APPENDIX X. CRYOGENIC MEASUREMENTS

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The thermal performance of two kinds of supports has been studied both by calculations and tests. The computer analysis made use of a Nodal Network Thermal Balance program[1] in which the support and cryostat parts are taken as a series of nodes interconnected by appropriate thermal and infrared radiation conductances. Two experimental tests were carried out for each support: 1) measurements of the thermal conductance of isolated supports and 2) flow measurements of the helium boiling off from an actual cryostat with magnet-simulating pieces instead of an actual superconducting coil.

The first kind of support is shown in Fig. X-1. It is fabricated out of NEMA G-10 plates and coated with a thin aluminum layer to reduce its emissivity. Scribed lines on the surface limit the conductance along the coating.

In the experimental study of the performance of this support a method was developed[2] for measuring the thermal conductance between the heat intercepts and the wall at liquid-helium temperature. This special method is based on thermal conductivity measuring techniques and discriminates conduction heat from radiation heat.

The results of single-support measurements[3] agree moderately well with calculations under the condition of no contact resistance. Experimentally, this condition was implemented by using indium gaskets at the points where the G-10 contacts the cryostat walls.

A more significant test[4] for the overall performance was carried out by actually assembling a typical 10-ft cryostat and measuring its boil-off. The cryostat was terminated at both ends with suitable cold boxes and transfer tubes that allowed cold helium gas to flow through its shield and liquid helium to be collected in the space that normally would contain the superconducting coil. Instead of the coil, magnet-simulating pieces were used at the spots needed for proper tensioning of the support. The cryostat was installed at an angle of 25° with the horizontal. The evaporation rate of the liquid as a function of the level

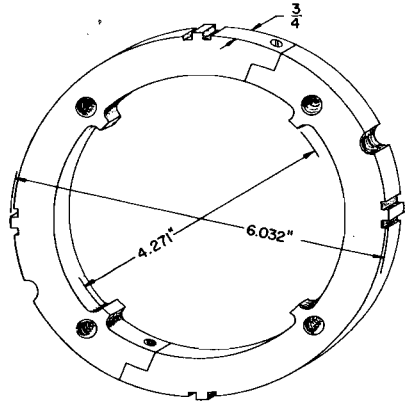

Fig. X-1. Support of first kind.

position depends on the heat load reaching the liquid. In Fig. X-2, we can see constant flow-rate sections resulting from a heat load independent of liquid level and sloping sections resulting from a variable load as the liquid level recedes from a magnet-simulating piece. The heat loads into the 4K environment associated with the individual supports as deduced from these change in flow rates are indicated in Fig. X-2. These heat loads reflect the actual contact resistance and therefore are expected to vary from support to support. An important finding was that this load is independent of the temperature of the shield. No substantial change in the heat load was observed when the shield temperature was raised from 23K to 78K. This effect is attributed to poor heat interception in the support. We also see that the shield can be operated at liquid-nitrogen temperature, placing the refrigeration requirements well within the estimated capacity. The heat load in the shield was deduced from the measured increase of the enthalpy of the gas as it flowed through shield piping. It was found to be close to 14W whether the average shield temperature was 23K or 41K.

The second kind of support is shown in Fig. X-3. It is based on rollers made of NEMA G-10 plate between the outside vacuum wall and the shield. A small block of NEMA G-10 between the shield and the 4K wall, under the roller position, completes the force-transfer path. This design takes advantage of the roller's small contact surfaces in the heat path and provides for automatic adjustment to thermal contractions. A stainless fixture spot-welded to the shield and a spring clip keep the roller aligned and in place. Four rollers at 90° from each other form the radial support unit. A single anchor tube substituting for one roller provides longitudinal support.

Knowledge of the thermal conductance of the contact surface is essential for the evaluation of roller thermal performance. Since this contact is a function of pressure, a cryostat that permitted the application of force to a roller positioned in vacuum inside a container submersed in liquid helium was built.

Experimental results[5] for a roller between 300K and 35K show the conduction varying from 0.21W for light contact to 0.47W for the contact caused by a force of 700 lb. For a coil-iron misalignment of 0.010 in., a force of 225 lb is expected to act on the roller, with a corresponding 0.38W conduction. A computer calculation[6] assuming a literature-quoted value for the contact conductance yields a value of 0.79W.

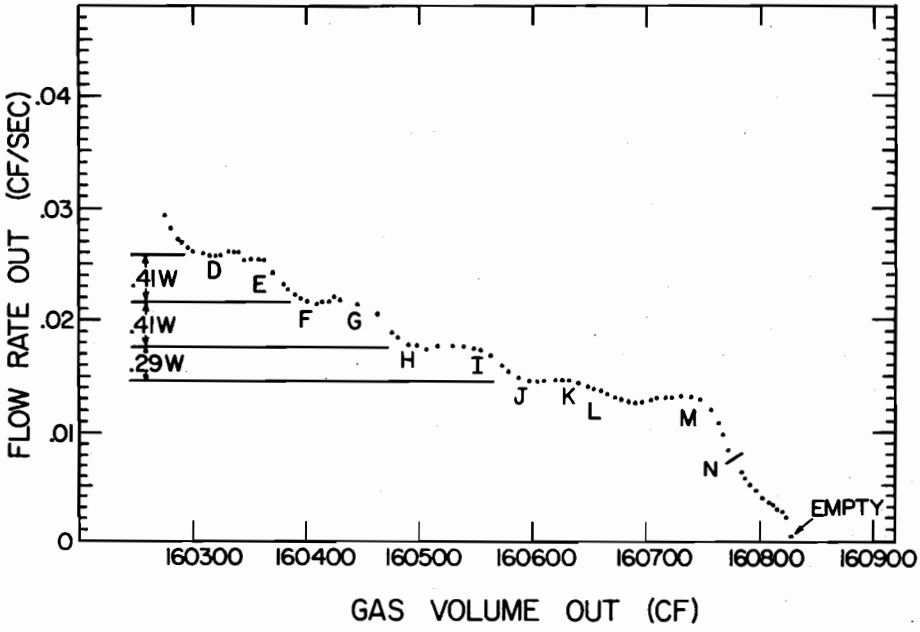

Fig. X-2. Boil-off of cryostat with supports of first kind and shield kept at liquid N_2 temperature.

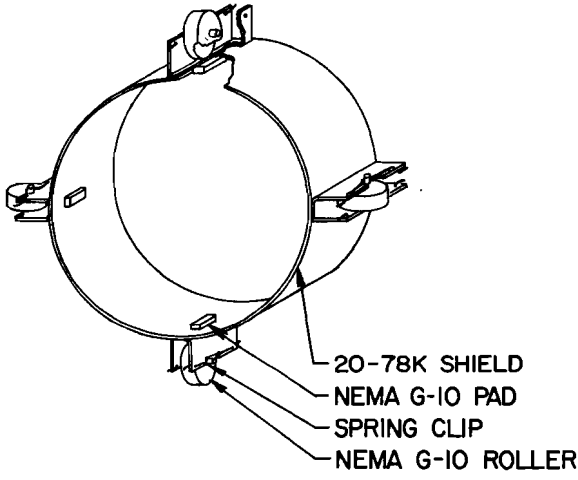

Fig. X-3. Second kind of support.

A boil-off test of a 10-ft cryostat using roller supports yielded the results shown in Fig. X-4, which should be compared with Fig. X-2. The overall improvement in performance is very encouraging. From an evaluation of all the data obtained in this test, it is concluded that the average heat load into the shield at 78K is no more than 12W, the average load at 4K due to a support with four rollers is 0.17W and the load from the anchor support (one anchor and three rollers) is 0.22W. Although these numbers carry little statistical weight, and are based on a discontinued cryostat series, they form a reasonable basis for a first estimate of the steady-state refrigeration requirements.

As part of the cryogenic-measurements support effort, several instruments and studies were made, among which the following might be mentioned:

1. A carbon-resistor calibration mini-cryostat that permits the simultaneous calibration of eight resistors over the range 4.2K to 300K to be done inside a regular storage dewar.[7] This device allows us to instrument magnet cryostats with non-recoverable thermometers.
2. A device for measuring thermal contraction of solid components when immersed in liquid nitrogen or liquid helium with a sensitivity of 5×10^{-6}cm.
3. A set-up for measuring the thermal-conductivity integral of solid or layered material from 4.2K or 78K to 300K. Preliminary measurements were made on fiberglass epoxy composites as well as stacks of dusted stainless foils, alumina chips and superinsulation.[8] The capability now exists for doing such measurements as functions of pressure.
4. A computer program for estimating the refrigeration load of a given magnet-cryostat design.
5. A procedure for simple fabrication of electrical vacuum feedthroughs with up to 40 or more wires that withstand thermal shocks, as well as liquid-helium temperatures.[9] These feedthroughs are known to be vacuum-tight for superfluid helium containment.
6. Set of measurements[10] of Bauschinger-effect heat developed in superconducting wire and cable under application or release of tension at cryogenic temperatures.
7. An experimental study of the efficiency of a heater discharging a capacitor as a quench-provoking element in a superconducting wire. This study and a program that calculates the temperature of 1 cm of super-

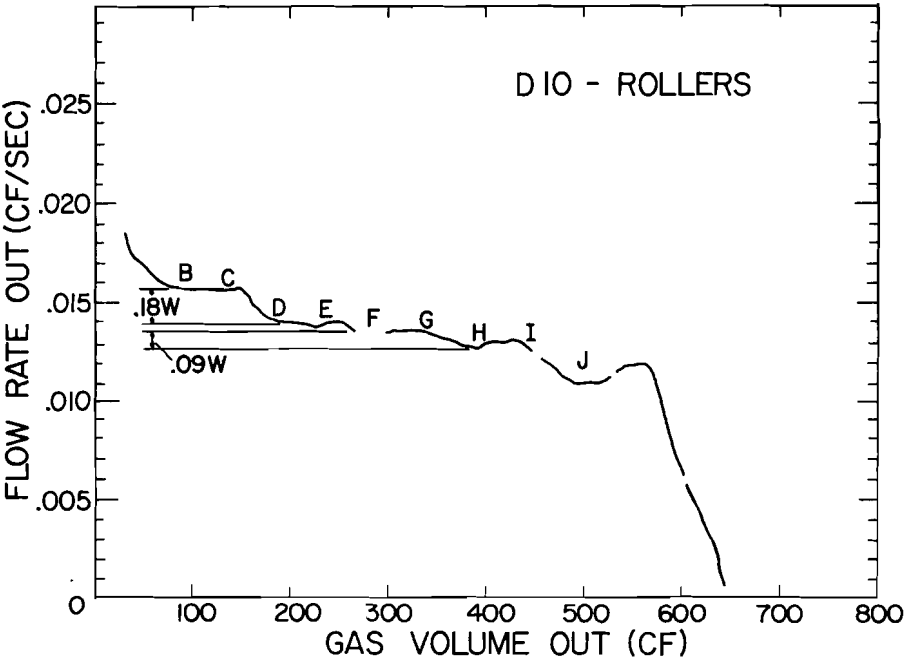

Fig. X-4. Boil-off of cryostat with roller supports and shield at liquid N_2 temperature.

conducting cable as a function of time and current, developed into a more complete study[11] of quench-propagation velocity in our magnets.

8. The capability for obtaining overnight photomicrographs of samples of multifilamentary wires and cables.

References

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[10]M. Kuchnir, Stress Heating of a Thermally Insulated Superconductor, presented at the 3rd NBS-ARPA Workshop, Vail, Colorado, April 1976.

[11]R. H. Flora, et al., Quench Development in Magnets Made With Multifilamentary NbTi Cable, to be presented at the 1976 Applied Superconductivity Conference, Stanford, California, August 17-20, 1976.