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5CM, NO IRON SSC DIPOLE 12M MODEL CRYOSTAT THERMAL PERFORMANCE*

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ABSTRACT

A 12 m long model of a 5 cm cosθ dipole cryostat has been constructed and its thermal performance measured. The model utilized heat intercepted fiberglass reinforced plastic posts to support the 12 m long, 4.5 K cold mass and the 10 and 80 K thermal shields. A superinsulation blanket system utilizing aluminized polyester with fiberglass mat spacing material was developed and installed on the 10 and 80 K thermal shields. The heat gain to 4.5, 10 and 80 K was measured. We have compared the results with the analytical predicted performance and it shows good agreement. The performance of the multilayer insulation system has been measured under several different system conditions and the results are reported.

INTRODUCTION

When considering the construction of a machine such as the Superconducting Super Collider (SSC)[1], it is desirable to measure the heat leak of the contemplated components as early as possible in the program to verify that the calculation methods used to determine heat leak are accurate. Early in the project, Fermilab decided to undertake such a program by constructing a 12 m long thermal model cryostat similar to one for an iron-less dipole magnet. This model simulates the major component in the accelerator system. The model has been completed and tests have been conducted. The data has been evaluated and is presented in this paper. Table 1 shows the objectives of the program.

DISCUSSION

The thermal characteristics or heat leak of an accelerator magnet cryostat is comprised of two major elements, thermal radiation and conduction through the support system.[2] The model described in this paper uses a fiberglass reinforced plastic (FRP); i.e., G-10, post support system.

The selection of a cryogenic insulation system for the SSC magnets involves several interesting technical/economic "trade off" decisions. A brief discussion of these is appropriate at this point.

Table 1. Thermal Model Test Objectives

- Build a 12m SSC cryostat
- Understand cryostat fabrication tolerances
- For a cryostat assembly, measure heat leaks to 4.5, 10 and 80K
- Provide a test facility for follow-on heat leak measurements
- Convertibility to MTF compatible cryostat for 12m coil magnetic testing
- Gain practical experience with prefabricated MLI insulation blankets

Cryogenic super-insulation systems underwent considerable development during the 1950's and 1960's. The advent of space research and exploration created a requirement for insulation systems that were highly efficient, lightweight and compact. The results of much of this work are summarized in published literature which describes the state of multilayer super-insulation systems during that period.[3,4]

In general, these insulation techniques worked well enough and very little additional information was developed during the recent period, with the possible exception of the interesting work of R. Fast at Fermilab[5].

It is now necessary to select the best possible insulation system for the SSC program. The system is huge, involving hundreds of miles of cryogenic storage and transport equipment. The size and cost of the expensive refrigeration/liquefacation facilities is a direct function of the efficiency of the selected cryogenic insulation system.

System requirements: 1) The insulation system must meet the stringent heat loss allowance as provided in the SSC Reference Design Report[1]. Typically for the dipole the radiant heat loss allowance is:

K	Q watts
5	0.05
10	0.735
80	8.3

2) The selected system should provide for the best possible performance in the event of increased insulating vacuum pressure. Typically the system should maintain good K factor at pressures up to at least 10^{-2} Torr. This requirement is generated from operating experience where there has been considerable difficulty with the Fermilab Tevatron insulating system at higher pressures during magnet quenches.

3) The system selected should utilize the most cost effective materials available.

4) The materials selected should be easy to obtain, to install and to fabricate. This will eventually be reflected in direct labor costs.

5) The system must be able to maintain near maximum thermal performance when subjected to slight compressive loading from adjacent cryostat parts possibly slightly mis-aligned and at different temperatures.

The insulation system selected must exhibit a mean apparent thermal conductivity (K factor) of 0.83 x 10^{-6} W $cm^{-1}K^{-1}$ in order to meet the heat leak design allowance. This can only be achieved using a multilayered, laminar insulation system.

There are several combinations of reflective sheets and spacing material which can be used to achieve this low K factor. A review of the references[3,4] describes many of these combinations and offers apparent K factor measurements as a function of pressure and compression.

A system using flat reflective aluminized polyester film as a radiation shield and fiberglass mat material having randomly oriented fibers as a spacer material was chosen. The application of these materials to meet the SSC insulation system specific requirements follows:

K Factor The only practical materials that can be considered for reflective shield in a multilayer insulation system are pure aluminum foils and aluminized plastic film materials. The early films had a thinner deposit of aluminum allowing the transmission of certain amounts of radiant heat. Recent samples appear much better showing no evidence of radiation transmission. It seems, therefore, that the conclusion of Kropschot, et al.,[3] that foil is better than film may not still be totally valid. Foil material is much more difficult to handle than the aluminized film materials, and additional aluminum material is electrically and magnetically undesirable. The spacer material (fiberglass mat) is 0.025 cm thick and provides very low thermal conductivity between reflective layers. The overall system in place provides 18 reflective layers per centimeter. This system gives an "apparent mean thermal conductivity" or K factor 0.62 X 10^{-6} W cm^{-1} K^{-1}. This will exceed the requirement by a substantial margin.

Poor Vacuum Performance The proposed laminar insulation system retains a good K factor at pressure up to 10^{-2} Torr. Figures 2 & 3 of Reference[4] show that the worst case deterioration at this pressure would result in a factor 4 in K factor. Although heat leak would increase somewhat, continued accelerator operation would be possible.

Material Handling (fabrication/installation costs) The various materials that comprise the insulation system are procured in rolled form such as paper and fabric products. There are several vendors offering both the reflective film and the spacer materials.

The labor intensive method used in the installation of the super insulation for the Fermilab Tevatron must be avoided in the SSC. The use of prefabricated insulation blankets would greatly simplify this task.

Compressive loading Examination of Figure 9 in Reference[4] shows that all multilayer insulation systems undergo a significant deterioration in K factor when subjected to compressive loading.

TEST DETAILS

Figure 1 shows a scale drawing of the test setup. Two end reservoir dewars were used, with the center 12 m long section being the test model cryostat. A typical cross section of the test model cryostat is shown in Figure 2. Figure 3 is a schematic drawing showing the three separate thermodynamic systems in detail. The liquid nitrogen (80 K) heat leak was measured by monitoring the nitrogen boiloff using gas meters and

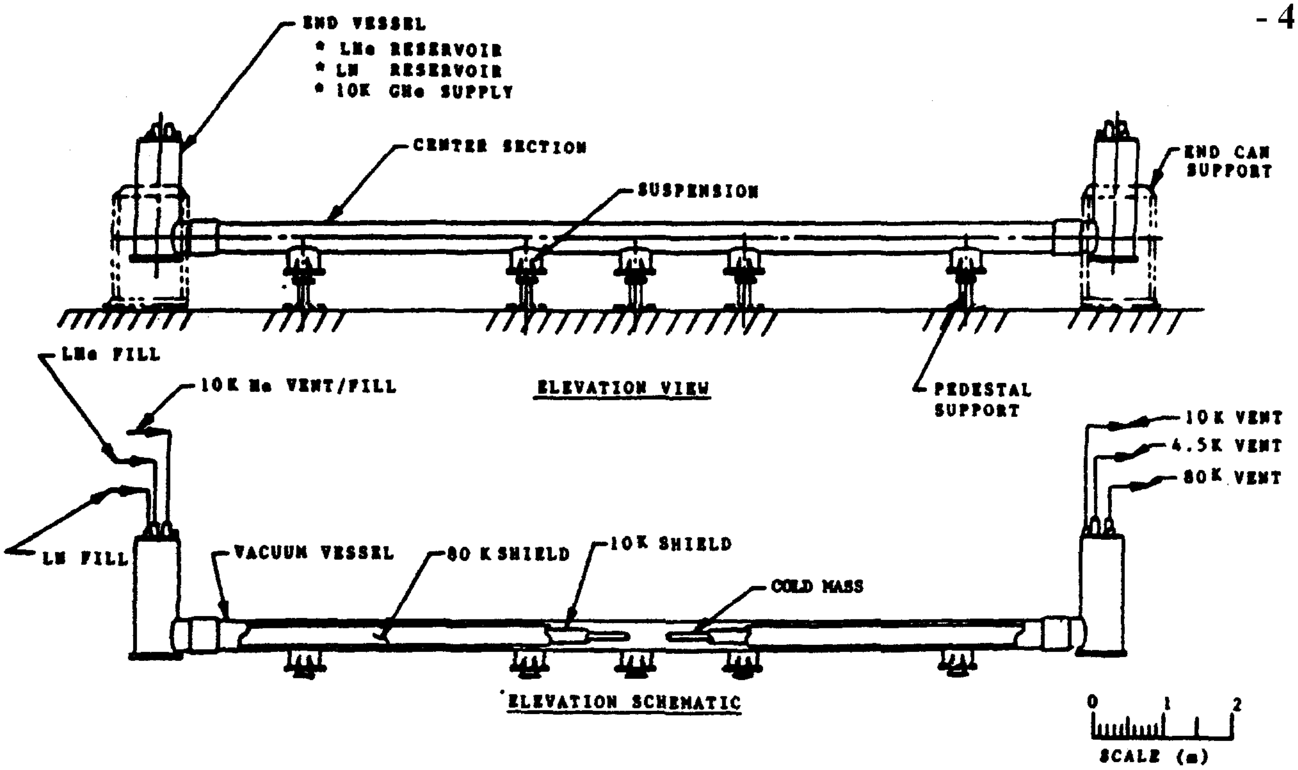

Fig. 1. 12 m heat leak measurement model

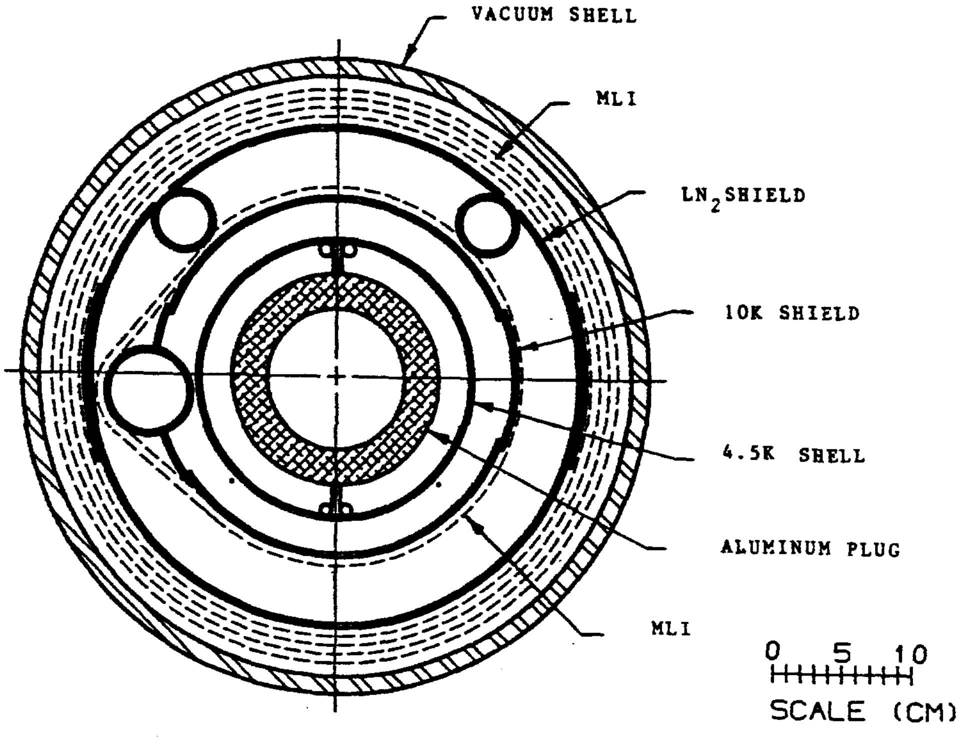

Fig. 2. Typical cross-section of thermal model cryostat

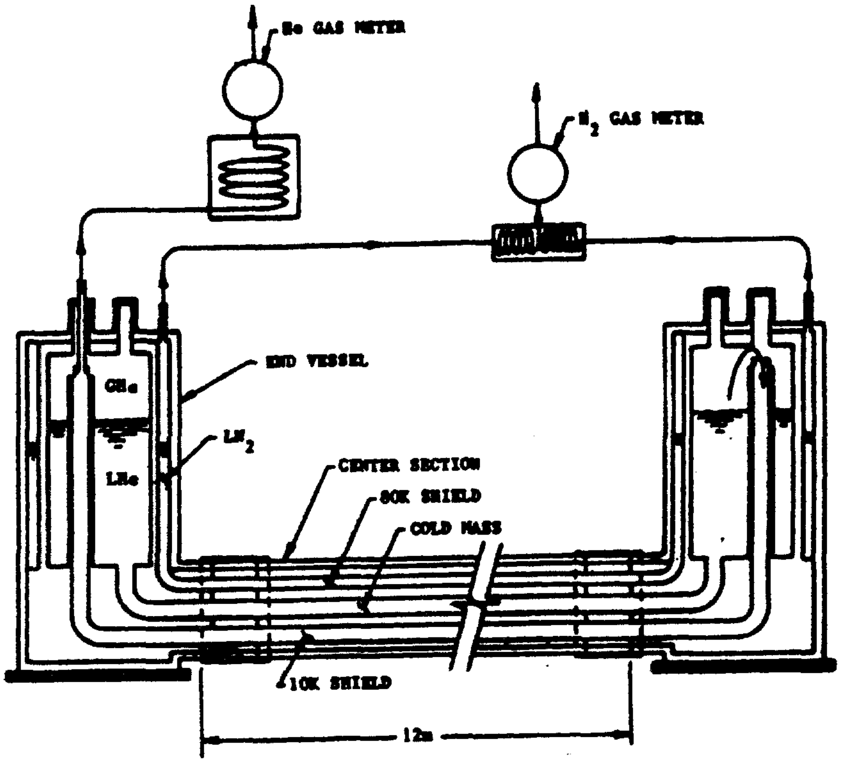

Fig. 3. Heat leak measurement model schematic

connecting them as shown in Figure 3. The heat input to the 10 K shield was measured by monitoring the mass flow and temperature rise of the gaseous helium flowing through the shield. Carbon resistance thermometers were used and gave excellent accuracy. We attempted to measure the 5 K heat leak by two methods, first by measuring the boiloff of the liquid helium system and secondly by measuring the temperature rise of a large aluminum tube which simulated the mass of a superconducting coil. Initially the end test dewars were measured alone to determine what heat leak to be subtracted from the overall system heat leak measured with the model cryostat installed.

In general the test worked out quite well with the exception of the enthalpy change measurement of the aluminum plug. The plan was to observe the temperature rise of the aluminum mass and calculate the enthalpy change which is equal to the 4.5 K heat leak. To eliminate heat transfer from the end test vessels it was necessary to lower the system pressure to the free molecular flow range. A failure in the external vacuum apparatus precluded evacuation of the 4.5 K volume when the liquid helium had all evaporated from the 4.5 K section of the experiment. The measurement was therefore dominated by end effects and did not give good results.

TEST RESULTS

The heat loss measurements showed very good agreement with the calculated values. Table 2 shows these results. It is apparent that heat leak to 80 K and 10 K can be very closely predicted while the 4.5 K heat leak calculation versus measurement appears to be within 20%. It should be noted that initially this heat leak was predicted to be much lower. An instrumented support post in another magnetic model prototype[6] showed that the temperature difference between the shield and the thermal intercept on the support post was on the order of 10 K. This increases the support post heat leak by a considerable factor. The results shown reflect the correction for the inefficiency of the thermal intercepts.

Table 2. Heat Leak Test Results

HEAT GAIN	ANALYTICAL PREDICTION		MEASURED VALUE	MEAS METHOD	MEAS ACCY
80K	. End vessels (measured)	22.0W		Boiloff	± 5%
	. Thermal radiation (calculated)	8.3			
	. Support conductor (calculated)	21.2			
		51.5W*	55.5W*		
10K	. Thermal radiation (calculated)	0.74W		Gas stream temp. rise	± 5%
	. Support conduction (calculated)	1.54W			
		2.28W	2.28W		
4.5K	. End vessels (measured)	450mW		Boiloff	± 5%
	. Thermal radiation (calculated)	2mW			
	. Support conduction (calculated)	440mW			
		892mW*	1060mW*		

* Corrected to reflect M-10 prototype instrumented post temperature profile.

The test setup provides an independent open cycle refrigeration system for 10 K shield, therefore, it is possible to vary the temperature of the shield and measure heat leak to 4.5 K as function of shield temperature. The results of these measurements are shown in Figure 4.

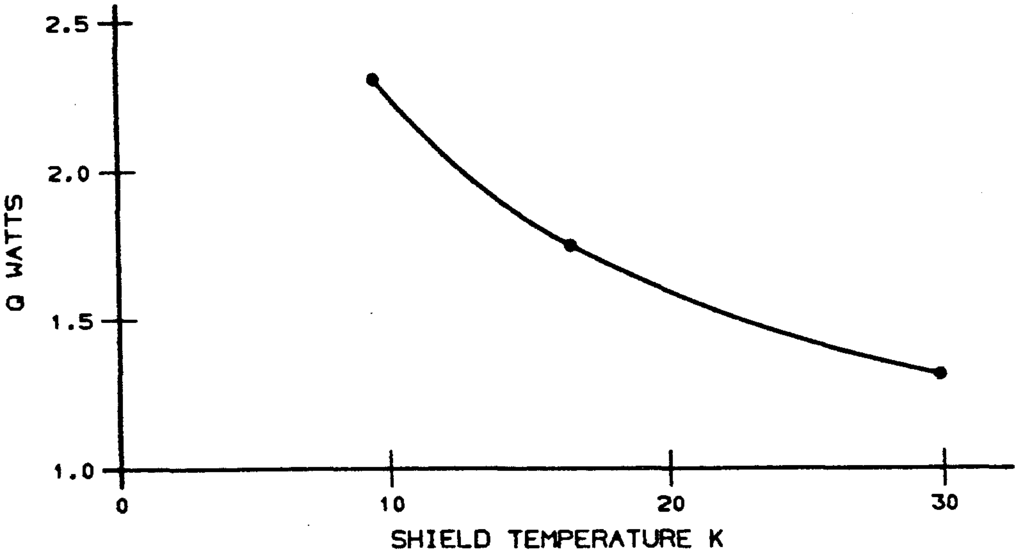

Fig. 4. Intermediate shield heat leak vs.temperature for the SSC thermal model

One of our initial goals was to provide an MLI system for particle accelerator cryostats that would work well at elevated insulating jacket pressures. Figure 5 shows a plot of pressure versus boiloff for the blanket system used. Typical published data for MLI systems is plotted on Figure 5 for comparison. Clearly the Fermilab blanket system tends to improve performance at higher pressures which is a very desirable characteristic.

CONCLUSIONS

This work clearly indicates that a 12 m no iron magnet cryostat is practical and reasonable to build. The tolerances can be managed within the SSC requirements.

The estimated heat leak of such cryostats can be calculated with good accuracy and agrees well with measured results. It is important, when using such post type supports, to provide heat intercepts which are well connected thermally to the cooling system to be sure they are operating at the design temperatures.

A full size facility now exists for any necessary heat leak measurements that may be required for cryostat components. If testing of 12 m coil assemblies is necessary the thermal model test facility can be easily altered to accommodate this task.

An insulation blanket system (MLI), has been developed and tested that is relatively inexpensive, not labor intensive and should be easy to acquire from industry.

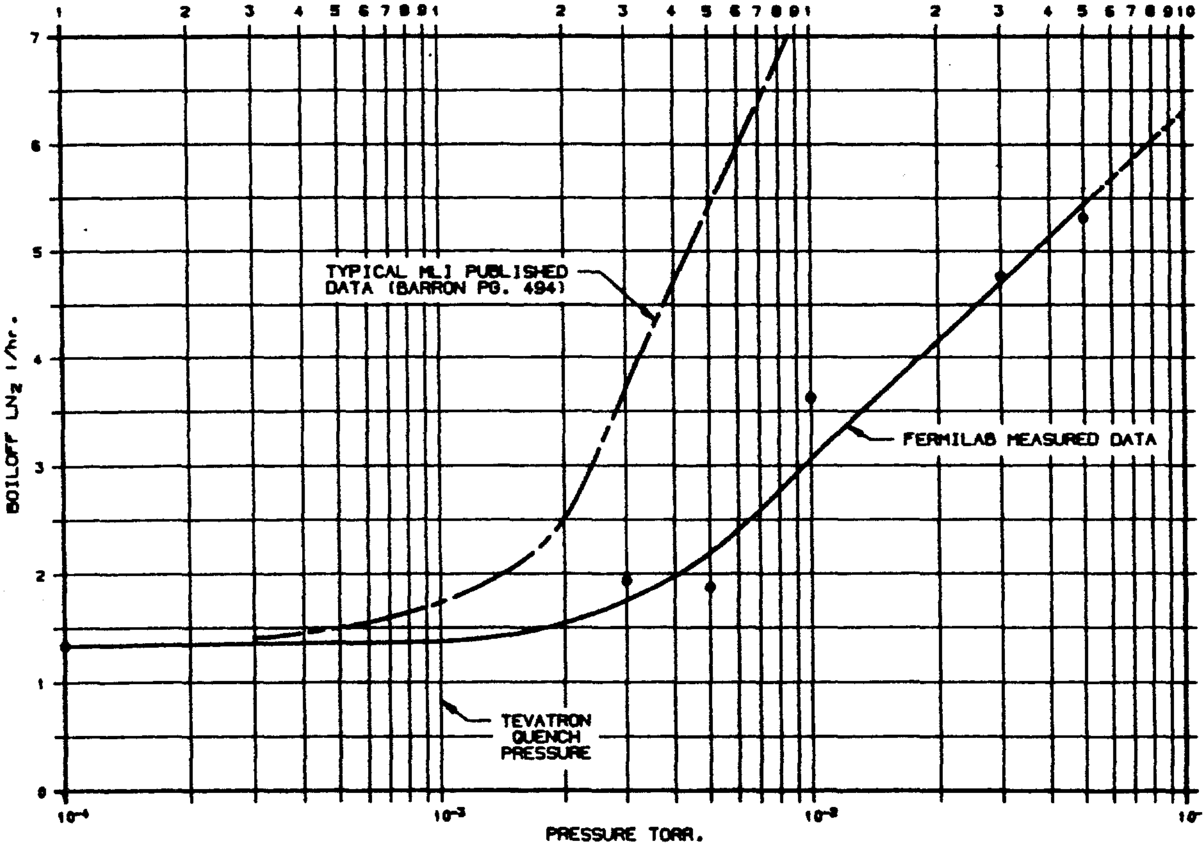

Fig. 5. Pressure vs. boiloff for SSC MLI blankets vs. published data

ACKNOWLEDGEMENTS

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