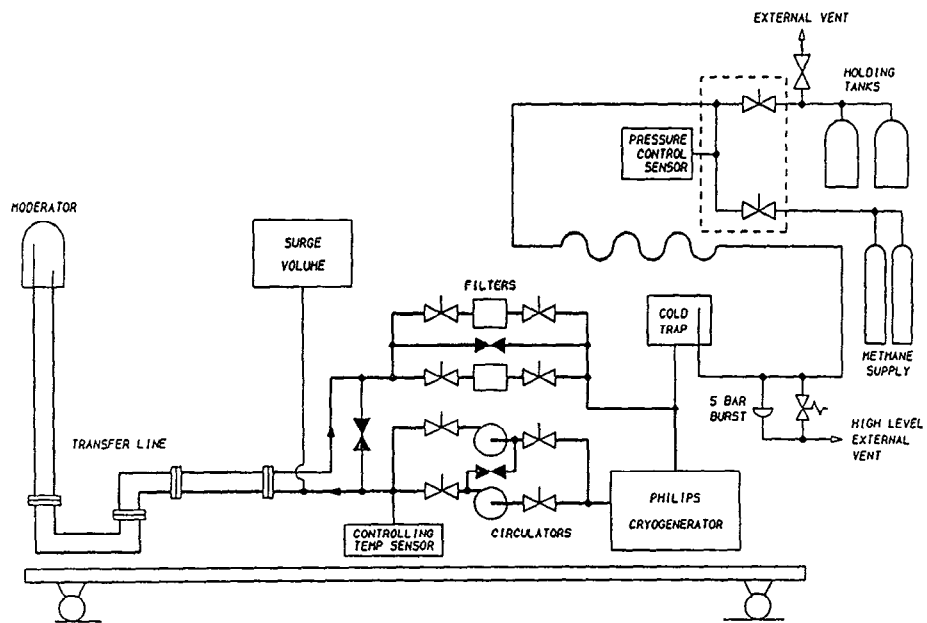


Fig. 4 ISIS CH<sub>4</sub> moderator flow schematic.

levels of  $30 \mu\text{A}$ , no radiation damage problems have been experienced in three years of operation. However, it is planned to re-site the cold box outside of the shielding during the major re-work of the target shielding in about three years time (see Fig. 5).

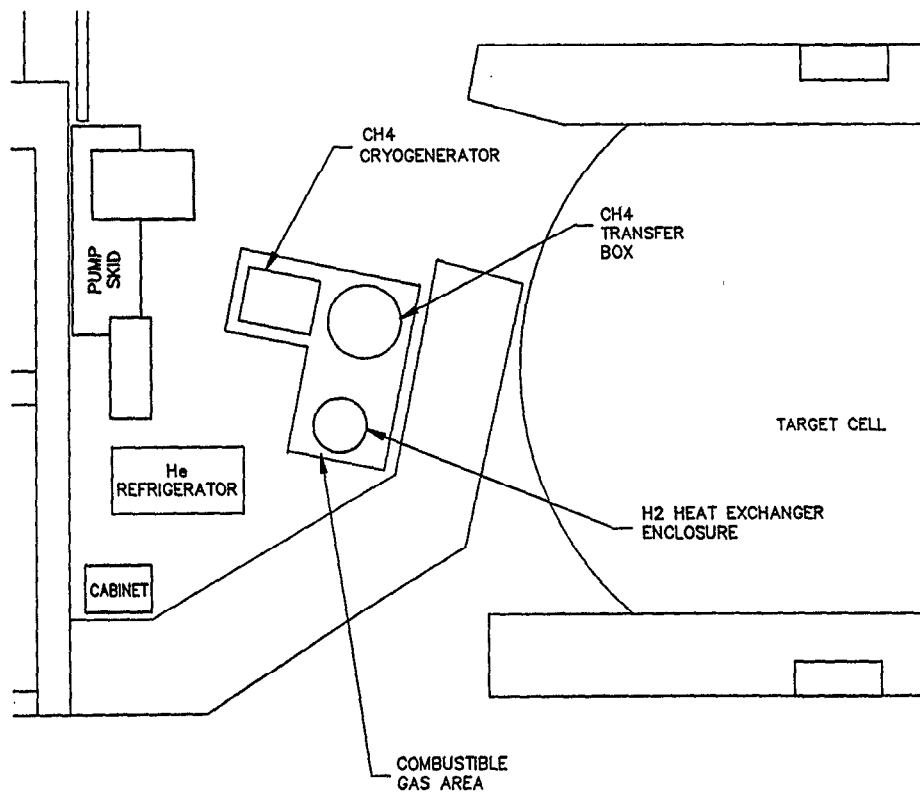


Fig. 5 LANSCE cryogenic equipment layout.

### LANSCE update

The LANSCE update will involve restructuring of the target-moderator-reflector (TMR) upper shielding and possibly some of the lower shielding. This will afford the opportunity to regroup the various feed pipes and transfer lines to improve the integrity of the upper shielding. It will also enable more preferred routes to be taken for the transfer lines to improve their flow characteristics.

The existing four-flux-trap-moderator windows might be reconfigured for cryogenic devices, depending on the experimental program requirements. The two moderator windows adjacent to the upper tungsten target will probably be opened up, also (see Fig. 6). Two or four methane moderators are possible, operating in one or two pairs. Each pair would share a refrigerator representing a heat load of about 1200 W at 100 K.

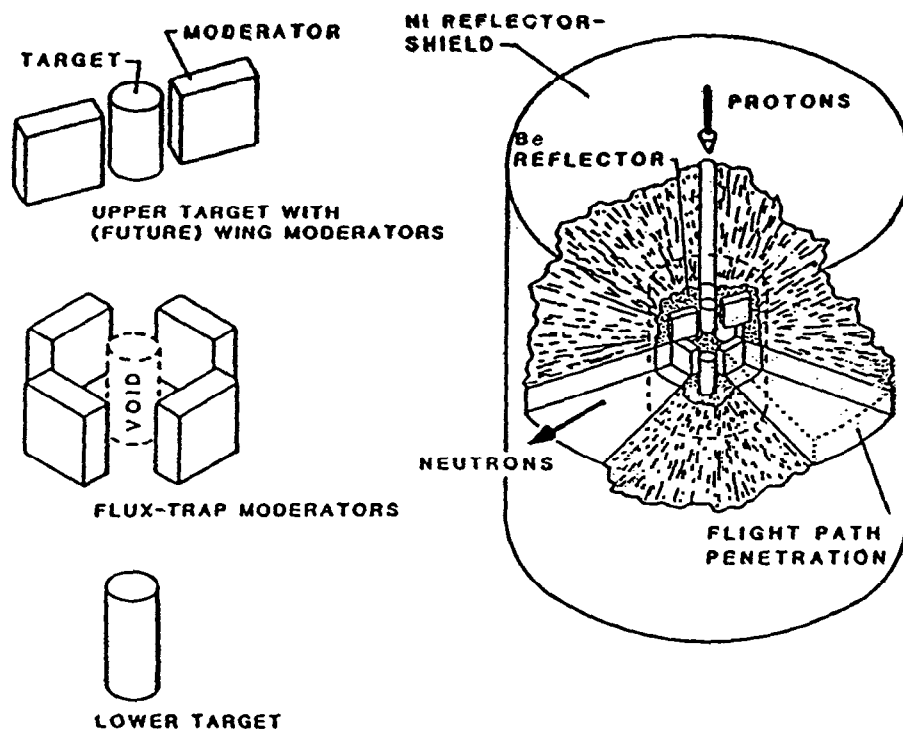


Fig. 6 LANSCE target system.

A complete design study of a liquid-methane system has been made, which indicates that by using a common transfer line for two moderators coupled in series, a Philips-Stirling cycle refrigerator with a listed output of 1500 W at 100 K would be sufficient (see Fig. 7).

A number of modifications to the ISIS refrigerator were found necessary to suit the particular application.

The heat exchanger is in the form of an annulus with the return liquid entering at the top center of the cold head. The outlet pipe was on the lower side of the annulus. This caused a variable flow pattern, which resulted in changes in heat transfer to the methane. The changes seemed to occur in response to some form of local turbulence, as the effect could be reversed by changing the flow or pressure of the liquid methane. A reasonably successful remedy was to insert fixed valves into the inlet pipe to create a rotary motion of the liquid. A second problem was local freezing of methane in the cold head during the initial cool down, as mass flow during the gas phase is very low. An electrical heater was eventually fitted in response to a sensor on the cold head. The powder insulation was also removed and the head vacuum insulated.

The LANSCE machine will be delivered suitably modified to avoid these requirements. The heat exchanger will be of a coiled pipe design with a heater wound

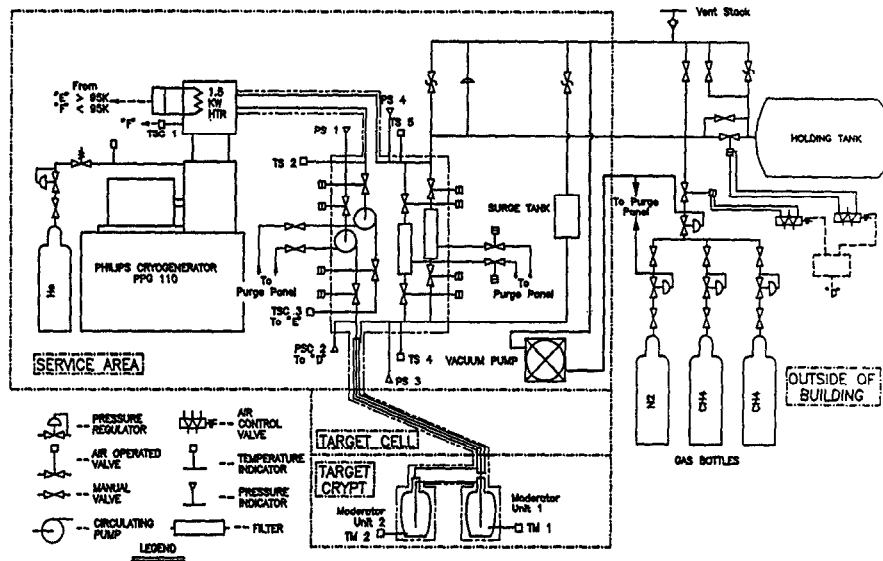


Fig. 7 LANSCE facility liquid methane moderator flow schematic.

between the coils during manufacture. A vacuum-insulated head will have both inlet and outlet pipes from the cooling coil brought out through a common side port in the vacuum chamber, which will enable the vacuum chamber to be integrated into the main pumping system. Various additional interlocks will also be added to a remote control facility for the helium gas refrigerant pressure (see Fig. 8).

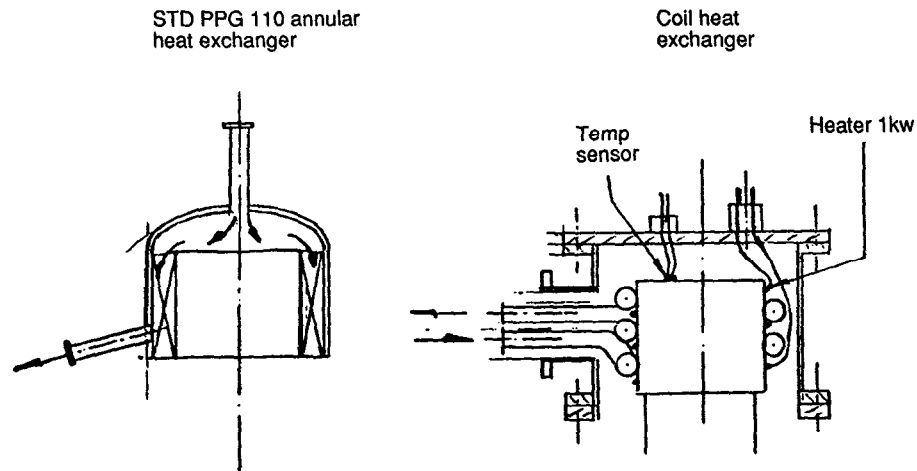


Fig. 8 LANSCE CH<sub>4</sub> refrigerator heat exchanger concepts.

### Circulators for cryogenic liquid

The circulators used for both of the ISIS cryogenic moderators were developed from Philips units originally designed for pumping high-pressure cold helium gas in heat-transfer circuits. They use a standard high-quality 50-Hz three-phase motor operating at 300 Hz to give a rotational speed of 1800° RPM. An extension of the motor shaft carries the overhung pump impeller. The unit is built into a pressure vessel because it operates in methane gas, which forms a static pocket connected to the main system. A secondary containment filled with an inert gas was originally required as a safety measure in the event of a methane leak. The complete outer vessel was later redesigned to incorporate this gas jacket, greatly improving ease of servicing. The greater duty of pumping relatively heavy liquids resulted in bearing-slip within the mountings, which caused high temperatures and loss of lubricant with premature bearing failure. The remedy was to clamp both inner and outer bearing races with ring nuts—the bearing assembly furthest from the impeller being carried by a thin metal diaphragm to accommodate thermal axial movement. Unfortunately, this thermally isolated the bearing and led to overheating. The source of this heat, however, is probably not purely frictional but might well derive from the waveform generated by a newly installed model frequency inverter. This is now under investigation (see Fig. 9).

The circulator used for liquid hydrogen in the LANSCE moderator runs at a much lower speed. The impeller is correspondingly larger, but in place of the overhung shaft is a long drive shaft with a cold bearing at the impeller end. This bearing makes the whole design much more flexible and results in a device with a much longer life and greater reliability. The bearing is manufactured by *Barden Precision* and is primarily for high-temperature application. A dry lubricant is sintered into the cage material, which sheds dry lubricant in operation. The LANSCE circulator remained serviceable after approximately 10,000 hours operation. The maximum bearing life achieved with the ISIS high-speed unit is around 2500 hours, but the average is much less. On the other hand, the latter are smaller, lighter, and easy to replace.

A circulator similar to that used for the LANSCE hydrogen system has been ordered for the methane moderator but in a modified form to enable replacement without breaking into the vacuum system. The impeller will also be modified to better help the cool-down operation through the two-phase flow stage (see Fig. 10).

### General layout of LANSCE cryogenic equipment

The hydrogen and methane cryogenic service equipment will be sited side by side in the service area. A new control cabin is to be built on the roof of the LANSCE target area accessible from the upper plant room. This will contain monitoring and control equipment. Adjacent to the cabin will be the methane gas-handling plant and operation panel (see Fig. 11).

### Radiation damage to methane

Liquid methane undergoes molecular changes in ionizing radiation. Long chain hydrocarbons are formed initially taking the form of yellow oils belonging to the



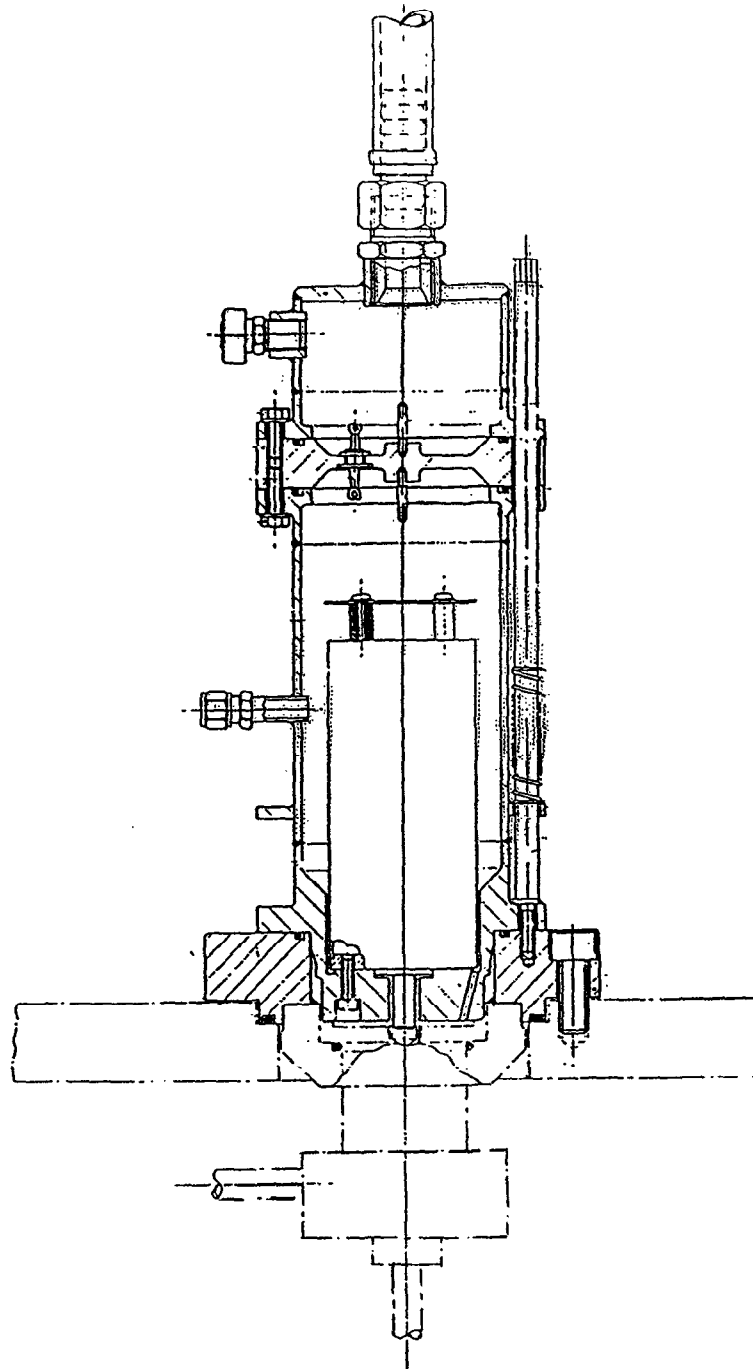


Fig. 9 ISIS CH<sub>4</sub> circulating pump.

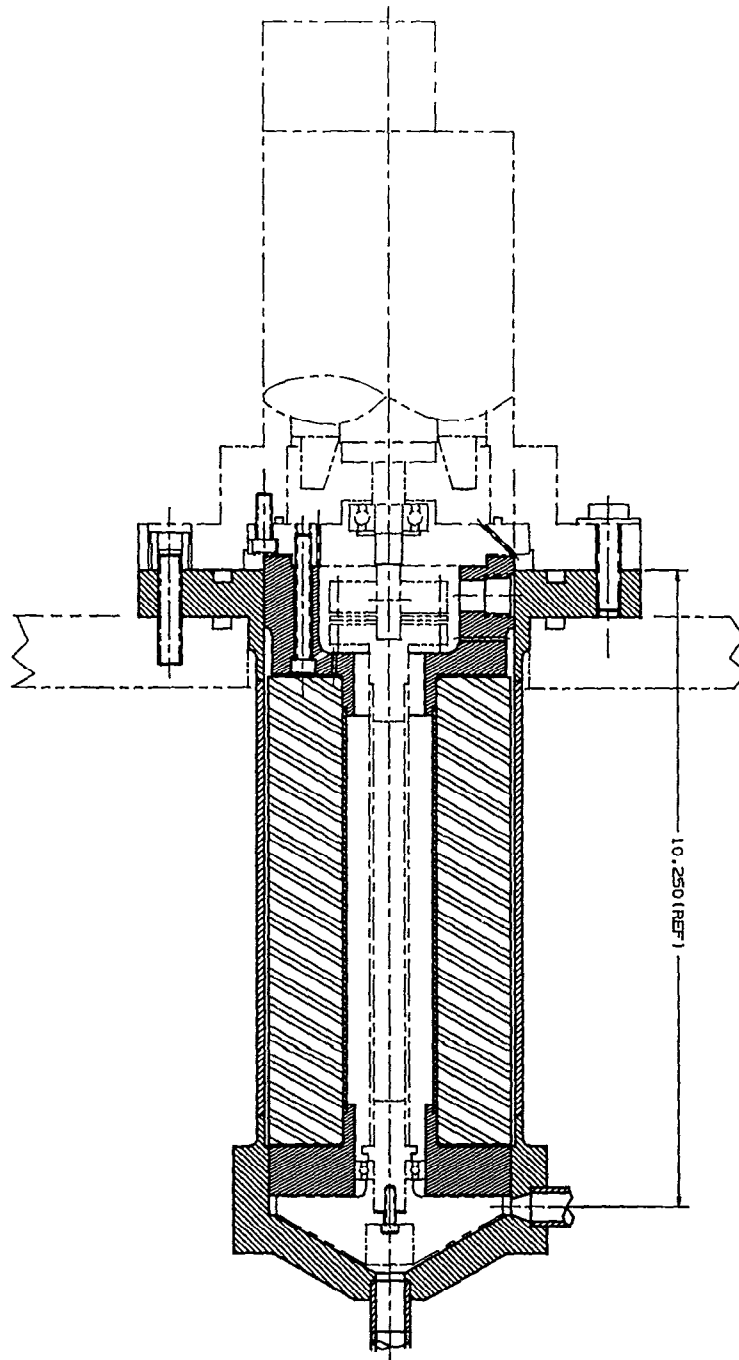


Fig. 10 LANSCE CH<sub>4</sub> circulating pump.

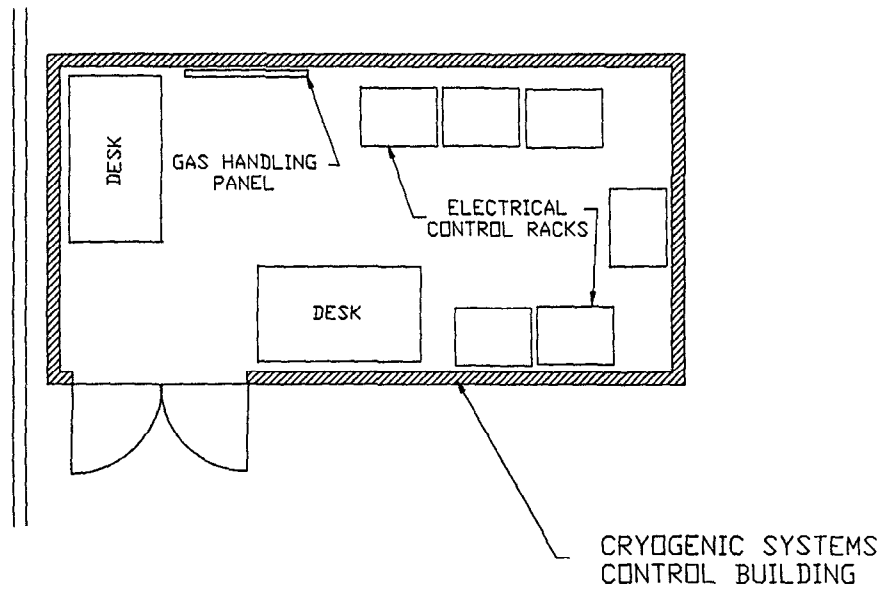


Fig. 11 LANSCE cryogenic control building.

paraffin group. Further radiation would probably result in the eventual formation of solids. The beam current at ISIS is now  $100 \mu\text{A}$ , and substantial levels of these paraffins are being produced. This does not appear to impair the neutronic efficiency of the moderator, but will ultimately result in a blockage that will be extremely difficult to remove. Most of the impurities are probably in solution with the methane liquid, but on warming up, the methane will be boiled off leaving the impurities behind as viscous liquid. Furthermore, it is likely that supersaturated levels of impurities will be produced. The present filters are, therefore, of limited value under such conditions, as some form of continuous separation and removal is required. This could be made possible by vaporizing the methane by raising its temperature or lowering its pressure and isolating the liquid impurities (see Figs. 12 and 13). However, either of these options would require development funds. A simpler method could be to centrifuge the liquids and remove the heavier fraction with a Pitot tube. This is worthy of examination because relatively small development costs would be required (see Fig. 14).

#### Combined $\text{CH}_4/\text{H}_2$ moderator

A separate report has been written about the idea of a combined  $\text{CH}_4/\text{H}_2$  moderator, which is based on some elementary calculations that indicate such a system is feasible thermodynamically. However, considerable experimentation and development would be needed to turn the idea into a working system, and a study of the neutronic gains would have to be evaluated before a decision can be made (see Fig. 15).

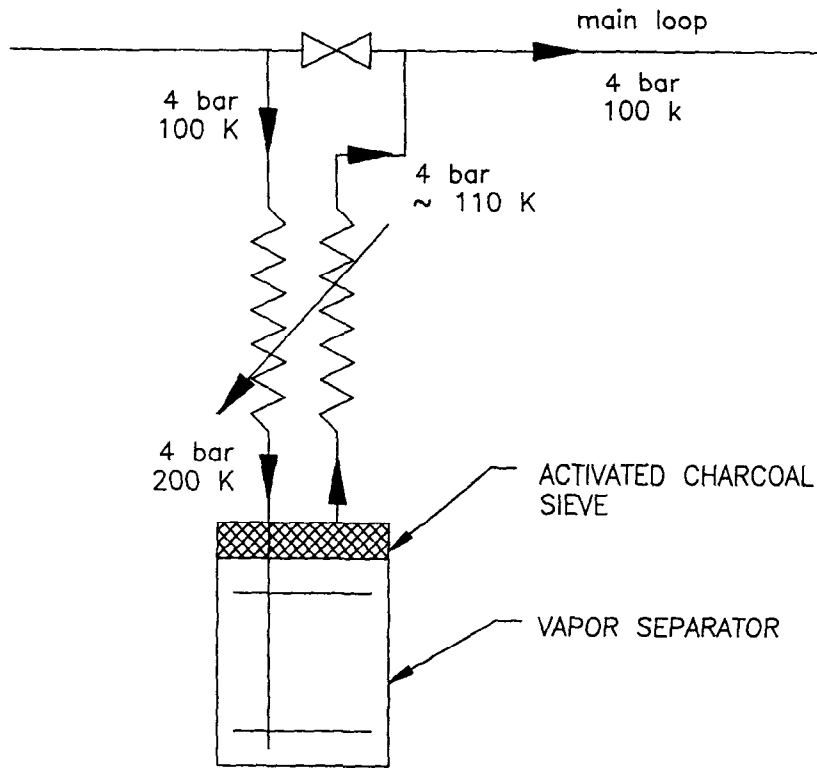


Fig. 12 Temperature vapor separator.

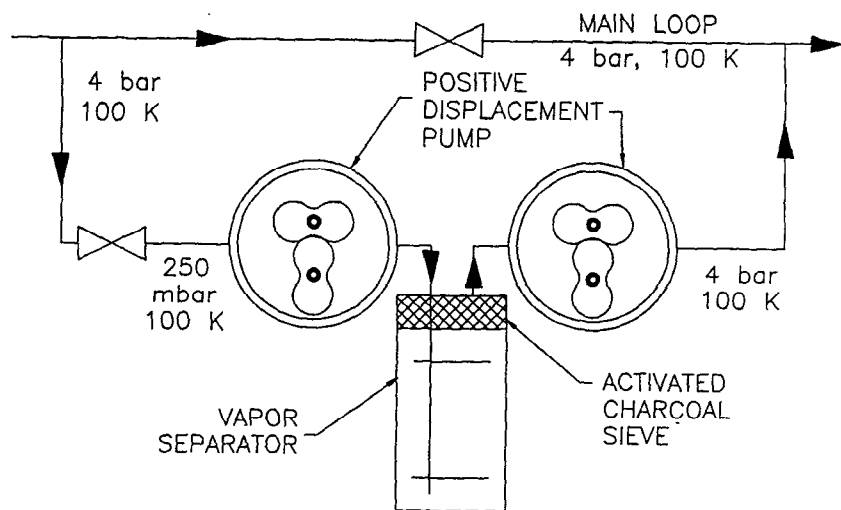


Fig. 13 Pressure vapor separator.

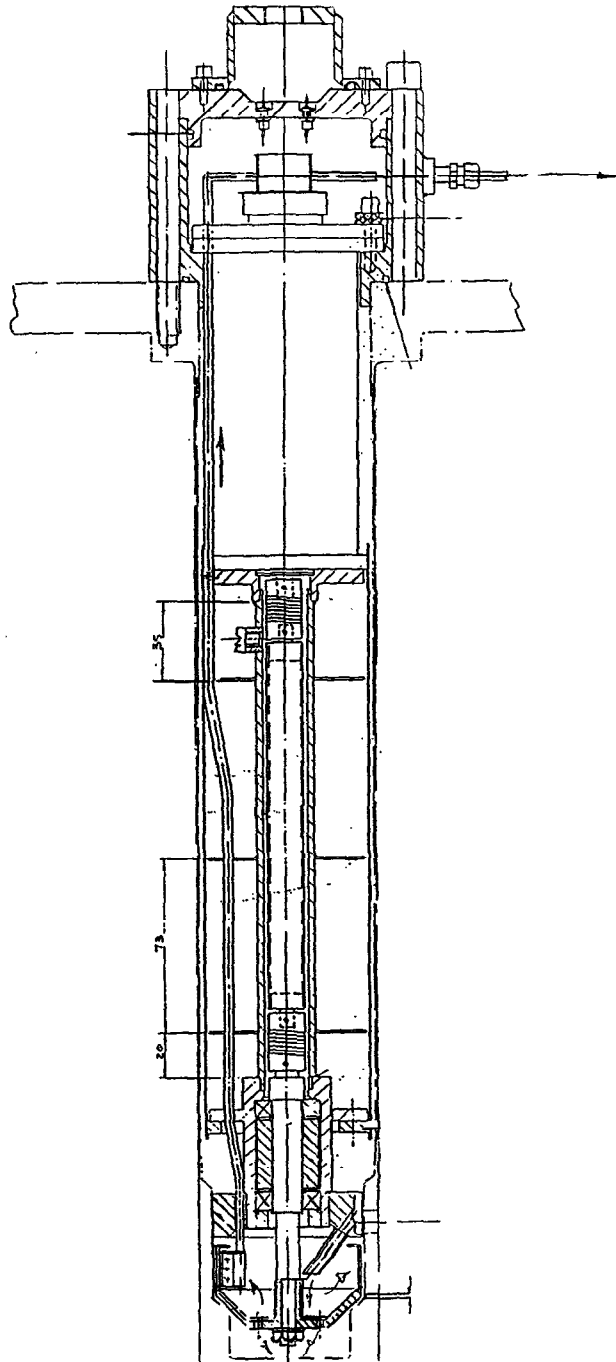
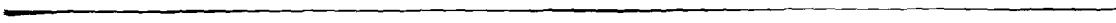


Fig. 14 Proposed centrifuge separator.



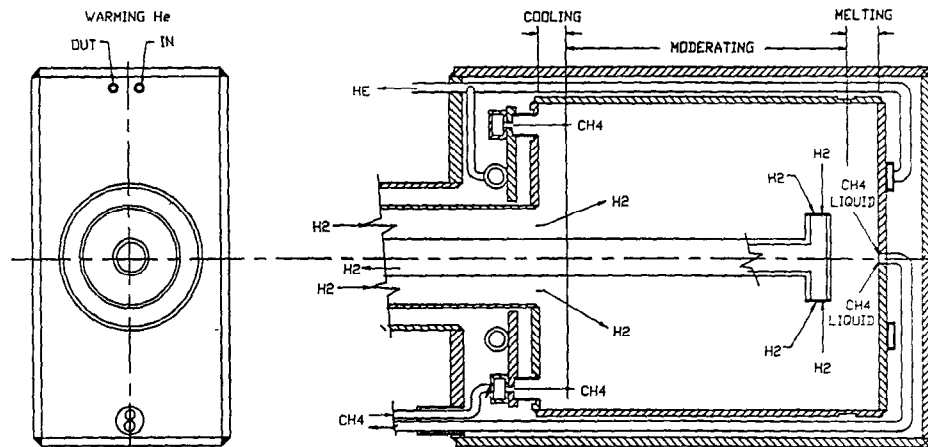


Fig. 15 Combined  $\text{CH}_4/\text{H}_2$  moderator.