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SPECIAL TRANSFER LINES FOR THE SPALLATION NEUTRON SOURCE

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ABSTRACT

Special transfer lines were required to transport supercritical hydrogen gas at 20 K and 1.5 MPa and liquid methane at 800 K and 0.4 MPa over a distance of about 18 m, to moderator vessels sited within a concrete shielded area.

The moderator vessels (1 L and ½ L volume respectively) are built into shielding material surrounding the uranium target which produces high energy pulsed neutrons. Energies up to 400 W can be deposited in the cryogenic fluid, which the control system must be capable of handling within less than one minute. The flow rates were designed to be 500 cm^3/sec for hydrogen and 220 cms^3/sec for methane. In order to maintain biological shielding integrity the lines had to be as compact in cross section as possible, and replacable using remote handling techniques. As commonly used plastic materials could not be used for spacers etc, on account of their poor radiation resistance, new techniques had to be developed to meet the long term requirements of the lines.

INTRODUCTION

The spallation neutron source (now called ISIS) at the Rutherford Appleton Laboratory of the Science and Engineering Research Council has been built to satisfy the needs of condensed matter science requiring intense pulses of neutrons. It is based on an 800 MeV proton synchrotron accelerator, the extracted beam being incident upon a uranium target. The fast neutrons produced by spallation and fission in the target are slowed down by an assembly of moderating materials and reflectors.

Four moderators are provided to give particular spectra, two being vessels filled with water, one with liquid methane at 95-100 K and 0.4 MPa pressure and the other with supercritical hydrogen at 20-25 K and 1.5 MPa pressure.

The methane is pressurised to avoid bubble formation within the moderator, the pressure of 4 bar representing about 30–35K of subcooling. The use of supercritical hydrogen rather than liquid is also to overcome bubble problems which would represent a non homogeneous density. The density of supercritical hydrogen at 1.5 MPa and 25 K is slightly higher than that of liquid at atmospheric pressure.

This paper describes the transfer lines used to feed the two cryogenic moderators, which by definition are situated in an intense radiation area, i.e. of the order of 10^6 Gy/h (10^8 rd/h). The refrigerators feeding the moderators are sited outside the primary shielding, but within a radiation level of 1.2 Gy/hr (12 rd/h). The refrigerator area can be rendered safe to personnel access when the beam is off by draining other cooling circuits which are serviced within the same area. The fluid flow rate was designed to be 500 cms^3/sec for hydrogen and 220 cms^3/sec for methane. The centrifugal circulators used were manufactured by [1]Philips Electrical Limited and were capable of a maximum head of 30 m.

TRANSFER LINE REQUIREMENTS

The somewhat unique combination of problems associated with the transfer lines required a very tight specification to be drawn up. This can be rationalised into seven headings as follows :

(a) Radiation hardness to levels of 10^{11} Gy (10^{13} rads).

(b) Design to allow installation and replacement within strict space limitations.

(c) Compatibility with remote handling techniques.

(d) High pressure capability with consideration to the hazardous gases used.

(e) Ruggedness of construction and high reliability.

(f) Compact cross section in order to minimise radiation shielding problems.

(g) Outer helium blanket over entire hydrogen system.

The general layout of the transfer lines is shown in Figure 1 which also indicates the overall dimensions. Each line was designed in three sections in order to meet requirement (b) and also to allow the possible replacement of a line or section of a line.

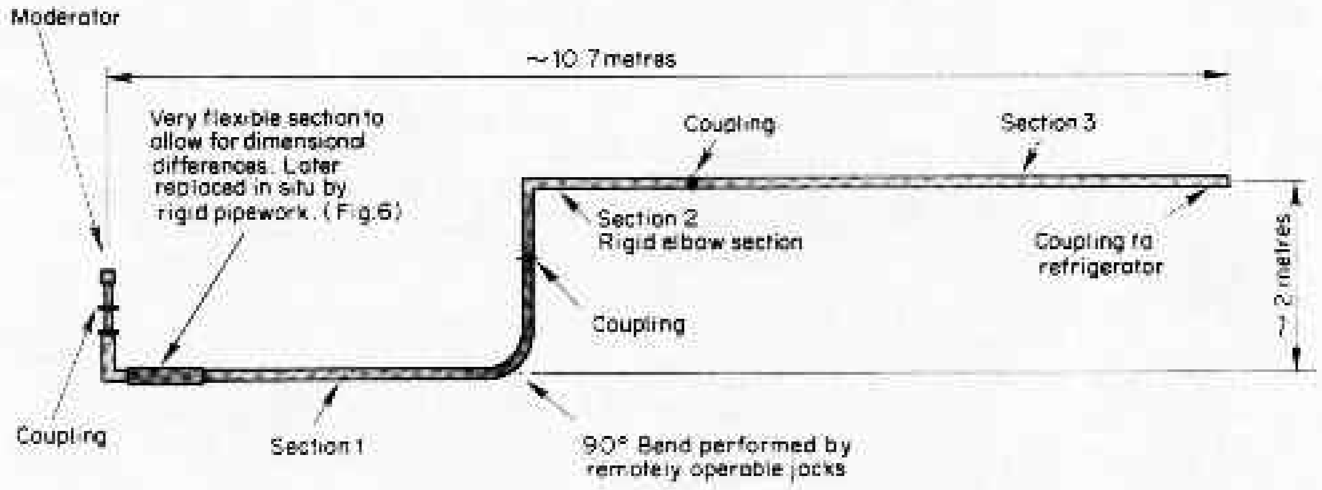

Fig. 1. Showing the general layout of the transfer lines.

Radiation Hardness

This posed a number of problems as the materials commonly used for insulation and sealing have poor resistance to ionizing radiation, PTFE being particularly poor. Since conventional aluminised plastic films could not be used, heat radiation shielding was provided by copper foil wrapped on to a spacer formed by a helically wound cord. This cord was about 2 mm diameter and woven from fibres of the oxides of aluminium, boron and silicon and marketed by [2]3M under the trade name of NEXTEL 312. As the transfer line heat inleakage represented only about 16% of the total cryogenic load, losses resulting from a lower thermal efficiency were compensated for by an increase in refrigeration power.

A careful study was made of various methods of demounting and remaking joints between sections of the transfer line using remote handling equipment. Controlled cutting of welds together with the development of a remotely operable orbital welding device was one consideration. However this indicated a considerable capital cost and a long development programme. Demountable cold couplings designed for remote operation were also considered, but it was felt that the required reliability could not be achieved mainly on account of the different thermal contraction characteristics of the various materials of construction. The final choice was to use a concentric design of the universally accepted long nosed coupling with an ambient temperature seal. A silver plated stainless steel helicoflex[3] seal was chosen, and its high clamping load of 23 K Nw was provided by a single bolt manacle clamp tightened to 27 Nwm. The clamp was a modified version of one developed by the same company as the seal, for use at the Joint European Torus laboratory at Culham, England. Modification was necessary in order to control the dimensions and configurations in the very limited space available, see Figure 8. It was then spring mounted on to a support platform (Figure 9).

The inner end of the coupling nose carried a Invar plug which located in a brass socket with a diametral clearance of 0.02 mm. At 100 K the difference in the coefficient of contraction between the two materials being about 0.3%, an effective seal was produced by relative contraction which separated the feed and return fluid (Figure 3).

Since this design of coupling does not provide continuity of the vaccuum system, captive vaccuum links using double bolt clamps and solid diamond section aluminium seals were used (Figure 2). The couplings were attached to the manacle clamp platforms so as to allow access to specialised bolt drive keys. This is clearly illustrated in Figures 9 and 10.

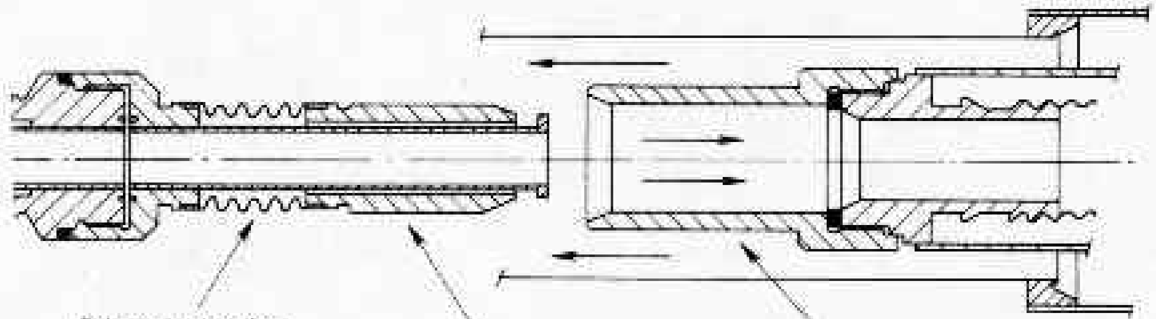

Fig. 3. Engagement of the plug and socket result in a gas tight joint at 100K.

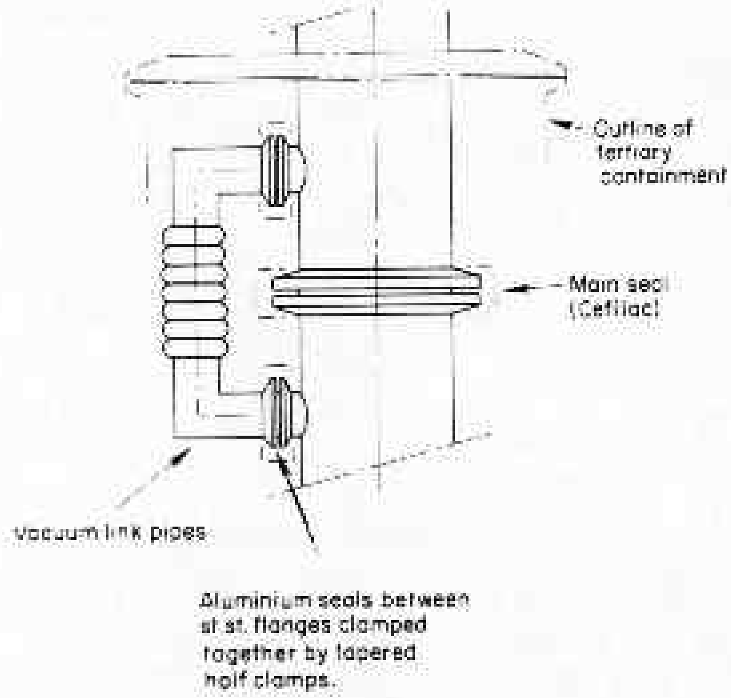

Fig. 2. The upper joint was made up prior to installation of the line and the lower joint made up with remote tools made possible by the captive two piece clamps.

Installation

Figure 4 shows the servicing arrangements of the target assembly equipment. The train of three trolleys can be moved back so that the primary shield plug assumes the normal position of the secondary shield plug. The void vessel and remote handling cell are then interconnected. Access is possible from both sides of the target assembly, including the moderators, by means of two pairs of manipulators, manufactured by [4]VNE Nuclear Limited, and a one ton capacity remotely operated crane (Figure 5). Direct viewing is possible through 1.6 m zinc bromide filled windows. As section 1 (Figure 1) of the transfer line will become highly radioactive it must be regarded as disposable in the event of failure.

To allow for build up of dimensional errors in the overall assembly the forward end of section 1 was required to be of a much more flexible design using radially convoluted stainless steel bellows. The inner pipes were wire braided to control extension, and the outer vacuum pipe and tertiary vessel were originally deep convoluted bellows of fairly heavy gauge. After shrinkage problems due to long term creep, the two outermost tubes were replaced by rigid tubes fabricated and welded on site (Figure 6).

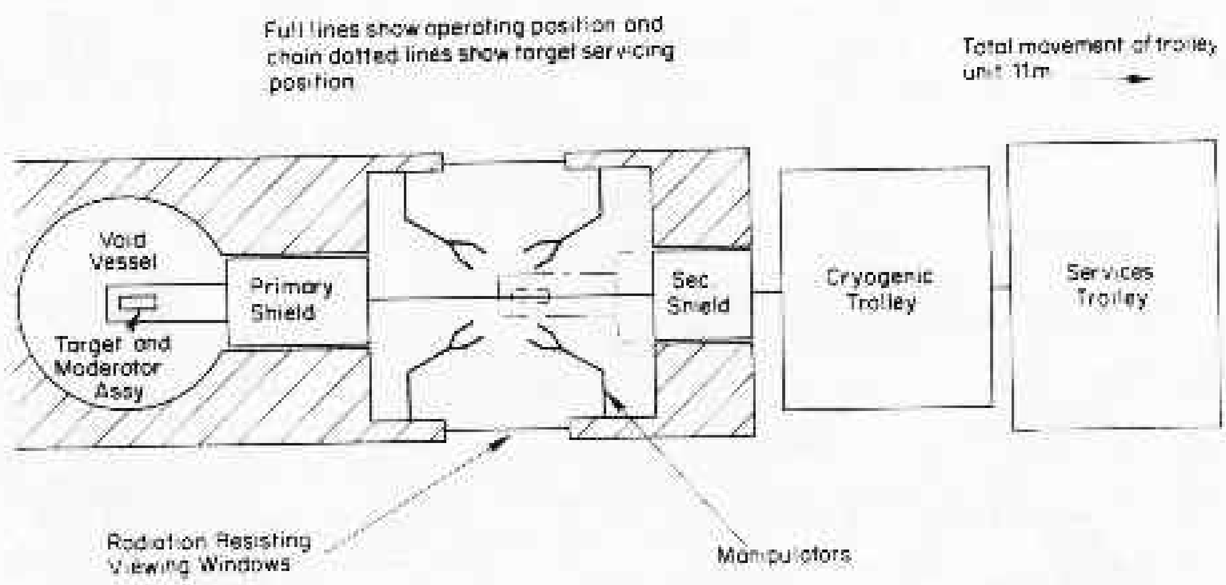

Fig. 4. The movable train comprises services trolley, cryogenic trolley, secondary shield trolley and primary shield trolley which also carries the target/moderator cantilever.

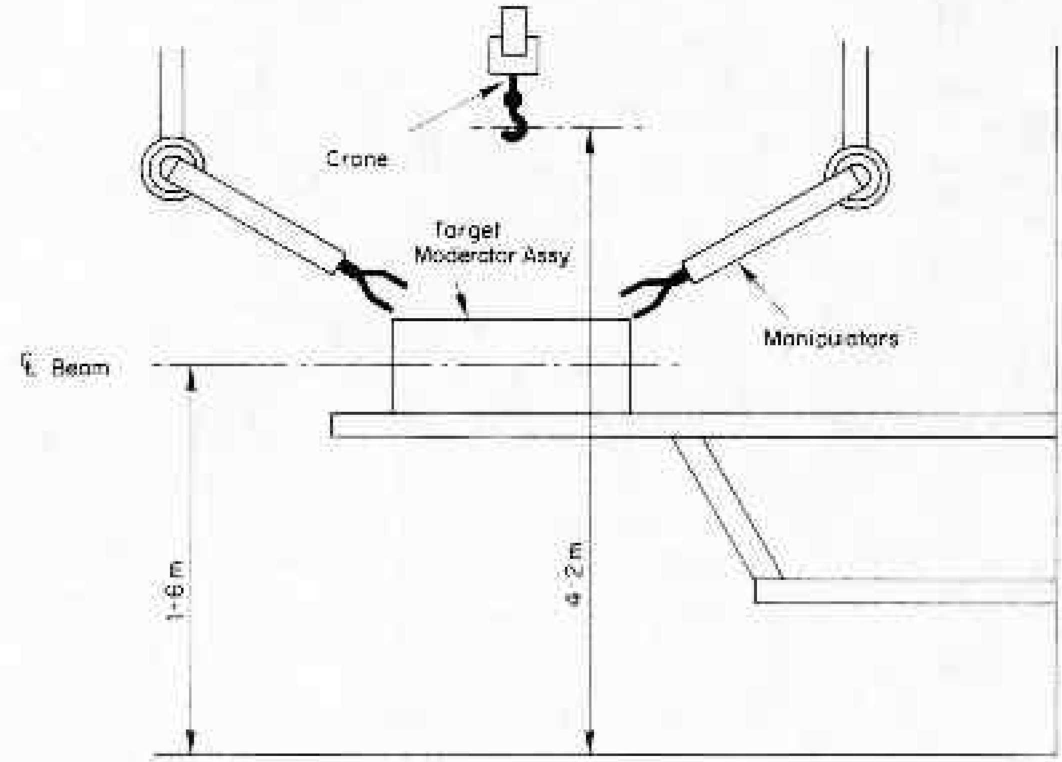

Fig. 5. The manipulators in addition to normal articulation can be transversed vertically by means of the telescopic vertical sections shown.

Sections 2 and 3 are both replaceable and are common to the two systems, although section 2 would require the use of remote handling techniques. A procedure has been evaluated for this operation aided by moving the train to appropriate positions. Removal of section 1, however, would require cutting away the 90° bend section. Replacement would then be from the forward side of the door, the bend being reproduced using permanently installed screw jacks as shown in Figure 7.

The purpose of the bend is to help overcome shielding problems, and to place the coupling out of direct neutron flux. Obviously a bend was only possible using a flexible line of this type in which the pipes would retain their relative dimensions and retain sufficient stiffness to

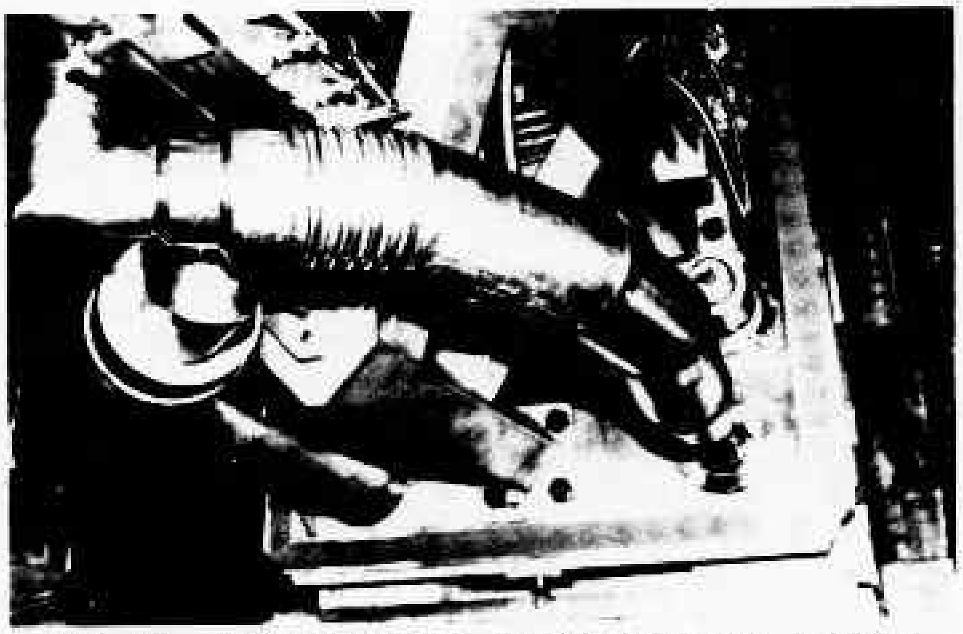

Fig. 6. Once installed the flexibility requirement of section 1 was no longer needed and the outer bellows were replaced by rigid pipes made up in half sections and seam welded.

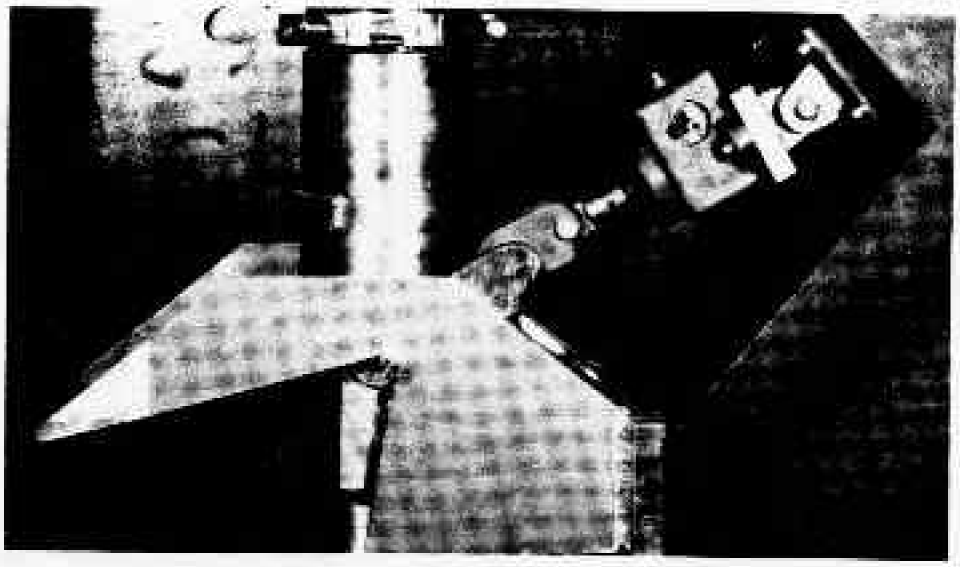

Fig. 7. The screw jack is actuated by a powered driver and the line is automatically orientated and positioned by the locating saddle.

withstand the pressures involved. In addition the helical convolutions help reduce the friction factor which was an important consideration with limited circulator head available. With section 2 in position the train could be moved back, thus exposing the second coupling in the services area for hands on connection to section 3.

Compatibility with Remote Handling Techniques

Remote handling generally requires the following guidelines to be observed:

1. All screw threads to be permanently engaged.

2. Nuts to be captive on their studs or bolts.

3. Loose pieces kept to a minimum and tethered to the main structure by light chains.

4. Nuts to be tightened to a pre-determined torque using a powered driver.

In this pretext, considerable time was devoted to the design of any component which could conceivably require replacement. Where possible this was further confirmed by experimentation with a dummy set up using actual manipulators. However, time precluded such trial work for the demounting and re-making of the main couplings, but Figures 9 and 10 illustrate the efforts made to achieve components that should at least make such operations feasible.

High Pressure and Hazardous Gas Operations

The transfer line is based on the continuous flexible tube technology. Each line comprises five concentric tubes made from austenitic stainless steel sheet, and each tube was tested for pressure integrity and resistance to thermal shock, and vacuum tightness to within a leak rate of 10^{-5} Pa L/sec.

All areas in the region of the main couplings are gas monitored to give an early warning of leakage. The refrigerators and associated equipment are covered by continuously pumped extractor hoods, being designated zone

2 areas with respect to hazardous gases. Consequently all electrical equipment was either isolated from high power by electrical barriers, or inert gas blanketed in line with [5]BS 5345. Both gas circuits are protected against overpressure by relief valves and burst discs set at 0.5 M Pa g and 1.9 M Pa g respectively. The insulating vacuum systems are likewise protected against positive pressure by burst discs.

Ruggedness of Construction and Reliability

Since the major heat load is produced by nuclear heating of the moderator the transfer line heat inleakage was not the major refrigerator load, and therefore reliability and ruggedness of construction could be traded for refrigeration power. This is particularly pertinent in consideration of the fact that remote handling could result in rougher than normal treatment. The construction of the couplings was therefore more massive than normal, whilst the internal spacers were inherently of a rugged design. A section of the line in fact suffered a fall of about 2 m without damage. These comments are particularly relevant to sections I where any fault whatsoever, no matter how minor, would almost certainly result in the need to replace that section and scrap the irradiated component.

High Cross Section Efficiency

As the holes in the shield plugs through which the transfer lines pass represent weaknesses in radiation shielding, it is clearly advantageous to keep their overall size to a minimum, also for the lines to present as dense a cross section of material as possible. The concentric pipe arrangement is obviously better in this respect than one using discrete flow and return pipes in a single vacuum tube. The latter has the advantage of thermal separation which is particularly important during cooldown where flow and return temperatures are very different. However this disadvantage of the concentric design was offset by interposing a vacuum annulus between the flow and return sections, this being possible

Fig. 8. The limited space afforded by the tertiary containment is shown. The tube is guided and can be actuated and clamped by remote handling techniques.

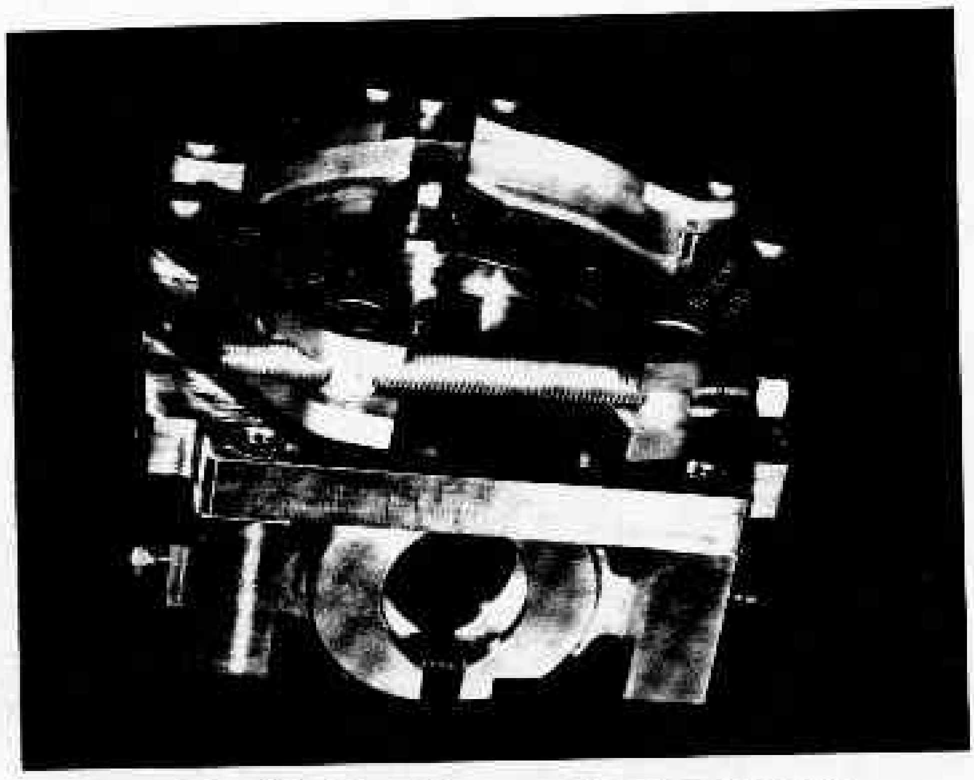

Fig. 9. Showing the manacle clamp on its platform and the vacuum clamp suspended below. The screw head just visible protruding from the anchor blocks are to allow the clamp halves to be backed off their taper flanges.

due to the small radial clearances required by the helical style of spacers used. The end of section 1, being turned up through 90°, made a considerable improvement in the radiation shielding efficiency as well as protecting the coupling from direct neutron bombardment.

Helium Filled Teriary Containment

It was essential to prevent the ingress of air into the hydrogen system vacuum as this would cryopump on to the cold surfaces. Under ionizing radiation, the solid constituents of air would be transformed into chemically unstable ozone and nitrides of oxygen capable of spontaneous explosion. The most sensible solution was to blanket the whole line and moderator unit in helium gas. This complicated the design of the coupling region as once more space was at a premium. An edge welded bellows was used to obtain continuity of the helium blanket over the couplings, fitted with flanges sealed by single bolt mannacle clamps. Open 'C' section stainless steel seals were used, Figure 10.

The helium pressure is kept slightly above atmospheric, but the containment is protected against overpressure such as could result from a leakage of the working fluid.

OPERATIONAL PROCEDURE

A measure of the heat inleakage of each of the two transfer lines was estimated by plotting temperature rise against time with the refrigerator and beam switched off. From the calculated enthalpy of the cold material, and with adjustments in the calculations to allow for the moderator and the refrigerator heat exchanger, the heat leakage of the line was evaluated. The 20 K line had an overall heat imput of 100 W, and the 95 K line 90 W. Both lines were a nominal 18 m in overall length. Whilst the method of assessing heat input was subject to some error, the numbers were useful in gaining a better understanding of the overall thermodynamic

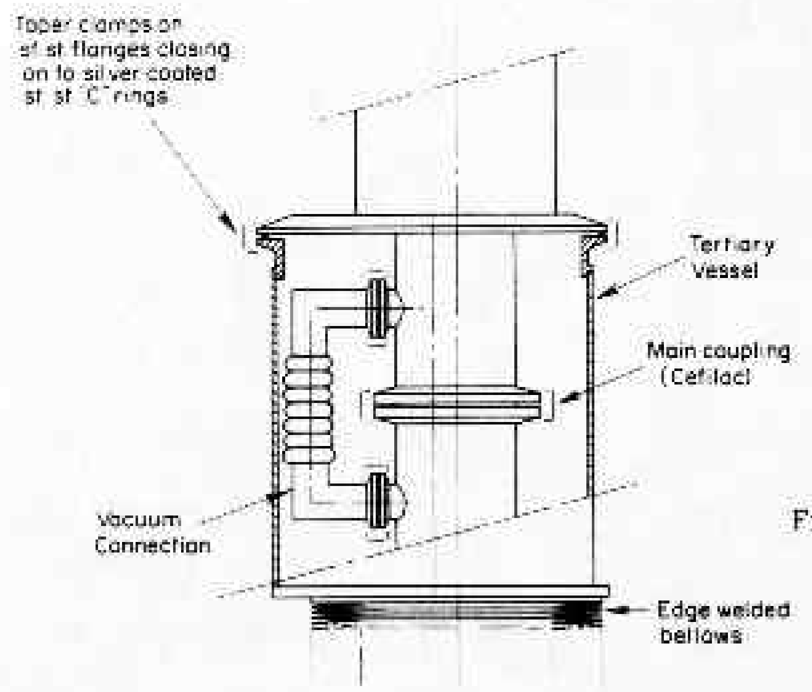

Fig. 10. The coupling assembly complete with vacuum link with the tertiary containment in position.

balance of each of the two systems. It was considered that if it had been possible to orientate all the couplings vertically, which would have resulted in more controlled convection currents within the gas surrounding the nose sections, a lower overall heat input would have resulted. It is appreciated that as the two lines were similar in construction the derived figures were not directly comparable. This would seem to indicate that radiation was the dominant mechanism of heat input.

ISIS is now operational though not yet running at full energy and both cryogenic systems are meeting the present requirements and give every indication of fulfilling the full specification.

REFERENCES

1. Philips Electrical Limited, Eindhoven, Netherlands.
2. 3M United Kingdom PLC, Croydon Road, London, SE20 7TR.
3. 'Helicoflex' is a trade name used by CeFilac Limited, 90 Rue de la Ruche du Geai, 42029 Saint-Etienne Cedex, France.
4. 'VNE Nuclear' Ltd, Swindon, UK.
5. BS 5345 - Code of Practice for selection, installation and maintenance of electrical apparatus used in potentially explosive areas.