Fermilab

Fermi National Accelerator Laboratory
Technical Support / Engineering
P.O. Box 500 - Batavia, Illinois - 60510
FAX: (708) 840-8036

TM-1794

TESLA Test Cell Cryostat
Support Post Thermal and Structural Analysis

Thomas H. Nicol
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, IL 60510 USA

August 15, 1992

INTRODUCTION

TeV Superconducting Linear Accelerator (TESLA) cryostats consist of eight, 1-meter-long radio frequency (RF) cavity modules cryogenically connected in series with one focusing quadrupole. Each module contains one, 9-cell superconducting RF cavity operating at 1.3 GHz in a 1.8K helium bath. Individual modules are self-contained in the sense that they have their own input couplers, high order mode couplers, and tuning mechanisms. Services common to the entire cryostat consist of 70K and 4.5K thermal radiation shields, shield supply and return lines, a 1.8K helium supply line, and a gas helium return pipe. All cavity modules, the quadrupole, and cryogenic services are contained in a single 12-meter-long vacuum vessel.

The goal of the present work on TESLA is the successful fabrication and test of four complete cryostat assemblies. These cryostats will be installed in a string, cooled to operating temperature, and powered. This test will address problems which may arise when modules are installed in a tunnel environment. It will also permit testing of the basic cooling concepts, measurement of static heat losses, and measurement of the RF performance of all cavities.[1]

All of the current design options utilize a post-type suspension system modeled after that developed for SSC collider dipoles. However, rather than a reentrant design like those in early SSC prototypes[2-5], this support uses a single filament wound composite tube. This latter design has recently been adopted for production SSC collider dipoles.[6]

Any successful design must be structurally adequate to meet the static and dynamic loads which occur during fabrication, shipping, installation, and operation. It must have low thermal conductivity to insulate the 1.8K helium volume from heat conducted from 300K and must be manufacturable at low cost. This report attempts to summarize the thermal and structural analysis leading to the selection of a candidate design for supports suitable for use in TESLA test cell cryostats.

DESIGN OVERVIEW

There are two conceptual designs being discussed with respect to support post mounting. One uses supports located on top of the vacuum vessel such that the cold mass hangs from the support. The second uses supports located on the bottom of the vacuum vessel such that the cold mass rests on the support. This second concept is the more conventional of the two options, however, in principal there is no reason that hanging the cold mass from the support poses any inherent installation or reliability problems. The advantage to the hanging concept is that it provides a readily accessible place from which to gather direct alignment data when the complete cryostat is installed in the test string. There are two substantive disadvantages. First, a cryostat with top-mounted supports requires reinforcing rings around the vacuum vessel at each support location to support the weight of the hanging assembly. Second, it moves the cavity centerline further from the fixed support base making it more sensitive to displacements occurring due to cooldown and to the action of external forces, e.g. forces acting through the input coupler. These effects will be discussed later in this report. Figures 1 and 2 illustrate the differences between these two design options. The cross section shown is that currently being developed at DESY and INFN.

There are also two conceptual designs being discussed with respect to the number of supports. One uses three supports as a means by which to minimize the cost of support assemblies and the cost of the vacuum vessel and thermal radiation shields. The other uses four supports to minimize axial contraction during cooldown. These latter two conceptual design differences have little effect on the analysis presented here, but will be discussed in more detail later in this report.

DESIGN ANALYSIS

There is little debate about the conceptual design of the support post itself. All of the design options being discussed utilize a single tube support developed as an alternative to the reentrant supports used in SSC collider dipole magnets.[2-6] The single tube support was developed primarily to reduce magnet cost.

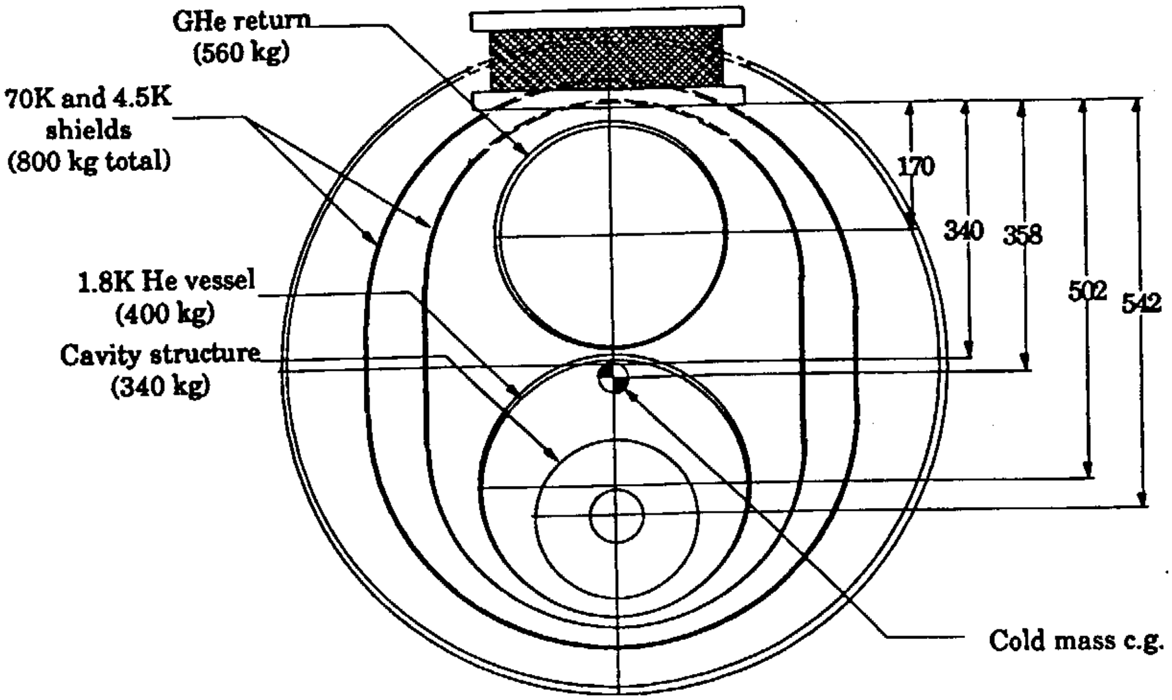

Figure 1. DESY Cross Section - Top Mounted Support

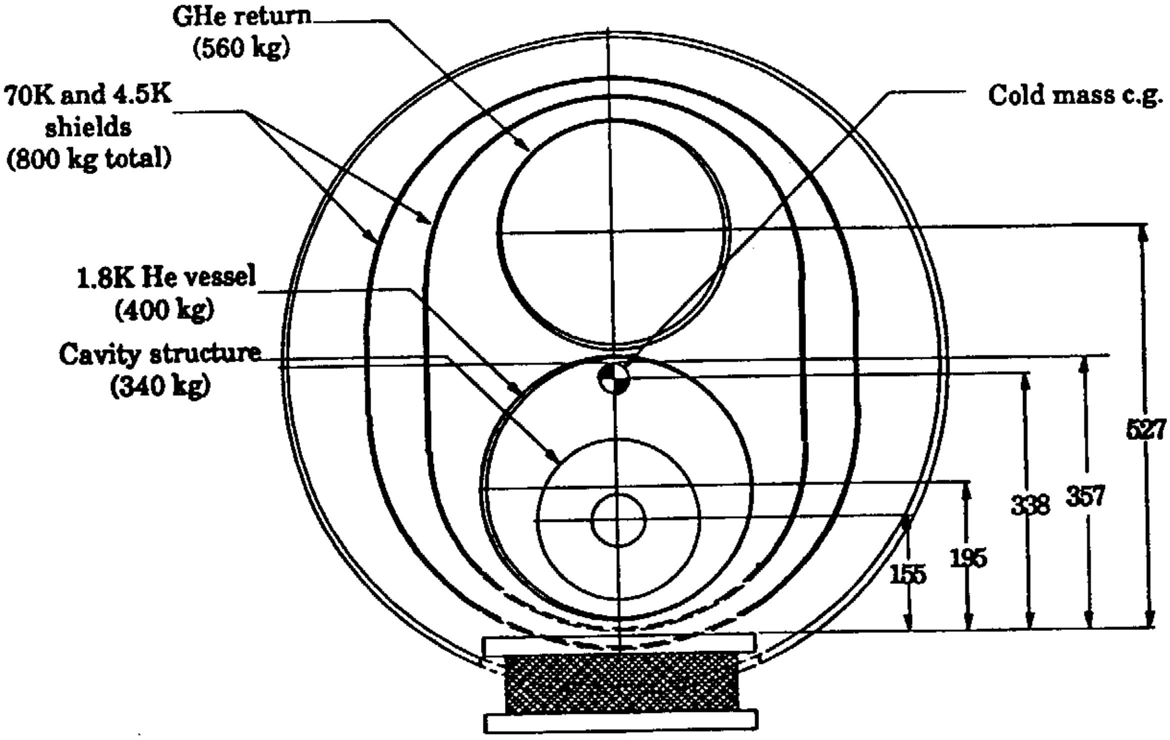

Figure 2. DESY Cross Section - Bottom Mounted Support

Thermal Path Length Optimization

The design of a TESLA cryostat support begins with a thermal analysis to determine the relative position of the thermal intercepts. There are intercepts at 300K, 70K, 4.5K, and 1.8K. The 300K and 1.8K positions are fixed at the ends of each support. The 70K and 4.5K intercept locations may be chosen anywhere along the length of the support. Their position is dictated by constraints on the allowable static heat load. For this analysis it is assumed that the goal is to minimize the refrigeration power required at room temperature. The heat load at each thermal intercept is translated into a corresponding refrigeration requirement at room temperature by using an expression for the ideal work defined by Carnot and a realistic refrigerator efficiency. The Carnot efficiency is given by the following.

$$\text{Carnot efficiency} = T \,/\, (300 - T) \qquad [1]$$

where T is expressed in K.

Realistic refrigerator efficiencies are more difficult to estimate. Experiences at Fermilab, with the Tevatron refrigeration system, and at DESY, with the HERA system, indicate that reasonable refrigerator efficiencies are 20% at 70K and 4.5K and 10% at 1.8K. Combining these with the Carnot efficiencies results in the following room temperature loads. The results are expressed in watts per watt (W/W), e.g. 328 watts of power at room temperature are required to produce one watt of refrigeration at 4.5K.

Table 1. Room Temperature Refrigeration Requirements

T	Carnot eff	Refrig eff	Combined eff	r.t. W/W
70K	30.43%	20%	6.09%	16
4.5K	1.52%	20%	0.30%	328
1.8K	0.60%	10%	0.06%	1657

Figure 3 is a thermal model of a single tube support illustrating the pertinent analysis parameters. The optimal thermal path lengths (l) as fractions of the total support height are functions of the thermal intercept temperatures, material thermal conductivity, and tube cross sectional area (A). Ideally, there are thermal resistances at each intercept and at the cold mass connection. For the sake of this and subsequent analyses, these are assumed to be perfect connections. In reality, this assumption leads to a conservative result, i.e. actual heat loads, particularly to 1.8K are somewhat smaller than calculated values. The material assumed for the support is S-glass in an epoxy matrix. The thermal conductivity curve for this material is shown in figure 4. The dimension nomenclature and the results from this analysis are shown in figures 5 and 6 respectively.

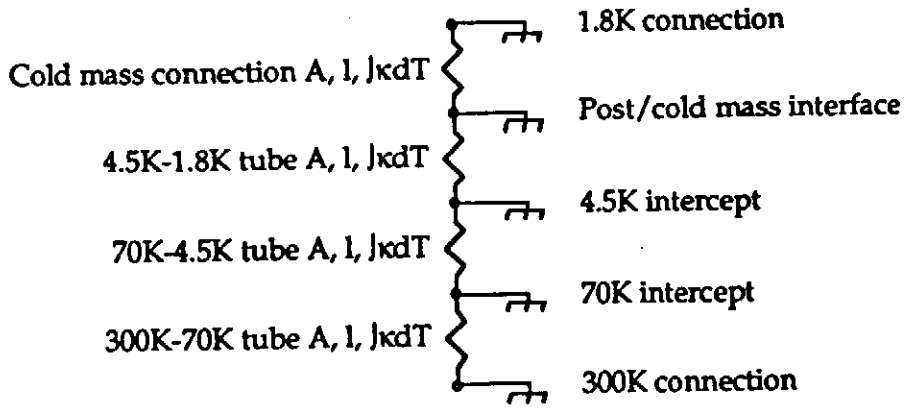

Figure 3. Single Tube Support Thermal Model

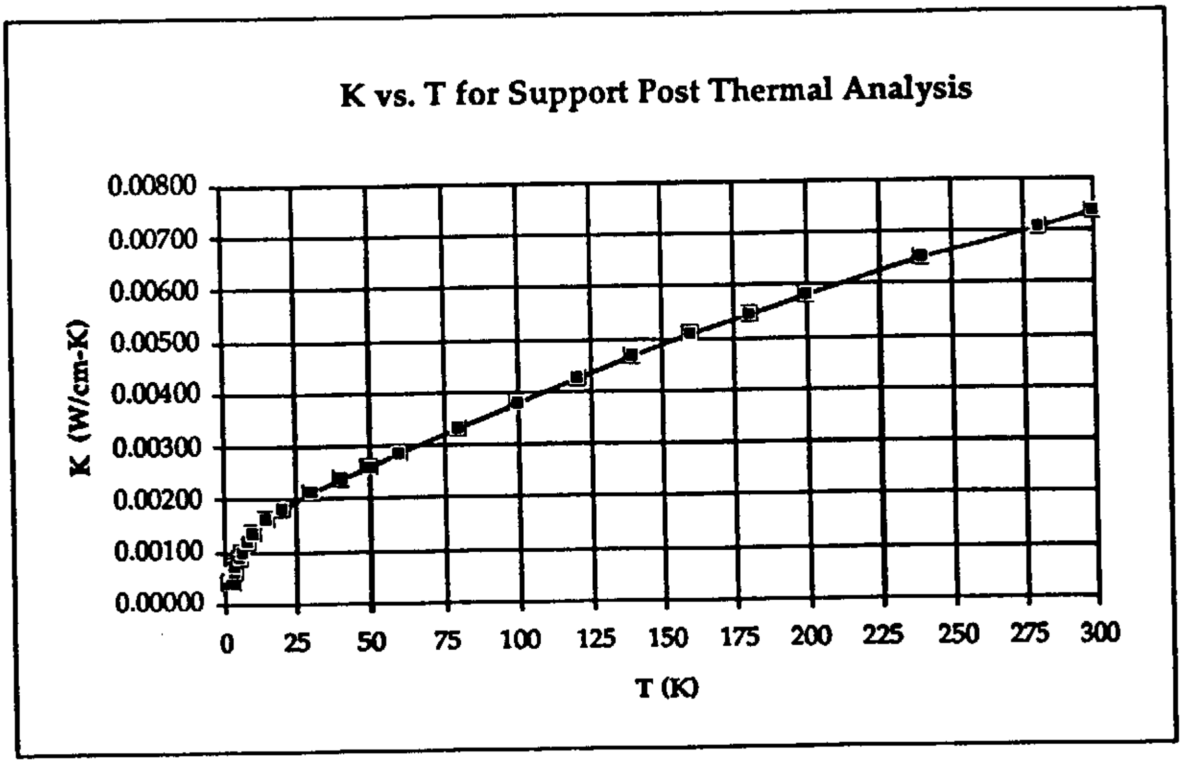

Figure 4. Support Post Material Thermal Conductivity vs. Temperature

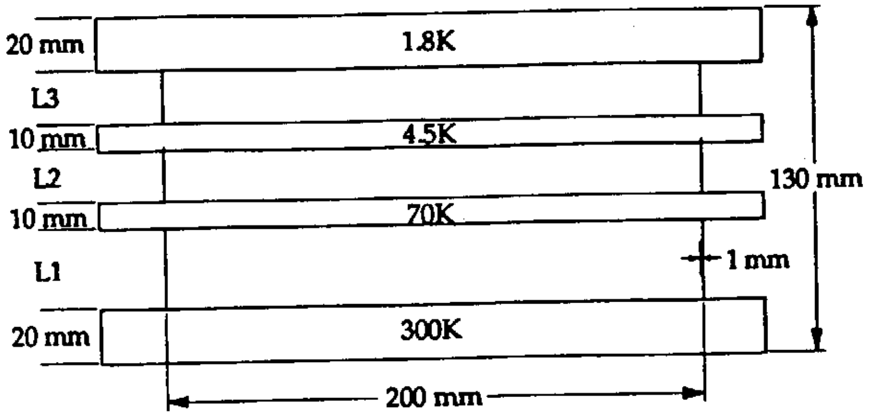

Figure 5. Thermal Path Length Analysis Support Dimension Nomenclature

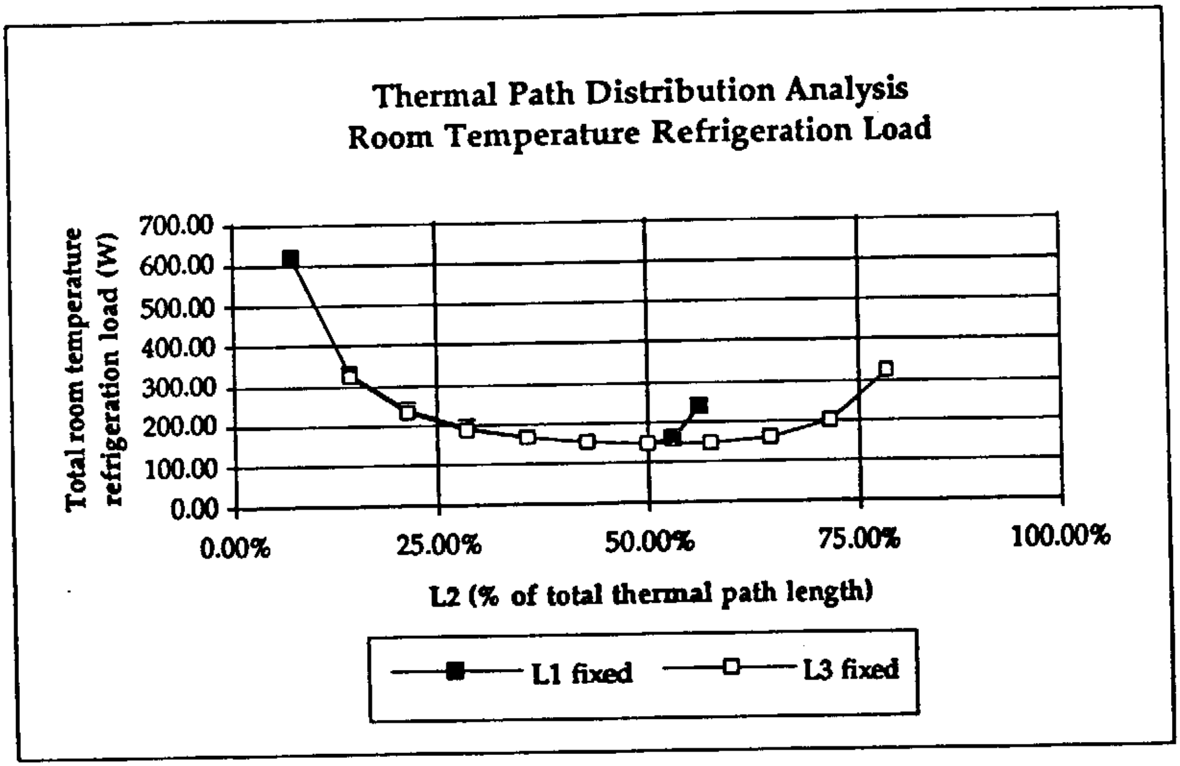

Figure 6. Thermal Path Length Analysis Results

Using figure 6, the minimum room temperature heat load occurs when L2, the 70K to 4.5K thermal path length, is 50% of the total thermal path length. This is the case when either L1 or L3 is held fixed. It is clear from figure 6 that the total room temperature heat load is rather insensitive to changes in L2 at its optimum, permitting relative freedom in positioning thermal intercepts as long as L2 is approximately 50% of the total thermal path length. This is especially true if L3 is fixed and only L1 and L2 are adjusted.

The path length optimization analysis also indicates that L3 should be as small as practical, approximately 5 mm for the support shown in figure 5. This is somewhat small when fabrication of the supports and subsequent assembly into the cryostat are considered. For mechanical attachment considerations, subsequent analyses will use 10 mm for L3, the thermal path length between 4.5K and 1.8K.

Detailed Thermal and Structural Analysis

The thermal path length optimization defines the position of thermal intercepts along the length of the support without regard for specified heat loads or structural requirements. The analysis of an actual support structure must consider the thermal and structural load constraints simultaneously. These are generally at odds with one another, that is low heat load implies low strength while high structural strength implies increased heat load. The budgeted heat loads and structural constraints are given in tables 2 and 3 respectively.[1]

Table 2. Budgeted Heat Loads per Meter of Cryostat Length (W/m)

70K	4.5K	1.8K
0.5	0.2	0.05

Table 3. Structural Load Constraints

Load Direction	Load
Vertical	1.0 g
Lateral	1.0 g
Axial	1.8 g

Given the room temperature heat load conversions in table 1 and the budgeted heat loads in table 2, an equivalent room temperature heat load budget may be defined by the following.

$$Q_{r.t.} = (0.5 \times 16) + (0.2 \times 328) + (0.05 \times 1657) = 156.45 \text{ W/m} \quad [2]$$

For a 12 meter long cryostat, this results in the following allowable heat loads per support.

Table 4. Budgeted Heat Loads per Support (W)

# of supports	70K	4.5K	1.8K	r.t. equivalent
3	2.00	0.80	0.20	626
4	1.50	0.60	0.15	469

The weights of all cold mass components are given in figures 1 and 2. These weights are estimated and include the GHe return pipe (560 kg), 70K and 4.5K shields (800 kg), 1.8K He vessels (400 kg), and RF cavity structures (340 kg). Weights for small components are included in the totals for each sub-system. There is an additional, estimated 140 kg quadrupole at one end of the cryostat assemble. The entire suspended cold mass weight is therefore 2240 kg. It is sufficiently accurate for the sake of this analysis to assume the weight is uniformly distributed among all supports. For the three and four support options, this results in the following lateral load per support.

Table 5. Lateral Loads per Support (kg)

# of supports	Lateral load (kg)
3	746.7
4	560.0

Using figures 1 and 2, the center of gravity of the cold mass assembly is nearly equidistant from the 1.8K surface of the post in both cases, 358 mm in the case of the top mounted support and 338 mm in the bottom mounted case. At this point in the design, there is enough uncertainty in the weights and final geometry to allow us to treat them as equal.

A physical envelope to limit the scope of the optimization study was chosen for the support post structure. Figure 7 illustrates the nomenclature used in the support post structural and thermal analysis. Table 6 lists all of the parameters and constraints used to define the dimensions for any particular analysis iteration. Note that the 70K to 4.5K thermal path length (LThrm2) is half the total thermal path length to minimize the room temperature heat load per the path length analysis above. The analysis program is capable of optimizing the wall thickness of each tube section, i.e. T1, T2, and T3 in figure 7. Ideally the tube can be machined with different thicknesses to take advantage of the decreasing bending stress along the support length. However, this has little effect on heat loads and decreases the lateral natural frequency of the support. Uniform wall thicknesses are assumed here to minimize machining cost on the complete assembly.

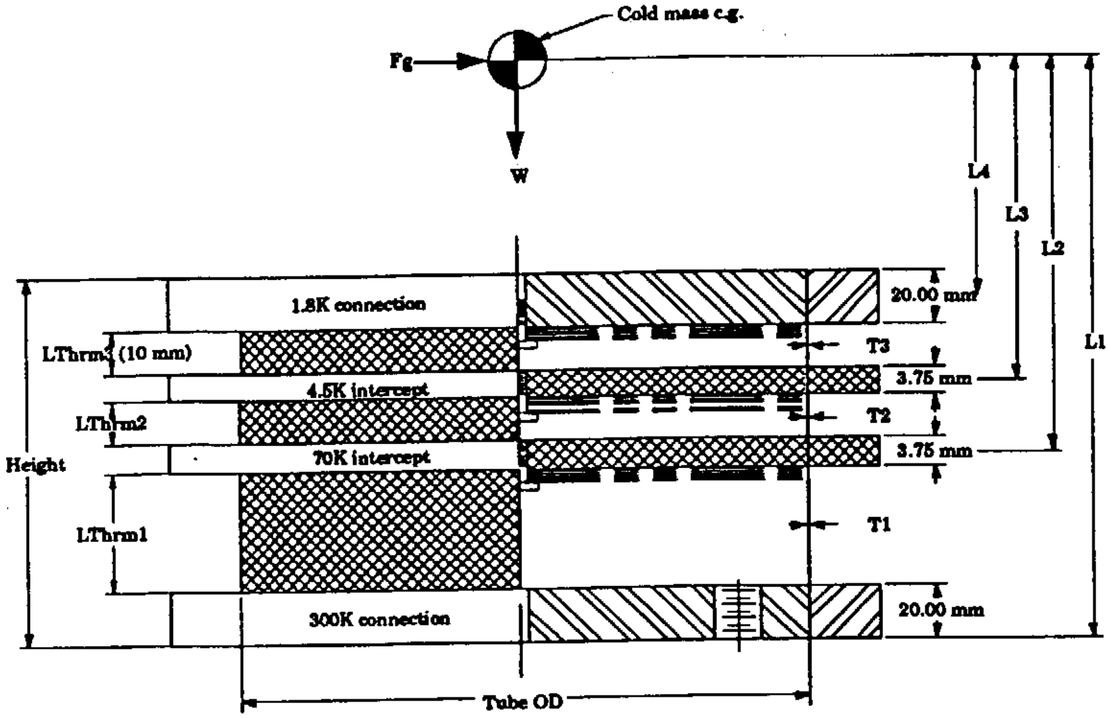

Figure 7. Support Analysis Nomenclature

Table 6. Support Post Dimensional Parameters and Constraints

Overall height range	100 mm - 250 mm
Outside diameter range	150 mm - 300 mm
Wall thickness	Uniform to satisfy strength, safety factor = 2
300K and 1.8K flange thkns	20 mm
70K and 4.5K intercept thkns	10 mm
LThrm1 (300K-70K path len)	Height - 60 mm - LThrm2 - LThrm3
LThrm2 (70K-4.5K path len)	(Height - 60 mm) / 2
LThrm3 (4.5K-1.8K path len)	10 mm
L1	Height + 348 mm
L2	L1 - LThrm1 - 30 mm
L3	L2 - LThrm2 - 20 mm
L4	358 mm
Fg (lateral c.g. force)	746.7 kg (3 supports), 560.0 kg (4 supports)
W	-Fg

Table 7 lists the applicable thermal and structural properties for the composite material assumed for these analyses.

Table 7. Support Post Material Thermal and Structural Properties

$\int$KdT (300K-70K)	1.249 W/cm
$\int$KdT (70K-4.5K)	0.146 W/cm
$\int$KdT (4.5K-1.8K)	0.0015 W/cm
E (Young's modulus)	27.58 GPa
n (Poisson's ratio)	0.2
G (Shear modulus)	2.62 GPa
s_{ult} (ultimate tensile and compressive strength)	275.8 MPa
t_{ult} (ultimate shear strength)	137.9 MPa

Thermal and Structural Analysis Results

Analyses were performed over the height and diameter ranges listed in table 6. The complete results for these analyses are shown in appendix A, table A-1 and figures A-1 through A-5 for the case of a cryostat with 3 supports and appendix B, table B-1 and figures B-1 through B-5 for the case using 4 supports. The analysis yields tube stresses, heat loads to 70K, 4.5K, and 1.8K, the equivalent room temperature refrigeration power required to meet these heat loads, the cold mass lateral deflection when subject to the lateral load (Fg), and an estimate of the lateral resonant frequency. Although not explicitly specified in the design requirements it is thought that the support resonant frequency should be above 10 Hz and below 25 Hz to minimize susceptibility to ground motion and electrically induced vibrations (50 Hz power) respectively. For this analysis a 12.5 to 18.75 Hz band has been defined within which the calculated resonance should fall. These values are 25% above and below the 10 Hz and 25 Hz limits respectively.

From tables A-1 and B-1 a total of five supports satisfy all of the above criteria, i.e. 70K, 4.5K, and 1.8K heat loads, structural constraints, and the constraint on resonant frequency. These are summarized in table 8 and shown in tables A-1 and B-1 in shaded, bold type.

Several things become clear when looking at the results shown in these tables and figures. The supports which satisfy all of the criteria outlined here tend to be larger than those in previous conceptual designs. Typical diameters have varied between 200 and 300 mm. Heights have varied between 100 and 190 mm. The larger diameters here are required to meet the proposed resonant frequency constraint. The greater heights are required to meet the heat load budget, given the increased diameters. Tube stresses are typically well below the allowable (defined as the ultimate strength derated by a safety factor of two). This is due to the fact that the governing structural criteria is elastic stability, i.e.

the tubes are sized to prevent local buckling of the material which occurs at stresses well below that causing tensile or compressive failure.[3,4]

Table 8. Analysis Summary of Candidate Supports (see appendices A and B for details) (heat loads are per support)

# of supports	Height (mm)	Diameter (mm)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Nat freq (Hz)
3	220	275	1.96	0.20	0.02	130	12.5
3	230	300	1.93	0.20	0.02	130	12.9
3	240	300	1.82	0.19	0.02	125	12.6
4	240	275	1.50	0.16	0.02	103	12.6
4	250	300	1.49	0.16	0.02	105	13.1

These results also indicate that the specified heat loads to 70K, 4.5K, and 1.8K are not consistent with minimizing the room temperature heat load. For example, for the first entry in table 8, the calculated heat loads which meet the 70K, 4.5K, and 1.8K specifications and minimize room temperature heat load are 1.96 W to 70K, 0.20 W to 4.5K, and 0.02 W to 1.8K resulting in a room temperature load of 130 W, nearly a factor of five below the value listed in table 4. If minimized room temperature heat load is, in fact, a viable specification, it would help the design process to broaden the range of individual thermal station heat loads. One could then, for example, look for a design solution that results in a resonant frequency more toward the middle of the 12.5 to 18.75 Hz band, or define a stiffness specification in some other way. All of the cases presented in appendices A and B have room temperature heat loads below the budget shown in table 4, some with 70K heat loads five times the 70K budget.

As an example, suppose that, rather than the absolute limits on the 70K, 4.5K, and 1.8K heat loads in table 2, the specification were rewritten as shown in table 9.

Table 9. Alternate Specification for Budgeted Heat Loads per Meter of Cryostat Length (W/m)

70K	4.5K	1.8K
< 1.0	< 0.25	< 0.025

This results in a new set of specifications for the heat load per support shown in table 10.

Table 10. Budgeted Heat Loads per Support (W) Using Alternate Specification in Table 9

# of supports	70K	4.5K	1.8K	r.t. equivalent
3	< 4.00	< 1.00	< 0.10	558 max
4	< 3.00	< 0.75	< 0.075	418 max

Even with all the above heat loads at their upper limit, the room temperature load is less than that given by equation [2] and listed in table 4. What this alternate specification does, however, is open up much of tables A-1 and B-1 for the selection of suitable support alternatives.

Top vs. Bottom Mounted Supports

As stated in the introduction to this report, there are no inherent difficulties with either top or bottom mounted supports from the standpoint of assembly or long term stability. Each has its merits and its drawbacks. There is however, one substantial difference, and that is in the deflection of the cavity centerline when subjected to external forces. Forces will act on the beam tube during cooldown by virtue of support from the gas helium tube and from thermal contraction which occurs in the input coupler. Although the magnitude is unknown, some relative differences can be calculated for each option. Figure 8 illustrates the beam tube centerline deflection for the support case highlighted in table A-1, page 3, and the cryostat dimensions in figures 1 and 2. Due to the distance the cavity lies from the support post base, the beam tube deflection in the top mounted case is more than a factor of two greater than in the bottom mounted case. Given the tight alignment tolerances required in the final installation, it seems that the design should strive for any alternatives which increase stiffness and thereby minimize deflections under the influence of outside forces.

SUMMARY

The analysis presented here is meant as a guide to the design of TESLA test cell cryostat supports. As in any complex device, there are many factors to be considered. Hopefully, most have been covered here, but some have been mentioned only briefly, e.g. alignment, cost, reliability, and ease of manufacture. Using criteria discussed throughout this report, a few conclusions can be drawn.

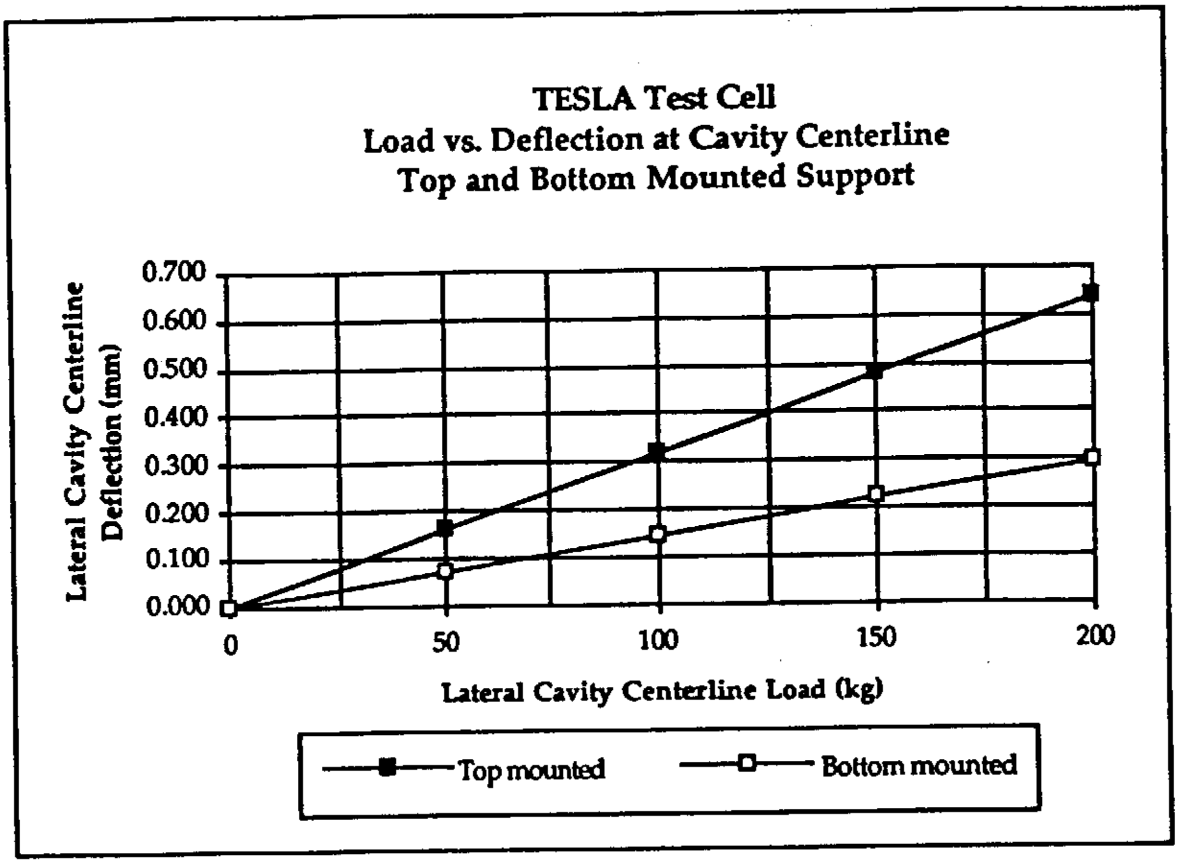

Figure 8. Load vs. Deflection for Top and Bottom Mounted Supports

First, assuming that minimizing the room temperature heat load is a viable basis for design development, the original heat load budgets to 70K, 4.5K, and 1.8K might warrant revision. Second, a firm specification on the suspension system lateral stiffness would be a useful means by which to assure a good overall design, not just one which meets the heat load budget. Third, thermally and structurally, there is no significant advantage to a cryostat using three or four supports. This is not surprising due to the fact that the structural and thermal analyses are largely linear. Cost and thermal contraction issues will likely play more significant roles in this choice. Finally, although potentially more practical in the alignment process, top mounted supports are probably not the best choice if one hopes to minimize lateral deflections of the cavity beam line during cooldown, alignment, and other operations which may subject the cavity or helium vessel to external forces.

The goal of this report has been to focus on issues critical to the development of a suspension system which addresses all of the pertinent design issues. Hopefully, it can serve as a guide for continued suspension system development and be useful as a tool to select or discount various conceptual design options.

REFERENCES

1. "A Proposal to Construct and Test Prototype Superconducting R.F. Structures for Linear Colliders", DESY, CERN, Cornell, TH Darmstadt, Fermilab, INFN Frascati, KFK Karlsruhe, INFN Milano, Saclay, Gesamthochschule Wuppertal, April 1992.

2. Nicol, T.H., et al., "A Suspension System for Superconducting Super Collider Magnets," Proceedings of the Eleventh International Cryogenic Engineering Conference, Vol. 11, Butterworths, Surrey, UK, 1986, pp. 533-536.

3. Nicol, T.H., et al., "SSC Magnet Cryostat Suspension System Design," Advances in Cryogenic Engineering, Vol. 33, Plenum Press, New York, 1987 pp. 227-234.

4. Nicol, T.H., J.D. Gonczy and R.C. Niemann, "Design and Analysis of the SSC Dipole Magnet Suspension System," Super Collider 1, Vol. 1, Plenum Press, New York, 1989, pp. 637-649.

5. Nicol, T.H., "SSC 50mm Collider Dipole Cryostat Design," presented at the 1991 CEC/ICMC Conference, Huntsville, AL, June 11-14, 1991.

6. Nicol, T.H., "SSC 50mm Collider Dipole Cryostat Single Tube Support Post Conceptual Design and Analysis", Fermilab TM-1745, SSCL-N-765, July 9, 1991, presented at the 1992 Industrial International Symposium on the Super Collider (IISSC), March 4-6, 1992, New Orleans, LA.

APPENDIX A

Thermal and Structural Analysis Results
3 Supports per Cryostat

Date: 8/13/92 Time: 8:22 Filename: Support analysis cases (si)

TESLA Test Cell Support Analysis
3 supports per cryostat
T.Nicol - Fermilab - August 1992

Refrigeration system W@r.t. to W@T		
T (K)	eff	W/W
70	20%	16
4.5	20%	328
1.8	10%	1657

Heat load budget/suppt		
T (K)	Q (W)	Q r.t. (W)
70	2.00	33
4.5	0.80	263
1.8	0.20	331

Data for plotting budget values (per support)						
Ht (mm)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Nat f (Hz)	Nat f (Hz)
100	2.00	0.80	0.20	627	12.50	18.75
250	2.00	0.80	0.20	627	12.50	18.75

Ht (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fg (kg)	dx (mm)	Nat f (Hz)
100.0	150.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.702	1.702	1.702	122.4	113.5	106.0	9.285	0.563	0.012	357.4	746.6	1.135	14.8
110.0	150.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.702	1.702	1.702	123.6	113.6	104.9	6.176	0.453	0.012	270.4	746.6	1.420	13.2
120.0	150.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.727	1.727	1.727	124.9	113.8	103.9	4.640	0.379	0.012	221.0	746.6	1.709	12.1
130.0	150.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.753	1.753	1.753	126.2	113.9	102.9	3.726	0.327	0.012	189.0	746.6	2.002	11.1
140.0	150.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.753	1.753	1.753	127.4	114.0	101.9	3.121	0.287	0.013	166.3	746.6	2.299	10.4
150.0	150.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.778	1.778	1.778	128.6	114.2	101.0	2.691	0.256	0.013	149.2	746.6	2.601	9.8
160.0	150.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.803	1.803	1.803	129.9	114.4	100.0	2.370	0.231	0.013	136.1	746.6	2.908	9.2
170.0	150.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.803	1.803	1.803	131.1	114.5	99.2	2.121	0.211	0.013	125.6	746.6	3.221	8.8
180.0	150.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.829	1.829	1.829	132.3	114.7	98.3	1.922	0.194	0.013	116.8	746.6	3.538	8.4
190.0	150.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.854	1.854	1.854	133.4	114.9	97.4	1.760	0.180	0.013	109.5	746.6	3.861	8.0
200.0	150.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.854	1.854	1.854	134.6	115.0	96.6	1.625	0.168	0.013	103.6	746.6	4.191	7.7
210.0	150.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.880	1.880	1.880	135.8	115.2	95.8	1.511	0.157	0.013	98.3	746.6	4.526	7.4
220.0	150.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.905	1.905	1.905	136.9	115.4	95.0	1.414	0.147	0.013	93.7	746.6	4.867	7.1
230.0	150.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.905	1.905	1.905	137.9	115.5	94.1	1.331	0.139	0.014	89.9	746.6	5.204	6.9
240.0	150.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.956	1.956	1.956	137.9	114.7	92.6	1.268	0.133	0.014	87.2	746.6	5.512	6.7
250.0	150.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.981	1.981	1.981	137.9	114.0	91.2	1.212	0.127	0.014	84.7	746.6	5.822	6.5
100.0	175.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.575	1.575	1.575	97.4	90.5	84.5	10.082	0.612	0.013	388.1	746.6	0.841	17.2
110.0	175.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.600	1.600	1.600	98.4	90.5	83.7	6.706	0.492	0.013	293.5	746.6	1.049	15.4
120.0	175.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.600	1.600	1.600	99.4	90.6	82.9	5.037	0.412	0.013	239.9	746.6	1.262	14.0
130.0	175.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.626	1.626	1.626	100.4	90.7	82.1	4.045	0.355	0.013	204.9	746.6	1.478	13.0
140.0	175.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.626	1.626	1.626	101.3	90.8	81.3	3.387	0.311	0.014	180.3	746.6	1.697	12.1
150.0	175.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.651	1.651	1.651	102.3	91.0	80.6	2.920	0.278	0.014	161.9	746.6	1.915	11.4
160.0	175.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.676	1.676	1.676	103.3	91.1	79.8	2.572	0.251	0.014	147.4	746.6	2.139	10.8
170.0	175.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.676	1.676	1.676	104.2	91.2	79.1	2.301	0.229	0.014	136.0	746.6	2.367	10.2
180.0	175.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.702	1.702	1.702	105.1	91.3	78.4	2.085	0.211	0.014	126.7	746.6	2.596	9.8
190.0	175.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.702	1.702	1.702	106.1	91.5	77.8	1.909	0.195	0.014	118.8	746.6	2.830	9.4
200.0	175.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.727	1.727	1.727	107.0	91.6	77.1	1.763	0.182	0.014	112.3	746.6	3.066	9.0
210.0	175.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.753	1.753	1.753	107.9	91.7	76.5	1.639	0.170	0.015	106.7	746.6	3.307	8.7
220.0	175.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.753	1.753	1.753	108.8	91.9	75.9	1.533	0.160	0.015	101.7	746.6	3.551	8.4
230.0	175.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.778	1.778	1.778	109.7	92.0	75.3	1.441	0.151	0.015	97.2	746.6	3.800	8.1
240.0	175.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.778	1.778	1.778	110.6	92.2	74.7	1.361	0.143	0.015	93.6	746.6	4.054	7.8
250.0	175.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.803	1.803	1.803	111.5	92.4	74.1	1.290	0.136	0.015	90.4	746.6	4.310	7.6

Table A-1: page 1

Date: 8/13/92 Time: 8:22 Filename: Support analysis cases (si)

Hi (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fg (kg)	dx (mm)	Nat f (Hz)
100.0	200.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.473	1.473	1.473	80.0	74.4	69.6	10.839	0.658	0.014	417.3	746.6	0.660	19.4
110.0	200.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.499	1.499	1.499	80.8	74.5	68.9	7.208	0.529	0.014	315.3	746.6	0.823	17.4
120.0	200.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.499	1.499	1.499	81.6	74.5	68.2	5.413	0.442	0.014	257.9	746.6	0.991	15.9
130.0	200.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.524	1.524	1.524	82.4	74.6	67.6	4.346	0.381	0.015	220.4	746.6	1.156	14.7
140.0	200.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.524	1.524	1.524	83.2	74.7	67.0	3.640	0.335	0.015	193.7	746.6	1.326	13.7
150.0	200.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.549	1.549	1.549	84.0	74.8	66.4	3.137	0.299	0.015	173.9	746.6	1.496	12.9
160.0	200.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.575	1.575	1.575	84.8	74.9	65.8	2.762	0.270	0.015	158.6	746.6	1.669	12.2
170.0	200.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.575	1.575	1.575	85.5	75.0	65.2	2.472	0.246	0.015	146.1	746.6	1.844	11.6
180.0	200.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.600	1.600	1.600	86.3	75.1	64.6	2.240	0.226	0.015	136.1	746.6	2.019	11.1
190.0	200.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.600	1.600	1.600	87.1	75.2	64.1	2.050	0.209	0.015	127.8	746.6	2.197	10.6
200.0	200.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.626	1.626	1.626	87.8	75.3	63.5	1.893	0.195	0.015	120.5	746.6	2.380	10.2
210.0	200.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.626	1.626	1.626	88.5	75.4	63.0	1.760	0.183	0.016	114.5	746.6	2.563	9.8
220.0	200.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.651	1.651	1.651	89.3	75.5	62.5	1.646	0.171	0.016	109.3	746.6	2.748	9.5
230.0	200.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.651	1.651	1.651	90.0	75.7	62.0	1.547	0.162	0.016	104.6	746.6	2.936	9.2
240.0	200.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.676	1.676	1.676	90.7	75.8	61.5	1.460	0.153	0.016	100.3	746.6	3.129	8.9
250.0	200.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.676	1.676	1.676	91.5	75.9	61.1	1.384	0.145	0.016	97.1	746.6	3.322	8.7
100.0	225.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.397	1.397	1.397	67.4	62.7	58.7	11.562	0.702	0.015	445.0	746.6	0.541	21.4
110.0	225.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.422	1.422	1.422	68.1	62.7	58.1	7.688	0.564	0.015	336.4	746.6	0.676	19.2
120.0	225.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.422	1.422	1.422	68.7	62.8	57.6	5.773	0.472	0.015	275.1	746.6	0.810	17.5
130.0	225.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.448	1.448	1.448	69.4	62.9	57.0	4.635	0.406	0.015	234.8	746.6	0.945	16.2
140.0	225.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.448	1.448	1.448	70.0	62.9	56.5	3.881	0.357	0.016	206.5	746.6	1.082	15.2
150.0	225.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.473	1.473	1.473	70.7	63.0	56.0	3.345	0.318	0.016	185.4	746.6	1.219	14.3
160.0	225.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.473	1.473	1.473	71.3	63.1	55.5	2.945	0.288	0.016	168.8	746.6	1.359	13.5
170.0	225.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.499	1.499	1.499	72.0	63.2	55.0	2.634	0.262	0.016	156.0	746.6	1.499	12.9
180.0	225.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.499	1.499	1.499	72.6	63.3	54.5	2.387	0.241	0.016	145.0	746.6	1.641	12.3
190.0	225.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.524	1.524	1.524	73.2	63.3	54.1	2.185	0.223	0.016	135.9	746.6	1.783	11.8
200.0	225.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.524	1.524	1.524	73.8	63.4	53.6	2.017	0.208	0.017	128.7	746.6	1.928	11.4
210.0	225.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.549	1.549	1.549	74.4	63.5	53.2	1.875	0.195	0.017	122.0	746.6	2.075	10.9
220.0	225.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.549	1.549	1.549	75.1	63.6	52.8	1.753	0.183	0.017	116.2	746.6	2.223	10.6
230.0	225.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.575	1.575	1.575	75.7	63.7	52.4	1.648	0.172	0.017	111.6	746.6	2.372	10.2
240.0	225.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.575	1.575	1.575	76.3	63.8	52.0	1.556	0.163	0.017	107.1	746.6	2.522	9.9
250.0	225.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.600	1.600	1.600	76.9	63.9	51.6	1.474	0.155	0.017	103.1	746.6	2.675	9.6

Table A-1: page 2

Date: 8/13/92 Time: 8:22 Filename: Support analysis cases (sl)

Ht (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fg (kg)	dx (mm)	Nat f (Hz)
100.0	250.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.346	1.346	1.346	57.8	53.8	50.4	12.258	0.744	0.016	471.6	746.6	0.457	23.3
110.0	250.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.346	1.346	1.346	58.4	53.9	50.0	8.150	0.598	0.016	356.7	746.6	0.572	20.9
120.0	250.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.372	1.372	1.372	58.9	53.9	49.5	6.119	0.500	0.016	291.4	746.6	0.686	19.1
130.0	250.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.372	1.372	1.372	59.5	54.0	49.0	4.912	0.430	0.016	249.0	746.6	0.798	17.6
140.0	250.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.397	1.397	1.397	60.1	54.0	48.6	4.112	0.378	0.017	219.0	746.6	0.914	16.5
150.0	250.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.397	1.397	1.397	60.6	54.1	48.2	3.544	0.337	0.017	196.3	746.6	1.029	15.5
160.0	250.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.422	1.422	1.422	61.1	54.2	47.7	3.120	0.304	0.017	179.2	746.6	1.143	14.7
170.0	250.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.422	1.422	1.422	61.7	54.2	47.3	2.791	0.278	0.017	165.0	746.6	1.260	14.0
180.0	250.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.448	1.448	1.448	62.2	54.3	46.9	2.528	0.256	0.017	153.4	746.6	1.379	13.4
190.0	250.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.448	1.448	1.448	62.7	54.4	46.5	2.314	0.236	0.017	144.3	746.6	1.496	12.9
200.0	250.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.448	1.448	1.448	63.3	54.5	46.2	2.136	0.220	0.017	136.0	746.6	1.615	12.4
210.0	250.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.473	1.473	1.473	63.8	54.5	45.8	1.985	0.206	0.018	129.2	746.6	1.737	12.0
220.0	250.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.473	1.473	1.473	64.3	54.6	45.4	1.856	0.193	0.018	123.3	746.6	1.857	11.6
230.0	250.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.499	1.499	1.499	64.8	54.7	45.1	1.745	0.183	0.018	117.9	746.6	1.981	11.2
240.0	250.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.499	1.499	1.499	65.3	54.8	44.7	1.647	0.173	0.018	113.4	746.6	2.106	10.9
250.0	250.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.524	1.524	1.524	65.8	54.9	44.4	1.561	0.164	0.018	109.4	746.6	2.230	10.6
100.0	275.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.270	1.270	1.270	50.4	46.9	44.0	12.931	0.785	0.017	497.7	746.6	0.399	25.0
110.0	275.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.295	1.295	1.295	50.9	47.0	43.6	8.596	0.630	0.017	376.2	746.6	0.495	22.4
120.0	275.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.295	1.295	1.295	51.3	47.0	43.2	6.454	0.528	0.017	307.2	746.6	0.594	20.5
130.0	275.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.321	1.321	1.321	51.8	47.1	42.8	5.179	0.454	0.017	262.7	746.6	0.693	19.0
140.0	275.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.321	1.321	1.321	52.3	47.1	42.4	4.336	0.399	0.017	230.8	746.6	0.790	17.7
150.0	275.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.346	1.346	1.346	52.8	47.2	42.0	3.736	0.356	0.018	207.1	746.6	0.889	16.7
160.0	275.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.346	1.346	1.346	53.2	47.2	41.7	3.289	0.321	0.018	188.7	746.6	0.988	15.9
170.0	275.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.372	1.372	1.372	53.7	47.3	41.3	2.942	0.293	0.018	173.8	746.6	1.087	15.1
180.0	275.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.372	1.372	1.372	54.2	47.3	41.0	2.665	0.269	0.018	162.1	746.6	1.189	14.5
190.0	275.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.397	1.397	1.397	54.6	47.4	40.6	2.439	0.249	0.018	151.9	746.6	1.288	13.9
200.0	275.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.397	1.397	1.397	55.1	47.5	40.3	2.251	0.232	0.018	143.4	746.6	1.389	13.4
210.0	275.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.397	1.397	1.397	55.5	47.5	40.0	2.092	0.217	0.019	136.2	746.6	1.491	12.9
220.0	275.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.422	1.422	1.422	56.0	47.6	39.7	1.956	0.204	0.019	129.8	746.6	1.595	12.5
230.0	275.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.422	1.422	1.422	56.4	47.7	39.4	1.838	0.192	0.019	124.4	746.6	1.699	12.1
240.0	275.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.448	1.448	1.448	56.8	47.7	39.1	1.735	0.182	0.019	119.4	746.6	1.803	11.7
250.0	275.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.448	1.448	1.448	57.3	47.8	38.8	1.644	0.173	0.019	114.9	746.6	1.908	11.4

Date: 8/13/92 Time: 8:22 Filename: Support analysis cases (sl)

Ht	OD	L1	L2	L3	L4	LTh1	LTh2	LTh3	T1	T2	T3	Sig1	Sig2	Sig3	Q70	Q4.5	Q1.8	Q r.t.	Fg	dx	Nat f
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MPa)	(MPa)	(MPa)	(W)	(W)	(W)	(W)	(kg)	(mm)	(Hz)
100.0	300.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.219	1.219	1.219	44.4	41.5	38.9	13.584	0.824	0.018	523.1	746.6	0.353	26.6
110.0	300.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.245	1.245	1.245	44.9	41.5	38.5	9.029	0.662	0.018	395.0	746.6	0.439	23.8
120.0	300.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.245	1.245	1.245	45.3	41.5	38.2	6.778	0.554	0.018	322.9	746.6	0.526	21.7
130.0	300.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.270	1.270	1.270	45.7	41.6	37.8	5.439	0.477	0.018	275.8	746.6	0.612	20.2
140.0	300.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.270	1.270	1.270	46.1	41.6	37.5	4.553	0.419	0.018	242.3	746.6	0.699	18.9
150.0	300.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.295	1.295	1.295	46.5	41.6	37.2	3.923	0.373	0.019	217.6	746.6	0.785	17.8
160.0	300.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.295	1.295	1.295	46.9	41.7	36.9	3.453	0.337	0.019	198.1	746.6	0.871	16.9
170.0	300.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.321	1.321	1.321	47.3	41.7	36.5	3.088	0.307	0.019	182.7	746.6	0.958	16.1
180.0	300.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.321	1.321	1.321	47.7	41.8	36.2	2.797	0.283	0.019	169.9	746.6	1.046	15.4
190.0	300.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.321	1.321	1.321	48.1	41.8	35.9	2.560	0.262	0.019	159.1	746.6	1.133	14.8
200.0	300.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.346	1.346	1.346	48.5	41.9	35.7	2.362	0.243	0.019	150.5	746.6	1.222	14.3
210.0	300.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.346	1.346	1.346	48.9	42.0	35.4	2.195	0.228	0.019	142.7	746.6	1.308	13.8
220.0	300.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.372	1.372	1.372	49.3	42.0	35.1	2.052	0.214	0.020	136.4	746.6	1.397	13.3
230.0	300.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.372	1.372	1.372	49.7	42.1	34.8	1.929	0.202	0.020	130.4	746.6	1.488	12.9
240.0	300.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.397	1.397	1.397	50.1	42.1	34.6	1.820	0.191	0.020	125.1	746.6	1.577	12.6
250.0	300.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.397	1.397	1.397	50.4	42.2	34.3	1.725	0.181	0.020	120.9	746.6	1.669	12.2

Table A-1: page 4

Date: 8/13/92 Time: 8:09 Filename: Support analysis cases (si)

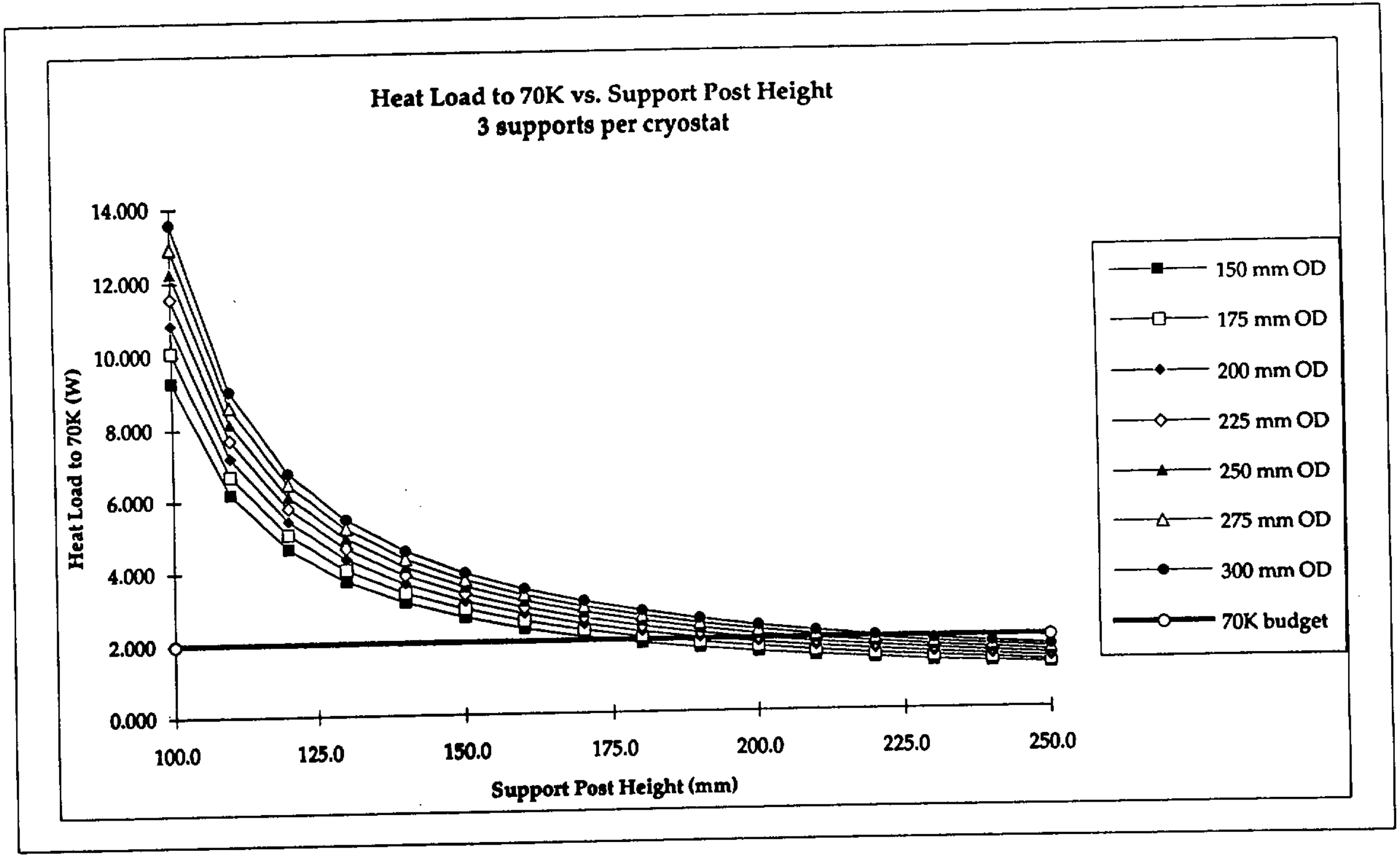

Figure A-1

Date: 8/13/92   Time: 8:09   Filename: Support analysis cases (si)

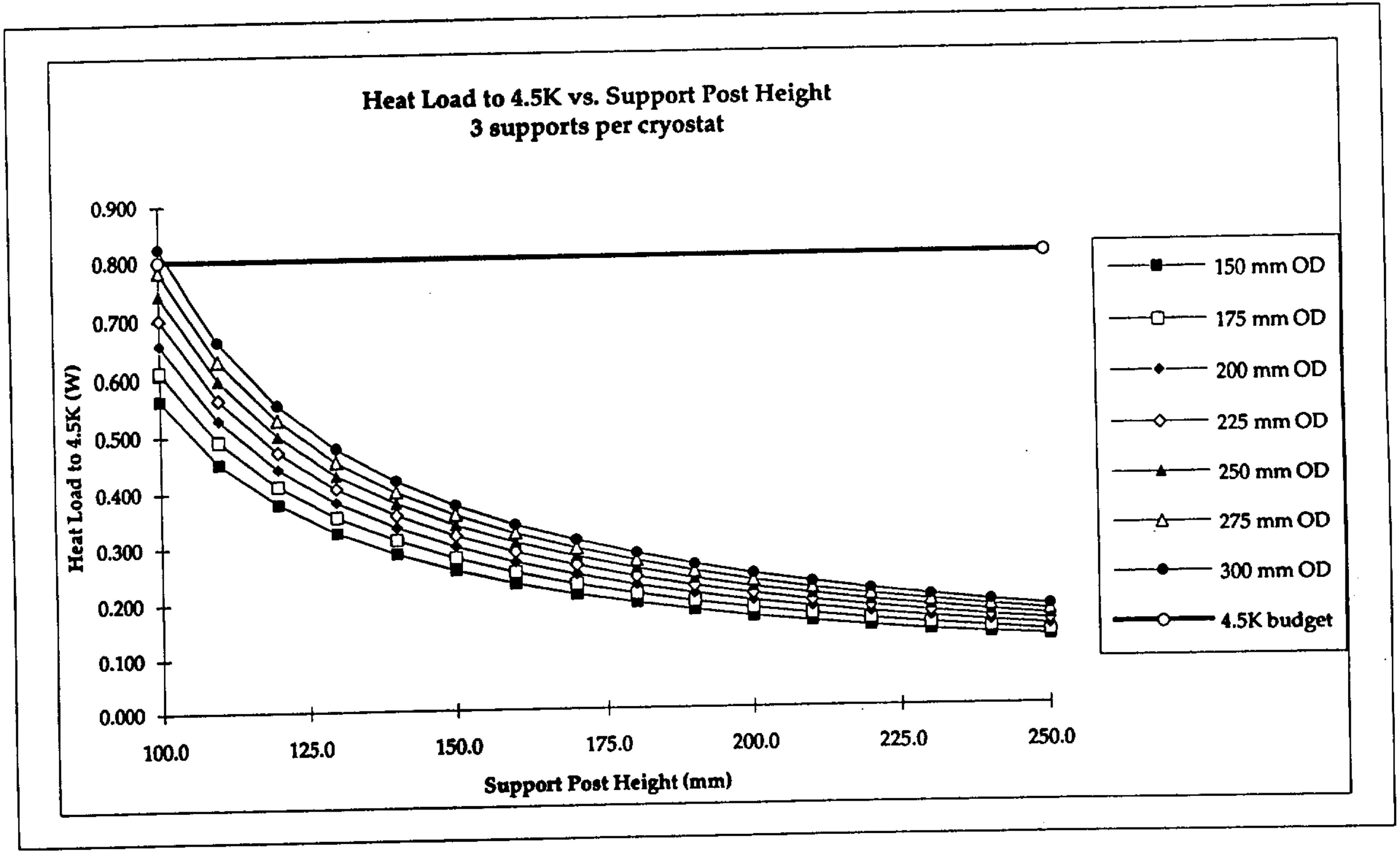

Figure A-2

Date: 8/13/92 Time: 8:09 Filename: Support analysis cases (si)

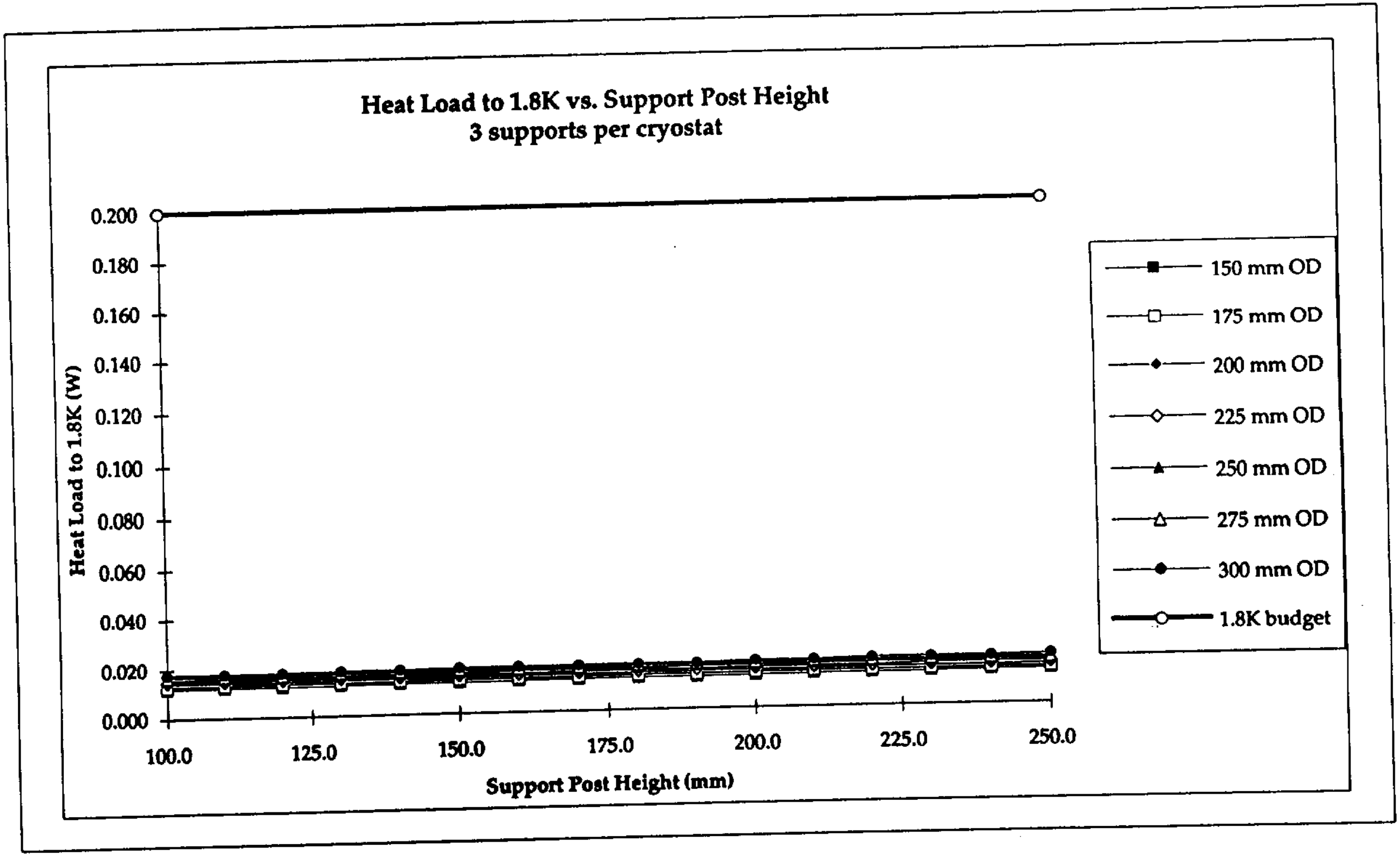

Figure A-3

Date: 8/13/92 Time: 8:09 Filename: Support analysis cases (si)

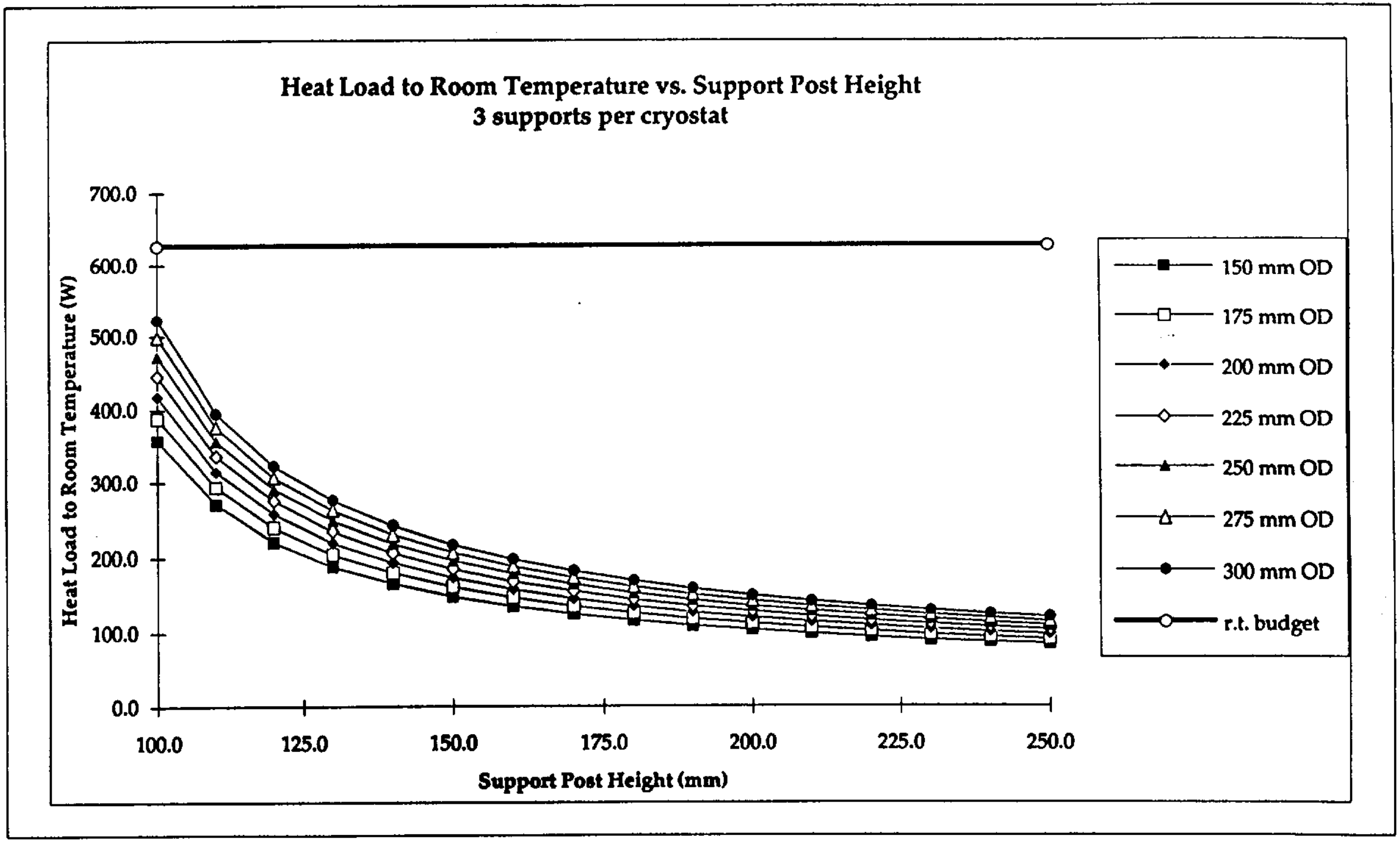

Figure A-4

Date: 8/13/92 Time: 8:09 Filename: Support analysis cases (sl)

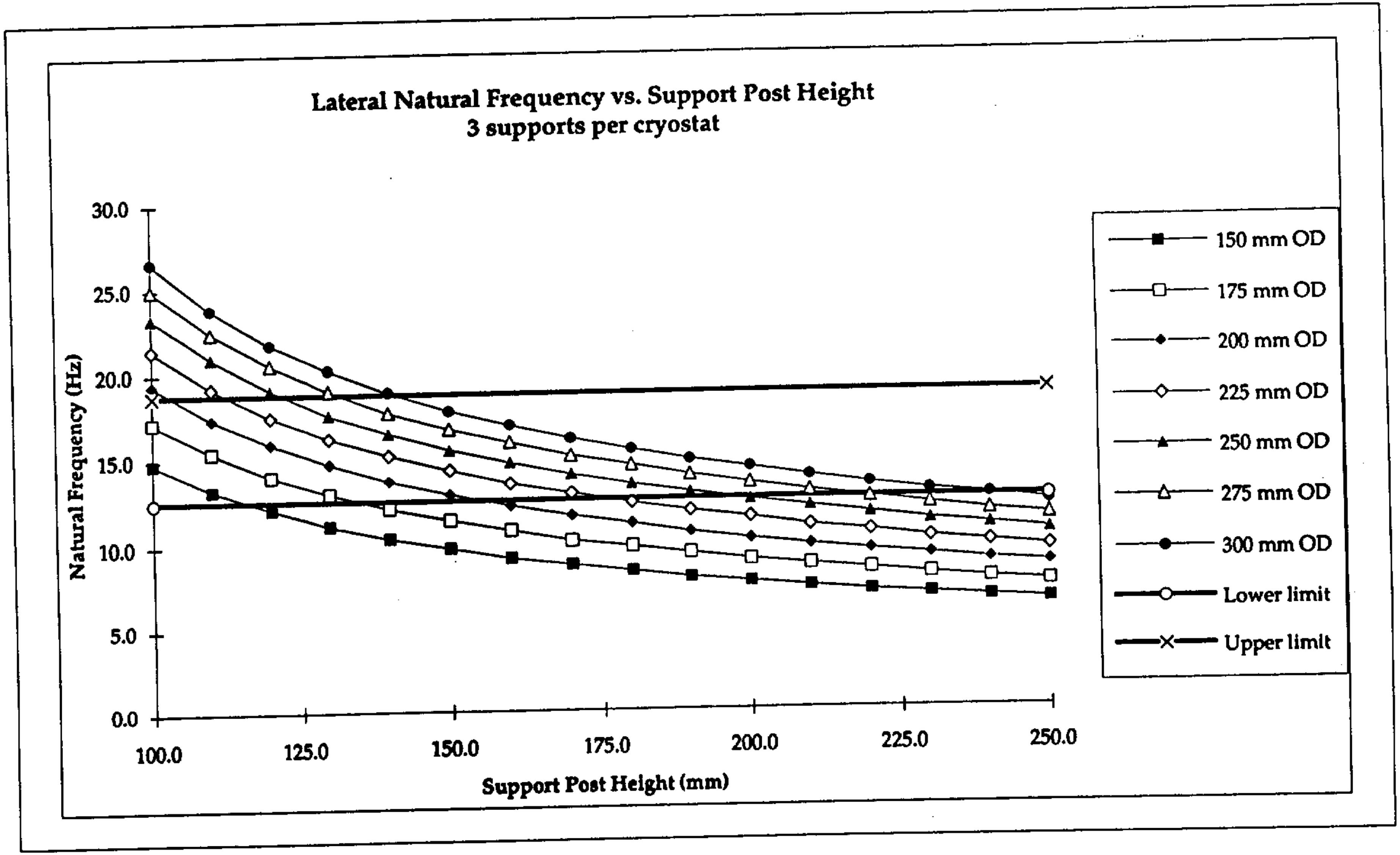

Figure A-5

APPENDIX B

Thermal and Structural Analysis Results
4 Supports per Cryostat

Date: 8/13/92 Time: 8:25 Filename: Support analysis cases (si)

TESLA Test Cell Support Analysis
4 supports per cryostat
T.Nicol - Fermilab - August 1992

Refrigeration System W@R.T. to W@T		
T (K)	eff	W/W
70	20%	16
4.5	20%	328
1.8	10%	1657

Heat Load Budget (W)		
T (K)	Q (W)	Q r.t. (W)
70	1.50	25
4.5	0.60	197
1.8	0.15	249

Data for plotting budget values						
Ht (mm)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Nat f (Hz)	Nat f (Hz)
100	1.50	0.60	0.15	470	12.50	18.75
250	1.50	0.60	0.15	470	12.50	18.75

Ht (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fg (kg)	dx (mm)	Nat f (Hz)
100.0	150.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.473	1.473	1.473	105.7	98.1	91.6	8.036	0.488	0.010	309.3	559.9	0.978	15.9
110.0	150.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.473	1.473	1.473	106.8	98.2	90.6	5.345	0.392	0.010	233.8	559.9	1.224	14.3
120.0	150.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.499	1.499	1.499	107.9	98.3	89.8	4.016	0.328	0.011	191.3	559.9	1.473	13.0
130.0	150.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.499	1.499	1.499	109.0	98.4	88.9	3.225	0.283	0.011	163.4	559.9	1.727	12.0
140.0	150.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.524	1.524	1.524	110.1	98.5	88.1	2.701	0.248	0.011	143.8	559.9	1.984	11.2
150.0	150.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.549	1.549	1.549	111.1	98.7	87.2	2.329	0.222	0.011	129.2	559.9	2.245	10.5
160.0	150.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.549	1.549	1.549	112.2	98.8	86.4	2.051	0.200	0.011	117.7	559.9	2.512	10.0
170.0	150.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.575	1.575	1.575	113.2	98.9	85.7	1.836	0.183	0.011	108.7	559.9	2.781	9.5
180.0	150.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.575	1.575	1.575	114.3	99.1	84.9	1.664	0.168	0.011	101.0	559.9	3.056	9.0
190.0	150.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.600	1.600	1.600	115.3	99.2	84.2	1.523	0.156	0.011	95.0	559.9	3.335	8.6
200.0	150.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.600	1.600	1.600	116.3	99.4	83.5	1.406	0.145	0.011	89.6	559.9	3.620	8.3
210.0	150.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.626	1.626	1.626	117.3	99.6	82.8	1.308	0.136	0.012	85.2	559.9	3.909	8.0
220.0	150.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.626	1.626	1.626	118.3	99.7	82.1	1.223	0.128	0.012	81.2	559.9	4.204	7.7
230.0	150.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.651	1.651	1.651	119.3	99.9	81.5	1.150	0.120	0.012	77.9	559.9	4.503	7.4
240.0	150.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.676	1.676	1.676	120.3	100.1	80.8	1.086	0.114	0.012	74.8	559.9	4.808	7.2
250.0	150.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.676	1.676	1.676	121.3	100.2	80.2	1.030	0.108	0.012	72.0	559.9	5.118	7.0
100.0	175.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.372	1.372	1.372	84.2	78.2	73.1	8.727	0.529	0.011	336.1	559.9	0.724	18.5
110.0	175.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.372	1.372	1.372	85.1	78.3	72.3	5.804	0.426	0.011	254.0	559.9	0.907	16.6
120.0	175.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.397	1.397	1.397	85.9	78.4	71.6	4.360	0.356	0.012	207.8	559.9	1.090	15.1
130.0	175.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.397	1.397	1.397	86.8	78.4	70.9	3.501	0.307	0.012	177.5	559.9	1.275	14.0
140.0	175.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.422	1.422	1.422	87.6	78.5	70.3	2.932	0.270	0.012	156.2	559.9	1.466	13.0
150.0	175.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.422	1.422	1.422	88.4	78.6	69.6	2.528	0.241	0.012	140.1	559.9	1.656	12.3
160.0	175.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.448	1.448	1.448	89.3	78.7	69.0	2.226	0.217	0.012	127.8	559.9	1.849	11.6
170.0	175.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.448	1.448	1.448	90.1	78.8	68.4	1.992	0.198	0.012	118.0	559.9	2.045	11.0
180.0	175.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.473	1.473	1.473	90.9	78.9	67.8	1.805	0.182	0.012	109.7	559.9	2.243	10.5
190.0	175.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.473	1.473	1.473	91.7	79.1	67.2	1.653	0.169	0.012	102.8	559.9	2.446	10.1
200.0	175.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.499	1.499	1.499	92.5	79.2	66.7	1.526	0.157	0.012	97.2	559.9	2.652	9.7
210.0	175.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.499	1.499	1.499	93.3	79.3	66.1	1.418	0.147	0.013	92.4	559.9	2.858	9.3
220.0	175.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.524	1.524	1.524	94.1	79.4	65.6	1.327	0.138	0.013	88.1	559.9	3.071	9.0
230.0	175.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.524	1.524	1.524	94.8	79.6	65.1	1.247	0.131	0.013	84.2	559.9	3.284	8.7
240.0	175.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.549	1.549	1.549	95.6	79.7	64.5	1.178	0.124	0.013	81.1	559.9	3.503	8.4
250.0	175.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.549	1.549	1.549	96.4	79.8	64.0	1.116	0.117	0.013	78.4	559.9	3.726	8.2

Table B-1: page 1

Date: 8/13/92 Time: 8:25 Filename: Support analysis cases (sl)

Ht (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fg (kg)	dx (mm)	Nat f (Hz)
100.0	200.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.270	1.270	1.270	69.2	64.3	60.2	9.383	0.569	0.012	361.3	559.9	0.569	20.9
110.0	200.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.295	1.295	1.295	69.9	64.4	59.6	6.240	0.458	0.012	273.0	559.9	0.711	18.7
120.0	200.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.295	1.295	1.295	70.6	64.5	59.0	4.686	0.383	0.012	223.3	559.9	0.856	17.1
130.0	200.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.321	1.321	1.321	71.3	64.5	58.4	3.762	0.330	0.013	190.9	559.9	1.001	15.8
140.0	200.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.321	1.321	1.321	72.0	64.6	57.9	3.151	0.290	0.013	167.7	559.9	1.146	14.7
150.0	200.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.346	1.346	1.346	72.6	64.7	57.4	2.716	0.258	0.013	150.7	559.9	1.293	13.9
160.0	200.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.346	1.346	1.346	73.3	64.8	56.9	2.391	0.233	0.013	137.4	559.9	1.443	13.1
170.0	200.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.372	1.372	1.372	74.0	64.8	56.4	2.140	0.213	0.013	126.6	559.9	1.593	12.5
180.0	200.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.372	1.372	1.372	74.6	64.9	55.9	1.939	0.196	0.013	117.7	559.9	1.745	11.9
190.0	200.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.397	1.397	1.397	75.3	65.0	55.4	1.775	0.181	0.013	110.6	559.9	1.900	11.4
200.0	200.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.397	1.397	1.397	75.9	65.1	54.9	1.638	0.169	0.013	104.4	559.9	2.057	11.0
210.0	200.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.422	1.422	1.422	76.6	65.2	54.5	1.523	0.158	0.013	98.9	559.9	2.215	10.6
220.0	200.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.422	1.422	1.422	77.2	65.3	54.1	1.424	0.149	0.014	94.5	559.9	2.377	10.2
230.0	200.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.448	1.448	1.448	77.8	65.4	53.6	1.339	0.140	0.014	90.7	559.9	2.540	9.9
240.0	200.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.448	1.448	1.448	78.4	65.5	53.2	1.264	0.133	0.014	87.0	559.9	2.705	9.6
250.0	200.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.448	1.448	1.448	79.1	65.6	52.8	1.198	0.126	0.014	83.8	559.9	2.873	9.3

100.0	225.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.219	1.219	1.219	58.3	54.2	50.8	10.010	0.607	0.013	385.4	559.9	0.467	23.1
110.0	225.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.219	1.219	1.219	58.9	54.3	50.3	6.656	0.488	0.013	291.2	559.9	0.584	20.6
120.0	225.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.245	1.245	1.245	59.4	54.3	49.8	4.998	0.409	0.013	238.1	559.9	0.701	18.8
130.0	225.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.245	1.245	1.245	60.0	54.4	49.3	4.012	0.352	0.013	203.4	559.9	0.818	17.4
140.0	225.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.270	1.270	1.270	60.6	54.4	48.9	3.359	0.309	0.013	178.6	559.9	0.935	16.3
150.0	225.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.270	1.270	1.270	61.1	54.5	48.4	2.896	0.276	0.014	160.4	559.9	1.054	15.4
160.0	225.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.270	1.270	1.270	61.7	54.6	48.0	2.549	0.249	0.014	146.3	559.9	1.176	14.5
170.0	225.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.295	1.295	1.295	62.2	54.6	47.6	2.281	0.227	0.014	134.7	559.9	1.295	13.8
180.0	225.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.295	1.295	1.295	62.8	54.7	47.2	2.066	0.209	0.014	125.5	559.9	1.420	13.2
190.0	225.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.321	1.321	1.321	63.3	54.8	46.8	1.892	0.193	0.014	117.8	559.9	1.542	12.7
200.0	225.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.321	1.321	1.321	63.9	54.9	46.4	1.746	0.180	0.014	111.1	559.9	1.669	12.2
210.0	225.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.346	1.346	1.346	64.4	54.9	46.0	1.623	0.169	0.014	105.3	559.9	1.793	11.8
220.0	225.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.346	1.346	1.346	64.9	55.0	45.7	1.518	0.158	0.015	100.9	559.9	1.923	11.4
230.0	225.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.372	1.372	1.372	65.4	55.1	45.3	1.426	0.149	0.015	96.4	559.9	2.052	11.0
240.0	225.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.372	1.372	1.372	66.0	55.2	44.9	1.347	0.141	0.015	92.5	559.9	2.182	10.7
250.0	225.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.372	1.372	1.372	66.5	55.3	44.6	1.276	0.134	0.015	89.4	559.9	2.314	10.4

Table B-1: page 2

Date: 8/13/92 Time: 8:25 Filename: Support analysis cases (sl)

Ht (mm)	OD (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	LTh1 (mm)	LTh2 (mm)	LTh3 (mm)	T1 (mm)	T2 (mm)	T3 (mm)	Sig1 (MPa)	Sig2 (MPa)	Sig3 (MPa)	Q70 (W)	Q4.5 (W)	Q1.8 (W)	Q r.t. (W)	Fx (kg)	dx (mm)	Nat f (Hz)
100.0	250.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.143	1.143	1.143	50.0	46.6	43.6	10.613	0.644	0.014	408.5	559.9	0.396	25.1
110.0	250.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.168	1.168	1.168	50.5	46.6	43.2	7.056	0.518	0.014	308.5	559.9	0.493	22.4
120.0	250.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.168	1.168	1.168	51.0	46.7	42.8	5.298	0.433	0.014	252.2	559.9	0.592	20.5
130.0	250.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.194	1.194	1.194	51.5	46.7	42.4	4.252	0.373	0.014	215.6	559.9	0.691	19.0
140.0	250.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.194	1.194	1.194	52.0	46.8	42.0	3.560	0.327	0.014	189.3	559.9	0.790	17.7
150.0	250.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.219	1.219	1.219	52.4	46.8	41.7	3.068	0.292	0.014	170.0	559.9	0.889	16.7
160.0	250.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.219	1.219	1.219	52.9	46.9	41.3	2.701	0.264	0.015	154.9	559.9	0.991	15.8
170.0	250.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.219	1.219	1.219	53.4	46.9	40.9	2.416	0.241	0.015	142.7	559.9	1.090	15.1
180.0	250.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.245	1.245	1.245	53.8	47.0	40.6	2.189	0.221	0.015	132.9	559.9	1.191	14.4
190.0	250.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.245	1.245	1.245	54.3	47.0	40.3	2.004	0.205	0.015	124.8	559.9	1.295	13.9
200.0	250.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.270	1.270	1.270	54.7	47.1	39.9	1.849	0.191	0.015	117.6	559.9	1.397	13.3
210.0	250.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.270	1.270	1.270	55.2	47.2	39.6	1.719	0.178	0.015	111.8	559.9	1.501	12.9
220.0	250.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.295	1.295	1.295	55.6	47.2	39.3	1.607	0.168	0.015	106.7	559.9	1.608	12.4
230.0	250.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.295	1.295	1.295	56.1	47.3	39.0	1.510	0.158	0.015	102.1	559.9	1.715	12.0
240.0	250.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.295	1.295	1.295	56.5	47.4	38.7	1.426	0.150	0.016	98.2	559.9	1.821	11.7
250.0	250.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.321	1.321	1.321	56.9	47.5	38.4	1.351	0.142	0.016	94.8	559.9	1.930	11.4

100.0	275.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.118	1.118	1.118	43.6	40.6	38.1	11.196	0.679	0.015	431.0	559.9	0.343	26.9
110.0	275.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.118	1.118	1.118	44.0	40.7	37.7	7.442	0.546	0.015	325.5	559.9	0.429	24.1
120.0	275.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.118	1.118	1.118	44.4	40.7	37.4	5.588	0.457	0.015	266.1	559.9	0.513	22.0
130.0	275.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.143	1.143	1.143	44.8	40.7	37.0	4.484	0.393	0.015	227.4	559.9	0.599	20.4
140.0	275.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.143	1.143	1.143	45.2	40.8	36.7	3.754	0.345	0.015	199.7	559.9	0.683	19.1
150.0	275.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.168	1.168	1.168	45.7	40.8	36.4	3.235	0.308	0.015	179.2	559.9	0.770	18.0
160.0	275.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.168	1.168	1.168	46.1	40.9	36.1	2.847	0.278	0.015	163.4	559.9	0.856	17.0
170.0	275.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.168	1.168	1.168	46.5	40.9	35.8	2.547	0.254	0.015	150.5	559.9	0.942	16.3
180.0	275.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.194	1.194	1.194	46.9	41.0	35.5	2.307	0.233	0.016	140.1	559.9	1.029	15.6
190.0	275.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.194	1.194	1.194	47.2	41.0	35.2	2.112	0.216	0.016	131.5	559.9	1.115	14.9
200.0	275.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.219	1.219	1.219	47.6	41.1	34.9	1.949	0.201	0.016	124.0	559.9	1.204	14.4
210.0	275.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.219	1.219	1.219	48.0	41.1	34.6	1.811	0.188	0.016	117.8	559.9	1.290	13.9
220.0	275.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.219	1.219	1.219	48.4	41.2	34.3	1.693	0.177	0.016	112.4	559.9	1.379	13.4
230.0	275.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.245	1.245	1.245	48.8	41.2	34.1	1.591	0.167	0.016	107.5	559.9	1.471	13.0
240.0	275.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.245	1.245	1.245	49.2	41.3	33.8	1.502	0.158	0.016	103.4	559.9	1.560	12.6
250.0	275.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.270	1.270	1.270	49.5	41.4	33.6	1.423	0.150	0.017	99.8	559.9	1.651	12.3

Date: 8/13/92 Time: 8:25 Filename: Support analysis cases (sl)

Ht	OD	L1	L2	L3	L4	LTh1	LTh2	LTh3	T1	T2	T3	Sig1	Sig2	Sig3	Q70	Q4.5	Q1.8	Q r.t.	Fx	dx	Nat f
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(MPa)	(MPa)	(MPa)	(W)	(W)	(W)	(W)	(kg)	(mm)	(Hz)
100.0	300.0	448.0	413.0	383.0	358.0	10.0	20.0	10.0	1.067	1.067	1.067	38.5	35.9	33.7	11.762	0.714	0.015	452.8	559.9	0.305	28.5
110.0	300.0	458.0	418.0	383.0	358.0	15.0	25.0	10.0	1.067	1.067	1.067	38.8	35.9	33.4	7.818	0.573	0.015	342.0	559.9	0.381	25.6
120.0	300.0	468.0	423.0	383.0	358.0	20.0	30.0	10.0	1.092	1.092	1.092	39.2	35.9	33.0	5.869	0.480	0.016	279.6	559.9	0.455	23.4
130.0	300.0	478.0	428.0	383.0	358.0	25.0	35.0	10.0	1.092	1.092	1.092	39.5	36.0	32.7	4.710	0.413	0.016	238.9	559.9	0.531	21.7
140.0	300.0	488.0	433.0	383.0	358.0	30.0	40.0	10.0	1.118	1.118	1.118	39.9	36.0	32.5	3.942	0.362	0.016	209.8	559.9	0.605	20.3
150.0	300.0	498.0	438.0	383.0	358.0	35.0	45.0	10.0	1.118	1.118	1.118	40.3	36.0	32.2	3.397	0.323	0.016	188.3	559.9	0.678	19.1
160.0	300.0	508.0	443.0	383.0	358.0	40.0	50.0	10.0	1.118	1.118	1.118	40.6	36.1	31.9	2.989	0.292	0.016	171.6	559.9	0.754	18.2
170.0	300.0	518.0	448.0	383.0	358.0	45.0	55.0	10.0	1.143	1.143	1.143	41.0	36.1	31.6	2.674	0.266	0.016	158.0	559.9	0.831	17.3
180.0	300.0	528.0	453.0	383.0	358.0	50.0	60.0	10.0	1.143	1.143	1.143	41.3	36.2	31.4	2.422	0.245	0.016	147.1	559.9	0.904	16.6
190.0	300.0	538.0	458.0	383.0	358.0	55.0	65.0	10.0	1.143	1.143	1.143	41.6	36.2	31.1	2.216	0.226	0.017	138.0	559.9	0.980	15.9
200.0	300.0	548.0	463.0	383.0	358.0	60.0	70.0	10.0	1.168	1.168	1.168	42.0	36.3	30.9	2.045	0.211	0.017	130.1	559.9	1.057	15.3
210.0	300.0	558.0	468.0	383.0	358.0	65.0	75.0	10.0	1.168	1.168	1.168	42.3	36.3	30.6	1.901	0.197	0.017	123.6	559.9	1.133	14.8
220.0	300.0	568.0	473.0	383.0	358.0	70.0	80.0	10.0	1.194	1.194	1.194	42.7	36.4	30.4	1.777	0.185	0.017	118.0	559.9	1.209	14.3
230.0	300.0	578.0	478.0	383.0	358.0	75.0	85.0	10.0	1.194	1.194	1.194	43.0	36.4	30.1	1.670	0.175	0.017	112.8	559.9	1.288	13.9
240.0	300.0	588.0	483.0	383.0	358.0	80.0	90.0	10.0	1.194	1.194	1.194	43.3	36.5	29.9	1.576	0.165	0.017	108.8	559.9	1.367	13.5
250.0	300.0	598.0	488.0	383.0	358.0	85.0	95.0	10.0	1.219	1.219	1.219	43.7	36.5	29.7	1.493	0.157	0.017	104.7	559.9	1.443	13.1

Date: 8/13/92 Time: 8:15 Filename: Support analysis cases (sl)

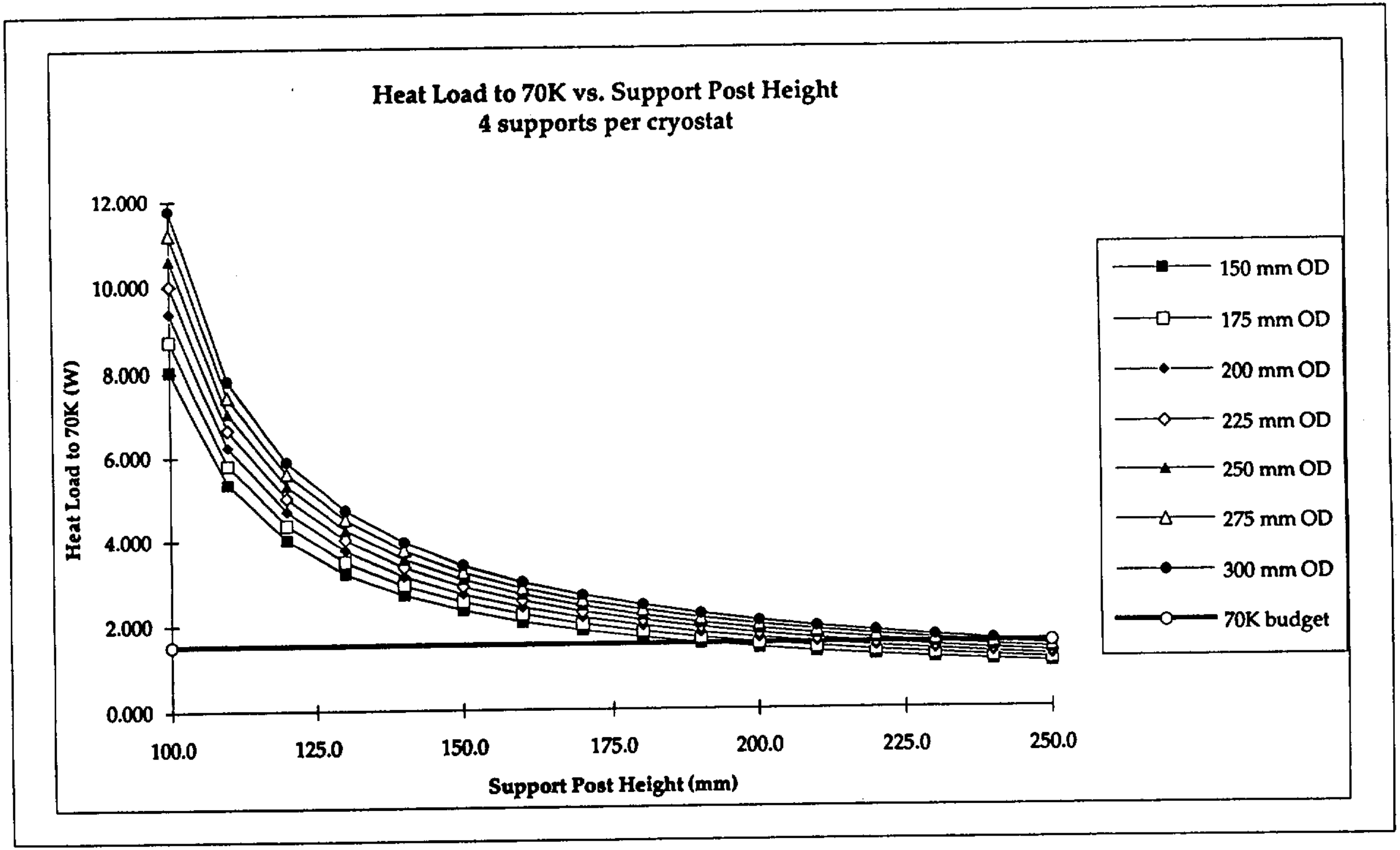

Figure B-1

Date: 8/13/92   Time: 8:15   Filename: Support analysis cases (si)

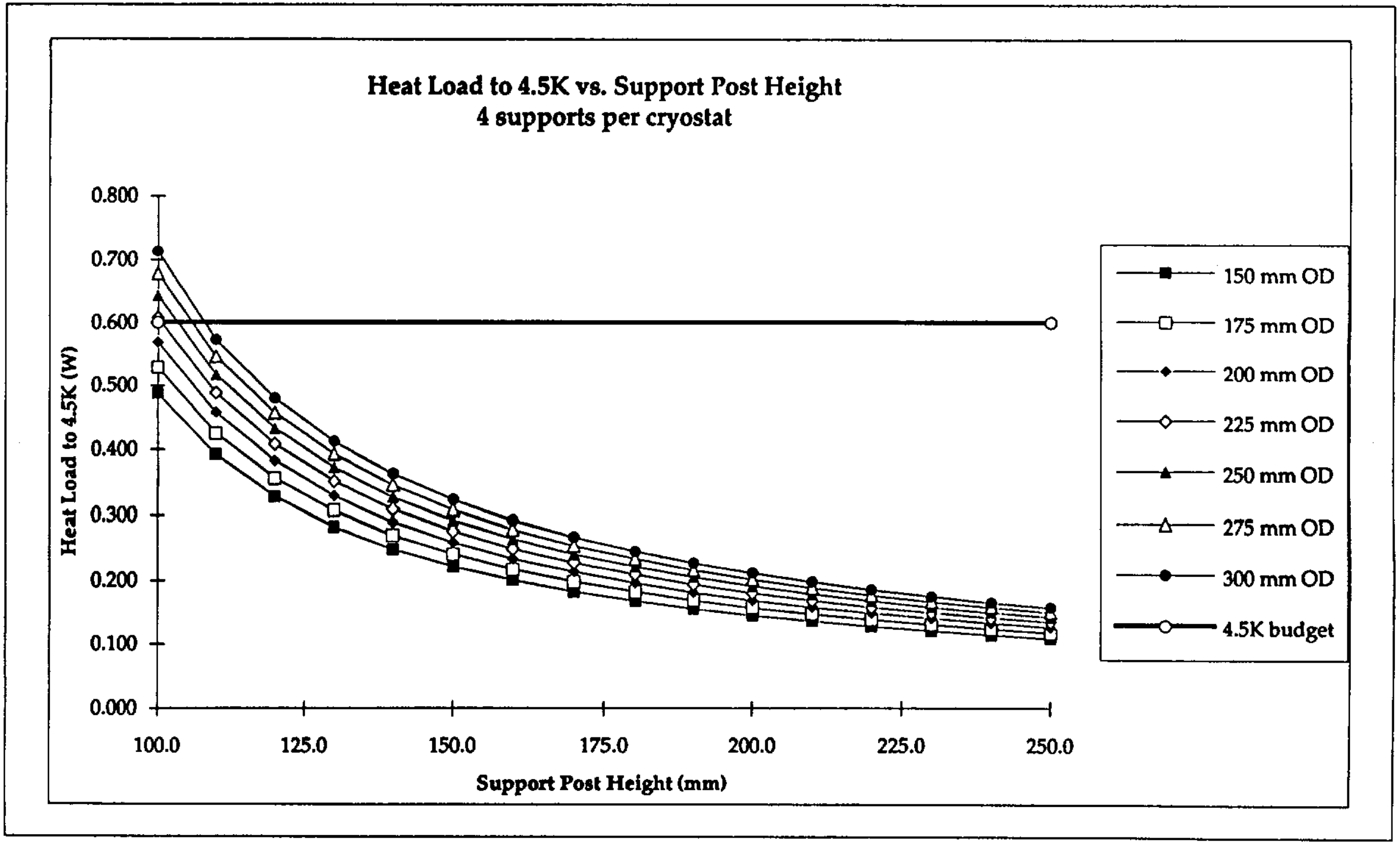

Figure B-2

Date: 8/13/92 Time: 8:15 Filename: Support analysis cases (si)

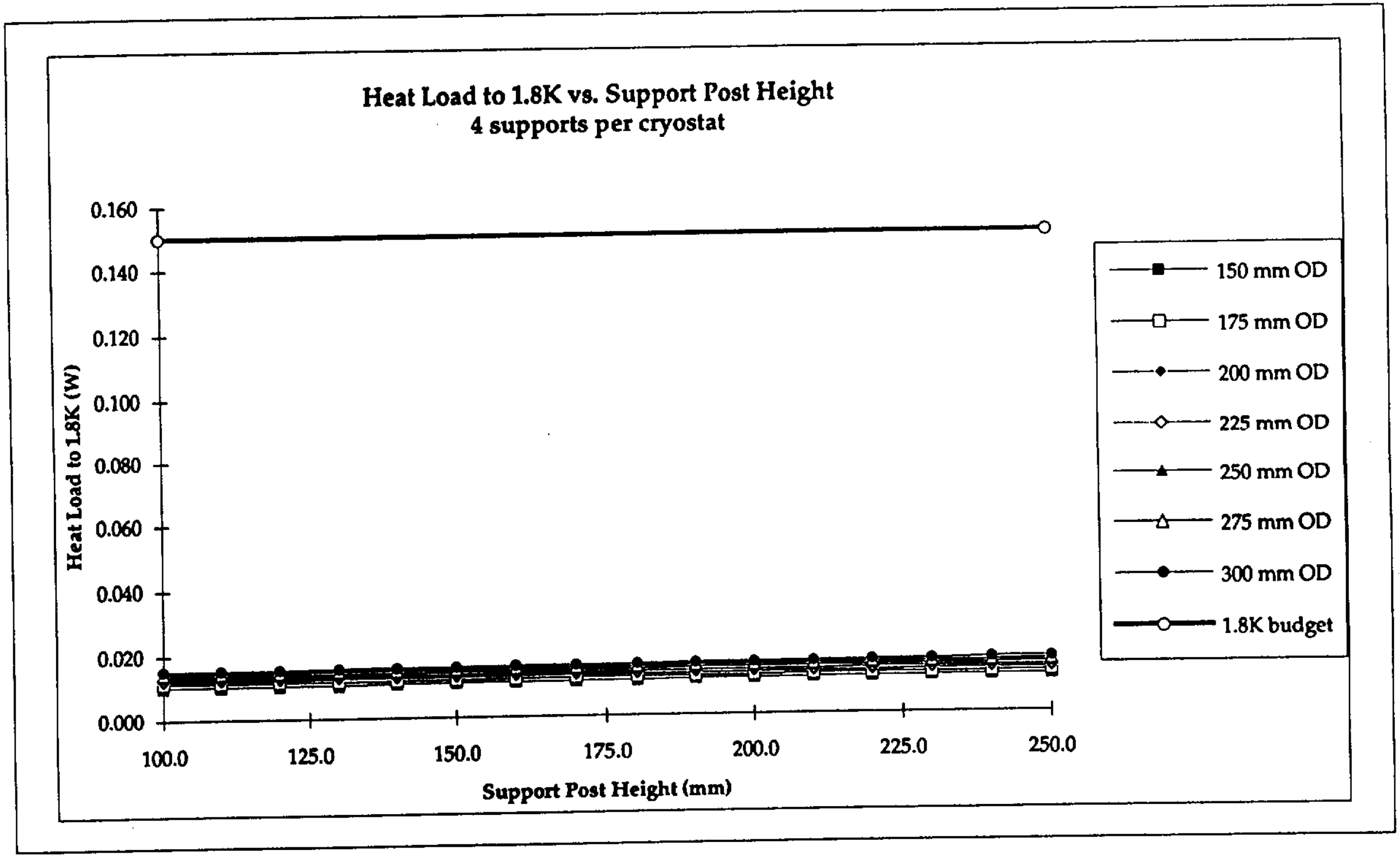

Figure B-3

Date: 8/13/92 Time: 8:15 Filename: Support analysis cases (si)

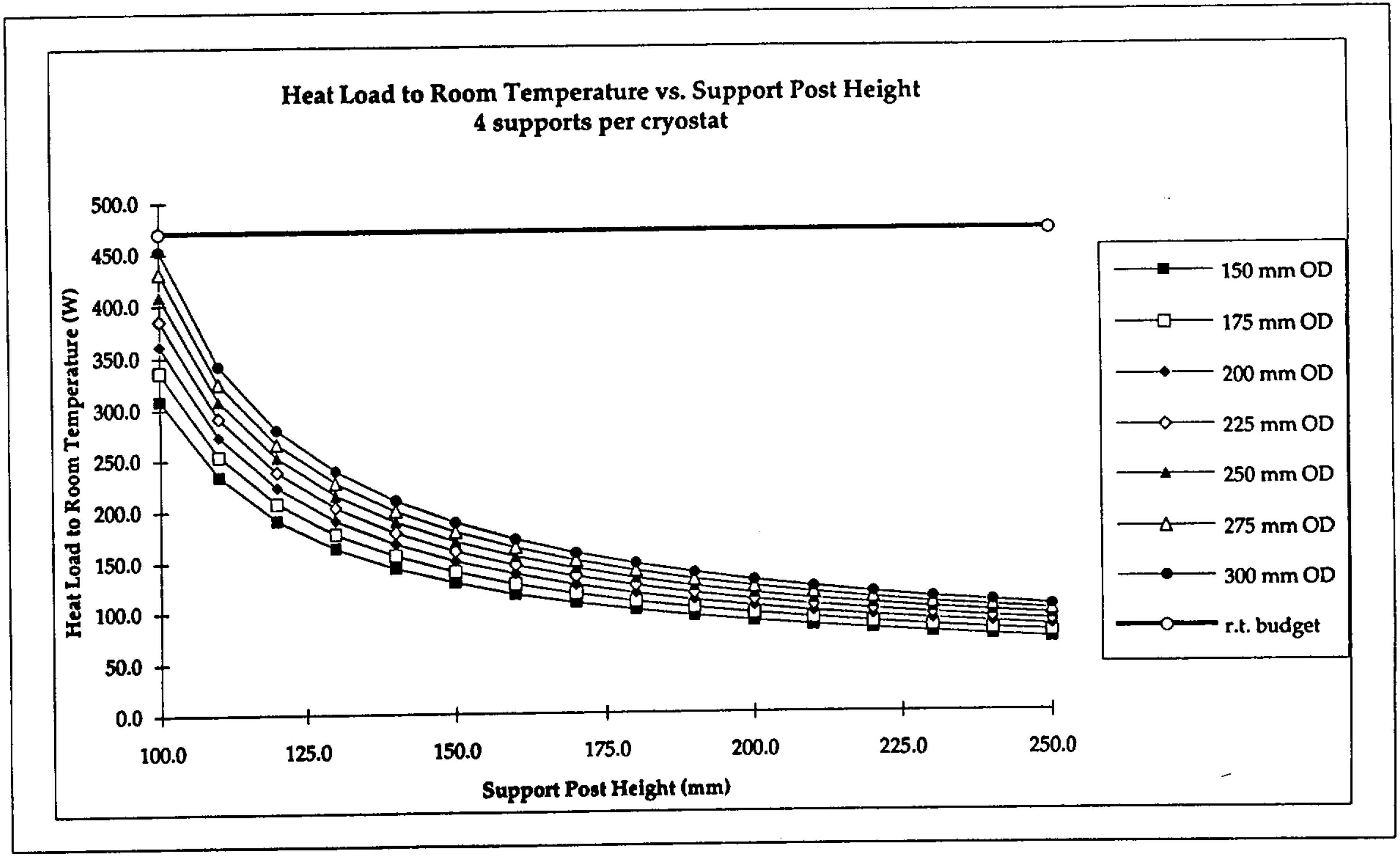

Figure B-4

Date: 8/13/92 Time: 8:15 Filename: Support analysis cases (sl)

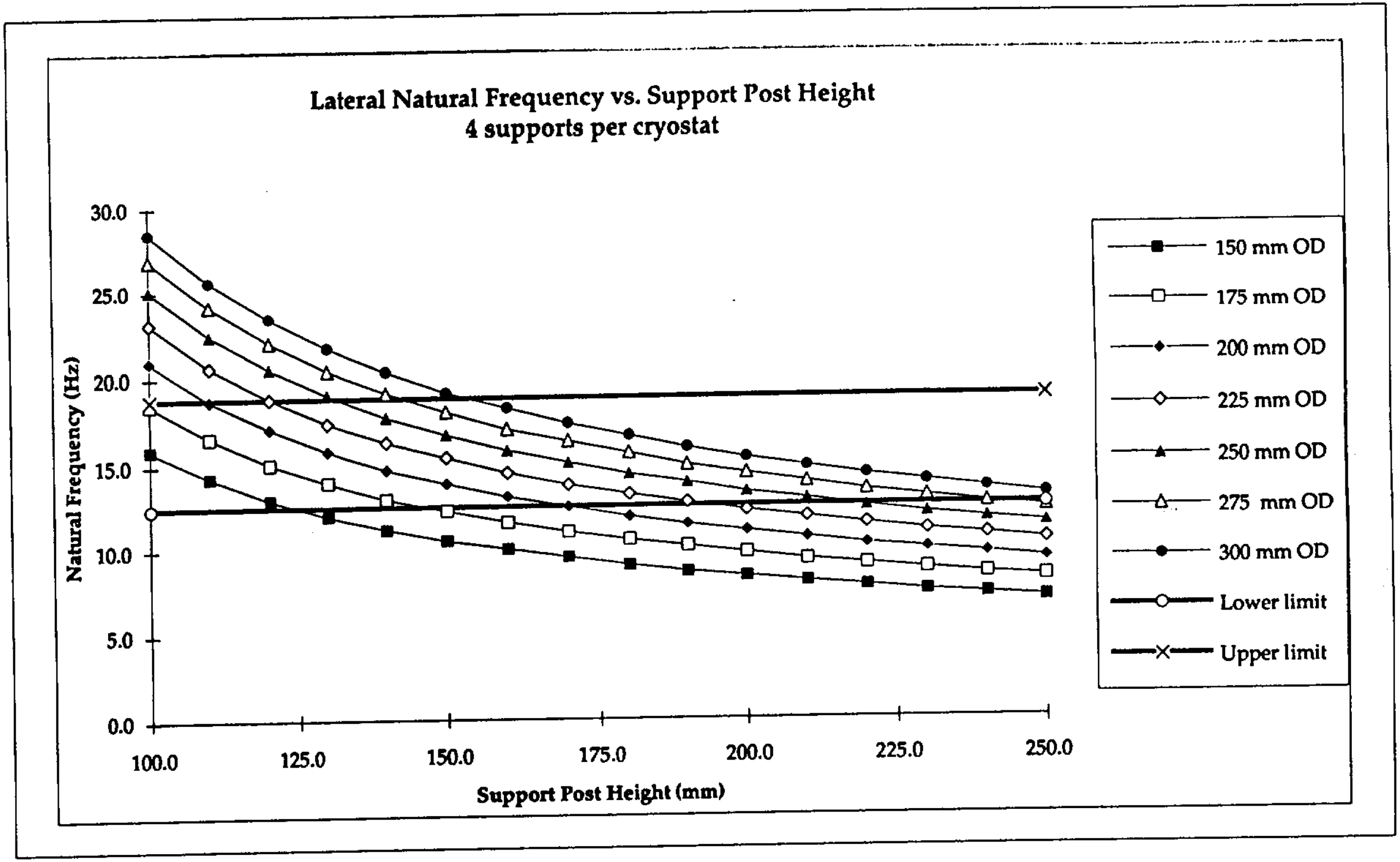

Figure B-5