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LEAK TESTING THE DRAGON REACTOR PRESSURE VESSEL

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ABSTRACT

This document gives details of test procedures and results obtained on leak tests carried out at the manufacturers' works under typical boiler-shop conditions and at the reactor site during the construction period.

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1. INTRODUCTION

Due to the radioactive nature of the Dragon Reactor Primary Circuit, the leak tightness specification for the Pressure Vessel, and all related components, is far more stringent than is normally associated with reactor gas coolant circuits. This means that the specifications for each individual component effectively calls for a laboratory standard of leak tightness from components that can often be classified as heavy engineering.

1.1 Leak Tightness Specification

Briefly the specification for each component calls for no detectable leaks from welds, plate material or forgings and the permitted leak rate from soft metal gasket seals is 10^{-10} atmospheric cm^3/sec/per cm of gasket length.

The above standard of leak tightness must be achieved at a test pressure of 1.1 x design pressure, i.e. 385 lb/sq in absolute. For the reactor components it would not be economic to carry out leak testing of large volume objects with 100% helium. To overcome this difficulty the component can be pressurised with a 10% helium-air mixture and the value of any leaks detected corrected for 100% helium pressure.

1.2 Helium Leak Test Instrument and Techniques

In order to achieve the standards required it was necessary to employ the most sensitive leak testing technique, i.e. the use of helium sensitive mass spectrometer. This instrument can be used in several different ways as shown in Figures 1a, b and c. The methods shown in 1a and 1b can only apply to comparatively small objects. Using these two methods the mass spectrometer is used in its most sensitive manner and the leakage readings are directly comparable with the calibrated standardising leak.

With large objects the only possible use of the mass spectrometer is as shown in Figure 1c. Whilst individual welds, etc. can be sniffed it would be most tedious and time consuming to sniff every square millimetre of the surface of the Pressure Vessel. This problem is overcome by enclosing the vessel under test in polythene sheet, in conveniently large areas, and monitoring the volume between the vessel and polythene for helium content after a period of isolation with the vessel at full test pressure. If the helium content should be up above normal atmospheric concentration in air, i.e. 5 ppm, this must be investigated further either by covering the suspect area with polythene sheets of a much smaller size or by sniffing.

As much of the work in Dragon Project leak testing involved the sniffing and isolating technique, considerable attention was given to the types of instruments to be used. When used in the vacuum condition most mass spectrometers have somewhat similar sensitivities. When used in the sniffing condition, the performance can vary considerably. Instruments used on Dragon Project leak testing had to satisfy two conditions:

(i) They must be able to detect the presence of helium in the atmosphere.

(ii) The instruments must also have an electronic control to balance out this signal thus enabling the instrument to switch to its most sensitive range.

2. LEAK TEST OF PRESSURE VESSEL AT MANNESMANN

For the tests carried out at Mannesmann the Pressure Vessel was sited in the boiler-shop on a specially constructed hard standing, with the vessel in the horizontal position. At the conclusion of the hydraulic test the vessel was opened at the main flange and all blanking-off plates removed. All gasket sealing features were examined and with the exception of flange C, were found to be in good order. (Flange C was eventually re-machined to a satisfactory standard.)

All flanges and gaskets were cleaned to the accepted standard and after Vacublasting operations on the inside of the vessel had finished, the vessel and flanges were given a final rinse in acetone. Aluminium gaskets were used for the leak test and all flanges were blanked-off and bolted up to a bolt loading of 20,000 lb/sq in. The bolt loading was checked by measuring the bolt extension produced for a given torque. Table 1 gives the value used and average extension obtained.

2.1 Pneumatic and Vacuum Test

The pneumatic test was made at a pressure of 385 lb/sq in absolute. When the pressure had reached its maximum value the surface of the vessel was painted with "Nikal"* solution. The surfaces were closely examined for bubble leaks but none could be seen. A similar examination was made on the flanges and with the exception of the stubs on the elbows of the coolant ducts all were found to be free from bubble leaks.

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*Nikal is a proprietary name for a soap solution plus wetting agent used in Germany for this type of test.

TABLE 1

Torque Values and Bolt Extensions for Flanges on Reactor Pressure Vessel

Flange	Applied Torque	Average Extension
A	40 M/kg	0.15 mm
B	7 "	0.036 "
C	8 "	0.07 "
D	14 "	0.10 "
E	24 "	0.070 "
F	13 "	0.09 "
G	7½ "	0.055 "
J	8 "	0.07 "
M	11 "	0.06 "
N	7 "	0.035 "
P	40 "	0.15 "
Q	34 "	0.18 "
R	12 "	0.09 "
S	6 "	0.058 "
T	8 "	0.07 "

The stubs on the elbows are used for holding and locating the Nimonic linings. For the purpose of the leak test the seal was of a temporary nature. However, with the degree of leakage first encountered the contamination of the atmosphere with excessive helium would have been an embarrassment. The seal in the stub was made by compressing an aluminium gasket between a flat disc and Dragon type gasket seal feature machined inside the stub. The stub seals were eventually made bubble-leak tight. Arrangements were also made for the flat discs to have a Dragon gasket seal feature machined on one surface at the conclusion of the leak testing. This would ensure that at any further testing of these stubs the quality of seal would be greatly improved.

The vacuum test was made with a Leybold S.60 vacuum pump, having a displacement of 60 m^3/hr (36 cu ft/min). The vacuum test specification calls for a reduction of pressure to 1.5 lb/sq in (76 mm Hg). After a period of approximately six hours pumping the pressure was reduced to 8 mm Hg.

At the conclusion of these tests the blanking-off plate of the Manhole flange (flange Q) was removed and the inside surface of the vessel was examined for oil contamination from the air compressor. The surface was found to be quite free from oil though there were charcoal granules from the filter in the compressed air line laying inside the pressure vessel.

The manhole was blanked-off again at the end of this inspection using a fresh aluminium gasket in preparation for the helium test.

2.2 Helium Mass Spectrometer Leak Test

The pressure vessel was prepared for leak test by covering the vessel in polythene sheet as can be seen in Figure 2. All flanges without gasket interspaces were sealed so that any leakage would accumulate and be detectable by the use of the sniffing probe.

The Pressure Vessel was brought up to test pressure, 385 lb/sq in absolute with a 10% helium-air mixture and the easily accessible penetrations into the vessel were sniffed for helium leaks.

With the exception of the stubs on the elbows of the coolant ducts there were no detectable leaks.

At the conclusion of the 24 hour isolation period all flanges were monitored for leaks. In many of the flanges there were no detectable leaks. Table 2 gives details of the measurable leaks from flanges.

The leakage from the flanges N gave a leak rate of up to 3×10^{-9} cm^3/sec/cm of gasket length. This figure was accepted because of the following. From the method of blanking-off, as shown in Figure 3, it can be seen that the blanking-off flange had to pass through the rubber O-ring. The dimensions of the O-ring supplied and hardness of the rubber made it impossible to push the flange into position by hand. The bolts had to be put in and tightened up by use of a spanner. It was considered that in doing this, part of the O-ring was being sheared off and the loose portion laying between the underside of the gasket and blanking flange. Thus the aluminium gasket was not being sufficiently compressed. (Subsequent examination showed this to be true, see Figure 4.)

Helium leakage was also detected coming from the temporary seals in the elbow stubs of the coolant ducts. The values varied between $4 \times 10^{-3} cm^3$/sec to $3.7 \times 10^{-11} cm^3$/sec. As these were temporary seals only the value of leakage was noted for record purposes only.

TABLE 2

Measurable Leaks from Flanges on Pressure Vessel at Mannesmann

Flange	Leak Rate cm^3/sec
A	4.05×10^{-8}
B	8×10^{-9}
D	2.7×10^{-8}
E	10^{-8}
F	4.2×10^{-9}
P	2.6×10^{-8}
N_1	6×10^{-8}
N_2	4.86×10^{-8}
N_3	1.04×10^{-9}
N_4	8.08×10^{-9}
N_5	5.94×10^{-8}
N_6	9.41×10^{-8}
Main Flange	10^{-8}

Monitoring of the helium content under the polythene sheeting gave no indication of leakage from the vessel. During this probing there was one period that gave some cause for concern. When monitoring the cone section of the vessel on the side nearest to the floor there were one or two occasions when a large signal was recorded which quickly faded away. Careful investigation showed that this signal came from drifts of helium coming from a safety valve in the line from the compressor and filling station.

The results of the tests carried out showed that the Pressure Vessel satisfied the leak tightness specification and was therefore acceptable. The Pressure Vessel was then prepared for shipment to Winfrith.

3. LEAK TEST OF PRESSURE VESSEL AT WINFRITH

After arrival on site and the final positioning of the lower half of the vessel preparations were made to leak test the Pressure Vessel in the vertical position. The previous test having been carried out with the vessel in the horizontal position.

Figures 5a, b and c show the pressure circuits and location of the Pressure Vessel. From Figure 5c it can be seen that the compressor and helium filling station were placed as remote as possible to the penetration of walls B, C and D. This was to ensure that the risk of contaminating the inside of the reactor building with helium, when changing cylinders, was kept to a minimum. This penetration was eventually sealed by two layers of polythene sheet.

The complete test circuit was designed and constructed so that the helium concentration in the building should be kept as near to normal as possible. The two valves sited on the Pressure Vessel in the inner containment, i.e. on pressure gauge and blow down line, were of the rubber diaphragm type. They had previously been tested in the laboratory for helium leaks with the mass spectrometer.

The other valves in the circuit were standard packed gland types. These were also tested in the laboratory after removing the composition gaskets and replacing them with thin lead foil gaskets. The standard of leak tightness accepted was that the valves should be free of bubble formation at 385 lb/sq in gas pressure. The complete filling line from compressor to Pressure Vessel was pressure tested at 500 lb/sq in before the commencement of helium test. Provision was also made to ventilate the building should the helium content increase to a figure that made sniffing techniques difficult.

After all flanges and blanking plates were cleaned to the required standard metal gaskets were cleaned and annealed and placed into position. Bolts were tightened up with a torque spanner, to the values used on the test at Mannesmann (see Table 1).

With the exception of the main flange aluminium gaskets were used in all flanges for the leak test. On the main flange a silver gasket was used.

When the Nimonic liners had been positioned and fitted, the stubs on the elbows of the coolant ducts were sealed with silver gaskets in position. The screw-in plugs applying the compressive force to the silver gaskets were welded to the stubs. After crack detection these welds were checked by pressurising the inside of the plug from a cylinder of helium; no leaks could be found by mass spectrometer sniffing techniques.

After checking that the bolt loading of the main flange was correct, the vessel was covered in polythene sheet. Figure 6 shows the commencement of this operation on the top half of the vessel. When this operation was complete, scaffolding and staging was erected so that the whole vessel and all flanges could be monitored for helium leaks with the mass spectrometer.

3.1 Helium Mass-Spectrometer Leak Test

Before introducing any helium into the circuit the vessel was pressurised with compressed air to a pressure of 50 lb/sq in. At this pressure an examination of all flanges was made to check the leak tightness.

This check being made by soap bubble technique.

Two leaks were found, one in a brazed joint in the pressure gauge connection to the diaphragm valve on the vessel, the other being from Flange P (precooler flange). Pressurising of the vessel was stopped and the vessel let down to atmospheric pressure. On examining the gasket on Flange P it could be seen that due to the fact that the gasket was a poor fit over the feature on the blanking off flange, the gasket had been nipped in two places, thereby reducing the compression on the rest of the gasket. The brazed joint was repaired and a new gasket put in Flange P.

Pressurising commenced again and at 50 lb/sq in another inspection of flanges, and pressure gauge, was made. No bubble leaks could be detected, therefore the pressure was increased to 75 lb/sq in etc., were once again inspected. As no leaks could be found the helium necessary for a 10% helium content at 395 lb/sq in absolute was put into the system.

The air compressor was started and the pressure slowly increased to 395 lb/sq in. During pressurising the flanges were checked for leaks at every increment of 40-50 lb/sq in.

On reaching 395 lb/sq in absolute another check on flange leakages was made and after this, the pressure was then reduced to 385 lb/sq in absolute. The Pressure Vessel was left in this condition for twenty-four hours.

At the commencement of the isolation period all flanges with gasket interspaces were, in turn, connected to the mass spectrometer, with the exception of the Main Flange, Main Entry Valve Flange (Flange E) and the flange for the Upper Dome (Flange A), there were no detectable leaks.

At the end of the twenty-four hours isolation the whole vessel was surveyed for helium leaks. At the commencement of the survey some concern was felt on account of a high reading of background helium in the vicinity of Flange A. Close inspection of the flange showed that two temporary seals in this flange were leaking. In normal operation of the reactor the penetrations which were temporarily sealed, form inlets to gasket interspaces between Flange A and the Charge Machine.

The results of the survey showed no helium signal under the polythene other than that due to normal atmospheric concentration; thus once again there were no detectable leaks from welds, forgings or plate material.

All flanges, with or without interspaces, were monitored for helium leaks and with the exception of one of the Absorber Rod Pressure Vessel Flanges (Flange G), the Main Flange, Main Entry Valve Flange and Upper Dome Flange, there were no detectable leaks. The results are given in Table 3.

Whilst the leak rate figures for Flanges A and E are at first sight greater than permitted, a satisfactory explanation of this can be given. The rubber O-rings necessary to form the gasket interspace were not available at the time of test. In order to carry out the test, homemade

O-rings were produced from available materials. The diameter of the available O-ring cord was not sufficient and in order to obtain a vacuum seal the O-ring was placed on top of a flat rubber strip 1/16" thick. This arrangement was not sufficiently good enough to enable a satisfactory vacuum to be maintained in the interspace. The leakage into the interspace from the outer atmosphere was air with a helium content greater than normal. The extra content coming from the leaking temporary seals in Flange A. This effect was of course more noticeable in the immediate vicinity of the source of leakage at flange A, as can be seen in Table 3.

TABLE 3

Measurable Leaks from Flanges on Pressure Vessel at Winfrith

Flange	Measured Leak cc/sec	Leak rate cc/sec/cm.
A	3.9×10^{-6}	5.4×10^{-8}
E	10^{-7}	2.5×10^{-9}
G	$\approx 10^{-10}$	$\ll 10^{-10}$
Main	2.5×10^{-8}	4×10^{-11}

Under these circumstances and the previous experience at Mannesmann, plus the fact that the preparation of sealing features, gaskets and bolting up procedures had been well supervised, there was no hesitation in accepting these two flanges as being capable of achieving the specified figures under more ideal conditions.

In order to obtain a gasket interspace on the Main Flange, a flat rubber gasket had been made and placed between the two weld features on the upper and lower half of the main flange. This seal provided an excellent vacuum seal and at the conclusion of the helium leak test the gasket interspace was pressurised with helium at 385 lb/sq in absolute. The rubber gasket withstood this pressure satisfactorily and on sniffing around the outer edge of the seal weld feature with the mass spectrometer probe, no leakage of helium could be detected.

At the conclusion of this final test both the Pressure Vessel and interspace were de-pressurised.

4. CONCLUSION

Both the test at Mannesmann and at the Dragon reactor site have shown conclusively that components normally classified as heavy engineering can be manufactured to attain standards of leak tightness usually associated with laboratory equipment. It has also been demonstrated that these results can be attained by the use of conventional manufacturing techniques. Considerable care, however, has to be exercised in the protection of fragile features, such as the machined grooves that form the Dragon type gasket sealing feature. Having achieved these standards, care must also be exercised in the cleaning of sealing features and the preparation of gaskets immediately prior to bolting up operations.

The results also show that the mass spectrometer techniques evolved during the work on the Mannesmann Test Vessel can be applied under two different sets of conditions. During the leak testing at Mannesmann there was free access to all parts of the vessel as can be seen from Figure 2. During the leak testing at the reactor site much of the work had to be carried out in confined spaces. Figure 7 gives a fair indication of these conditions under which tests were made. The vertical height of the vessel also presented problems of getting mass spectrometers, ancillary equipment and operators at the required positions. In order to give mobility to the mass spectrometers, special cradles were made that enabled the instruments to be raised and lowered by a specially erected pulley block and tackle. By this means the mass spectrometers could be moved as required whilst they were still operating. Figure 8 shows the instrument in use under these conditions.

5. ACKNOWLEDGMENTS

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The co-operation and assistance given by the Mannesmann organisation, U.K.A.E.A. Construction Group Winfrith and Matthew Hall Ltd., are also duly acknowledged.

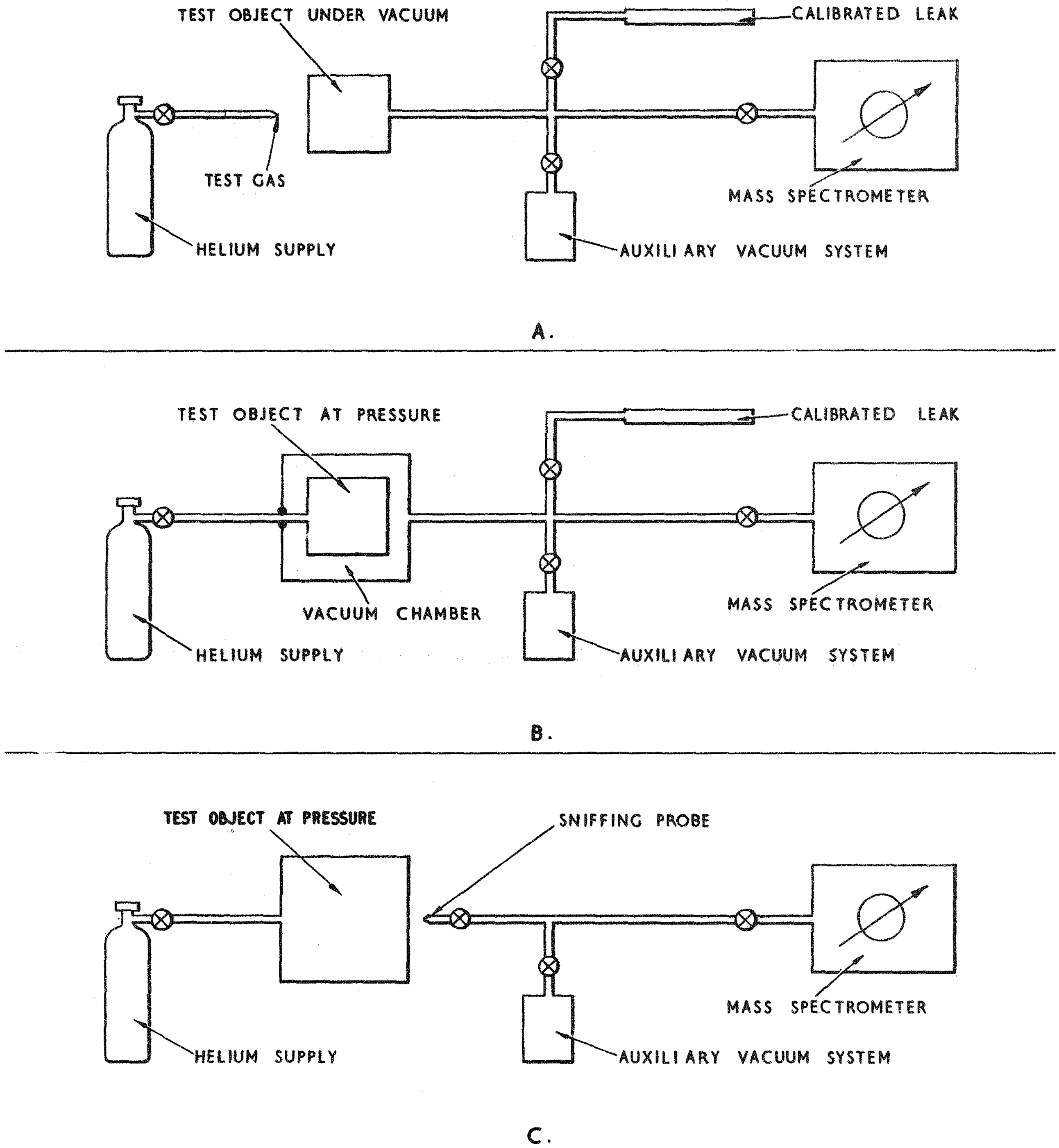

FIG. I METHODS OF USING MASS SPECTROMETERS FOR LEAK DETECTION

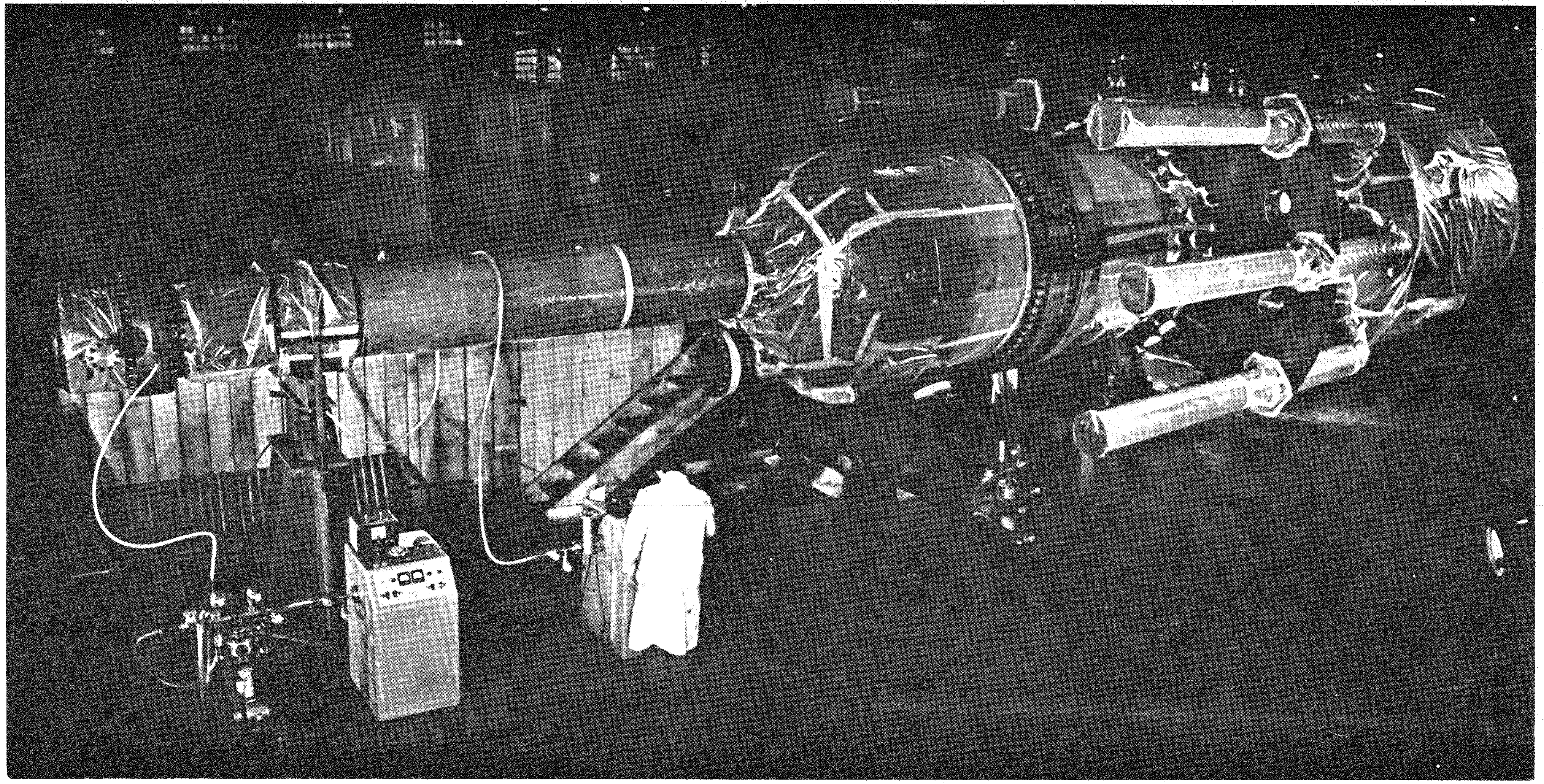

FIG. 2. DRAGON REACTOR PRESSURE VESSEL UNDERGOING HELIUM MASS SPECTROMETER LEAK TEST AT MANNESMANN A.G. HÜCKINGEN.

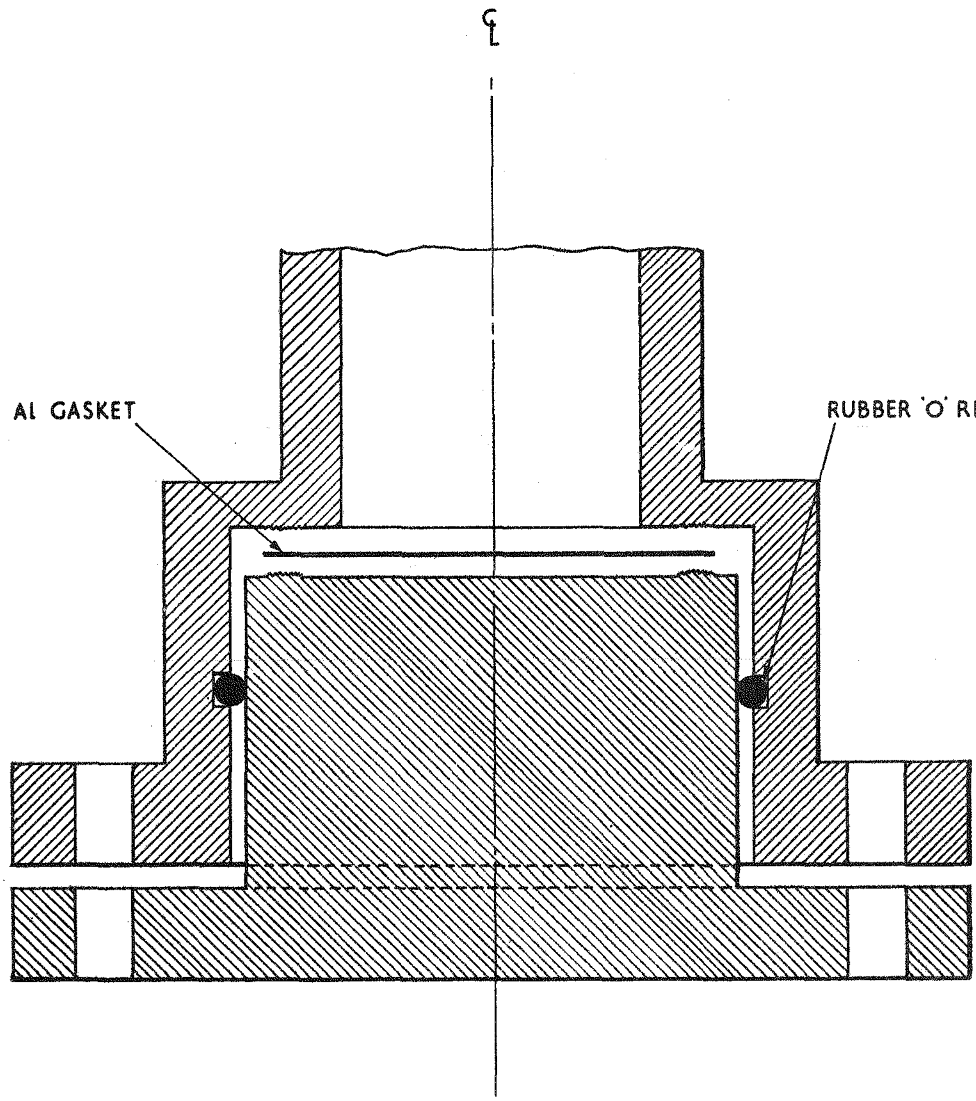

FIG.3 METHOD OF BLANKING-OFF FLANGES N. OF PRESSURE VESSEL

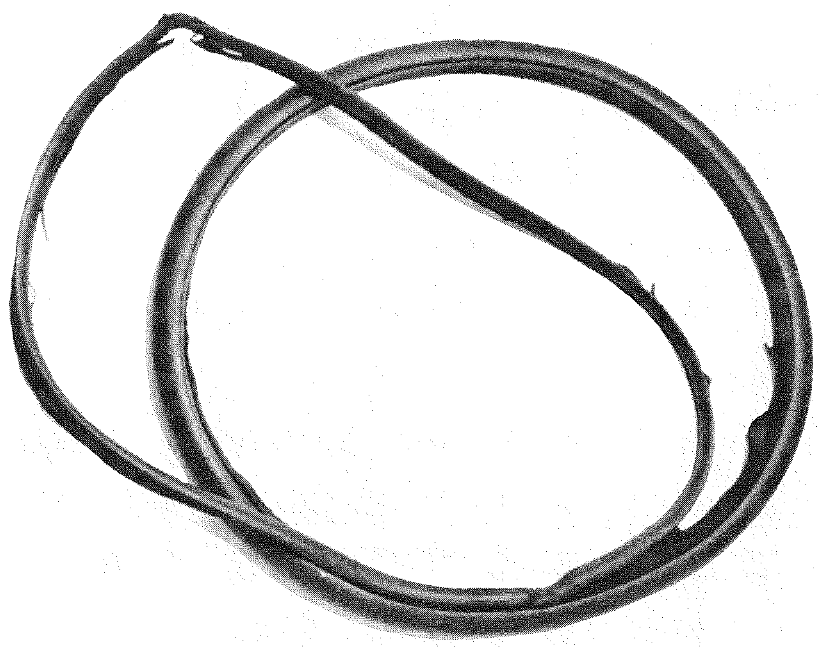

FIG. 4. RUBBER O-RING AFTER BEING USED TO FORM GASKET INTERSPACE IN ONE OF FLANGES N

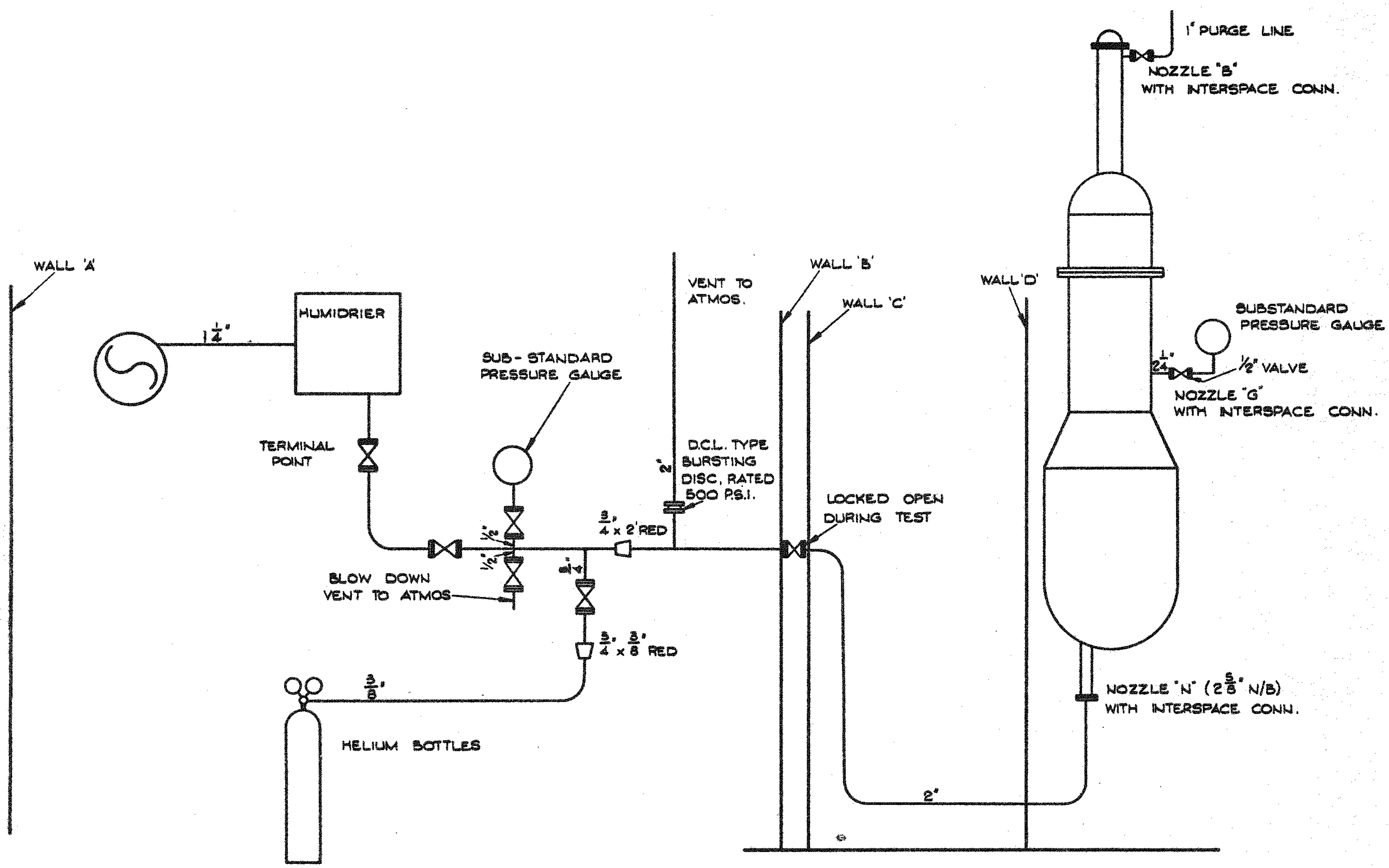

FIG. 5A DIAGRAMMATIC LAYOUT FOR TESTING PRESSURE VESSEL.

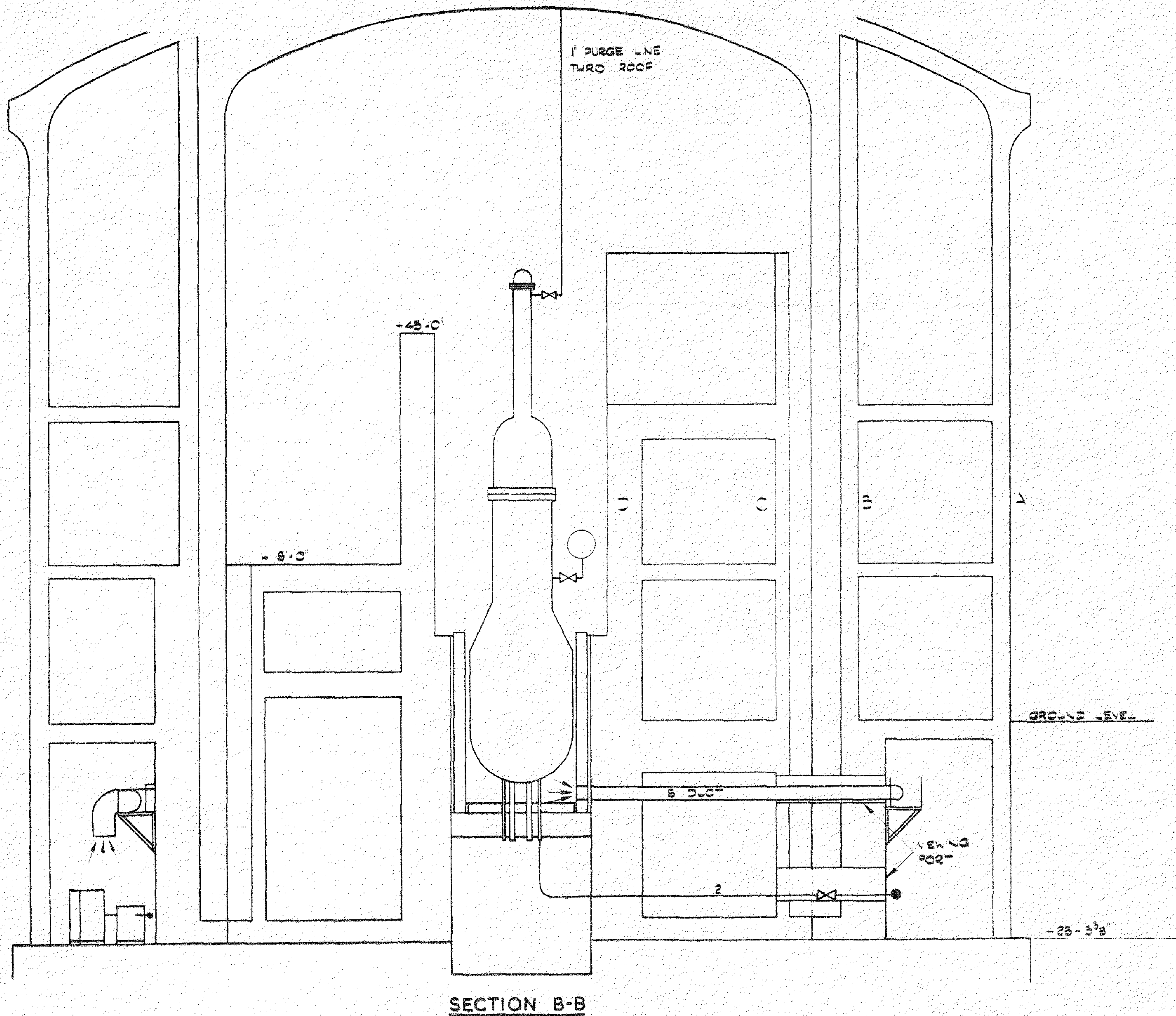

FIG. 5B LOCATION OF PRESSURE VESSEL WITHIN REACTOR BUILDING.

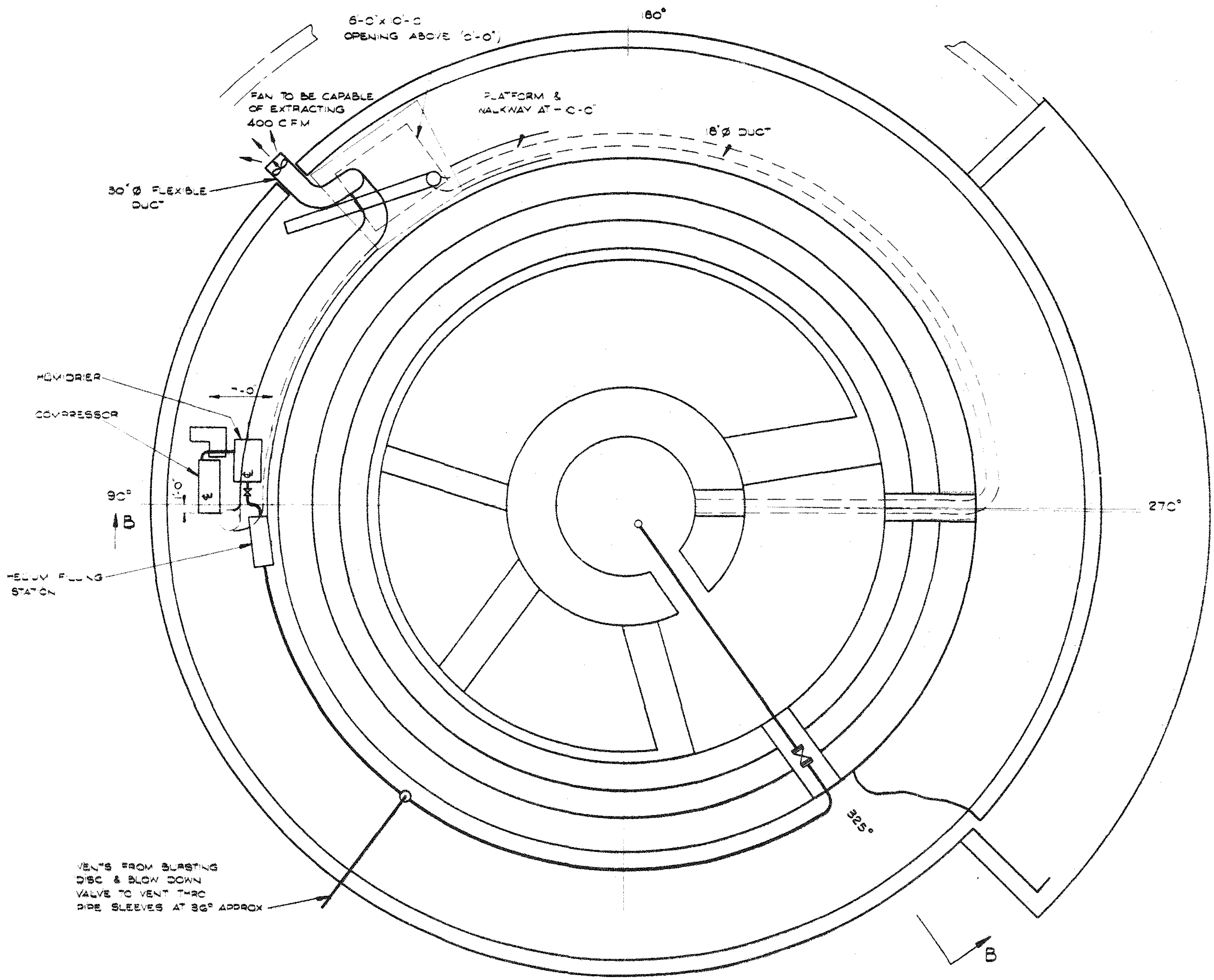

FIG. 5C LOCATION OF COMPRESSOR AND HELIUM FILLING STATION RELATIVE TO PRESSURE VESSEL.

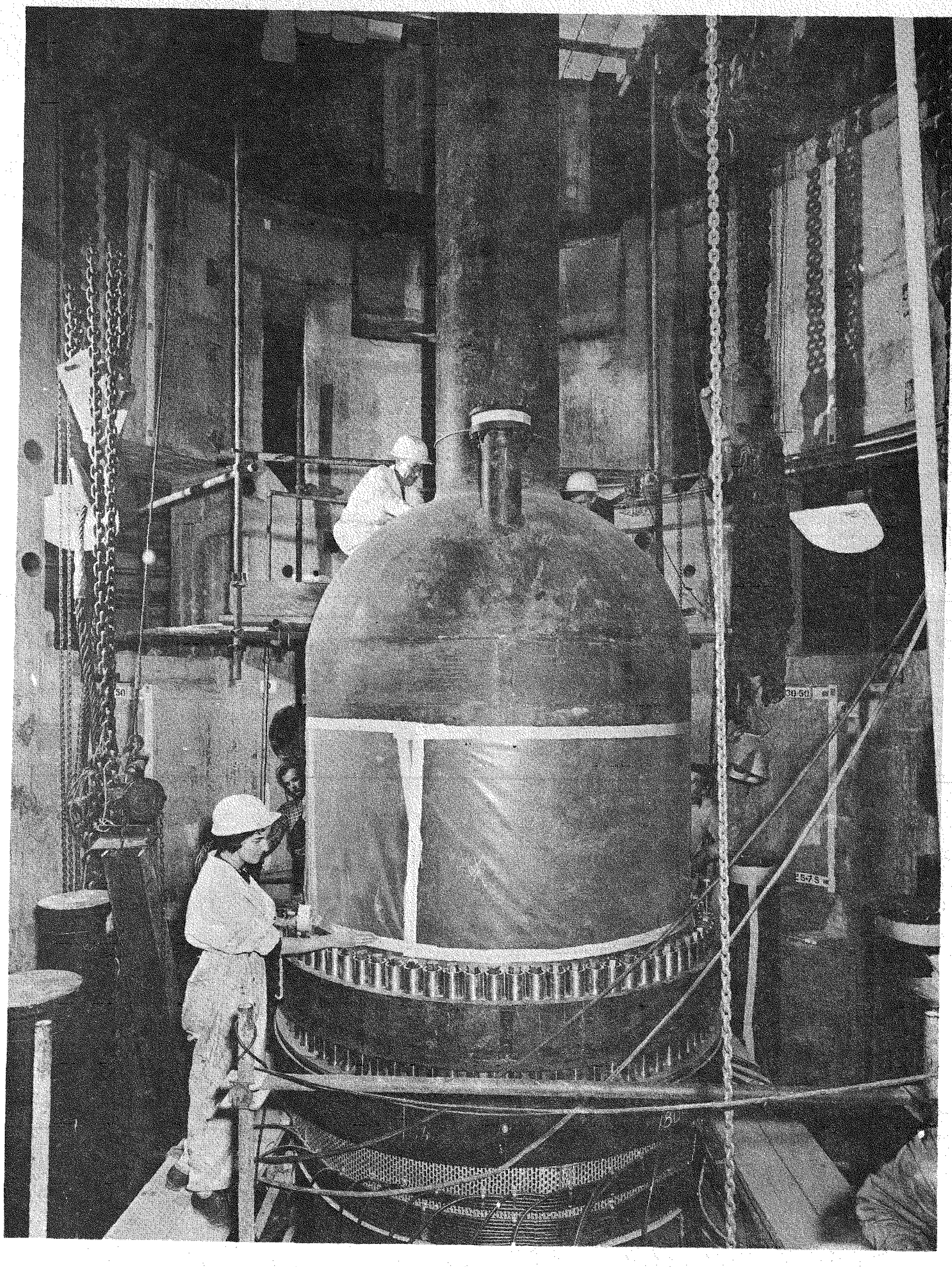

FIG. 6. TOP HALF OF PRESSURE VESSEL BEING COVERED IN POLYTHENE

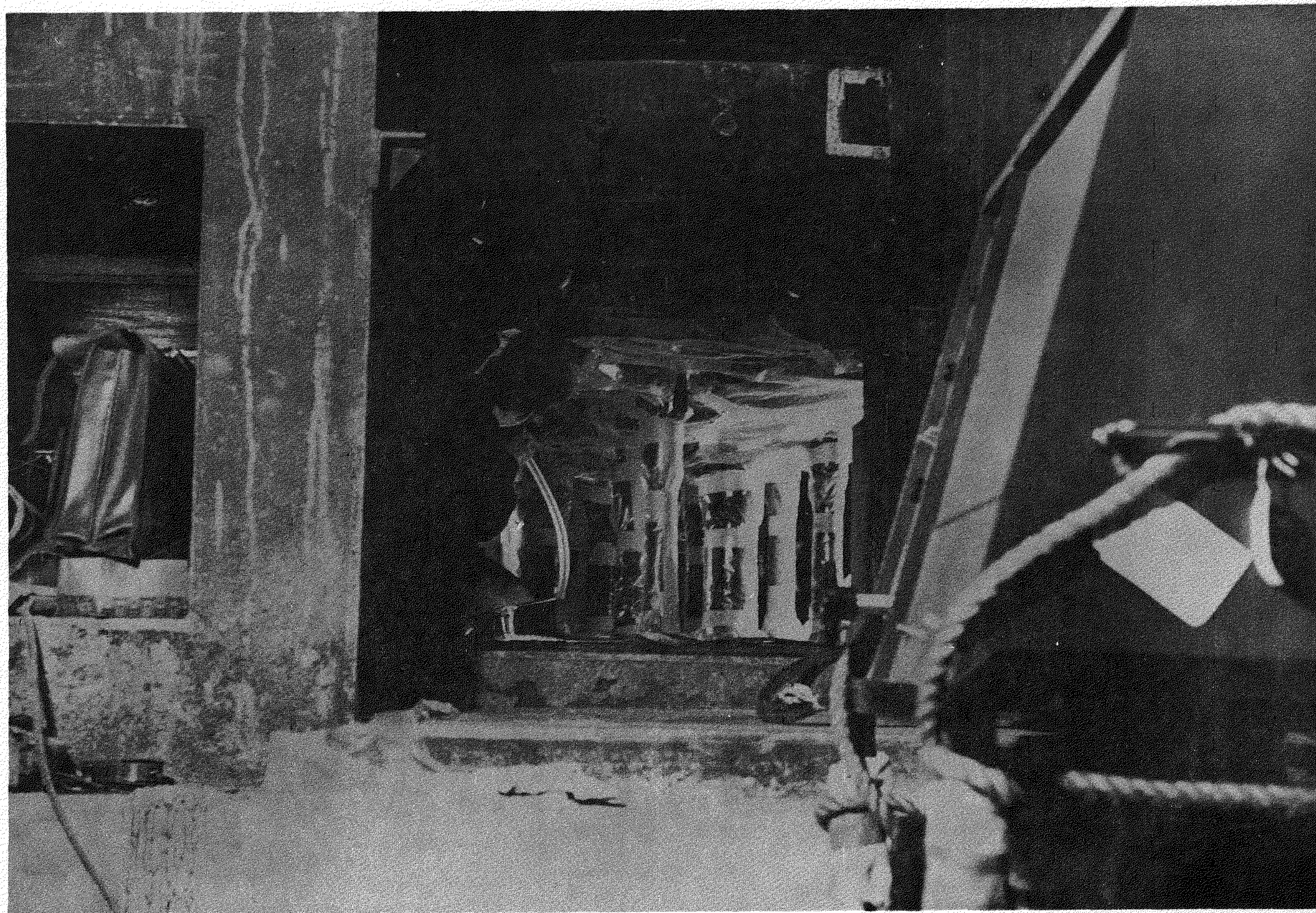

FIG. 7. LEAK TESTING UNDER-SIDE OF PRESSURE VESSEL IN VICINITY OF BOTTOM BIOLOGICAL SHIELD

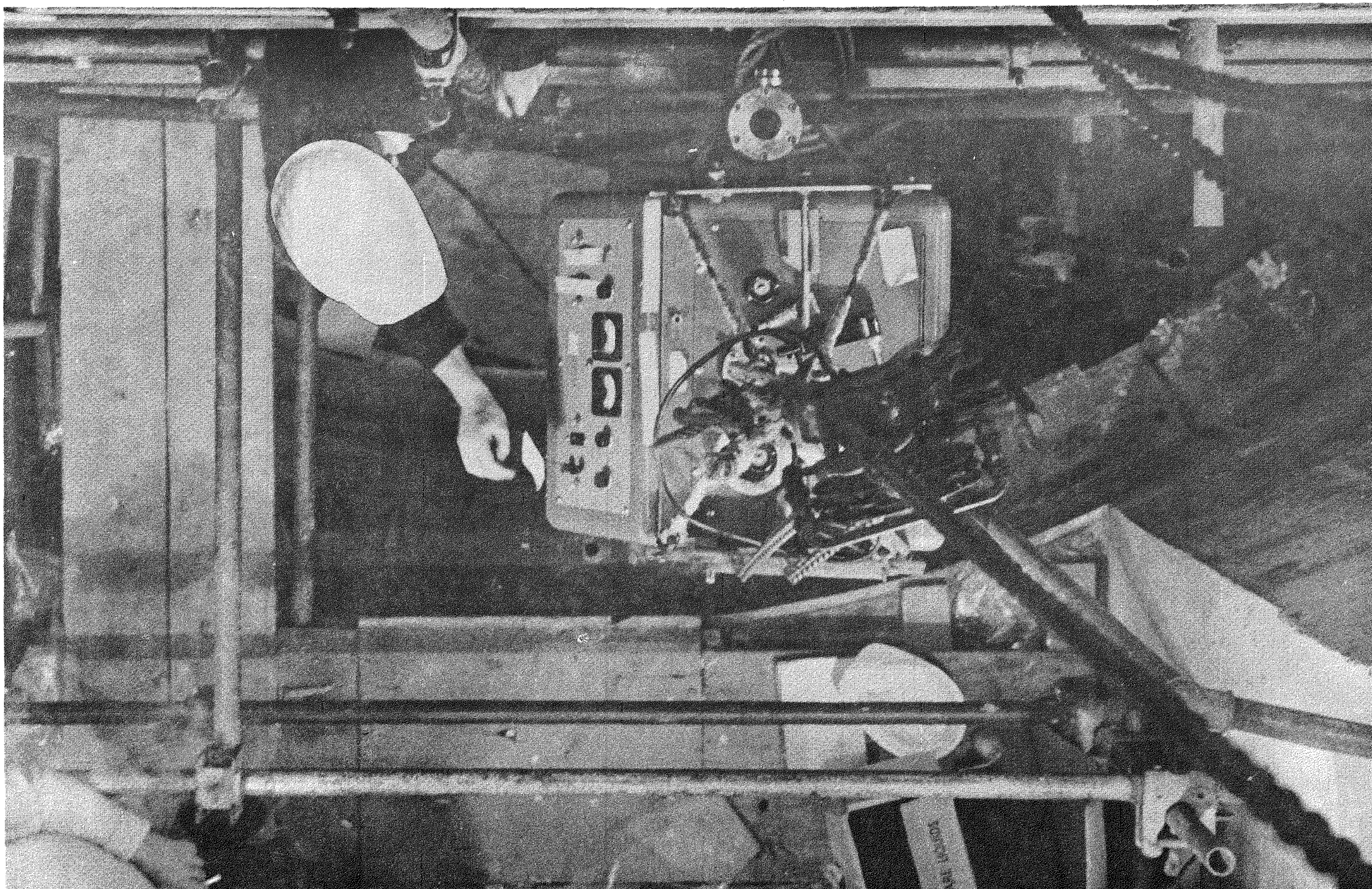

FIG. 8. MASS SPECTROMETER OPERATING SUSPENDED IN CARRYING CRADLE