SSCL-N-880

SSCL-N-880
October 1994
Distribution Category: 400

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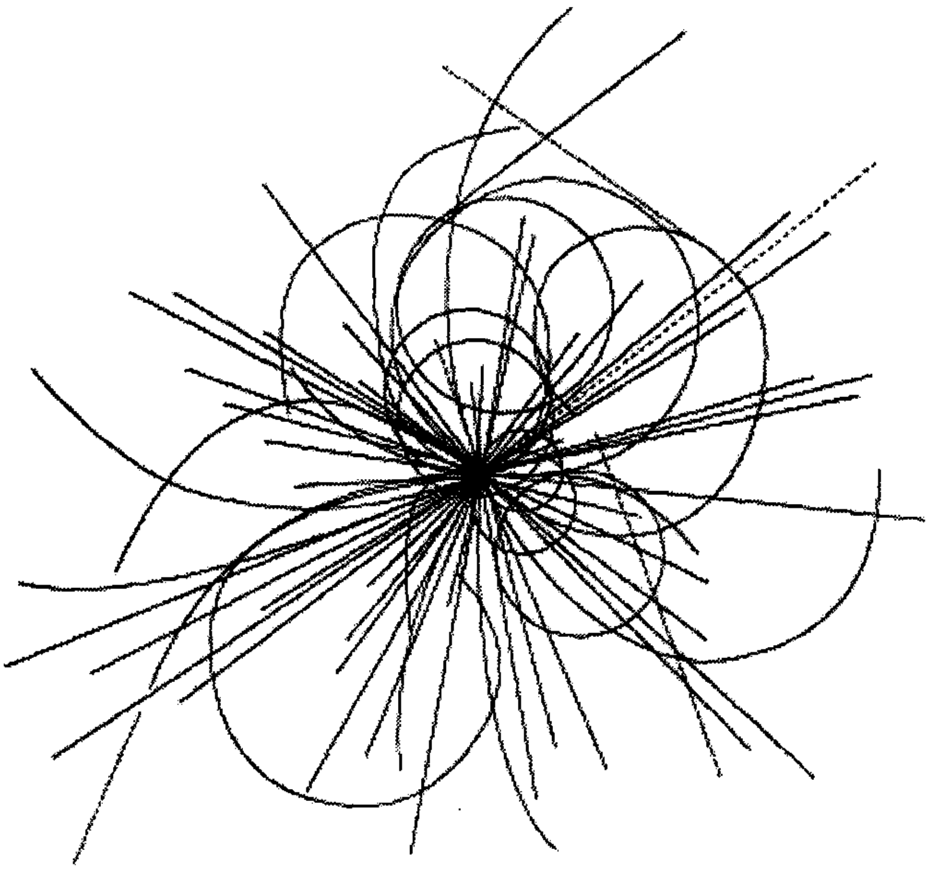

Superconducting Super Collider Laboratory

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Nitrogen Shield Temperature Distributions

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October 1994

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

NITROGEN SHIELD TEMPERATURE DISTRIBUTIONS

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August 1992

Introduction

In the General Dynamics cryostat design for the Collider Dipole Magnets, the extruded aluminum nitrogen lines are replaced by stainless steel pipes, and copper straps are used to provide the thermal connections between the aluminum shields and the pipes. This design increases the thermal path for the heat removal from the shields. The thermal resistance is higher not only due to the strap resistance and the relatively low conductivity of stainless steel (compared to aluminum), but also due to the discontinuous or discrete nature of connections between the shields and the stainless pipes.

A study was conducted for the 80 K shield temperature distributions to understand the effects of increased resistance between the shield and the nitrogen lines (sinks). Separate –and conservative– heat conductance values were used for the straps linking the shield to the liquid nitrogen line and to the vapor line which carries two-phase stratified flow. The steady-state shield temperature distributions and the shield average emissive power for specified sink (liquid and vapor line) temperatures were calculated. In the analysis, additional thermal contacts between the shield and the pipes (e.g. at the bottom of the pipes) were neglected. The results of the study are presented below.

Effective strap conductance

The proposed design uses copper straps to link the thermal shields (Al 6061-T6) to cryogenic pipes (304L CRES). The straps are 12 cm long, and have a cross-sectional area of 1.55 cm^2. With a thermal conductivity of 5.1 W/cm-K around 80 K, the thermal strap has a nominal conductance of $H = k/L = 0.425$ W/cm^2-K. There is an additional resistance, however, that results from the periodic "discrete" mode of heat transfer to nitrogen in the stainless pipes, combined with the relatively low thermal conductivity of stainless steel (0.1 W/cm-K at 80 K). This additional resistance is estimated conservatively, allowing for temperature variations along and around the pipes (60 mm OD, 1.5 mm thick). The straps are assumed to be placed approximately 40 cm apart and connected to the pipes at the top. The total effective heat transfer conductance for a strap connection, including the additional resistance of the pipe, is estimated to be 0.20 W/cm^2-K for the liquid nitrogen line, and 0.05 W/cm^2-K for the vapor line with two-phase stratified flow.

Shield temperature distributions

The 1.6 mm thick shield is assumed to be 15 m long with a circumference of 1.95 m. It is subjected to uniform radiant heat flux of 0.6154 W/m^2 (18 W total) from the 300 K vacuum vessel inner surface (through the MLI). The shield is supported at five locations by the support posts (3.12 m apart), with an additional heat input of 3.2 W per post. Two series of straps, separated by approximately 71.5 cm, link the shield to the two nitrogen lines. Assuming symmetry, only one-half of a section of the shield between the support posts (1.56 m long) is analyzed (See Figure 1). The total heat load on this half-section is 3.45 W, of which 1.85 W is due to radiation and 1.6 W is due to support post conduction. For simplicity, the support post hole is represented by a square, 26 cm on a side. The section contains four straps per line, that is, four heat sinks to the liquid line and four heat sinks to the vapor line, to remove the heat load on the shield. A two-dimensional conduction code was developed to compute the steady state temperature distributions on the shield under various sink temperatures and conditions. These cases and results are summarized in Table 1.

The vapor line temperature is fixed at 80 K in all cases, while the liquid line temperature was varied between 80K and 92K. Cases 1a-1d represent situations where the heat load is removed by both the vapor and liquid nitrogen lines. The corresponding temperature distributions are given in Figure 2. The temperature distributions display a peak next to the support post connection, and dips at the strap connections. Results for Case 1 indicate that most of the heat load is removed by the liquid line when the temperatures in the vapor and nitrogen lines are close to each other. The vapor line becomes a more "active" sink if the liquid line temperature is increased further, and will carry most of the heat load for relatively high liquid line temperatures. As the liquid nitrogen line temperature increases, the shield temperatures rise overall, resulting in higher emissive power values. The emissive power values presented in the tables are the average T^4 values for the shield normalized with respect to the emissive power of the shield at 84 K, i.e.

$$EmissivePower\,(Normalized) = \iint \left(\frac{T(x,y)}{84}\right)^4 dxdy$$

Thus the emissive power is indicative of the radiant heat leak from the 80 K shield to the 20 K shield. It can be viewed also as a measure of the relative error in the radiant heat leak calculations for the 20 K shield when a uniform temperature of 84 K is used for the 80 K shield.

Cases with good thermal contact assumed between the straps and the nitrogen pipes were also analyzed. Neglecting the resistance of the pipes, the nominal conductance value of 0.425 W/cm^2-K was used for all the straps connecting the shield to the vapor and liquid lines (Cases 2a-2d). With improved heat transfer conductance, the overall temperature levels and shield emissive power are lower as shown in Figure 3. The heat load is divided equally between the two lines for equal sink temperatures (Case 2a). If the liquid line temperature is raised, most of the heat is carried away by the vapor line (Case 2b). For sufficiently high liquid line temperatures (Cases 2c and 2d), the liquid line no longer acts as a sink, but as an additional source of heat load for the shield (and the vapor line). This additional load indicated by the negative values in the table, together with the imposed load of 3.45 W, is carried out by the vapor line.

Finally, cases were considered where there are no straps linking the shield to the vapor line and the heat load is solely carried out by the liquid nitrogen line. The results for these cases (Cases 2 and 3) are presented in Table 2. Cases 3a-3d are for a heat conductance value of 0.20 W/cm^2-K. Figure 4 shows the temperature distributions for these cases. Compared to Case 1, the overall temperature levels are elevated, due to having only one sink which results in higher emissive power values. Results for Cases 4a-4d, where a conductance value of 0.425 W/cm^2-K is used for the liquid line, are similar to those for Cases 3a-3d, with lower temperature and emissive power levels due to the improved heat conductance value.

Summary

The 80 K shield temperatures can differ substantially from the corresponding nitrogen temperatures in the liquid and/or vapor lines depending on the location around the ring. The thermal resistance of the copper strap connections between the shield to the stainless pipes has a strong influence on the temperature differences realized between the shield and nitrogen lines and needs to be quantified accurately for realistic predictions of shield performance.

Table 1: Heat removed by the vapor and liquid nitrogen lines, and the shield average emissive power (shield connected to both lines)

Case No	Vapor line conditions		Liquid line conditions		Heat Removed		Shield Emissive Power (Normalized wrt 84 K)
	Temp (K)	Strap Conductance (W/cm^2K)	Temp (K)	Strap Conductance (W/cm^2K)	Vapor line (W)	Liquid line (W)	
1a	80	0.05	80	0.20	0.95	2.50	1.12
1b	80	0.05	84	0.20	1.32	2.13	1.28
1c	80	0.05	88	0.20	1.69	1.76	1.45
1d	80	0.05	92	0.20	2.07	1.38	1.64
2a	80	0.425	80	0.425	1.73	1.73	0.93
2b	80	0.425	84	0.425	2.68	0.77	1.03
2c	80	0.425	88	0.425	3.64	-0.19	1.13
2d	80	0.425	92	0.425	4.59	-1.14	1.24

Table 2: Heat removed by the vapor and liquid nitrogen lines, and the shield average emissive power (shield connected to liquid line only)

Case No	Vapor line conditions		Liquid line conditions		Heat Removed		Shield Emissive Power (Normalized wrt 84 K)
	Temp (K)	Strap Conductance (W/cm^2K)	Temp (K)	Strap Conductance (W/cm^2K)	Vapor line (W)	Liquid line (W)	
3a	80	0	80	0.20	0	3.45	1.27
3b	80	0	84	0.20	0	3.45	1.51
3c	80	0	88	0.20	0	3.45	1.79
3d	80	0	92	0.20	0	3.45	2.10
4a	80	0	80	0.425	0	3.45	1.11
4b	80	0	84	0.425	0	3.45	1.33
4c	80	0	88	0.425	0	3.45	1.58
4d	80	0	92	0.425	0	3.45	1.87

80 K Shield: Al 6061-T6, 15m x 1.95m, 1.6 mm thick

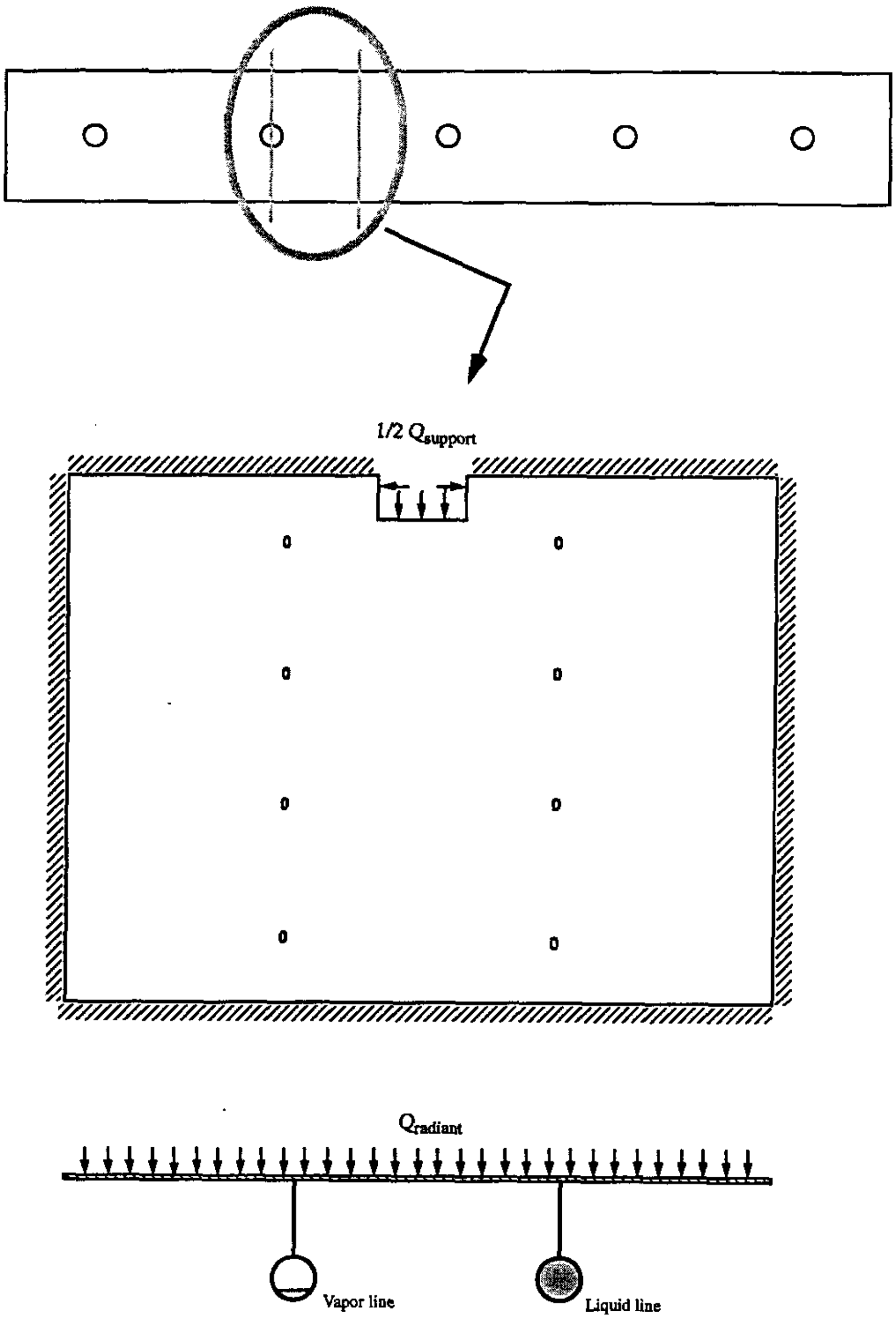

Figure 1. Nitrogen shield schematic

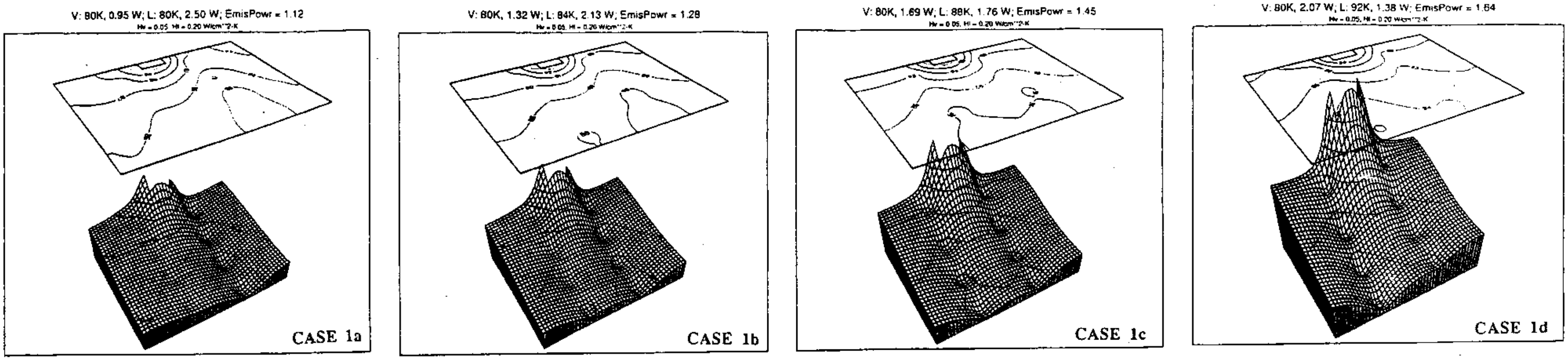

Figure 2

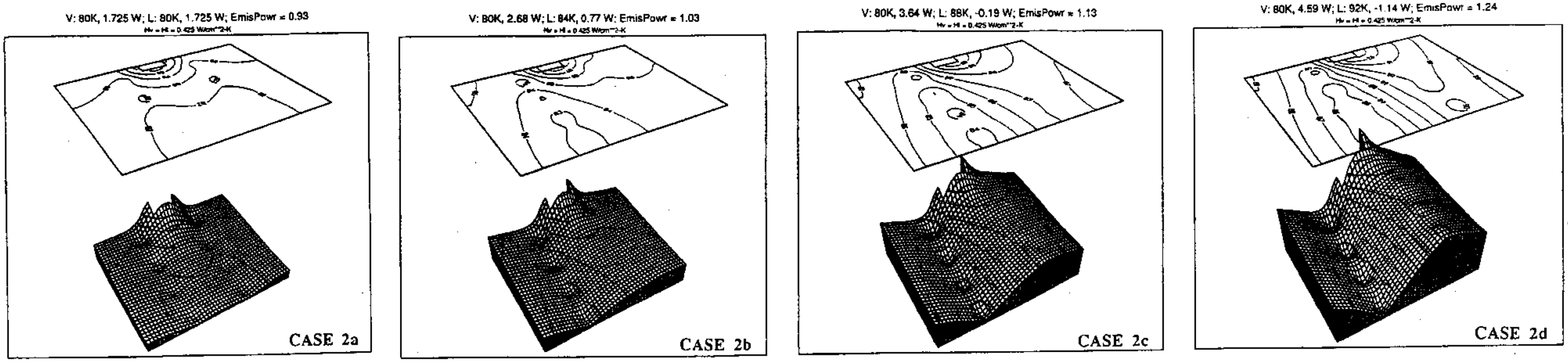

Figure 3

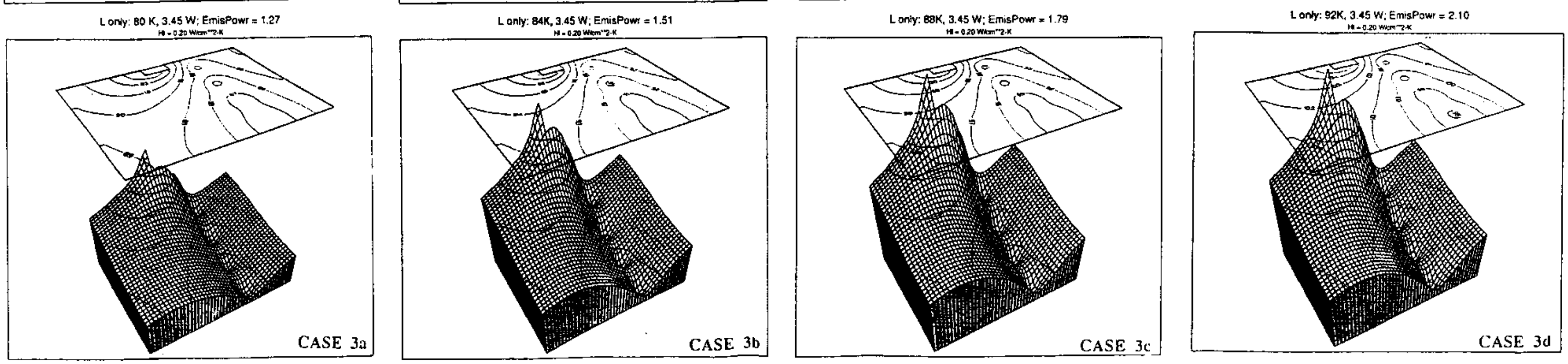

Figure 4