·2

CONF-791102--154

GA-A15652

DOUBLET III NEUTRAL BEAM INJECTOR TEST TANK CRYOPANEL DESIGN

by

D. W. DOLL, J. H. KAMPERSCHROER
and P. VANDER AREND

MARCH 1980

GENERAL ATOMIC COMPANY

GA-A15652

DOUBLET III NEUTRAL BEAM INJECTOR TEST TANK CRYOPANEL DESIGN

by
D. W. DOLL, J. H. KAMPERSCHROER
and P. VANDER AREND*

This is a preprint of a paper to be presented at the 8th Symposium on Engineering Problems of Fusion Research, November 13-16, 1979, San Francisco, California.

Work supported by
Department of Energy
Contract DE-AT03-76ET51016

*Cryogenic Consultants, Inc., Allentown, Pennsylvania

GENERAL ATOMIC PROJECT 3296
MARCH 1980

GENERAL ATOMIC COMPANY

DOUBLET III NEUTRAL BEAM INJECTOR TEST TANK CRYOPANEL DESIGN*

D. W. Doll, J. M. Kamperschroer
General Atomic Company, San Diego California 92064
and
Peter Vander Arend
Cryogenic Consultants, Inc., Allentown, Pennsylvania

Summary

A simple condensing cryopanel has been designed for the Doublet III neutral beam test tank with a 320,000 liters per second pumping capacity for hydrogen. This maintains a vacuum in the test tank which simulates the Doublet III vessel, 1.3×10^{-3} Pa ($\sim 10^{-5}$ torr.) The hydrogen gas load comes from the beam striking the test tank calorimeter and amounts to about 7.2 torr liters per second. The cryopanel is cylindrical shaped with a liquid helium (LHe) surface that pumps through liquid nitrogen (LN) cooled aluminum chevrons located in squirrel-cage fashion around the inside surface of the cylinder. The LHe cooled surface is a smooth cylinder 2.09m in diameter by .69m long with LHe flowing in a ~ 1mm annular space between concentric cylinders. The chevrons which are not blackened are cooled from each end with LN flowing in ring manifolds that serve as the primary cryopanel structure. The LHe is force fed at 55.2 kPa remaining in the liquid phase through the panel. External heat exchanger capability permits use of helium at 3.8 – 4.2°K. Normal operating flow rate is 1.4 g/sec for a heat load expected to be 12.2 W total.

Introduction

The Neutral Beam Injector Program for Doublet III has as its initial goal to supply 7.2 MW of power to the hydrogen plasma for 0.5 sec pulses.[1] This power is extracted from two neutral beam injectors, each having two ion sources, accelerators and neutralizers. The first injector was designed and built by Lawrence Berkeley Laboratories with the second being a copy built by commercial vendors. Completion of the program will include a pre-operational testing period of the first beamline on a test stand.

The actual conditions on the Doublet III machine are simulated as closely as possible on the test stand.[2] An entrance simulator duplicates the geometry of the vacuum vessel port entrance. Inside the test tank which is cylindrical in shape and the same diameter as the injector are calorimeter and a cylindrical cryopanel. The calorimeter consists of a "Vee" shaped set of cooled copper plates which intercept the beams, one on each of the two plates. Imbedded thermocouples monitor the plate temperature and, hence, the beam power impinging on it.

The cryopanel described in this paper is coupled during the testing period to the same cryogenic feed lines as the two cryopanels used in the first neutral beam injector.[3] During the testing phase of the program, the performance of the three cryopanel designs will be compared. From this comparison, several conclusions can be drawn as to the importance of surface emissivity control and configuration efficiency. A later paper will report these findings.

Description

The test tank cryopanel is installed in the rear of the test tank away from the beam entrance port (Figure 1). It essentially surrounds the calorimeter which is mounted onto a frame that bridges the length of the cryopanel. The outside diameter fits concentrically with the test tank vessel leaving an annular gap of ~ 2.5 cm. Within this space is mounted two closely spaced aluminum sheets which provide a thermal radiation barrier to the vacuum vessel wall. Without the radiation barrier the vessel wall would become wet and frosted during operation.

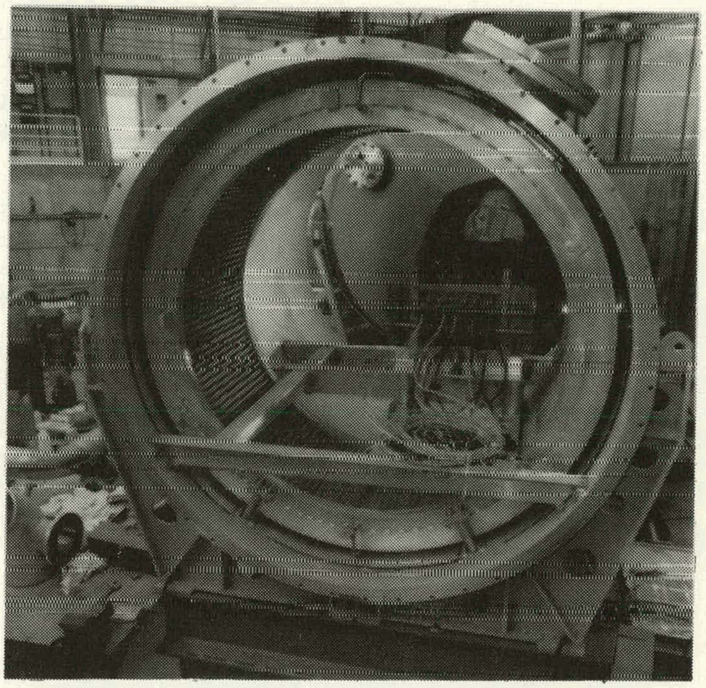

Figure 1. Doublet III Neutral Beam Test Tank View Looking Toward Beamline

Cryogenic feed lines enter the vessel at 30° from vertical at the top of the cryopanel. This unusual arrangement was used in order to align the cryogenic feed line manifold with the neutral beam cryopanel feed-through ports which use the 30° offset to avoid interference with Doublet III diagnostics.

Table I
Basic Parameters

Pumping Speed, H_2	320,000 liters per second
Effective Pumping Area	4.2 m^2
Liquid Helium Pressure	55.2 kPa
Operating Temperature, LHe	3.8–4.2°K
Operating Temperature, LN_2	77°K
Pressure Drop Through LHe Circuit	2.55 kPa
Net Capture Probability	0.17
Helium Heat Load	12.2W

The design approach for the test tank cryopanel was to provide a single phase liquid helium cooled cylindrical surface with a LN cooled concentric cylindrical jacket having chevrons to shadow the pumping surface. Basic parameters are summarized in Table I. Helium is pumped through a 0.7mm annular space between two concentric cylinders which are kept separated by a wire mesh. The stainless steel mesh is No. 24 with .04 mm wire size. The LN panel consists of two ring manifolds which conduct heat from each end of the interconnected chevrons. The design intent for both panels was to avoid vapor binding problems due to hot spots by providing redundant liquid flow paths and vapor collection zones.

The flow circuits for the LHe and LN are shown in Figure 2. LHe is supplied from a refrigeration system designed by Vander Arend[3] (Figure 2a). An extension of the transfer lines used to supply

---

*Work supported by DOE Contract DE-AT03-76ET51011.

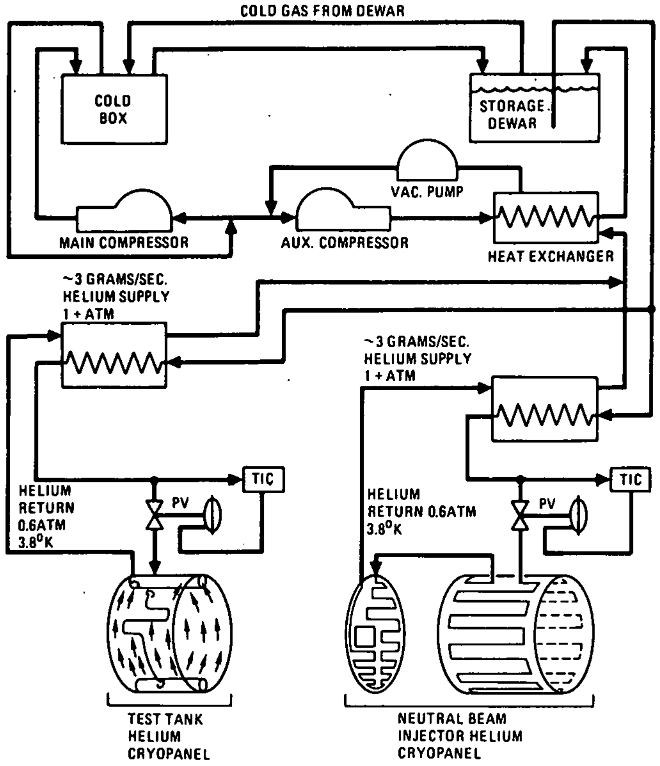

Figure 2a. Liquid Helium Flow Path

the injectors provides the cryogens necessary for the test tank. The LN system is a simple once through evaporation scheme as shown in Figure 2b.

The LHe enters at the bottom of the cryopanel and exits at the top. The cryogenic feed line enters the vessel at 30° off-vertical and follows the outside diameter of the helium panel, avoiding direct exposure to room temperature surfaces (Figure 2a). A manifold at the bottom of the helium panel distributes the helium uniformly across the 0.69m length. Entering the annular space through a series of holes, the LHe flows upward to a manifold at the top which also contains two rupture discs. Gaseous helium collects in this volume allowing the liquid to be drawn into the return line located in the middle of the manifold. At each end of the upper manifold, liquid return lines allow excess liquid to recirculate to the lower manifold. This allows for liquid storage and fast response to liquid demand before the JT valve can respond, thus, minimizing the potential for oscillations. Within the annular flow space, wire mesh keeps the inner and outer surfaces from touching but allows space for LHe to circulate. A path is left in the center of the panel without mesh to ensure startup circulation and allow a "wick" effect to draw liquid into the spacing mesh. These design features are shown in Figure 3.

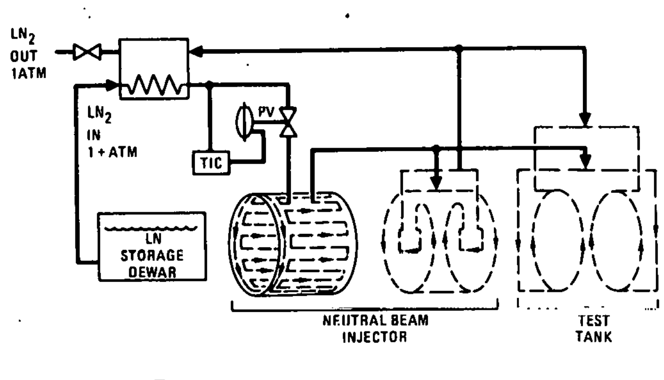

Figure 2b. Liquid Nitrogen Flow Path

In case of an up-to-air accident, the helium panel is exposed to a rapid change in heat transfer from radiative to convective. The result is that the LHe flashes to gas and cannot be vented fast enough to prevent a run-away rise in pressure. Since the stress limited pressure differential for the cryopanel wall is 203 kPa (29.5 psi), two rupture discs are included in the upper manifold to limit the peak pressure to 157 kPa (22.8 psi). Should the rupture disc release the helium inventory into the test tank vessel, the pressure rise would be less than 1 atmosphere ensuring no pressure vessel type failure.

The LHe panel is suspended at each end within the LN cooled structure with 8mm diameter rods that wrap 180° around the circumference. Three equally spaced sets of stainless steel rods stabilize the LHe panel in all radial directions. Six axial 8mm diameter rods are welded onto the LHe panel and are bolted to the outside of the LN outer enclosure. The entire assembly is mounted to the test tank vacuum vessel with four posts that bear on the bottom of the vessel 30° off center and attach to the LN panel.

The cryopanel is fabricated from Type 304 stainless steel and type 6061–T6 aluminum. The LN surfaces are aluminum up to the cryogenic feed lines. An aluminum to stainless transition is welded into the LN vessel wall and to the stainless steel feed lines. The entire LHe circuit is fabricated from 304 SS. A foil type seal is used at the transition to the main cryogenic feed line.

The two hollow cylindrical rings that support each end of the chevrons and provide the basic cryopanel structure are also the LN supply reservoirs (Figure 4). From the feed-line entrance, the LN is supplied through a "Tee" to both ring reservoirs; vapor and liquid are removed from the top of the rings in a similar fashion. Nested in each ring is a liquid return tube that allows for liquid recirculation to the bottom. The chevrons are arranged around the inside of the cryopanel in a squirrel-cage fashion and welded to the end rings. Typical spacing is 37 mm max. for the standard 51x51x06 mm (2x2x¼) angle sections used.

The heat load on a LHe surface in a cryopanel is due to several contributions. These are conduction along supports, radiation, and the arrival of warm gas (warm being defined here as warmer than the pumping surface) at the cold surface. The heat load due to radiation is a function of the emissivities of the various surfaces involved: LHe surface, LN chevrons, and surrounding room temperature items. Based upon the photon transport model assumed below, a study was made to determine the radiation heat load on the cryopanel as a function of the emissivities of the surfaces involved. Conclusions as to the necessity of blackening the LN chevrons can then be drawn.

Our model assumes that the fraction of photons incident on a surface of emissivity, ϵ, which rebound from that surface is $1 - \epsilon$; the remaining fraction, ϵ, is adsorbed. We assume that this attenuation mechanism is valid on both the LN and the LHe surfaces. (Unity sticking probability is not assumed for incident radiation. In the present analysis the incident photon flux can be tremendously reduced by interation with the chevrons.)

Interactions with the surfaces were analyzed with a Monte Carlo computer code.[4] Specular reflection was assumed. Two thousand trajectories were randomly initiated outside the chevrons and followed until they either reemerged or suffered 100 interactions. Surface interactions were noted along with the type of surface involved. The incident photon heat flux was normalized to

$$\frac{460\ \text{watts/m}^2}{1/\epsilon_{\text{room}} + 1/\epsilon_{\text{LN}}}$$

where ϵ_{room} is the emissivity of the surrounding room temperature surfaces; $\epsilon_{\text{room}} = 0.7$ here.

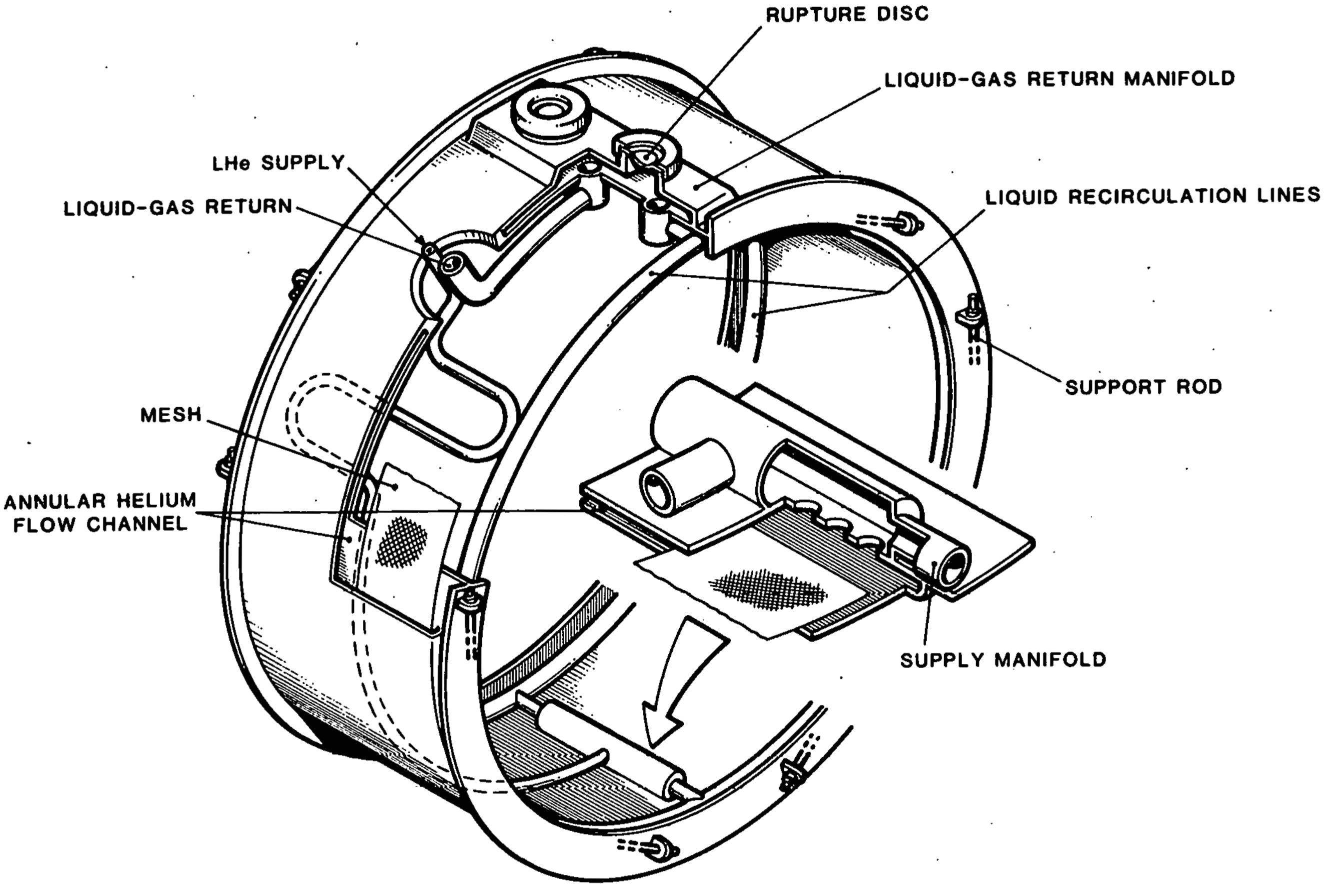

Figure 3. Liquid Helium Panel Design

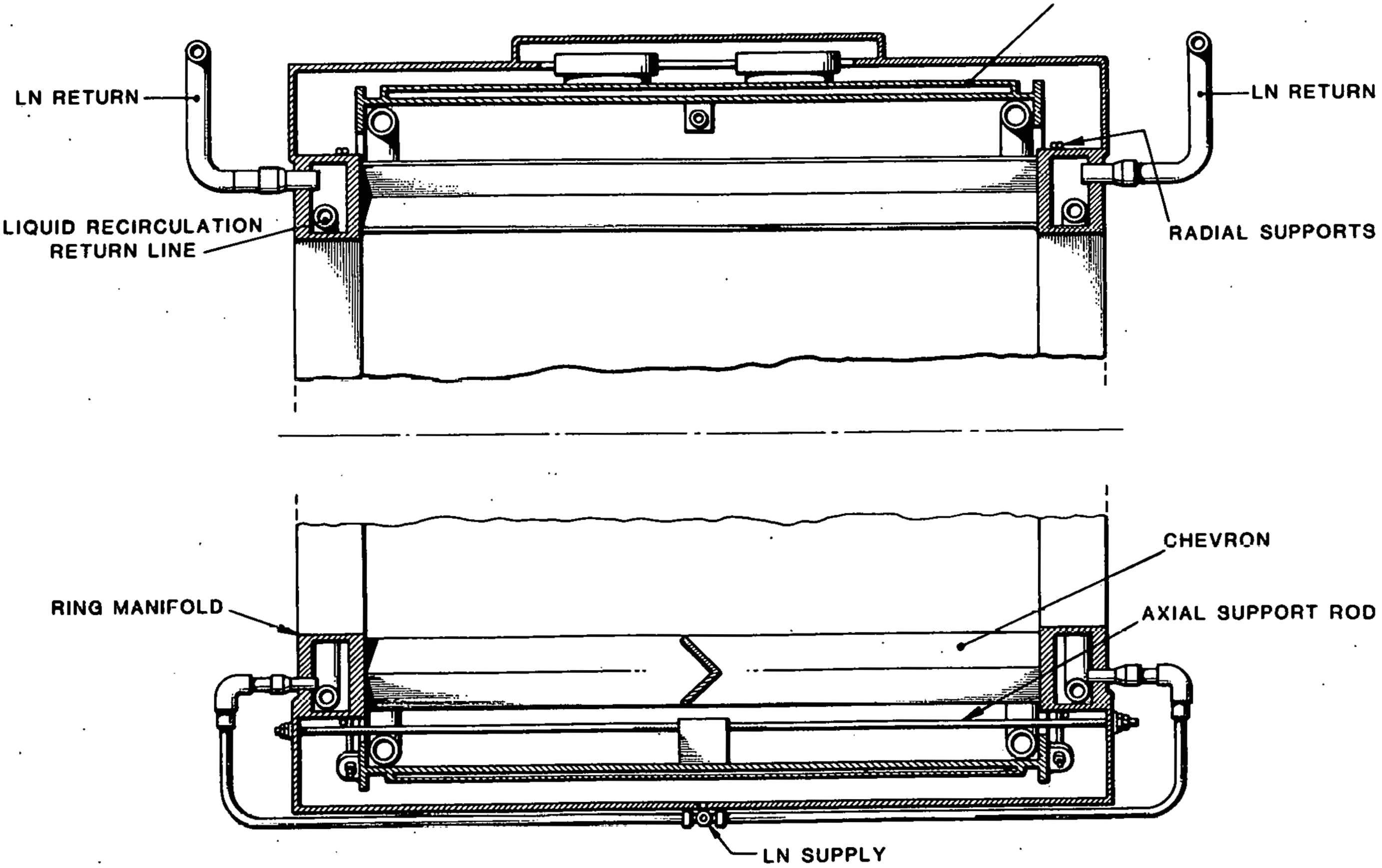

Figure 4. Cross Section View Through Upper and Lower Manifolds

Results of this analysis are shown in Figure 5, where the heat load is displayed as a function of ϵ_{LN} with ϵ_{LHe} as a parameter. Unpainted aluminum should have an initial emissivity of ~0.2 which requires that $\epsilon_{LHe} < 0.2$ to keep the total radiation heat load to $\leqslant$ 10 watts for a 4.2 m^2 cryopanel. A shiny LHe surface is therefore required. As both surfaces become coated with condensibles, the heat load is decreased. If heat loads of 10 watts are acceptable due to radiation alone, then blackening of the aluminum chevrons appears unwarranted.

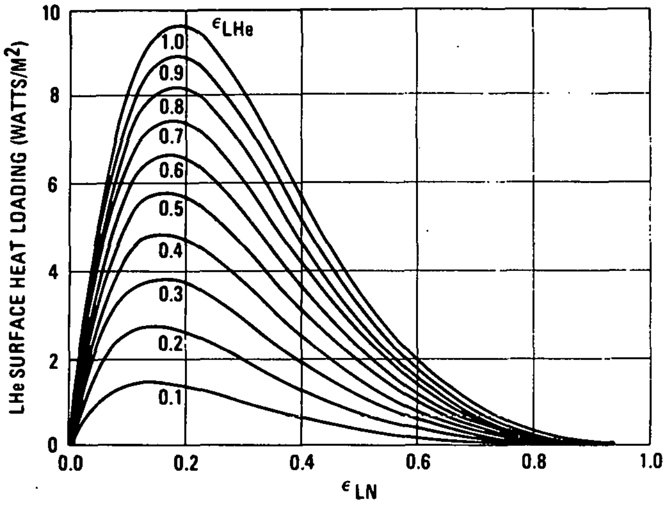

Figure 5. Heat Load to LHe Panel Due to Specular Reflection

The radiative heat load is the largest contributor to the helium system and the one most sensitive to surface emissivity changes. Assuming the chevrons oxidize and frost with use, ϵ_{LN} will approach ~0.3 or, perhaps, larger. The stainless steel will start at about 0.1 and gradually increase to ~0.2. This will give a radiative heat load of ~8W total. Heat leaks from other sources include 1.7W from radial support rods and 1.3W from axial stabilizing rods. The heat load due to frosting hydrogen is estimated assuming 77° gas temperature. Cool down and latent heat of freezing amount to 1.2W (0.6W each). The only other contribution to the helium panel heat load is the resorption exchange between the LHe and LN panels. Gas molecules will come off the LN panel and migrate to the LHe panel at some rate expected to be small. The resulting heat load is therefore considered insignificant compared with the other contributions. This brings the total estimated heat load (less the pass-through heat leak) to the refrigeration system of 12.2W.

Diagnostics

The cryopanel performance is monitored by measuring the temperature and flow rate of the LHe entering and exiting. A simple calculation can then give the heat transferred to the fluid:

$$Q = m_f C_p (T_{OUT} - T_{IN})$$

where,

m_f = mass flow rate of LHe
C_p = specific of LHe
T = measured temperatures

A venturi flow meter located on the inlet line measures the liquid flow rate. Vapor bulb thermometers are used to measure temperature.

The temperatures of several locations on the panel surfaces are measured with carbon glass resistors.[5] On the helium panel, these are located on the inlet and outlet manifolds and a point midway up the pumping surface. On the LN panel, these are located on the inlet manifold surface, a chevron at the reservoir and at the middle of the same chevron. Special care was taken to ensure that heat leaks down the resistor leads would not affect the readings. High resistance wire was used with cold shorting both on the LN and LHe panels. A stainless steel tab was welded over the resistor attached to the LHe to avoid the effects of radiation heat transfer.

The hydrogen pumping speed will be measured by injecting gas at a known rate and monitoring the pressure with an ion gage. When equilibrium is reached, the inlet flow rate should be the pumping speed.

Conclusions

The cryopanel designed for the Doublet III tank incorporates several unique features that have simplified the fabrication and reduced the risk of cool-down and system oscillation problems. The annular design is inherently less resistant to up-to-air accidents, but the replaceable rupture discs should prevent damage to the panel itself.

The operational performance comparison of this cryopanel design with the neutral beam cryopanel designs should prove both interesting and useful for designing future cryopanels.

Acknowledgements

We wish to acknowledge the fine contributions of Mike Morgan, who provided much needed information and guidance during the fabrication of the cryopanel, and Meyer Tool Company, Chicago, Illinois, who fabricated the cryopanel to specification and on schedule.

References

1. Harder, C. R., Holland, M. M., and Parker, J. W., General Atomic Company (GA), San Diego, California; Gunn, J., and Resnick, L., Lawrence Berkeley Laboratories (LBL), Berkeley, California, "Doublet III Beamline–As Built"; paper presented at this conference.

2. Doll, D. W., Kamperschroer, J. H. (GA), and Vander Arend, P. Cryogenic Consultants, Allentown, Pennsylvania, "Doublet III Neutral Beam Injector Test Tank Design"; paper presented at this conference.

3. Tanabe, J., Yammamoto, R. (LBL), and Vander Arend, P. (Cryogenic Consultants), "The Doublet III Neutral Beam Source Cryopanel System"; paper presented at the Particle Accelerator Conference, San Francisco, California, March 12-14, 1979.

4. The Monte Carlo Code MONTE, written by J. Tanabe, LBL, was run through the courtesy of R. Yammamoto, also of LBL.

5. Anderson, A. C., "Carbon Resistance Thermometer"; paper presented at Fifth Symposium on Temperature, Washington, D. C., June 21-24, 1971.

INTERNAL DISTRIBUTION

E. Bailey
J. Beal
A. Colleraine
L. Davis
D. Doll
J. Gilleland
R. Harder
M. Holland
H. Horner
J. Kamperschroer
J. Kohli
J. Miller
M. Otavka

EXTERNAL DISTRIBUTION

Dr. Richard Aamodt, Director
Laboratory for Applied Plasma Studies
Science Applications, Inc.
P.O. Box 2351
La Jolla, California 92037

Dr. Charles C. Baker
Argonne National Laboratory
Fusion Power Program, Bldg. 208
9700 S. Cass Avenue
Argonne, Illinois 60440

Dr. John E. Baublitz
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Dr. Frank Coffman
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Mr. Daniel Cohn
MIT National Magnet Lab
170 Albany Street
Cambridge, Massachusetts 02139

Dr. Robert Conn
University of California, Los Angeles
405 Hilgard Avenue
Los Angeles, California 90024

Dr. N. Anne Davies
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Dr. Melvin E. Gottlieb
Plasma Physics Laboratory
Princeton University
P.O. Box 451
Princeton, New Jersey 08540

Mr. Charles R. Head
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Mr. Edwin E. Kintner, Director
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Dr. G. Kulcinski
Dept. of Nuclear Engineering
University of Wisconsin
Madison, Wisconsin 53706

Mr. Donald L. Kummer, Manager
Materials and Processes
McDonnell Douglas Astronautics
St. Louis, Missouri 63166

Mr. M. Murphy
Office of Fusion Energy
Department of Energy, MSG-234
Washington, D.C. 20545

Dr. Don Steiner
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, Tennessee 37831

GENERAL ATOMIC

GENERAL ATOMIC COMPANY
P. O. BOX 81608
SAN DIEGO, CALIFORNIA 92138