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INFORMAL REPORT

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PROCEEDINGS OF THE WORKSHOP ON CRYOGENICS FOR THE SUPERCONDUCTING SUPER COLLIDER

January 17-19, 1984
Brookhaven National Laboratory

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, LONG ISLAND, NEW YORK 11973

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UNITED STATES DEPARTMENT OF ENERGY

93

Some leaders of the Workshop. Seated L. to R.: W.B. Fowler, Organizing Committee Chairman; P.M. Mantsch, Chairman of Magnet Cryostat Group; R. Longsworth, Chairman of Refrigeration Machinery Group; C.E. Taylor, Chairman of Magnet Cooling System Group; Standing L. to R.: R.I. Louttit, Host Member of Organizing Committee; G.T. Mulholland, Chairman of Systems Simulation, Controls and Instrumentation Group; J. Smith, Chairman of Refrigeration Cycles Group.

TABLE OF CONTENTS

PROCEEDINGS OF THE WORKSHOP ON CRYOGENICS FOR THE SSC

SUMMARY

Attendance at the workshop and information meeting on Cryogenics for the SSC held at Brookhaven National Laboratory on January 17-18 and 19, 1984 consisted of 109 Engineers and Scientists from 19 industrial organizations and 18 laboratories and universities - CERN, DESY, Grenoble, KEK and Saclay were represented. About one-third of the participants were from Brookhaven National Laboratory and Fermi National Laboratory. There was general agreement that a good balance of knowledge and experience helped in the effectiveness of the meeting.

Talks which concentrated on informing the audience of the present status of the SSC research and development activities and progress towards design of the components were given by M. Tigner, P. VanderArend, P. Mantsch, C. Rode, R. Palmer and C. Taylor. Experience with the cryogenic system of the Tevatron was reported by J. Theilacker and T. Peterson. A wrap-up session on the last day where each of the five Workshop Leaders gave a summary of their group's discussions and conclusions closed the conference. A brief summary of these presentations follows, with the detailed information gathered by the group leaders forming the bulk of these proceedings. No details were submitted for groups C and E.

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
Upton, Long Island, New York 11973

4779

December 5, 1983

WORKSHOP ON CRYOGENICS FOR THE SSC

Dear Colleague:

Thank you for your interest in the Workshop on Cryogenics for the Superconducting Super Collider. The primary purpose of the workshop, at this very early stage of R & D planning for the SSC, is to identify questions which must be answered and ideas which should be studied. Since space for both meeting rooms and housing will be very limited, the total attendance must be limited to match. The Organizing Committee seeks participation by all those who can make some positive technical contribution to the subject of the Workshop, and can attend full-time. If the response exceeds BNL's logistic capacity, it may be necessary to limit the attendance from each institution or company.

A registration fee of $40.00 will be charged in order to cover most of the direct costs of the Workshop. A check for the amount should accompany your registration form.

The agenda for the Workshop is attached. The five groups into which it will be divided are as follows, with the group leader indicated for each:

A. Magnet Cooling System - Magnet cooling considerations for portions of the system at liquid helium temperature, including superconductor cooling requirements and operating temperatures; distribution of coolant between refrigerators; magnet cross-sections, and cooldown.
C. Taylor (LBL)

B. Magnet Cryostat - Design of portions outside liquid helium temperature, including shield, supports, insulation and vacuum. Also magnet-magnet interfaces, thermal contraction and cooldown stresses.
P. Mantsch (FNAL)

C. Refrigeration Cycles - Examination of questions of efficiency and reliability for various possible cycles for an SSC, including consideration of the many factors affecting cycle choice and of the cycles themselves.
J. Smith (MIT)

D. Refrigeration Machinery - Discussions of hardware, existing, under development or possible, which could be used for an SSC system, including compressors, expanders, cold circulators, ejectors, heat exchangers, transfer lines, storage dewars, etc.
R. Longsworth (Air Products)

E. Systems Simulation, Controls and Instrumentation - Examination of existing programs for simulation of performance of refrigerators and extended systems including cool-down, steady state, warm-up and upset recovery. Also applicable process control systems and instrumentation for temperature, pressure and flow measurement.
C. Mulholland (FNAL)

If you decide to attend, be sure to indicate your first two choices of group on the registration form. The Organizing Committee will try to maintain a reasonable balance between groups when making final assignments.

If you have technical reports related to the purposes of the Workshop which you believe would be of interest to other attendees, please send them to the secretary by no later than January 6 in order that they may be copied for distribution at the Workshop.

The plenary sessions on the first and last days of the Workshop will be held in Berkner Hall in the Cafeteria building. The Workshop Groups will meet in the newly completed Collider Center (previously the CBA Service Building). In fact, this will be the very first use of this building, so the atmosphere will be bright, new and Spartan, all befitting an SSC study. Logistic information will be found in the enclosed letter from Ms. Anne Flood, the Workshop Secretary.

Sincerely yours,

ORGANIZING COMMITTEE FOR THE WORKSHOP ON CRYOGENICS FOR THE SSC

W.B. Fowler - FNAL, Chairman
W. Gilbert - LBL
R. Louttit - BNL
D. Sutter - DOE
M. Tigner - Cornell
E. Courant - BNL, Division of Particles and Fields Executive Committee

RIL/amf
Enclosures

WORKSHOP ON CRYOGENICS FOR THE SSC

A G E N D A

January 17, 1984

BERKNER HALL	
8:00 AM	Registration
9:00	Welcome - N.P. Samios, P.J. Reardon
9:15	SSC Overview - M. Tigner
9:45	Low Field Option - R. Huson (Magnets and Machine) - P. VanderArend (Cryogenics)
10:45	Coffee Break
11:00	Medium Field Option - P. Mantsch (Magnets & Machine) - C. Rode (Cryogenics)
12:00	High Field Option - R. Palmer (NbSn Magnets & Machine) - C. Taylor (NbTi Alternate)
1:00 PM	Lunch
2:00	Cryogenic Operating Experience with the FNAL Doubler - J. Theilacker (Systems) - T. Peterson (Hardware)
COLLIDER CENTER	
2:45	Coffee Break
3:00	Attendees join Workshop Groups
BERKNER HALL	
6:00	Cocktails
7:00	Dinner

January 18, 1984

COLLIDER CENTER	
8:30 AM	Workshop Groups
1:00 PM	Lunch
2:00	Tour of BNL facilities
3:00	Workshop Groups

January 19, 1984

COLLIDER CENTER	
8:30 AM	Workshop Groups - Preparation of Summary
BERKNER HALL	
10:00 AM	Summary of Workshop findings by Group Leaders
1:00	Lunch
3:00	Workshop Closes

WORKSHOP ON CRYOGENICS FOR THE SSC

January 17-19, 1984

Group A - Magnet Cooling System

About 20 participants were in Group A, which concerned itself with magnet cooling and associated refrigeration flow. A short organizational meeting took place Tuesday, January 17 at which a few technical issues were discussed and an agenda for the following day and a half was developed. As for general discussion; it was felt desirable to have the large number of talks so that all participants would understand the SSC problems.

Agenda - Group A

8:30	9:30	P. VanderArend (CCI) - Cryogenic design of SSC Systems
9:30	9:50	R. Shutt (BNL) - Internal magnet cooling passages for BNL design
9:50	10:10	Coffee
10:10	10:30	D. Brown (BNL) - Cryogenic system for cold iron high field BNL design
10:30	11:00	G. Horlitz (DESY) - H E R A
11:00		Sub-Group meet 1. Helium II system - S. Van Siver (U. Wisc.) 2. Refrigeration distribution system - C. Taylor (LBL)
4:30	5:30	3. T. Frederking (UCLA) - Pumping of cryogenic fluids 4. J. Schmid (CERN) - Two phase flow 5. P. Martin (FNAL) - Synchrotron radiation and resistive heating
5:30		Summary - all sub-groups return to main group

Thursday - January 19, 1984

8:30		Entire group meeting to prepare summary

SUMMARY

Group A - Magnet Cooling System

Brief summaries of the discussions are listed as follows:

Magnet Replacement

A major technical issue addressed was how long could one allow for replacement of a defective magnet. This in-and-out time depends on the number of magnets in a cryogenic section, the expected magnet failure rate, and the detailed cryogenic valve and piping design. Some FNAL participants suggested that Tevatron experience extrapolated to a requirement of one day for magnet warm up, one day change over, and one day cooldown. Since a cold iron design has a large cold mass, a six week cooldown is calculated if the entire ring is cooled together. After spirite?d discussion, it was generally agreed that:

1. There will be plenty of refrigeration capacity to heat and cool a section of the ring in a few days, even for a cold iron system.

2. Thermal stresses in the magnet and cryostat will be more critical in limiting warm up and cool down rate than will be the availabilty of adaquate refrigeration.

3. A detailed analysis of magnet reliability and magnet change out time must be done in the R&D program.

4. A magnet change out time of one to three days is probably satisfactory if the number of magnet failures is sufficiently low. See item (3) above.

Cryogenic Designs of SSC Systems - P. VanderArend (CCI)

Work on SSC cryogenics started at FNAL in August 1983 with cold iron dipoles. With a 5 tesla cold iron design, bowing due to uneven cooling is a serious problem. Solution is to use the large space between the magnets and the vacuum vessel for large diameter pipes to carry the return and cooldown gases. The cooldown time was greater than 3 weeks with the attendant problem of change outs - deemed unsatisfactory at the time.

Next look was at intermediate temperature iron with concentric thin wall tubes between the magnet and the iron. One design had iron at 15-25 K. Another had iron at 60 K, which would heat to only 70 K after 1 week with no refrigeration. This thermal inertia allows magnet quencn energy to go into the iron. The cool down is still long.

With warm iron, design has a thin cryostat between the magnet and the iron, with large separate pipes to carry gases. The cold mass is low but there is a large heat loss.

Finally a "no iron" case has been developed, but it is too new to say much about.

There was also a presentation of a helium return system that avoided two phase flow through the use of separation pots such that gas would flow in one line and liquid in another. There were some questions raised about gravitational effects and the stability of the system. The work is still in progress.

Internal Magnet Cooling Passages for BNL Design - R. Shutt (BNL)

Requirements for low pressure drop along the length of the magnet string and maximum temperature differences of less than 0.3 K led to a design in which the helium coolant is carried in two large holes in the magnet iron. These two holes in the magnet iron are approximately 2 inches in diameter, reduce magnetic field errors, and are placed above and below the iron center line. Orifices are placed in these passages, one at the exit end and one at the entrance end of the other passage to create a pressure difference between the two. Helium flow then takes place from one passage to the other and magnet temperatures are kept constant to 0.2-0.3 K. Cross-flow occurs between the iron yoke laminations.

Refrigeration Systems for 8 Tesla SSC - D. Brown (BNL)

The refrigeration system for the BNL 8 tesla SSC was presented. An operating temperature of 4.5 K is assumed. Eighteen refrigerators spaced 3.8 km apart are used. The cold iron system has a cold mass of 50×10^6 kg and an inventory of helium of 8×10^4 kg. Assuming one cools the entire ring down from room temperature and uses no liquid nitrogen, 42 days are needed for cooldown. If liquid nitrogen is brought to the site for speeding the cooldown, the time is reduced to 14 days and the liquid nitrogren use rate is 120,000 liters/day.

HERA System - G. Horlitz (DESY)

Two magnet designs, warm and cold iron, are being pursued and a decision on which to use is scheduled for December 1984. The cooling system has single phase through the magnets, two phase for return, with heat exchangers on the magnets. The system can run with one refrigerator out of service.

There are four refrigerators each of which provides:

5 kW at 4.2 K + 8.1 g/s +17.3 kW @60 K

The central compressor room is at the DESY site.

Pumping of Cryogenic Fluids - THK Frederking (UCLA)

In liquid helium, useful flow rates can be obtained by thermally-induced or thermal siphon-induced pumping. These can be divided into "classical" thermo-siphon systems and fountain effect pumps in Helium II (abbreviated as "thermopumps" for the present discussion).

A "classical" effect, is that, for instance, for a duct dimension of the order 1 cm, about 1 milli-$K\Delta T$ is sufficient to start natural convection for unstable T-gradients. For thermopumps, the maximum, ideal pressure difference

(ΔP) established is about 1/2 atm for the lowest T (e.g. LBL 1.8K system) to the lambda point ($T\lambda$). There are two types of thermopumps:

A. Heater-activated thermopumps with $\Delta T > 0$ at the heated location;

B. Cooler-activated thermopumps ($\Delta T < 0$); e.g. cooling is established via vapor pressure difference or refrigerator. Performance constraints result from the main component, the porous medium which permits establishment of a finite ΔT in the liquid. Very small pores show a lambda point depression which is not serious at 1.8 K. Their critical velocity is high ($\approx$10 cm/s by order of magnitude), i.e. large pumping speeds are achieved (compared to conventional gravitational thermosiphons). Though the fine pores do not show large, absolute flow rates one may readily enlarge the porous media cross section, by suitable shapes, to achieve the desired absolute volumetric flow rate. For large pores, the ΔP attained becomes small. In other words the full thermo-static fountain pressure (thermomechanical pressure) of the London theory is not reached. Thus, there should exist an optimum with thermodynamically favorable conditions for liquid circulation pumps. The advantage of these thermopumps is the lack of moving parts.

In addition, there is the option of using a thermopump during regular beam operation and an auxiliary mechanical pump to cope with high loads and quenches. The existing liquid hydrogen mechanical pumps may be used, despite low efficiency if a "brute force" approach is needed. In tne long run, very efficient novel pumps ought to be developed.

CONCLUSIONS

1. Refrigeration Distribution Schemes

All of the schemes that have been examined for cooling the SSC have the following features in common.

1. Several (12 to 24) reasonably large capacity (several kW at liquid helium temperature) refrigeration plants are distributed around the circumference of the facility.

2. Pressurized, single phase helium coolant is circulated through the magnet string; this coolant is periodically re-cooled at intervals of several hundred meters, to limit the temperature difference between recool stations to a few tenths K.

3. The re-cooling stations all consist of heat exchangers in which the pressurized helium coolant is re-cooled by boiling liquid helium. The boiling liquid is provided by drawing off a small flow of pressurized coolant and expanding it through a valve or orifice (Joule-Thompson expansion) to about one atm pressure.

The main differences among the different systems are due to the manner in which the gas from the boiling liquid is returned to the refrigerator. Three basic schemes have been proposed and are illustrated schematically in Figure 1, and described as follows:

Scheme A: 2-phase helium flows from the expansion valve back to the refrigerator in a separate pipe, passing through recoolers along the way. Gas is separated from the liquid at the recoolder and returns in a separate tube. Liquid levels in the re-coolers are determined by gravity and pressure drops in the system.

Scheme B: There is a separate expansion valve in each recooler that is controlled to maintain a stable liquid level. Gas from the recoolers returns in a separate tube.

Scheme C: 2-phase helium flows from the expansion valve back to the refrigerator through passages in the magnet that are in good thermal contact with the pressurized helium. Thus. the re-cooler is incorporated into the magnet.

It was concluded that, although there are many differences between the various schemes that have been examined, all appear to be technically feasible and there should be no great cost differences between the cryogenic systems.

Care should be taken when specifying the maximum allowable temperature rise between re-coolers in a string of magnets because an excessively small allowable temperature rise, requiring large helium flow rates may be costly in pumping power (additional heat load) and may increase magnet costs (space for helium flow).

2. Two-Phase Flow

Two-phase flow was discussed in some detail. In large extended systems certain special problems can occur and must be avoided or accomodated by careful design. Some of these problems are illustrated schematically in Figure 2(*).

Figure 2a. Oscillations that are difficult to predict can occur in flows, where at certain locations, the pressure drop varies with the local liquid-gas fraction.

Figure 2b. Since the liquid-gas fraction is not controlled by temperature or pressure, the helium inventory between parts of the system is difficult to control.

Figure 2c. Difficult control problems can arise when attempting to regulate liquid level in one part of a large system.

It is concluded that

1) There is very little useful data available for the design of two phase liquid helium systems.

2) Use should be made of the Fermilab saver cryogenic system to get two-phase data.

3) Special problems that must be accomodated in the SSC, because of the very long length of coolant loop, are

   a. Elevation changes around the ring, and between ring and refrigeration plant must be considered in control of pressures, temperatures, and liquid levels.

   b. Very long control system transients (hours) can be expected.

3. Cryogenic System Components

Nearly all components of the refrigeration distribution system, piping, valves, etc. will involve straightforward engineering and in many cases, existing designs. However, there may be a requirement to develop an exceptionally high degree of reliability in certain special components, because of their large number and remote location - for example, relief valves that could cause loss of helium if leaking, a problem encountered in the FNAL Saver, or control valves for the many re-coolers.

4. Helium II Refrigeration

A special sub-group considered Helium II systems since operation of superconducting cables at temperatures as low as 2 K results in significantly higher current density in the superconductor, and increased electrical stability because of very good heat-conduction of Helium II. Conclusions are:

- A system design should be made for a complete Helium II-cooled accelerator to help evaluate the costs and technical problems.

- Very little design data is available on pressure drop and heat transfer in Helium II Systems.

SSC COOLING SCHEMES

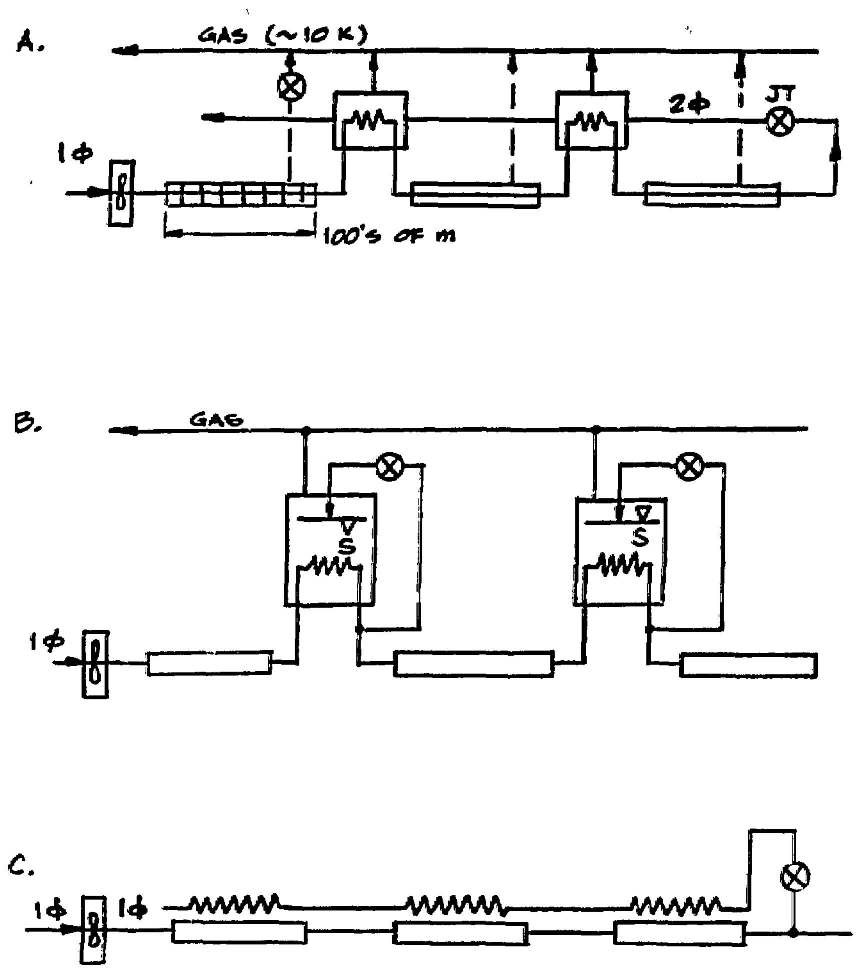


FIG. 1

PROBLEMS OF 2 PHASE FLOW IN EXTENDED SYSTEMS

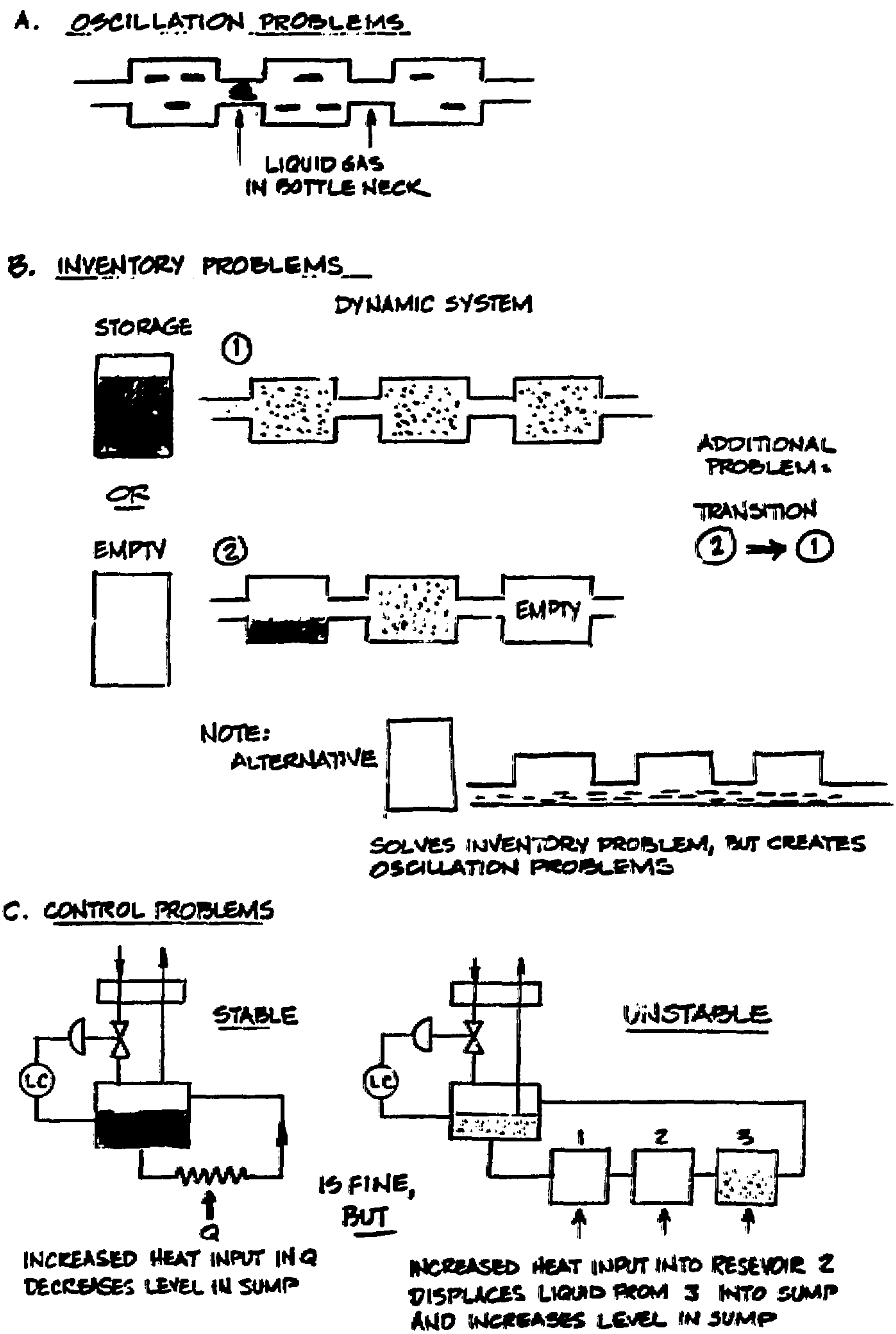


FIG. 2

Fermilab

SESSION B

MAGNET CRYOSTATS

The workshop session on magnet cryostats covered a number of topics relavent to cryostat design:

General Cryostat Consideration

Cold Mass Suspension

Radiation Insulation

Materials

Helium II Cryostats

Production Engineering

Initially discussion focused on the current cryostat design of the several magnet styles presented at the opening session of the workshop. Contributors to cryostat design from Berkely, Brookhaven, Texas, and Fermilab described their work.

Against this background of examples, details of cryostats were discussed. For added coherence the review which follows will be organized under general topic headings rather than the order in which the discussions took place.

At the end of the workshop sessions conclusions were drawn up and a number of recommendations were made for continued study.

The participants in the workshop represented a broad range of experience in universities, national laboratories, and in industry. The real benefit of the discussions was in the stimulating exchange of ideas among those who will be intimate with the design work of the SSC. The open and honest interaction as experienced at Brookhaven will help insure that the best possible design will emerge. To transmit this spirit or even the substance of the discussion is this review is very difficult. The best that can be done is to give a flavor of the topics considered. The conclusions and recommendations may appear at first glance to be self-evident. They, however, bear the weight of careful thought by a group of knowledgeable and experienced people.

MAGNET CRYOSTATS: A CRITICAL REVIEW

Norb Engler described the current Fermilab magnet concept (Engler 1, 2). Of particular interest was the configuration of the ends. The intention is to use aluminum for the shields and for the beam pipe. Aluminum is used for its high thermal conductivity as well as for low cost. To maintain the continuity of material , aluminum bellows must be used and a reliable method of welding must be learned.

A discussion on the use of aluminum bellows produced several points.

1. Aluminum is extensively and successfully used at KEK and LEP (at room temperature).

2. Aluminum bellows have hydroformed convolutions and are thick at the ends to accept welding.

3. The bellows should be compressed or extended only 10% of its length and limited to a few thousand cycles.

4. Welding of aluminum is understood. It is best done automatically.

5. Surrounding the beam pipe weld with the 1Ø helium is risky even if there is a small possibility of welds that leak.

Peter Limon of Fermilab described the Saver installation experience. It was his opinion that the decision to use seals or weld the intermagnet connections should depend the probability of magnet failure. The number of Saver components replaced during installation due to warm leaks was:

Component	Percent Replaced	Total in Ring
Dipoles	3%	774
Quads	$5\frac{1}{2}$%	216
Spools and other Components	13%	300

Limon noted that the installation needs to be well planned with good leak check procedures, equipment and discipline. The Saver magnets (with seals) were very time consuming to install (about 50 man hours per magnet).

Claus Rode added a statistic on weld integrity. On the transfer line around the Saver Ring there were 2000 welds and 7 leaks.

LBL CRYOSTAT DESIGN

Dick Wolgast described the LBL Cryostat design. The magnet is a 2-in-1 with side by side apertures and cold iron. There are 4000 magnets in the ring each 60 feet long with 4 supports. There are several support systems under consideration.

1. Nested columns (Heim type support, see Wolgast-1).

2. An epoxy fiberglass ring girder suspension (Wolgast-2).

3. Titanium tubes with spherical ball joints (Wolgast-3).

LBL has assumed a deflection of ≤.040 between supports.

BNL MAGNET CRYOSTAT

Bill Schneider described the BNL Nb_3Sn magnet cryostat. The magnet is also a 2-in-1 with side by side apertures. There are 4 supports per 15m meter magnet. The epoxy fiberglass strap support system has a heat leak of 0.2W/m. There is no intermediate termperature heat intercept. (Schneider-1)

TEXAS WARM IRON CRYOSTAT

Glen McIntosh who is consulting on the Texas warm iron cryostat began his comments with some generalized design criteria for cryostats:

1. Use round pipes.

2. Support system preferences (in order).
   a) Tension
   b) Compression (including folded columns)
   c) Bending

3. Size pipes adequately for pressure drop.

4. Consider Differential Contraction carefully.

5. Weld
   a) Epoxies are potentially unreliable.
   b) For aluminum use electron beam welds.

McIntosh described the Texas design which uses G11 supports. The magnet is designed for either 4.2 or 1.8K operation. The heat load per 1000m is 45W at 4.2K. The transparencies show warm iron cryostat concepts and suspension details along with performance numbers (McIntosh 1-10).

He also reviewed his experience in the manufacture of dewars.

MATERIALS AND COMPONENTS FOR CRYOGENIC USE

Gerry Nolen described superferric magnets being used on the beam lines at the MSU cyclotron laboratory (Nolen 1). He then initiated a discussion of materials and components used in the fabrication of cryostats (Nolen 2).

Cryogenic valves in particular, was a lively topic. Given the low levels to which we intend to push the heat leak, valves, reliefs, and other devices which penetrate the cryostat require attention. Existing valves if used in the quantites envisaged for the SSC, would contribute a substantial fraction of the total heat leak. It appears that a program should be started to specify the needs of the SSC and to work with industry to accomplish the necessary development work.

PRODUCTION ENGINEERING OF THE LBL CRYOSTAT

Mike Kimmy of General Dynamics described the conceptual design of the cryostat for LBL and a production study of the magnet. The cold mass support is a flexible $\frac{1}{4}$ inch thick G10 "ring girder". The magnet is anchored at the middle by chains. The supports flex to accommodate thermal contraction.

The production study outlined the fabrication steps and necessary tooling to produce the 4032 magnets. A proposed production schedule was developed. The magnets are to be made at the rate of 1 every 4 hours.

Transparencies (Kimmy 1-6) show the General Dynamics program, magnet suspension and anchor detail and a production schedule. Kimmy also showed a series of drawings of the magnet production procedure. One example frame of this sequence is reproduced (Kimmy-7).

SUPERFLUID HELIUM CRYOSTAT

High field (>~8T) NbTi magnets operate in superfluid helium. Until recently superfluid helium refrigeration has been in use only on a laboratory scale. Uncertainty about the technology of superfluid refrigeration and magnet cryostat design has tended to discourage the use of 8-10T NbTi magnets for the SSC.

The French/Euratom research fusion machine Tore Supra is a large scale application of superfluid technology. Jacques Verdier of Grenoble described the refrigeration system and magnet cryostat to be used in that project. (See Verdier 1-3)

INSULATION SYSTEMS

Ron Fast of Fermilab reviewed the sources for design information on multilayer insulation and the performance of various systems. He described studies done on an insulation system for 4.2K to 80K done at Fermilab several years ago. He proposed that in light of the significant part which MLI plays in capital and operating cost, it is important to extend these studies to benefit SSC design. (See Fast 1-10)

MATERIAL PERFORMANCE

Rich Smith of Fermilab showed a table of mechanical and thermal properties of materials at cryogenic temperature. (Smith 1)

MATERIAL CREEP

Ralph Niemann reviewed a series of measurements of creep in composites made by Finley Markley at Fermilab. These measurements were made in response to concerns about the suspension system in the Saver magnets. The first transperency shows the time dependence of the strain on the stress (Niemann 1). This relationship contains two parts. The constant term is really the very short (tens of seconds) response while the second term is the measurable long term response. The parameters used, the apparatus and the results are shown in N-2 through N-7.

STRUCTURAL MEASUREMENTS ON A COMPOSITE STRAP SUPPORT

Niemann also described tests made on an epoxy fiberglass tension support used in the U25-MHD magnet built at ANL. The support member and magnet support geometry are shown in N-8 and N-9. Creep curves for various stresses are shown in N-10.

SUPERCONDUCTING MAGNET DESIGN WORK IN EUROPE

Paul Mantsch described development work underway in the superconducting magnet centers of Europe. This effort now centers on the HERA machine at DESY in Hamburg. At the same time a group at CERN has started to organize development work that will lead to a hadron collider in the LEP tunnel using high field (8T) superconducting magnets.

Two and perhaps three magnet styles are being considered for the 800 GeV protron synchrotron at DESY. The warm iron dipole (Mantsch 1) is based on the Saver design. A cold iron dipole has been proposed by Brown Bovari C. of Manheim (Mantsch 2). The BBC magnet features lower fabrication cost and lower heat leak. Saclay has designed the quadrupole for HERA (Mantsch 3). The collared coil is supported from the steel vacuum vessel with also serves as the flux return.

CERN has left a space in the LEP tunnel for a protron magnet ring (Mantsch 4). Their concept is a 2-in-1, NbSn, 8-10T magnet that would give 8 to 10 TeV protron energy (Mantsch 5).

The technology of Superconducting magnets in accelerators has come of age. New ideas for generation of magnets beyond the Saver abound both in Europe and the U.S. The SSC will benefit greatly from this work.

CONCLUSIONS

The cryostat workshop session ended with a summary of conclusions based on discussion that had taken place.

1. Cryostats can be built using standard materials and methods to give a reasonable refrigeration power requirement (50MW).

2. Cryogenic considerations should be integrated into the magnet from the outset.

3. The cryogenic piping should be sized for an efficient refrigeration system.

4. Welding is the preferred method for vessel closure.

5. Composite supports are preferred if they are carefully designed.

6. The cryostat should be sized to accept a reasonable insulation scheme.

7. Mild steel is acceptable for vacuum vessels if magnetic transients are understood.

8. Early involvement by industry is important.

RECOMMENDATIONS

The group compiled a list of recommendations for studies and development programs that would support SSC cryostat design.

1. Develop standard guidelines for:
   a) Sag between supports
   b) Twist limits
   c) G loads
   d) Synchrotron radiation
   e) Code requirements

2. Study creep in composites.

3. Study composites for support system.

4. Study quality of welds in stainless steel and aluminum where Helium surrounds beampipe welds.

5. Understand the use of aluminum Bellows and transition pieces.

6. Study insulation in tough situations
   a) Penetrations
   b) Ends
   c) At overlap of MLI insulation blankets

7. In depth study of insulation systems (superinsulation, preparation of surfaces).

8. Learn about welding of aluminum (automatic & manual).

9. Develop material testing standards for cryostat materials particularly at 4K.

10. Understand transient thermal and magnetic (eddy current) effects in cyrostat components.

11. Make cost studies of critical materials.

12. Include production engineering in magnet design.

13. Involve industry in SSC workshops and reviews.

14. Study new approaches to current leads.

The last recommendation is in the form of a proposal that could address many of the above items.

We propose a DOE sponsored effort to develop materials (and material standards) that are critical to magnet fabrication. This effort would encompass:

1. Develop testing standards for materials (particularly at low termperature).

2. Perform cost studies that would uncover cost advantage for quantity of special materials, for example aluminum vs. steel, mild steel vs. stainless, clad materials, and superinsulation.

3. Develop new materials such as alloys and composites.

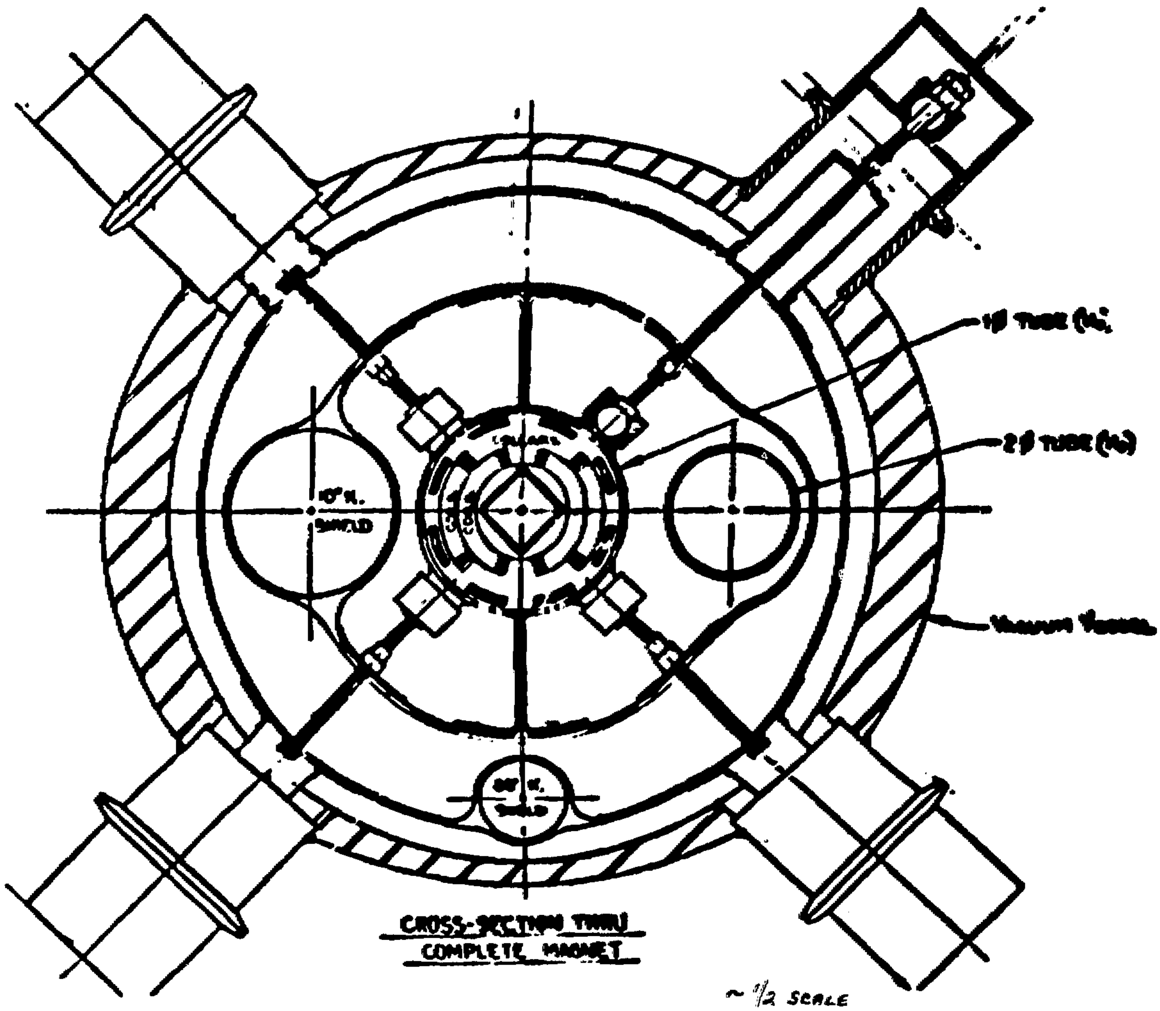


Figure 6

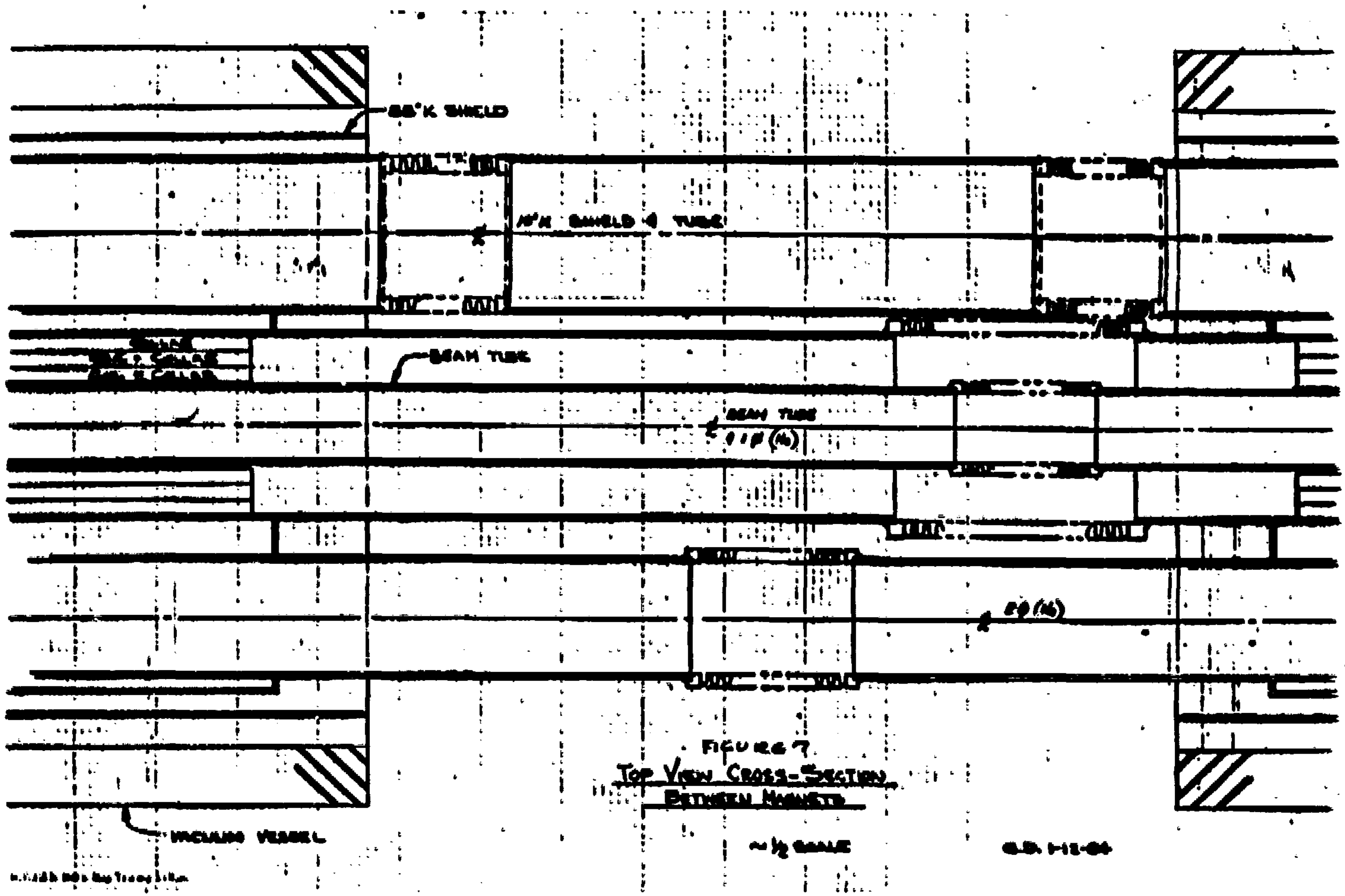
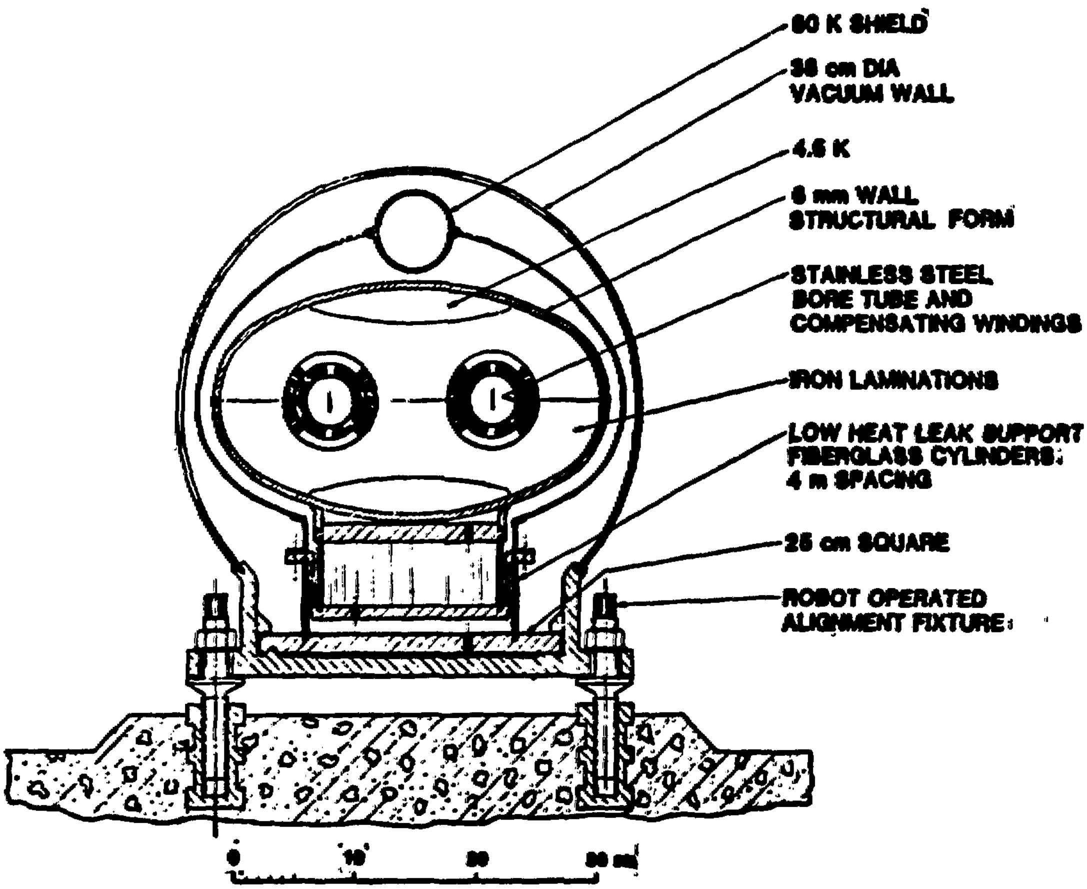
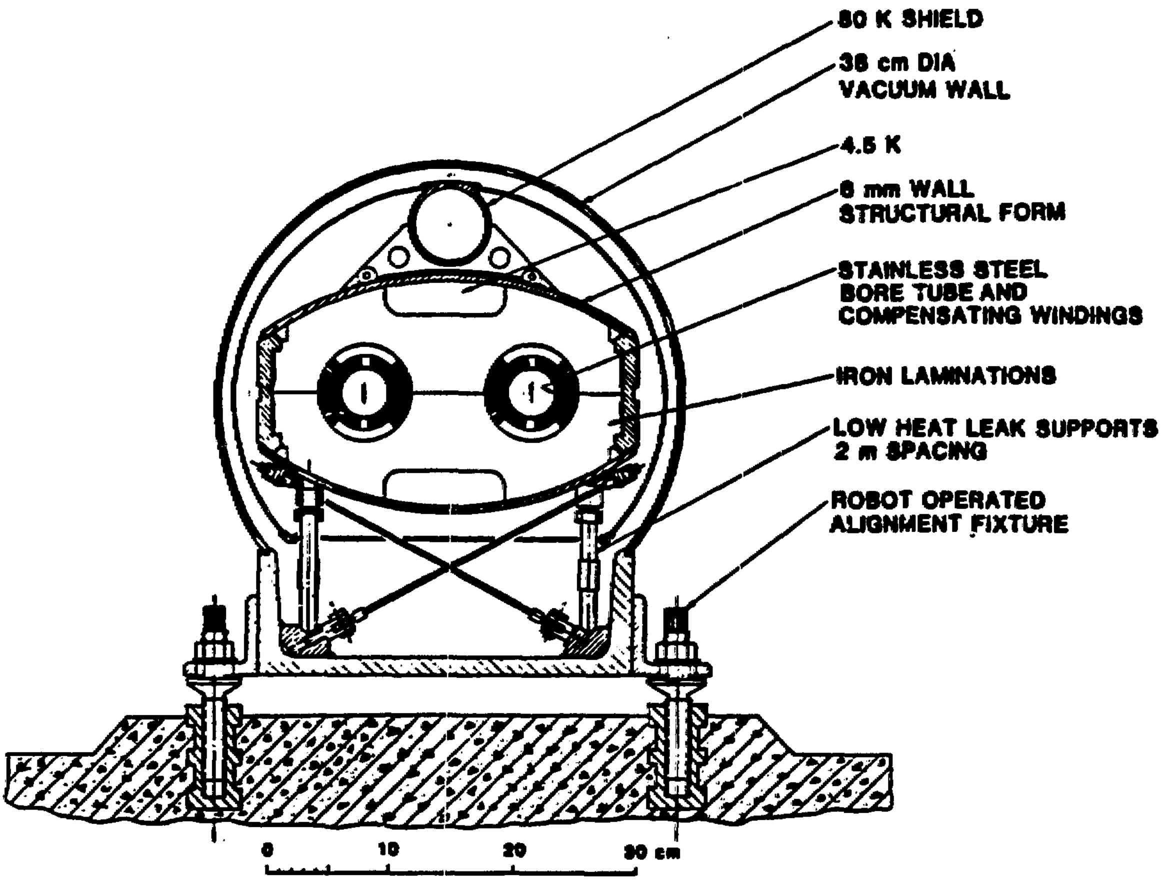


FIGURE 7
Top View Cross-Section
Between Magnets

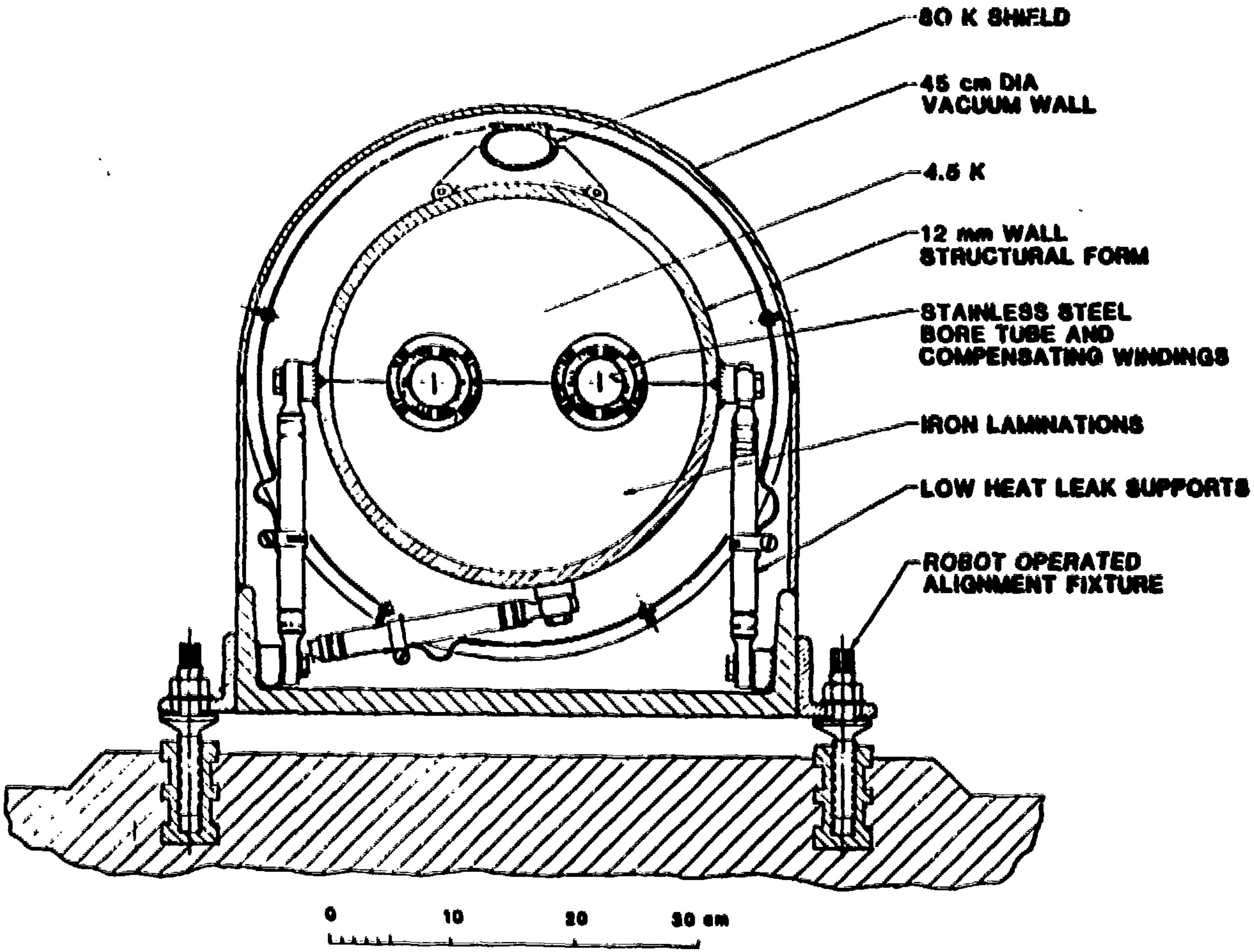
6.5 TESLA, 4.5 K, 4 cm COIL I.D.
13.4 cm BETWEEN BEAM ℄'s

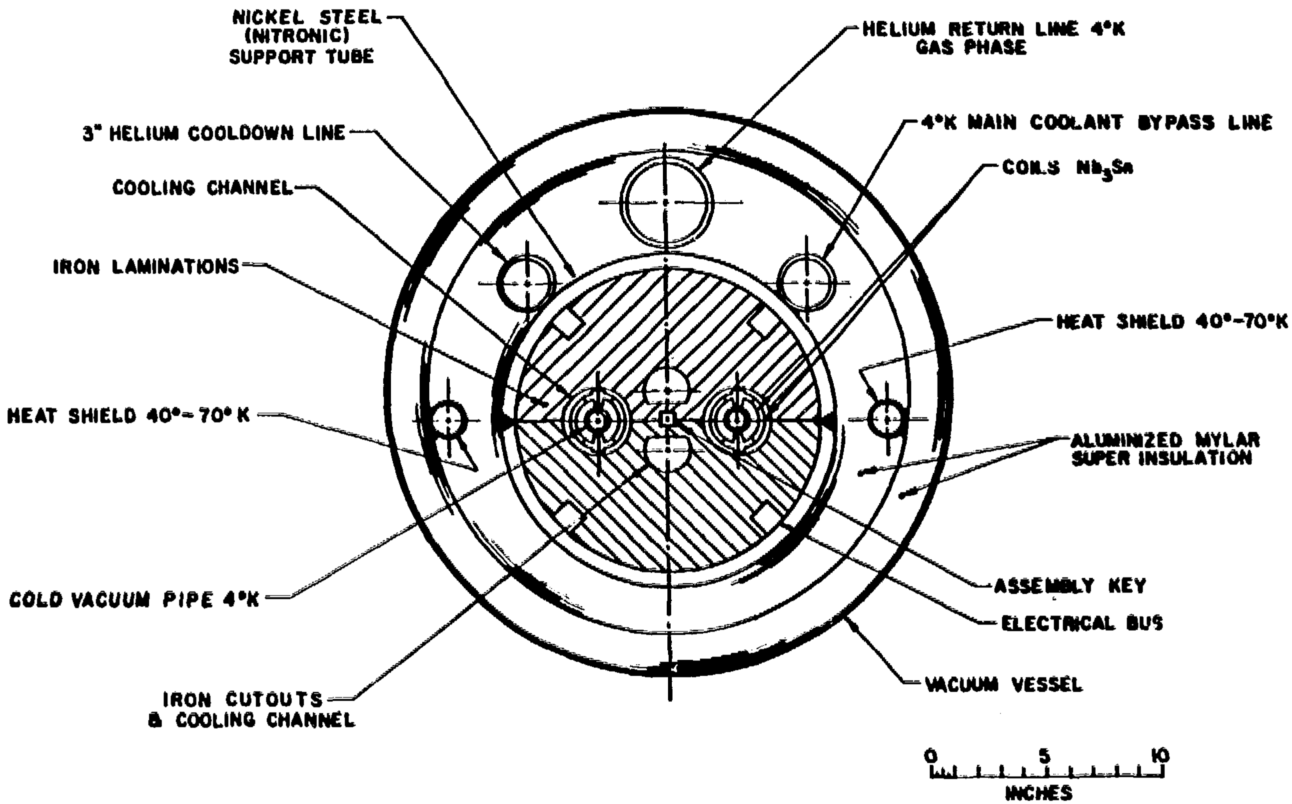


6.5 TESLA, 4.5 K, 4 cm COIL I. D.
13.4 cm BETWEEN BEAM ℄ 's



6.5 TESLA, 4.5 K, 4 cm COIL I. D.
13.4 cm BETWEEN BEAM ℄'s





SCHEMATIC CROSS SECTION OF 2 IN 1 DIPOLE

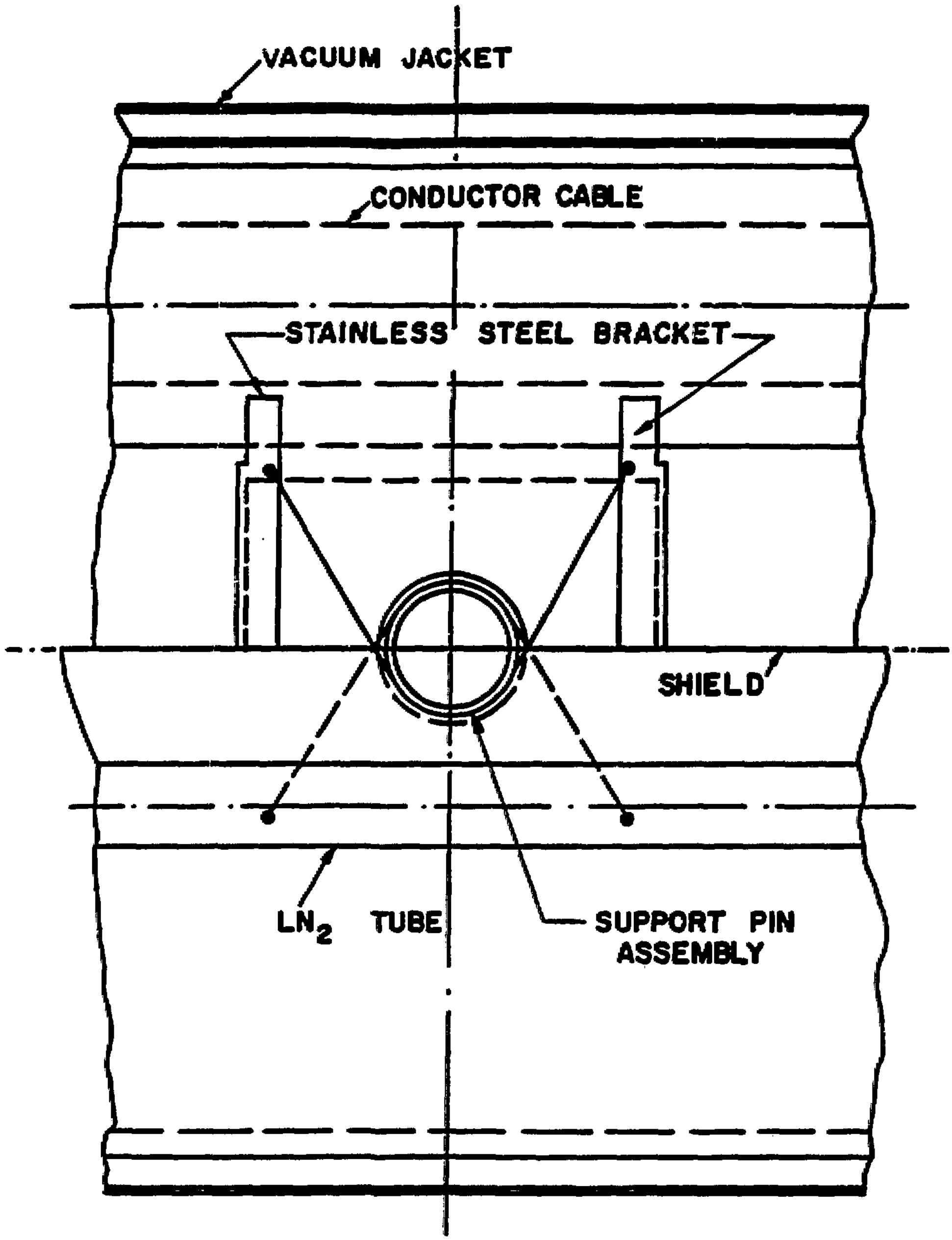


FIG.2 SHIELD/INNER LINE SIDE VIEW - 2X

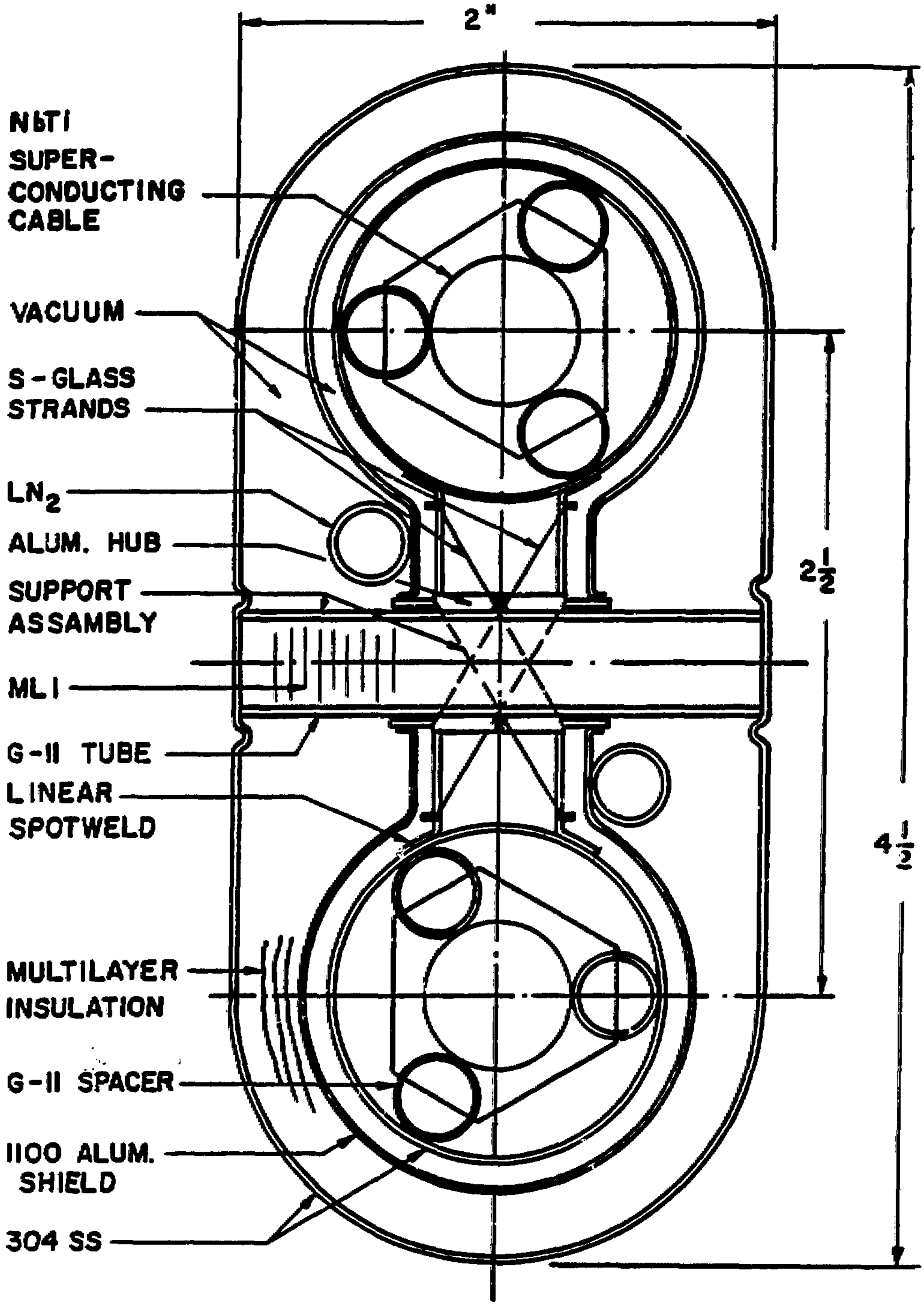


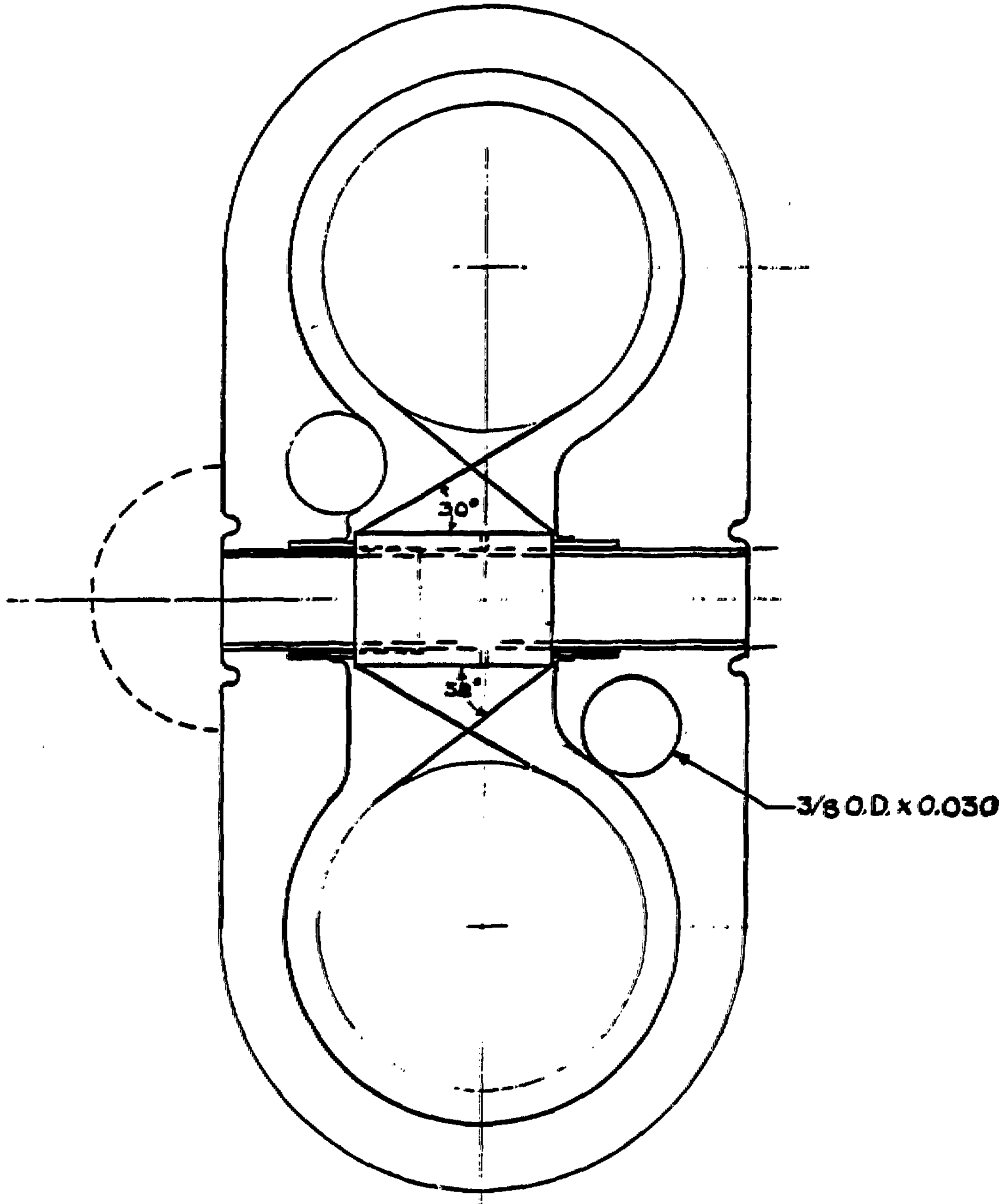
Fig.3 CRYOSTAT CROSS SECTION - 2X

Sub-Cooled Normal Helium

Flow	22.68 g/s
V	0.312 m/s
Inlet Temp.	4.0 K
Inlet Pres.	2.0 atm
Pressure Drop	0.0703 atm (1.033 psi)
Flow Work	1.2 W
Heat Leak	10 W
Temp. Rise	0.1015 K

The liquid nitrogen-cooled thermal shield

Flow	15.75 g/s
V	0.609 m/s
Inlet Temp.	65 K
Inlet Pres.	11.9 atm
Pressure Drop	4.9 atm (71.9 psi)
Flow Work	9.7 W
Heat Leak (per tube)	625 W
Temp. Rise	20 K

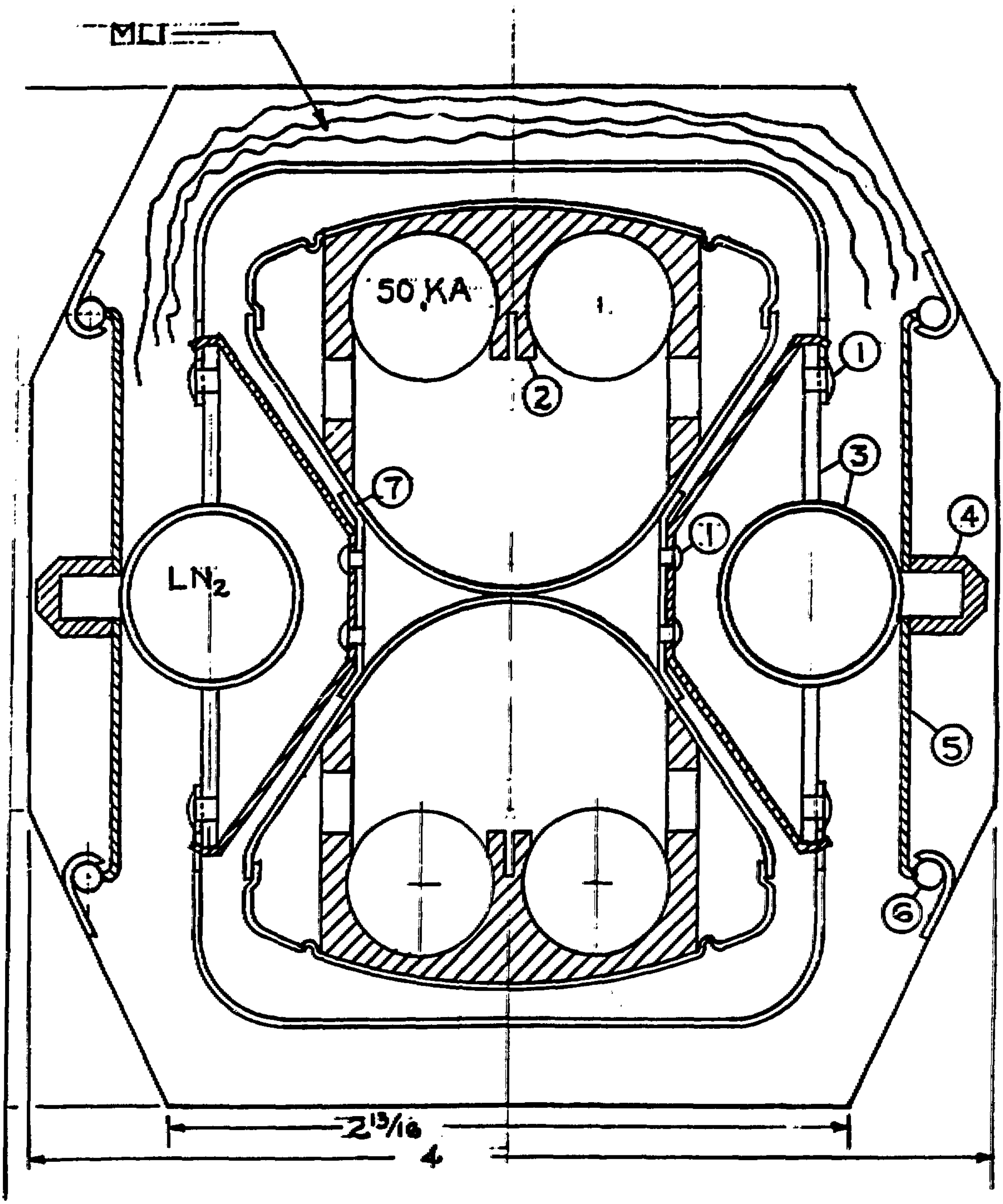


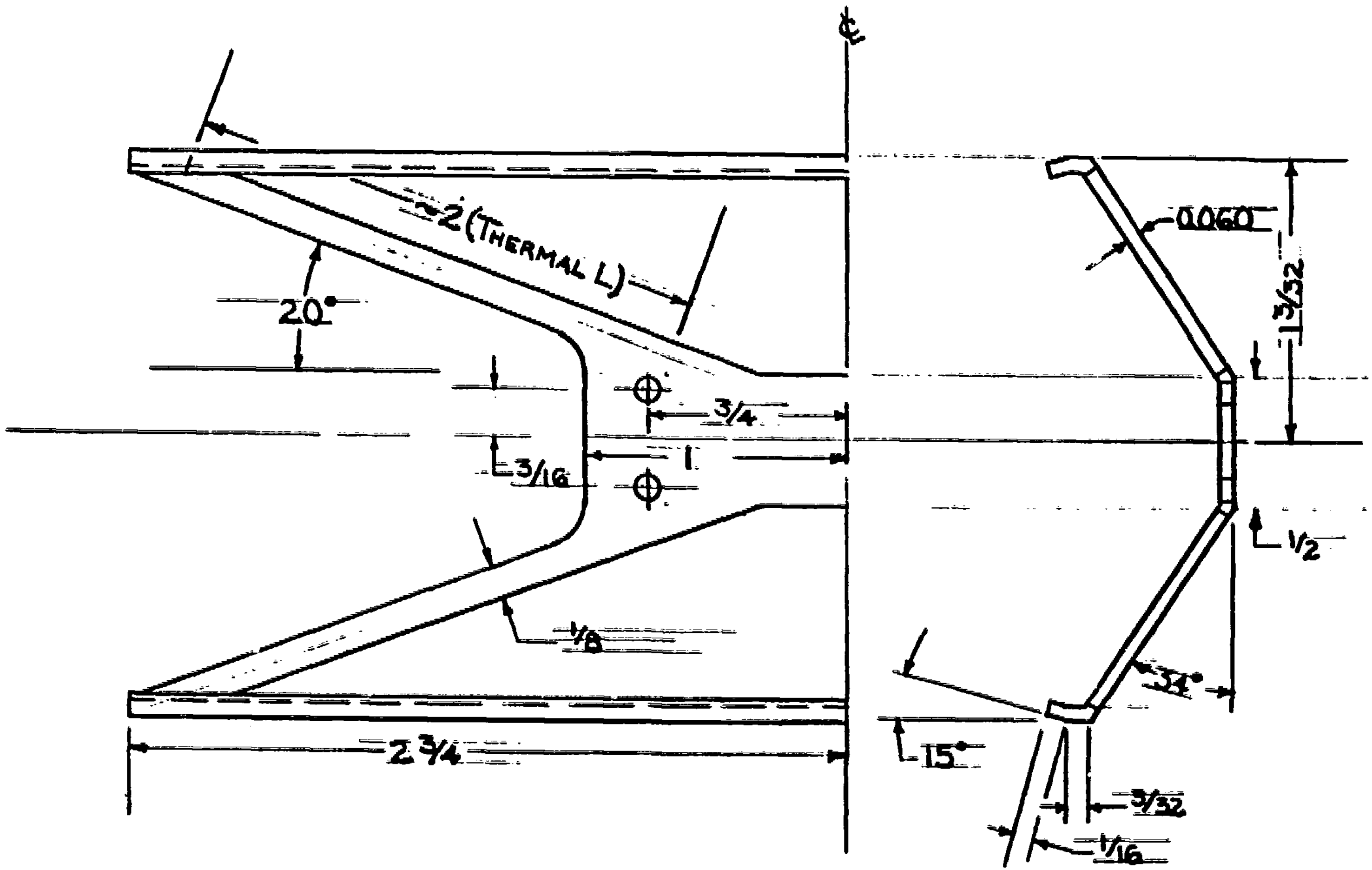
REVISED TEXATRON SKETCH 2X

GEM 10-18-83

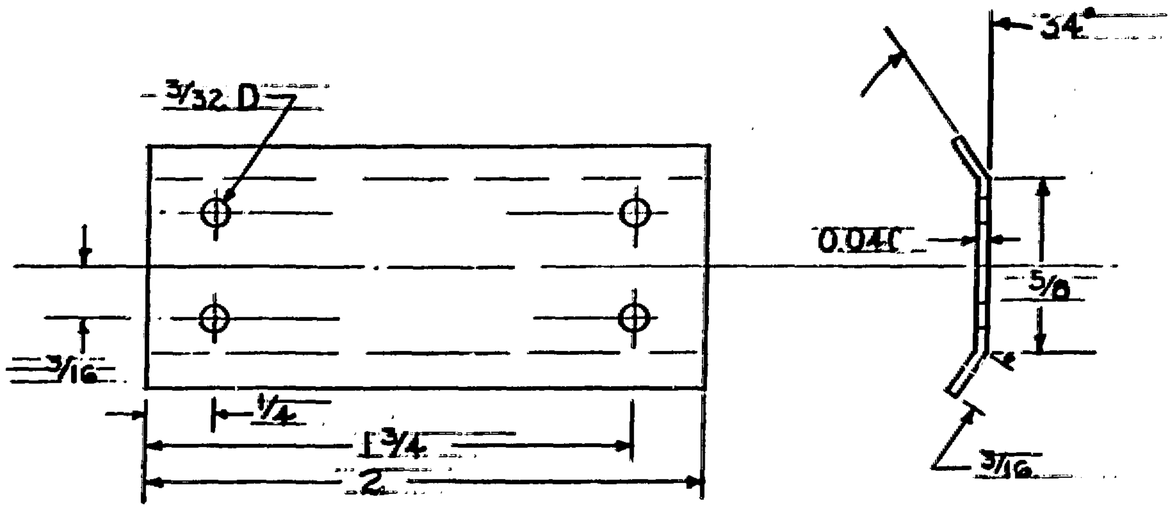
Normal and Superfluid Refrigeration Loads

	4.0 K Normal	1.8 K He II
Heat load/1000 m	45 W	45 W
Carnot work ratio	74 W/W	166 W/W
Carnot refrigeration	3,330 W	7,455 W
Carnot efficiency	20%	15%
Actual power	16.65 kW	49.7 kW
160 km power	2.664 MW	7.952 MW

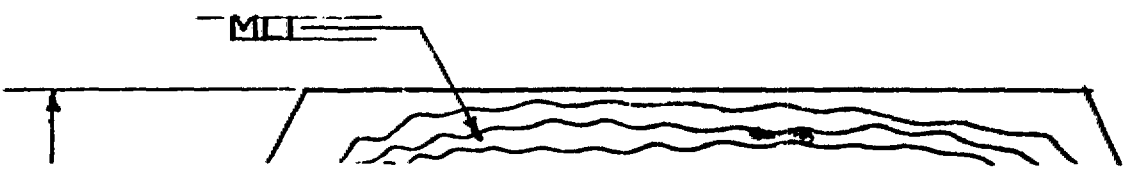

MLI
50 KA
LN2
1
2
3
4
5
6
7
2 13/16
4



INNER ASSEMBLY SUPPORT - G-11



TUBE SUPPORT CLIP – SS



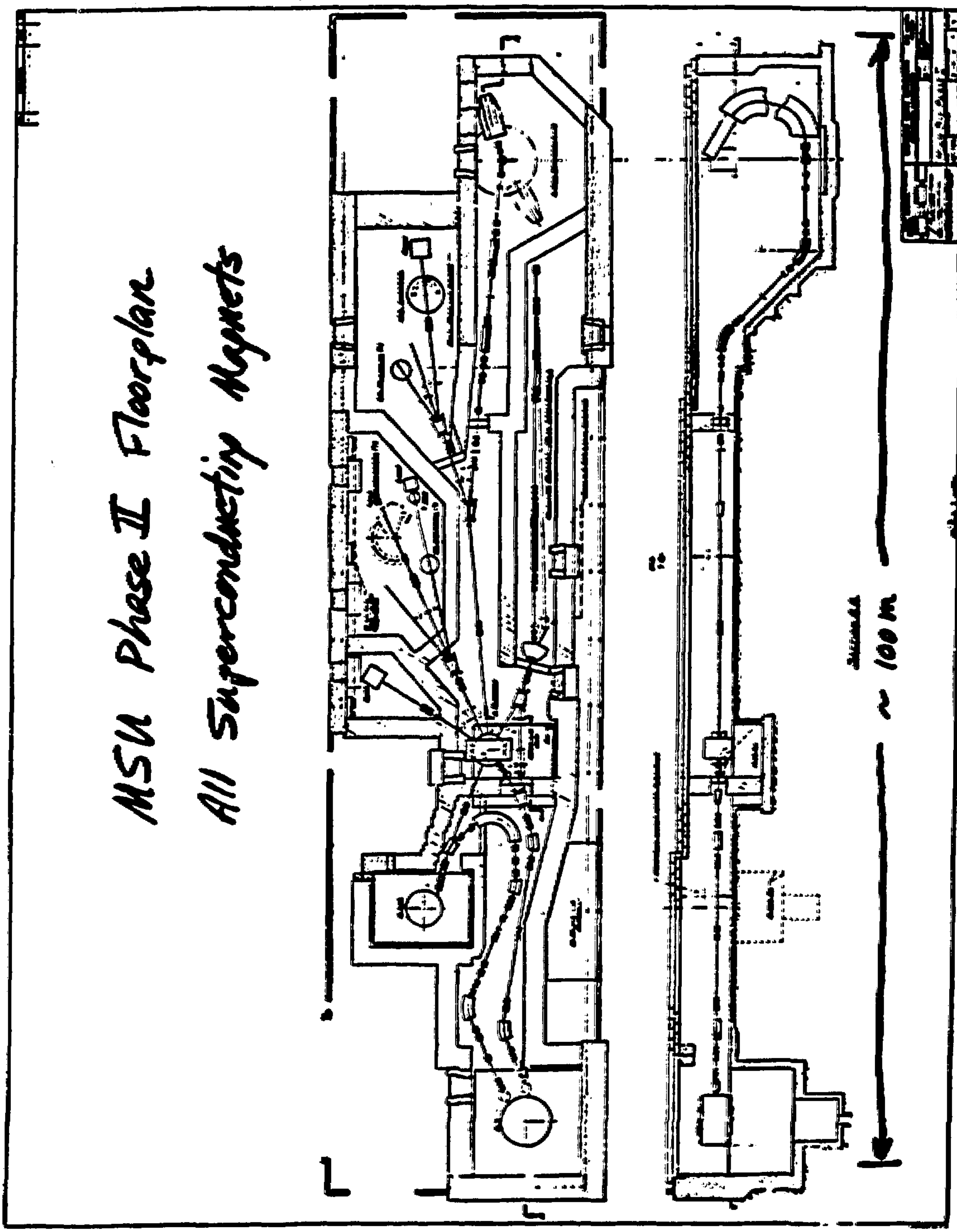
C Magnet Cryogenic Performance

Helium

Flow	32.3 g/s per tube
V	0.3 m/s
Inlet Temp.	4.0 K
Inlet Pres.	2.0 atm
Pressure Drop	0.062 atm/km (0.91 psi)
Flow Work	1.51 W/tube/km
Heat Leak	17.5 W/tube/km
Temp. Rise	0.126 K
Total Heat Leak & Flow Work /Magnet	38-40 W/km
Estimated Heat Load of Two Return Paths	40 W/km

Liquid Nitrogen

Flow	100 g/s
V	0.26 m/s
Inlet Temp.	66.7 K
Inlet Pres.	11.9 atm
Pressure Drop	0.31 atm/km (4.55 psi)
Flow Work	4 W/km
Heat Leak	668 W/km
Temp. Rise	3.6 K/km


MSU Phase II Floorplan
All Superconducting Magnets
~ 100 m

1. Valves ? ~ 1 W each
Cryolab - ?

2. Alternates to G-10 : Glastic
Ravidolite
(Kevlar)
- use between 4 + 80
to avoid creep ?

3. Invar tubing $\frac{1}{10}$ $\frac{\Delta l}{l}$ of S.S.

4. Cu clad S.S. ~ \$5/ft
Al clad S.S. Vac. tight

5. 32% Mn S.S. (no Ni)
non-mag.
stable
strong + ductile at 4 K

6. Conduction cooled leads (Wires)
LN_2 intercepted
no warm gas return or controls
Cu ≳ vapor cooled
Be ~ vapor cooled

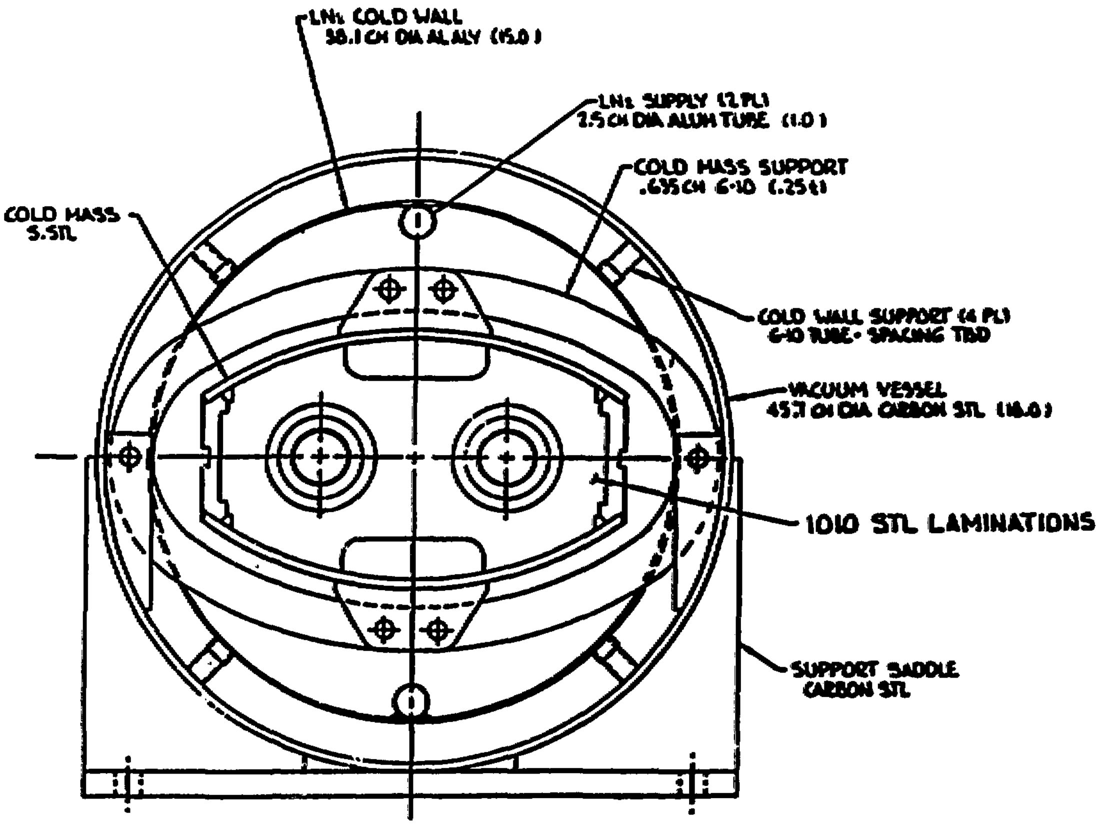
LAWRENCE BERKELEY LABORATORY
CONTRACTED WITH
GENERAL DYNAMICS
FOR

- CONCEPTUAL DESIGN OF A CRYOSTAT
- STRESS AND HEAT FLOW ANALYSIS
- A MANUFACTURING PLAN (CRYOSTAT + COLD MASS)
- A PRELIMINARY COST ESTIMATE (CRYOSTAT + COLD MASS)

1/13/84

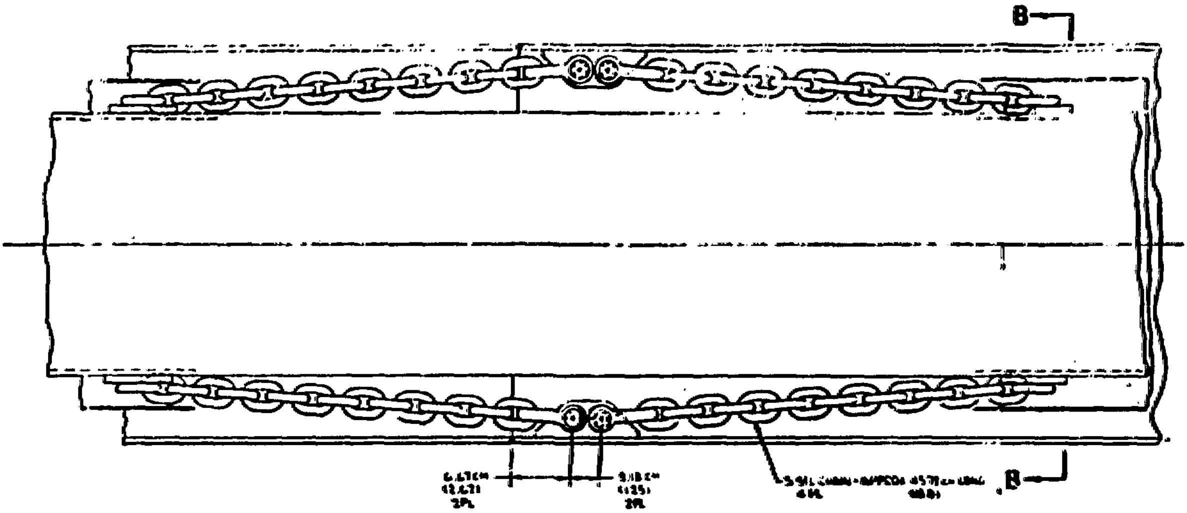
SSC MAGNET STUDY

GENERAL DYNAMICS
Convair Division



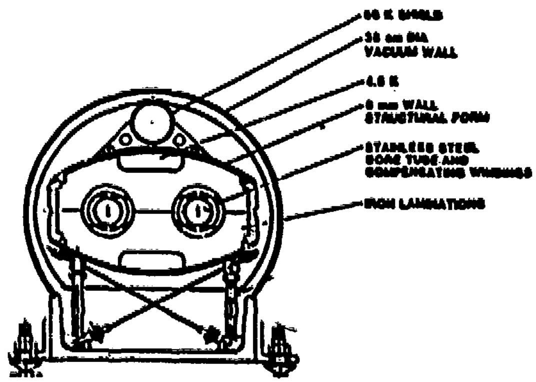
1/13/84

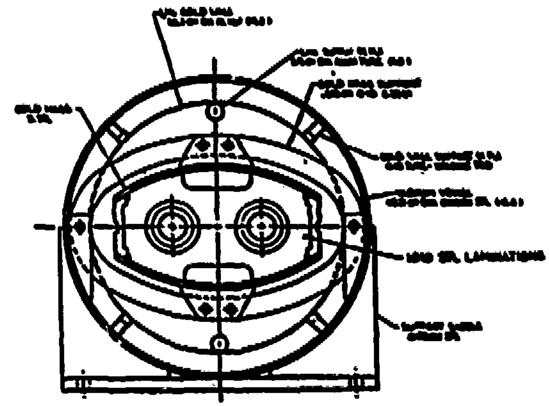
SSC MAGNET STUDY
AXIAL SUPPORT



1/13/84

HEAT LEAK COMPARISON
(60 FT. LONG MAGNET)





HELIUM HEAT LEAK
(WATTS)

	PER SUPPORT	PER MAGNET
G-10 RODS	0.286	1.144
TITANIUM RODS	0.098	0.392
LN_2 SUPPORT	0.05	0.02
	0.438	1.560
RADIATION	-	0.620
TOTAL		2.180

LN_2 HEAT LEAK
137 WATTS

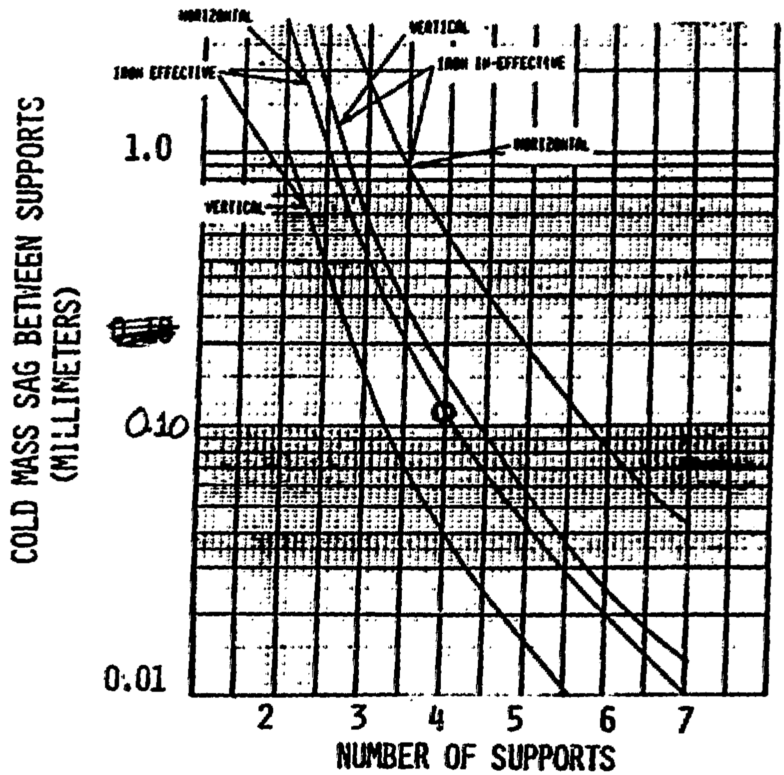
HELIUM HEAT LEAK
(WATTS)

	PER SUPPORT	PER MAGNET
G-10 RING	0.090	0.360
AXIAL SUPPORT	0.004	0.004
	0.094	0.364
	-	0.62
TOTAL		~~0.426~~ 0.984

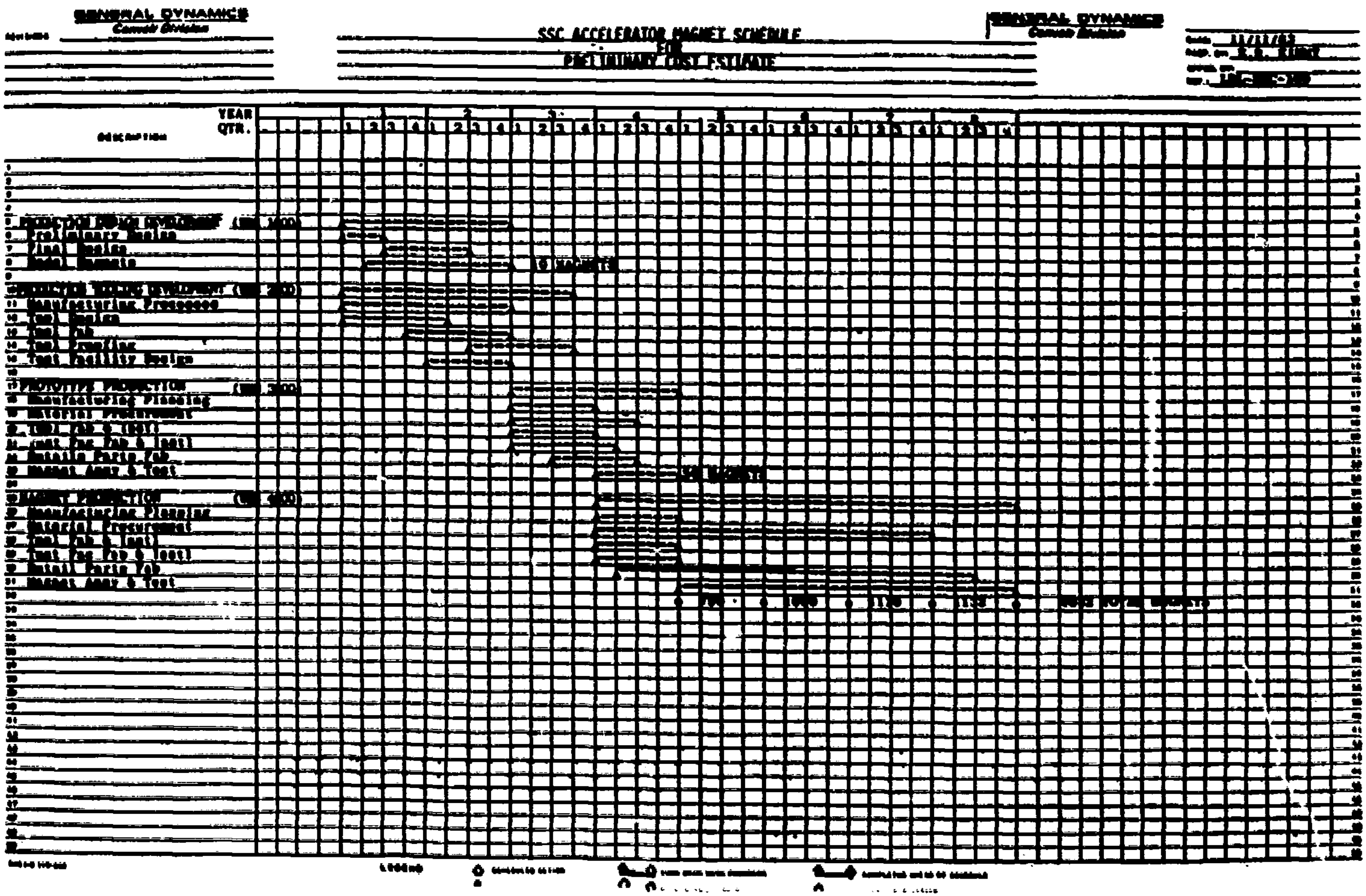
LN_2 HEAT LEAK
138 WATTS

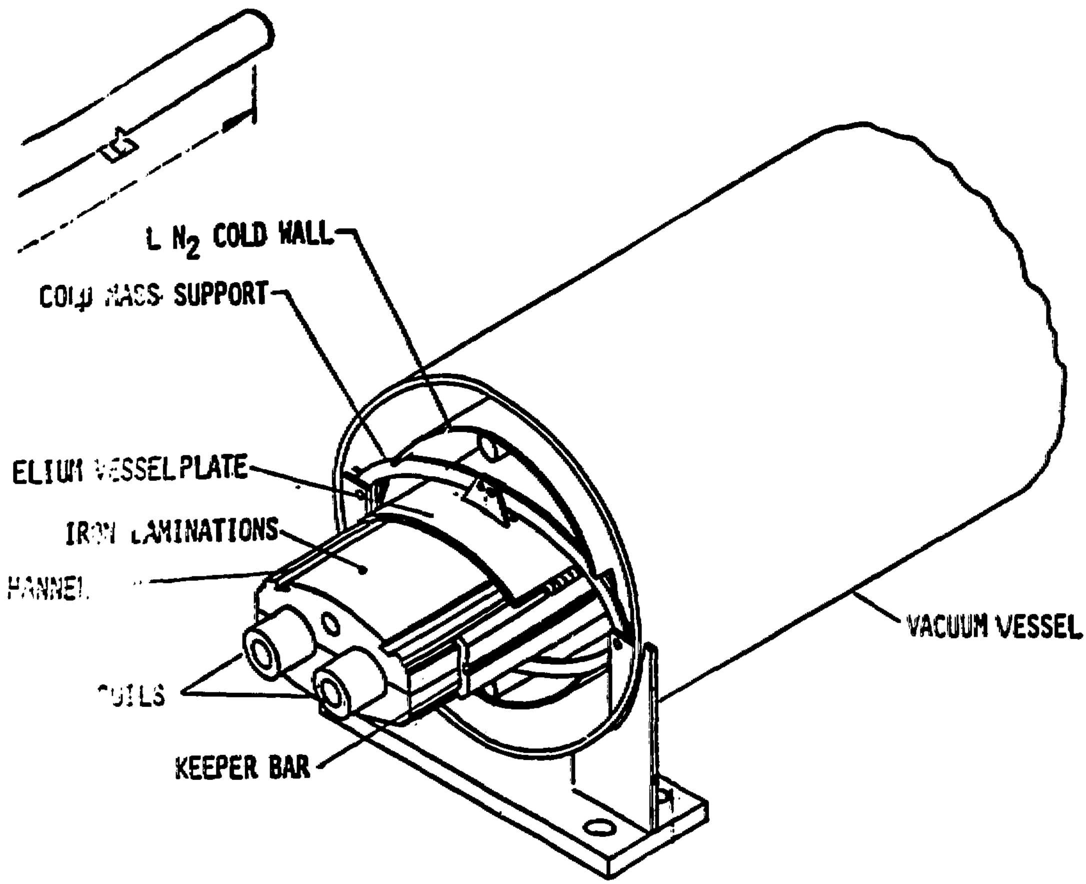
1/13/84

SSC MAGNET STUDY
COLD MASS SUPPORT SPACING



1/13/84


GENERAL DYNAMICS
Convair Division
SSC ACCELERATOR MAGNET SCHEDULE
FOR
PRELIMINARY COST ESTIMATE
GENERAL DYNAMICS
Convair Division
YEAR
QTR.
DESCRIPTION
PRODUCTION DESIGN DEVELOPMENT
Preliminary Design
Final Design
Model Magnets
10 MAGNETS
PRODUCTION TOOLING DEVELOPMENT
Manufacturing Processes
Tool Design
Tool Fab
Tool Proofing
Test Facility Design
PROTOTYPE PRODUCTION
Manufacturing Planning
Material Procurement
Tool Fab & Instl
Test Eqp Fab & Instl
Detail Parts Fab
Magnet Assy & Test
MAGNET PRODUCTION
Manufacturing Planning
Material Procurement
Tool Fab & Instl
Test Eqp Fab & Instl
Detail Parts Fab
Magnet Assy & Test
LEGEND



GENERAL DYNAMICS, CONVAIR DIV.

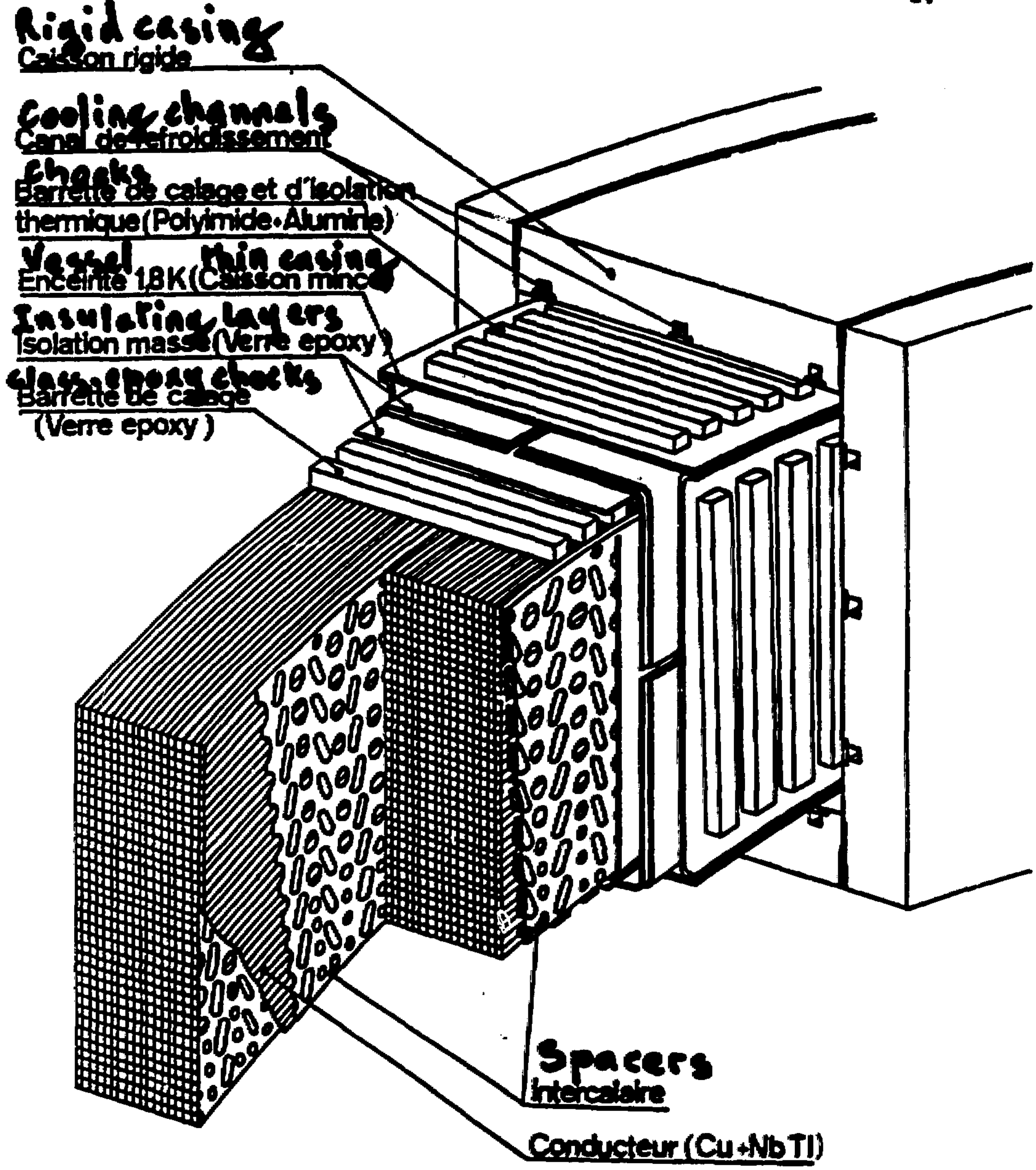
SSC

(SUPER SUPERCONDUCTING COLLIDER)

"PRELIMINARY"

MANUFACTURING SEQUENCE AND FLOW

2.



PERSPECTIVE DE LA BOBINE SUPRA

Superconducting winding cut off.

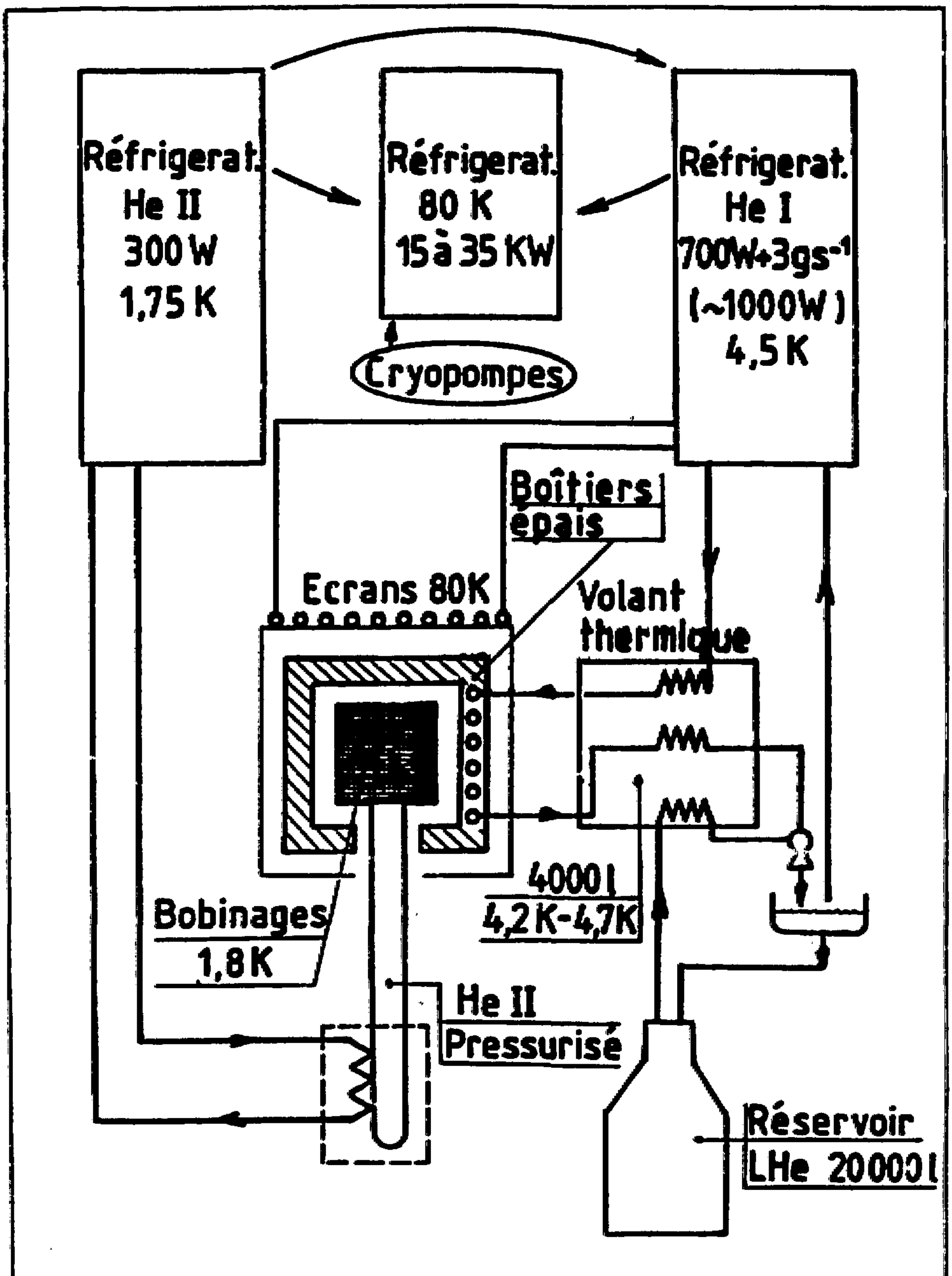
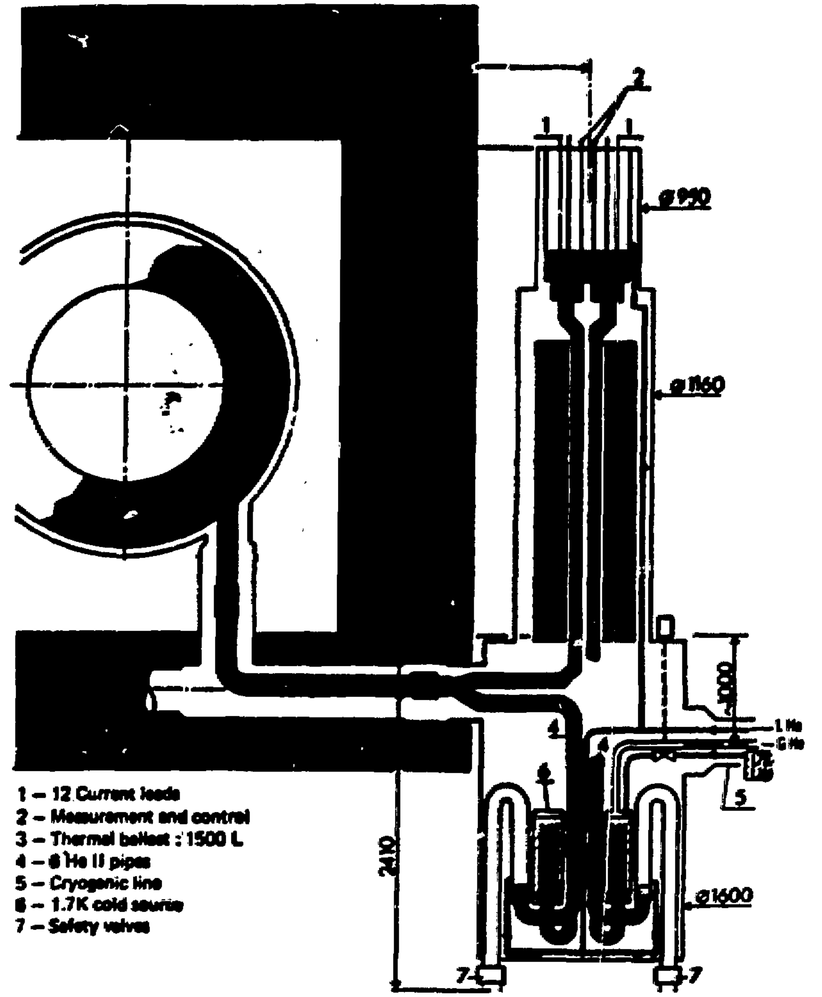


FIG. : 1
SCHEMA DE PRINCIPE
DU CIRCUIT CRYOGENIQUE



One atmosphère He II circuit in cryo satellite.

HELIUM I

HELIUM II, LOW PRESSURE

HELIUM,II, ATMOSPHERIC PRESSURE

Desirable Characteristics of Insulation Systems

R. W. FAST

Good Handleability - Not easily damaged after application

Good Thermal Performance - Low heat leak

Good Predictability of Thermal Performance - Sensitivity to application technique & Stable performance with time

Good Vacuum Performance - High longitudinal pumping speed & Low outgassing rate

Low Cost. - Materials & Application

Present Situation With MLI

Temp. Ranges of Interest	MLI Data	Relevent Experience
300 → 77 K	Lots	Storage tanks, Transfer lines
77 → 10 K	Lots to 20K Some to 10K	SC magnets, LH_2 tanks
10 → 5 K	Little	Little
77 → 4.5 K	Little	SC magnets, LIN shielded storage tanks

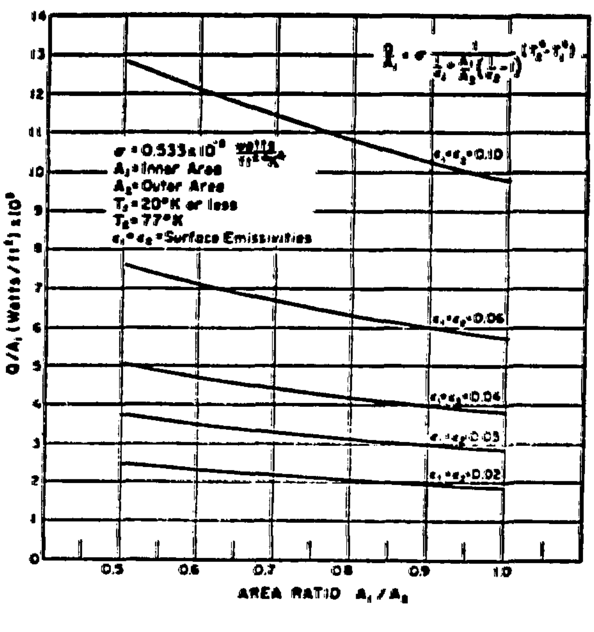
CRYOGENIC ENGINEERING

by

RUSSELL B. SCOTT

Chief, National Bureau of Standards Cryogenic Engineering Laboratory

INSULATION



NASA SP-5027

THERMAL INSULATION SYSTEMS

A SURVEY

By Peter E. Glaser, Igor A. Black,
Richard S. Lindstrom, Frank E. Ruccia,
and Alfred E. Wechsler

Prepared under NASA Contract
by Arthur D. Little, Inc.
Cambridge, Massachusetts

Technology Utilization Division
OFFICE OF TECHNOLOGY UTILIZATION 1967
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

NASA-CR 72605
LMSC-A903316
NTIS N71-24300

INTERIM REPORT

THERMAL PERFORMANCE OF MULTILAYER INSULATIONS

by

G. R. Cunnington, C. W. Keller and G. A. Bell

LOCKHEED MISSILES & SPACE COMPANY
Sunnyvale, California 94088

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

20 April 1971

CONTRACT NAS3-12025

Nasa Lewis Research Center
Cleveland, Ohio 44135
James R. Barber, Project Manager
LIQUID ROCKET TECHNOLOGY BRANCH

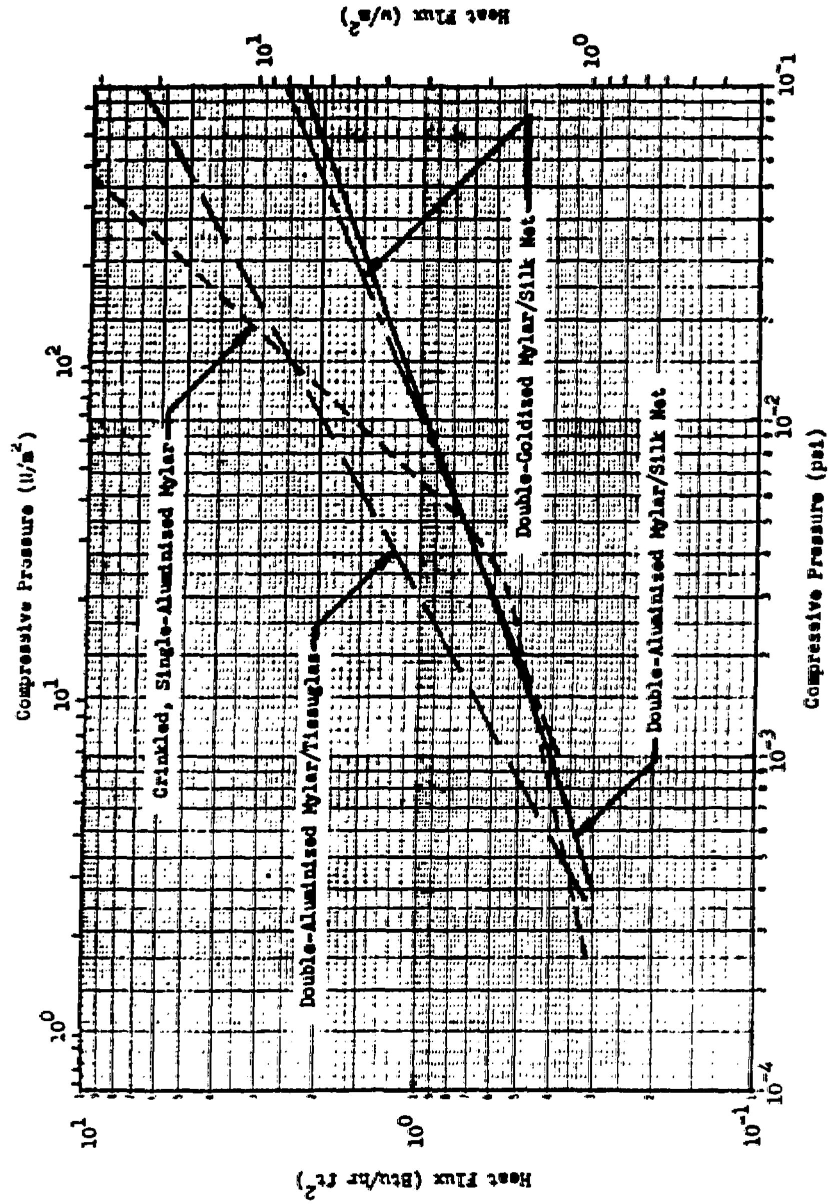
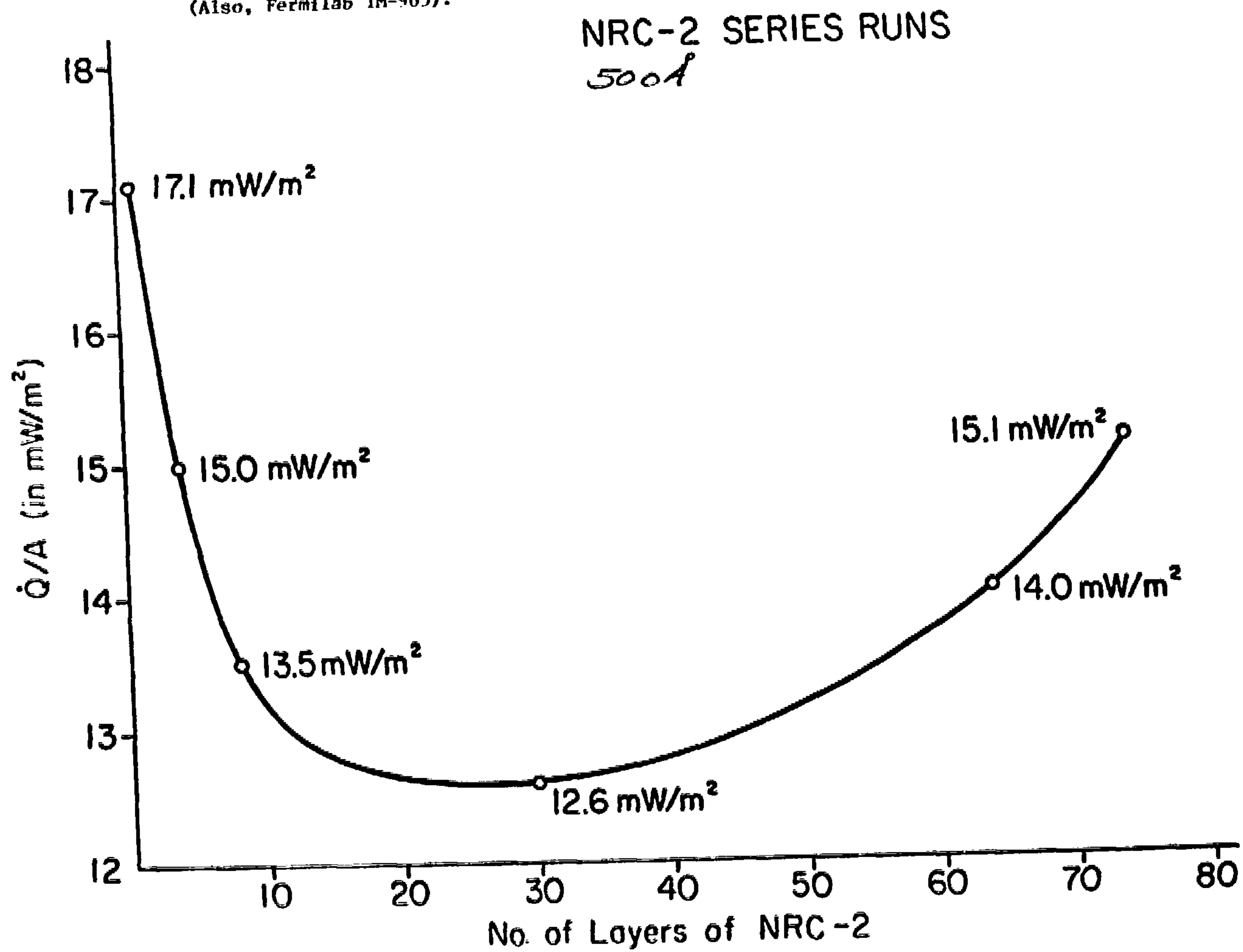


Fig. 5-1 Heat Flux as a Function of Compressive Pressure for Four Multilayer Insulations with $T_H = 500^{\circ}R (278^{\circ}K)$

From: Leung, et. al., Techniques for Reducing Radiation Heat Transfer between 77 and 4.2 K, in "Advances in Cryogenic Engineering, Vol. 25," Plenum, New York (1980), p. 489. (Also, Fermilab TM-905).



From: Leung, et. al., Techniques for Reducing Radiation Heat Transfer between 77 and 4.2 K, in "Advances in Cryogenic Engineering, Vol. 25," Plenum, New York (1980), p. 489. (Also, Fermilab TM-905).

<u>Table I. Heat Transfer from 77.4K to 4.2K</u>

Run No.	System		Heat Transfer Rate Unit Area in mWm^{-2} (mW/ft^2)	Remarks
	4.2K surface	77K surface		
1.	Eccoshield Al tape	Eccoshield Al tape	15.1 ± 0.5 (1.40 ± 0.05)	Calculated value = 16.5 mW/m^2 using emissivities values deduced from paper of Chaussy, et al.
2.	Eccoshield Al tape	Eccoshield Al tape	14.9 ± 0.5 (1.38 ± 0.05)	Same surfaces after being left in lab and in apparatus for 6 months. No degradation observed. Repeatibility of data checked.
3.	Electrolytic Tough Pitch Cu (rinsed with Bright Dip and cleaned with Oakite)	Electrolytic Tough Pitch Cu (rinsed with Bright Dip and cleaned with Oakite)	15.6 ± 0.8 (1.45 ± 0.075)	Experiment was run for 11 days continuously. No sign of degradation observed. Typical method used on large magnets previously constructed at Fermilab.
4.	3M Al tape	3M Al tape	12.4 ± 0.5 (1.15 ± 0.05)	Industrial Tape #425 seems to have better adhesive property at 77K than Eccoshield Tape.
5.	Blackened with black 3M Velvet paint; then 8 layers of NRC-2 wrapped around the black surface	1 layer of Double-side aluminized Mylar epoxied to 77K Cu surface using Crest #7344 epoxy.+	28.8 ± 0.5 (2.00 ± 0.05)	Aluminized Mylar, measured to have a 500 Å aluminum layer on each side.* Outgassing of epoxy detected.

*King-Seeley Company, same supplier as NRC-2.

+Crest Products Company, Santa Anna, California 92704.

Evaluation of Insulation Systems

Method	Handle-ability	Therm. Perf.	Predictability Appl.	Predictability Stability	Vac. Pump Spd	Perf. Outgas	Cost
Low ε Surfaces (plating)	VG	VG	VG	VG (Al or Au)	VG	VG	L
Low ε Surfaces (Al tape)	VG	VG	VG	? (adhesive)	VG	G	L/M
Low ε Surfaces (2-3 layers A.M.)	F/P	VG	G	F (fragile)	G	VG	M
MLI (8-10 layers)							
D.A.M. + Spacer (net or paper)	F/P	G	F	G (fragile)	P	F	M/H
C.S.A.M.	F/P	G	P	G (fragile)	P	G	M/H
Dimpler	F/P	G	F	G (fragile)	F	G	M/H

A.M. = Aluminized Mylar
D.A.M. = Double aluminized Mylar
C.S.A.M. = crinkled single aluminized mylar

MECHANICAL/THERMAL PERFORMANCE σ/λ

		4-80 K		80-300 K		4-300 K	
		PHYS	SI	PHYS	SI	PHYS	SI
SST 304/316	σ	175	1200	75	500	75	500
	λ	3.5	350	30.6	3060	34.1	3410
	σ/λ	50	3.4	2.5	0.16	2.2	0.15
INCONEL 718 50 NI - 18 CR	σ	150	1050	115	800	115	800
	λ	4.6	461	21.6	2160	26.2	2620
	σ/λ	33	2.3	5.3	0.37	4.4	0.31
TITANIUM ALLOY TI 6AL-4V	σ	240	1650	160	1100	160	1100
	λ	2.1	210	12.2	1220	14.3	1430
	σ/λ	114	7.9	13	0.90	11	0.77
EPOXY-GLASS S-GLASS/NASA 2	σ	300	2100	220	1500	220	1500
	λ	0.2	19.9	1.23	123	1.43	143
	σ/λ	1500	106	179	12.2	154	10.5

PHYSICS : σ = KSI, λ = W/CM

SI : σ = MPA, λ = W/M

σ = TENSILE, ULTIMATE

MECHANICAL/THERMAL PERFORMANCE σ/λ

		4-80 K		80-300 K		4-300 K	
		PHYS	SI	PHYS	SI	PHYS	SI
SST 304/316	σ	175	1200	75	500	75	500
	λ	3.5	350	30.6	3060	34.1	3410
	σ/λ	50	3.4	2.5	0.16	2.2	0.15
INCONEL 718 50 NI - 18 CR	σ	150	1050	115	800	115	800
	λ	4.6	461	21.6	2160	26.2	2620
	σ/λ	33	2.3	5.3	0.37	4.4	0.31
TITANIUM ALLOY TI 6Al-4V	σ	240	1650	160	1100	160	1100
	λ	2.1	210	12.2	1220	14.3	1430
	σ/λ	114	7.9	13	0.90	11	0.77
EPOXY-GLASS S-GLASS/NASA 2	σ	300	2100	220	1500	220	1500
	λ	0.2	19.9	1.23	123	1.43	143
	σ/λ	1500	106	179	12.2	154	10.5

PHYSICS : σ = KSI, λ = W/CM

SI : σ = MPA, λ = W/M

σ = TENSILE, ULTIMATE

STRAIN, STRESS, TIME RELATION

$$e = \sigma J = \sigma (J_0 + J_1 t^n)$$

WHERE,

e = STRAIN (in/in)

σ = STRESS (lb/in^2)

$J = \frac{e}{\sigma}$ = CREEP COMPLIANCE (in^2/lb)

$J_0 = \frac{e_0}{\sigma}$ = TIME INVARIANT CREEP COMPLIANCE (in^2/lb)

$J_1 = \frac{e_1}{\sigma}$ = TIME VARIANT CREEP COMPLIANCE (in^2/lb)

t = TIME (min)

n = SLOPE OF $\ln(J-J_0)$ vs. $\ln t$ CURVE (1)

DETERMINATION OF EQUATION PARAMETERS

- FROM EXPERIMENTAL OBSERVATION, FOR THE MATERIALS UNDER STUDY,

$$J_0 = \frac{1}{E_0} \approx \frac{1}{E_{77K}}$$

and $\qquad E_{77K} \approx 2E_{300K}$.

Thus, $\qquad J_0 \approx \frac{1}{2\,E_{300K}}$.

AT NORMAL LOADING RATES,

$$E_{300K} \approx \frac{1}{J_{1\,min}} .$$

Thus, $\qquad J_0 \approx 0.5\,J_{1\,min}$.

- EXPRESSING THE CREEP RELATION IN LOG FORM

$$\sigma\,J = \sigma\,(J_0 + J_1 t^n)$$

$$J = J_0 + J_1 t^n$$

$$J - J_0 = J_1 t^n$$

$\ln(J - J_0) = \ln J_1 + n \ln t$ OR $\ln(J - .5\,J_{1\,min}) = \ln J_1 + n \ln t$

- DATA TAKEN

  - F)
  - A) $\sigma = \frac{F}{A}$

  - Δl)
  - l) $\frac{\Delta l}{l} = e$

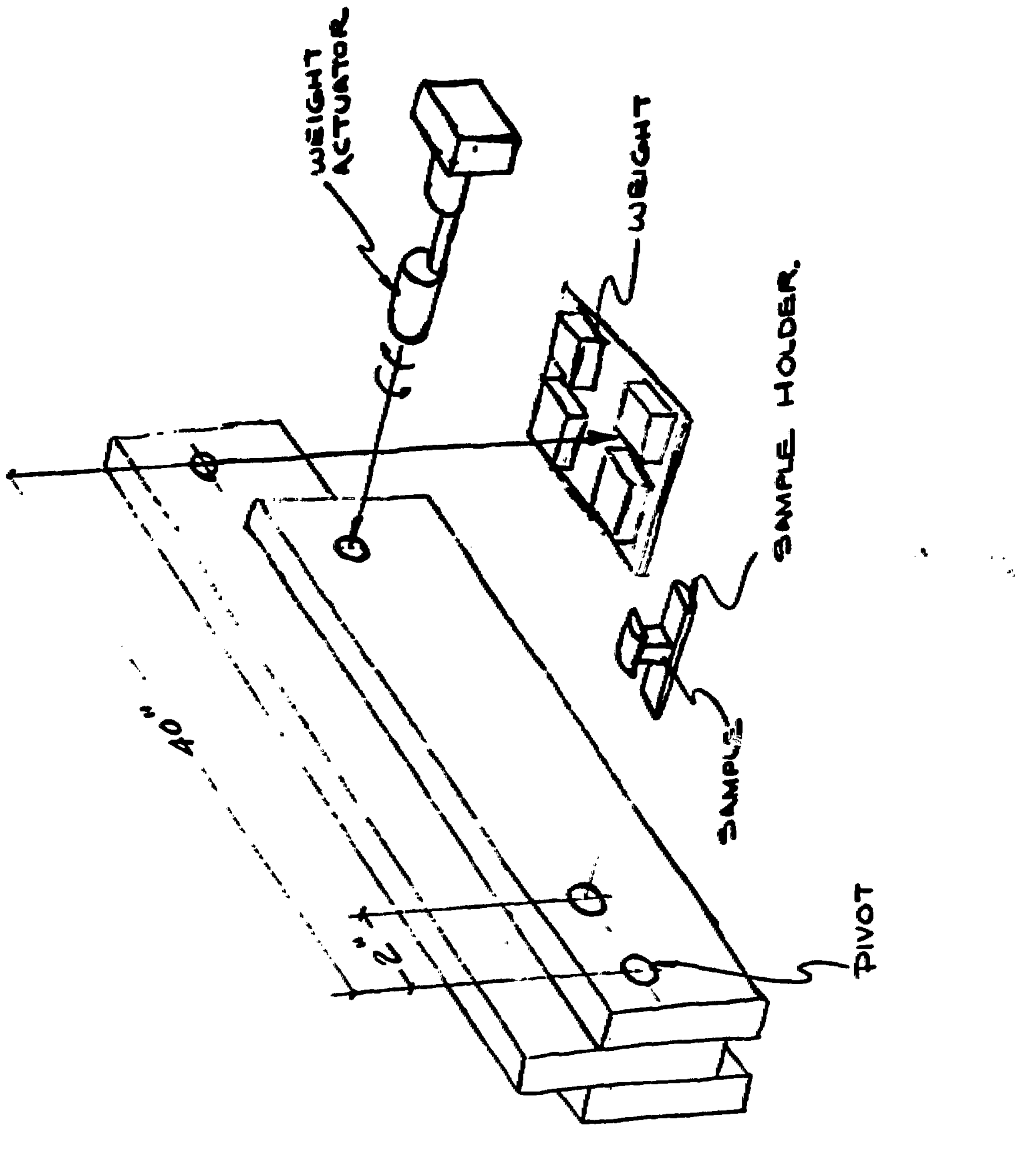
  - t

- FROM DATA TAKEN

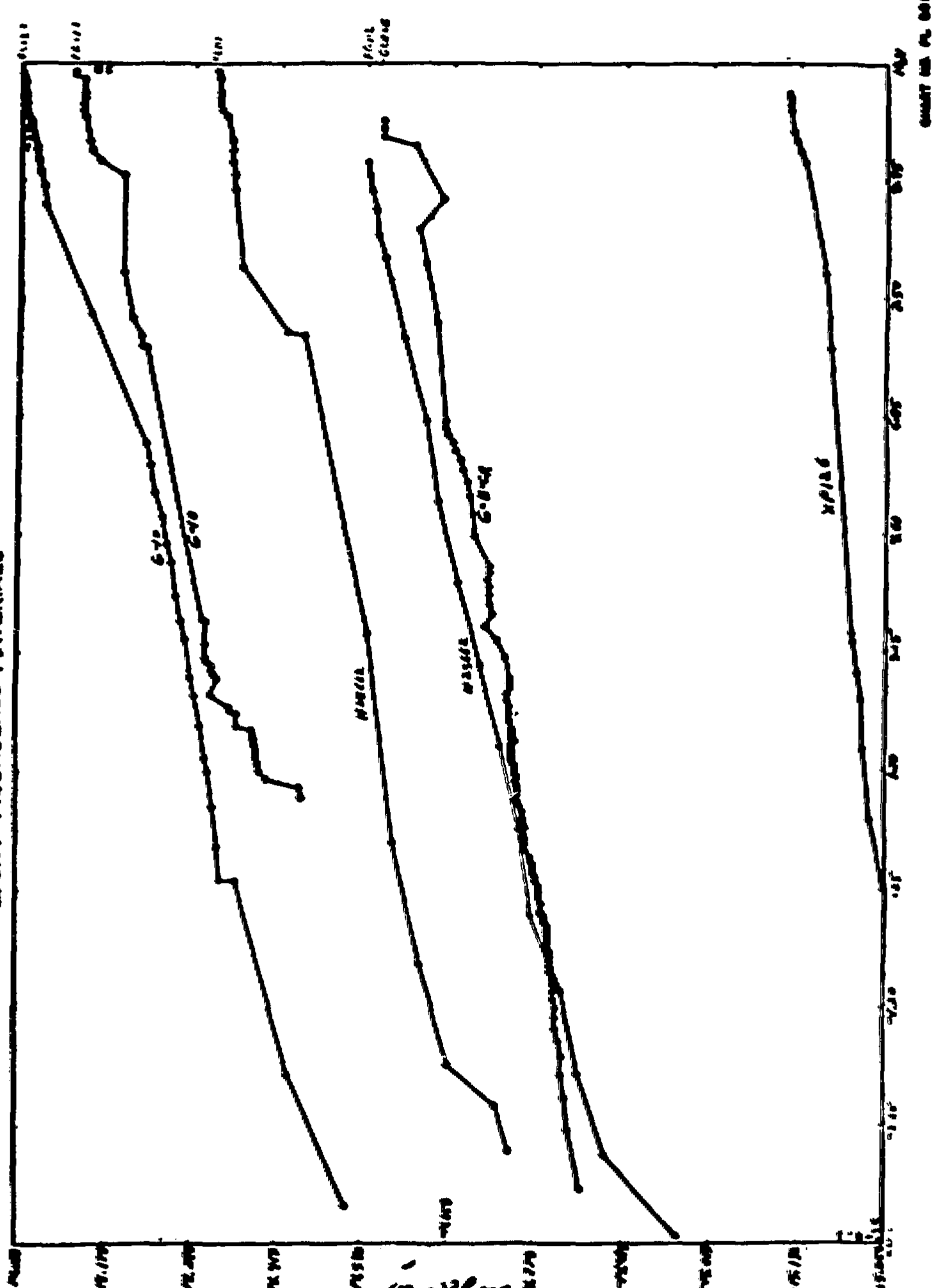
  - $J_{1\,min} = \frac{e_{1\,min}}{\sigma}$
  - $J = \frac{e}{\sigma}$

- FROM THE PLOT OF $\ln(J - .5\,J_{1\,min})$ vs $\ln t$

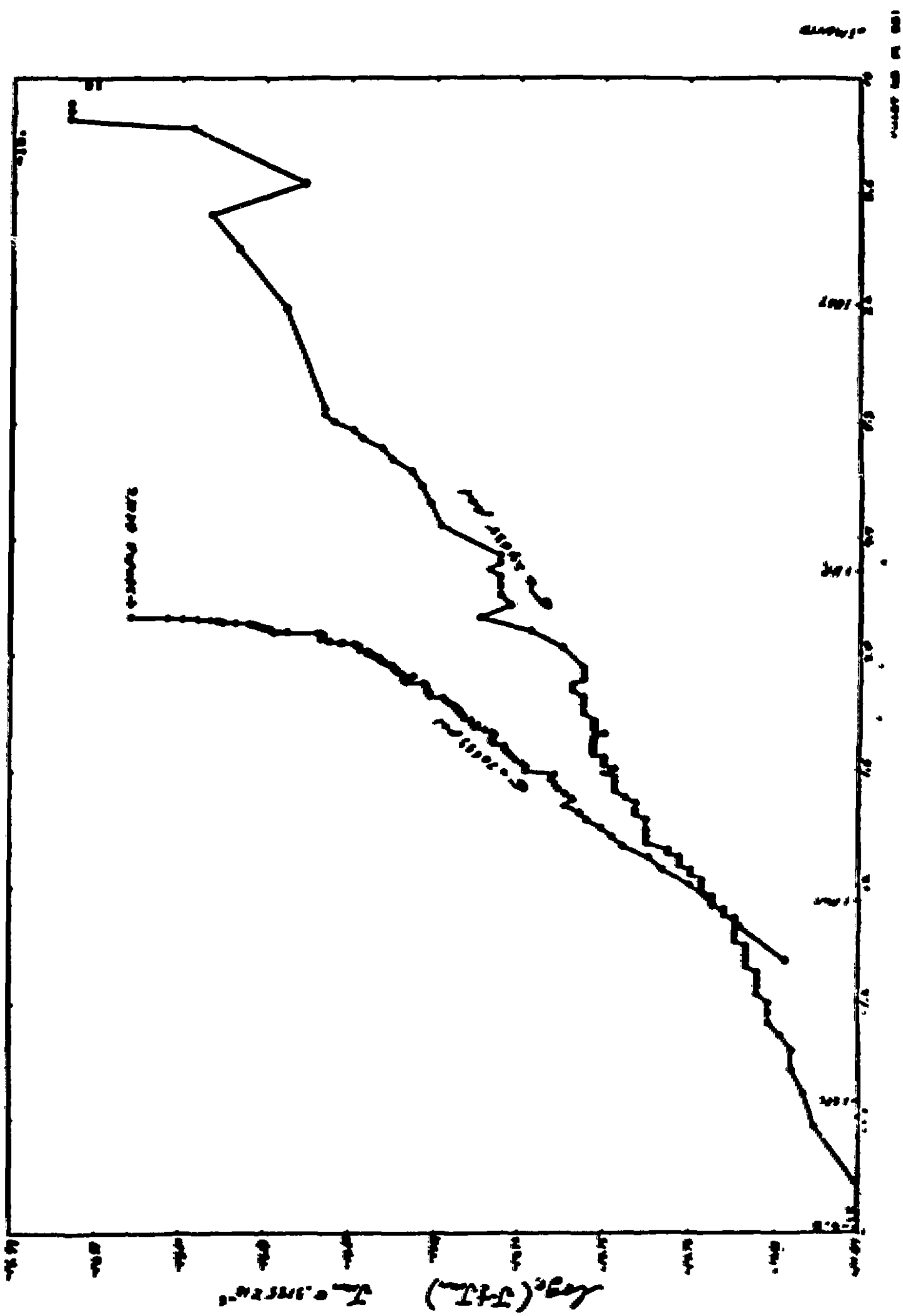
  - n (slope)
  - J_1 (J at t = 1 minute)


WEIGHT ACTUATOR
WEIGHT
SAMPLE HOLDER
SAMPLE
40"
2"
PIVOT

Creep of Various
Epoxy Fiberglass Materials



CREEP OF G-11-CR
FIBERGLASS LAMINATE



CREEP MEASUREMENT RESULTS[1]

Sample[2]	J_0	J_1	n	Manufacturer
G-10 #1	$.5356 \times 10^{-6}$	$.5378 \times 10^{-6}$	.02963	Westinghouse
G-10 #2	$.5649 \times 10^{-6}$	$.5659 \times 10^{-6}$	.03183	Westinghouse
H25662 #1	$.4450 \times 10^{-6}$	$.4437 \times 10^{-6}$	.02975	Westinghouse
H25662 #2	$.3763 \times 10^{-6}$	$.3754 \times 10^{-6}$	.02904	Westinghouse
G-11 #2	$.3786 \times 10^{-6}$	$.3789 \times 10^{-6}$	.0207	Spaulding

Notes

1 All loading compressive at 300K.

2 Standard sample size corresponds to Saver Standoff (.250" wide x 0.600" lg. x 0.350" high). Standard sample load corresponds to Saver Load (38,000 psi). Load is normal to plane of cloth.

EXAMPLE CALCULATION

- Estimate the strain in a G-10 sample after 1 year at 10,000 psi compressive stress
- From the experimental results table, using sample data G-10 #2:

  $J_0 = .5649 \times 10^{-6}$

  $J_1 = .5659 \times 10^{-6}$

  $n = .03183$

- $e = \sigma J = \sigma(J_0 + J_1 t^n)$

  $e = 10000 \left[.56485 \times 10^{-6} + (.5659 \times 10^{-6})(525,600)^{.03183}\right]$

  $e = 10^{-2} \left[.56485 + (.5659)(1.521)\right]$

  $e = .0143$ in/in

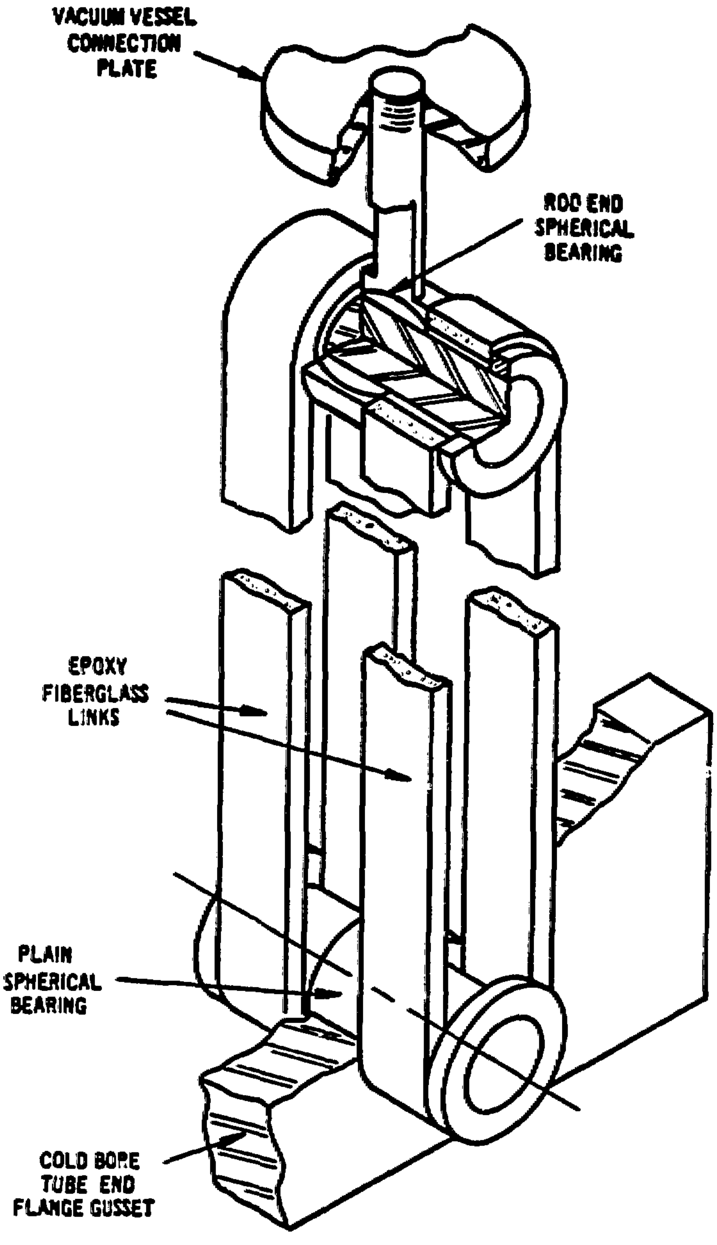

VACUUM VESSEL
CONNECTION
PLATE
ROD END
SPHERICAL
BEARING
EPOXY
FIBERGLASS
LINKS
PLAIN
SPHERICAL
BEARING
COLD BORE
TUBE END
FLANGE GUSSET

FIGURE 1

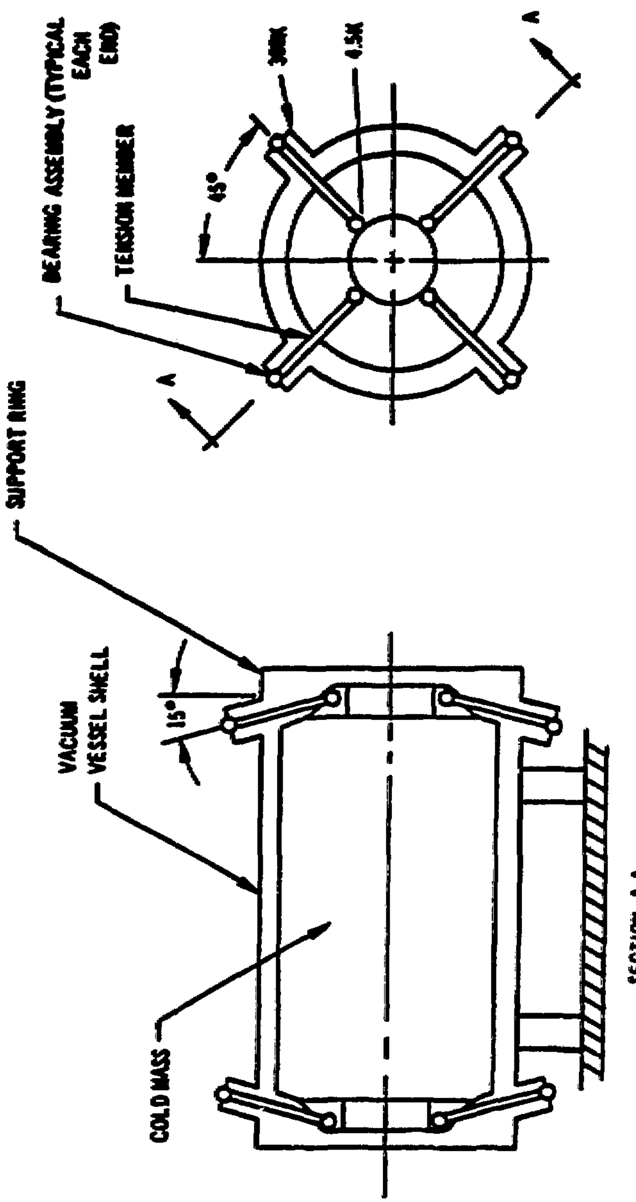

BEARING ASSEMBLY (TYPICAL EACH END)
TENSION MEMBER
300K
4.5K
45°
A
A
SUPPORT RING
VACUUM VESSEL SHELL
15°
COLD MASS
SECTION A-A

FIGURE 2

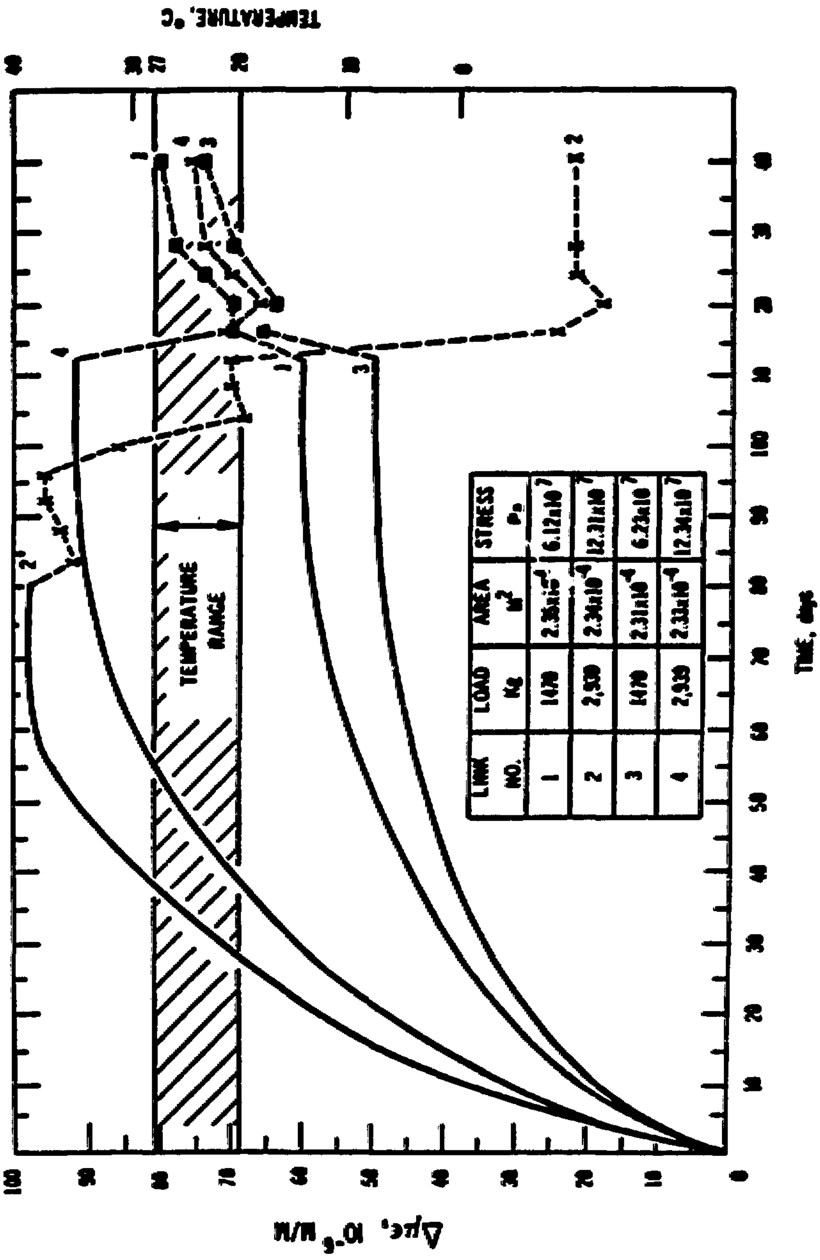
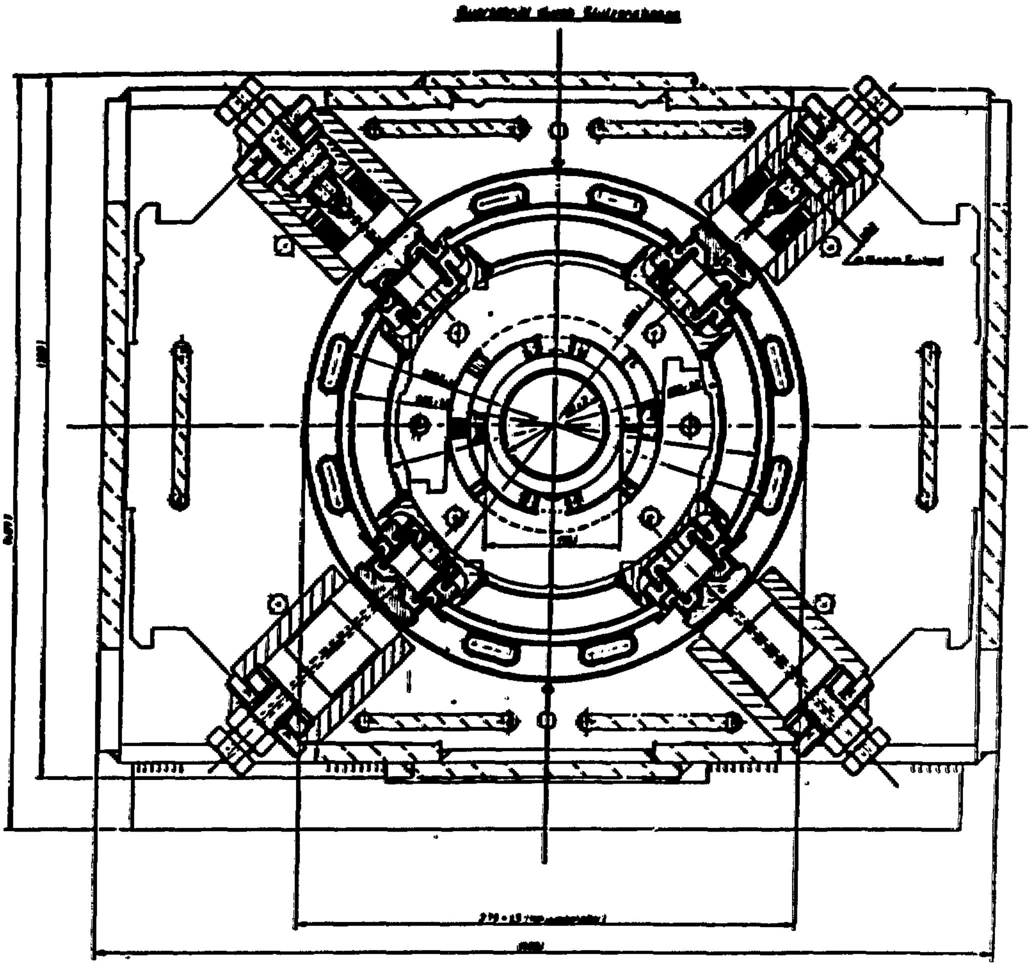
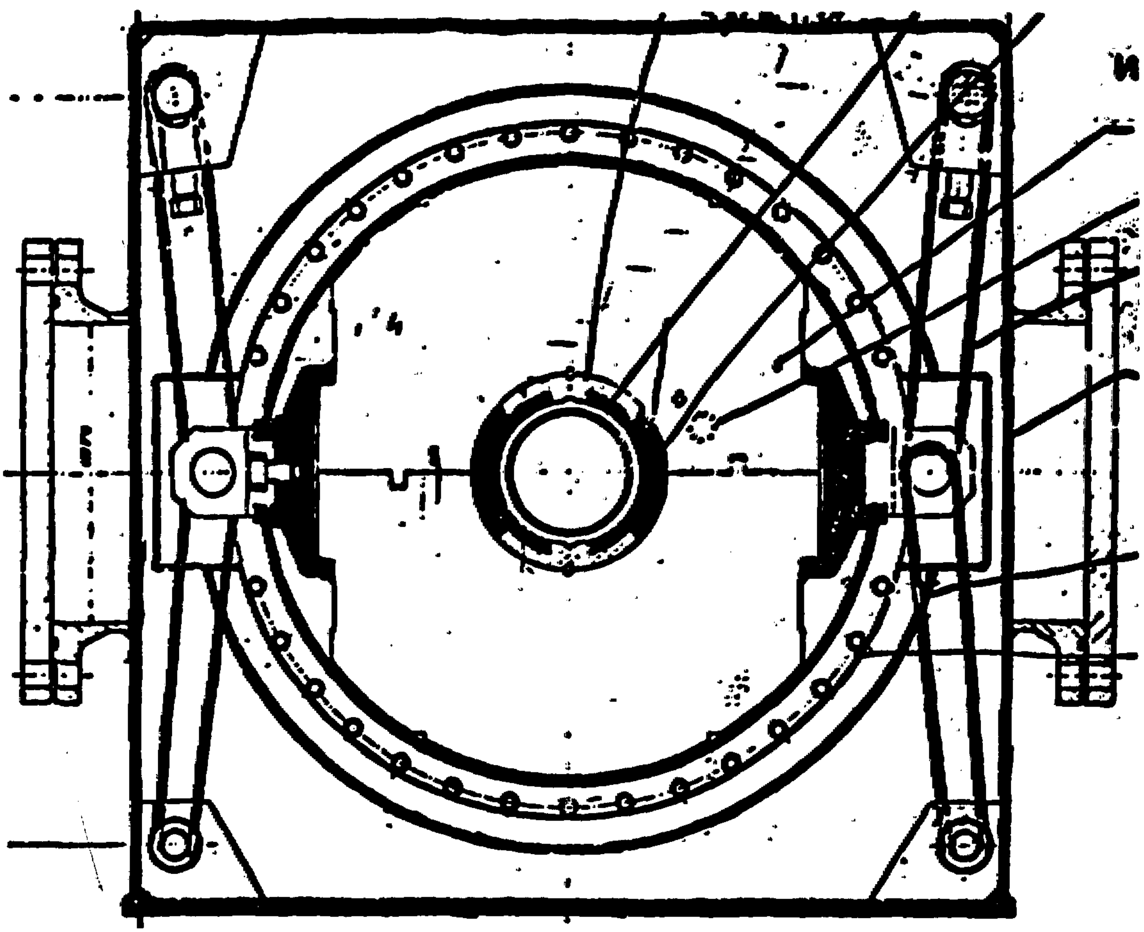

TEMPERATURE, °C
TEMPERATURE RANGE
TIME, days
Δμε, 10^-6 M/M
LINK NO.
LOAD Kg
AREA m²
STRESS Pa
1
1470
2.36x10^-4
6.12x10^7
2
2,930
2.34x10^-4
12.31x10^7
3
1470
2.31x10^-4
6.23x10^7
4
2,939
2.33x10^-4
12.34x10^7

FIGURE 5



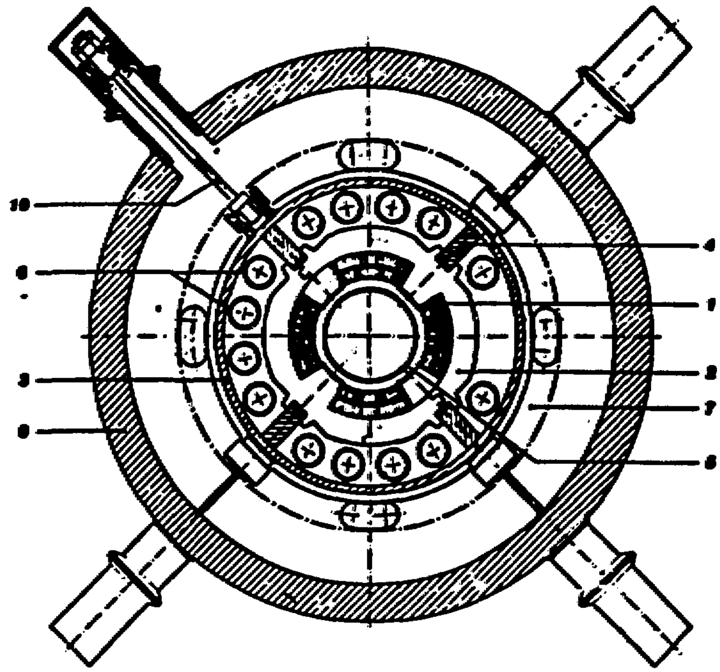
DESY - HERA

WARM IRON DIPOLE

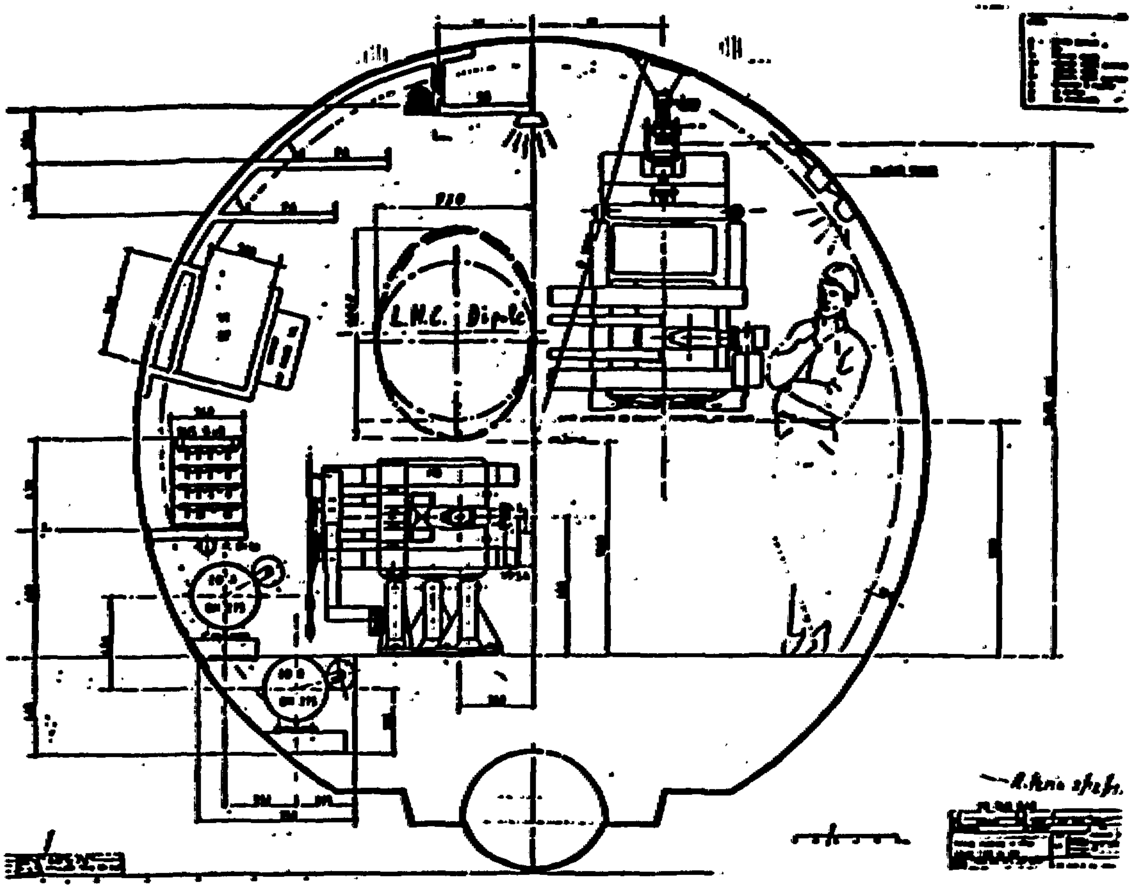


BBC COLD IRON DIPOLE

(The vacuum vessel in rectangular only at the suspension points)

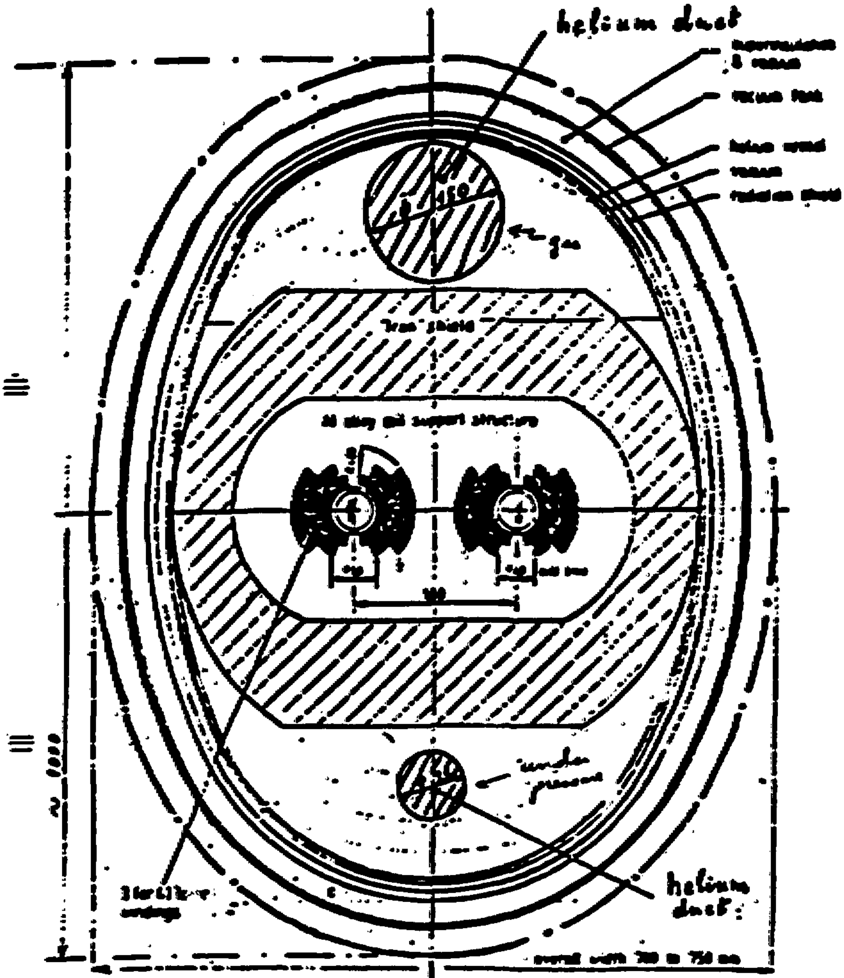


SACLAY QUADRUPOLE FOR HERA



CERN - LHC

LOCATION IN THE LEP TUNNEL



Twin bore (2 in 1) Magnet for the
Large Hadron Collider

$B_0 = 10\,T$
$J_m = 300\,A/mm^2$

CERN - LHC

DIPOLE CONCEPT

REFRIGERATION CYCLES

J. SMITH
Massachussetts Institute of Technology

A broad general discussion was carried out on various possibilities of providing the refrigeration required by the magnet system of the SSC. Highlighted comments are as follows:

1. Capital cost of the refrigeration system can be expected to be a small fraction of the total machine. However, the operating cost of the refrigeration system is estimated to be at least one-half of the total for the accelerator. Therefore, improving efficiency of the refrigerator is more important than initial cost.

2. Magnet design needs to be optimized for lowest cryogenic system operating cost.

3. Compressors represent the largest inefficiency and therefore improvements here are important.

4. Heat load measurements need to be precise otherwise an oversize refrigerator which might not operate efficiently at lower capacity would be implemented.

REFRIGERATION EQUIPMENT WORKSHOP AGENDA

R.C. Longsworth

This workshop will provide a forum for discussing experience with existing helium refrigeration equipment and recommending equipment and system concepts to be incorporated in the SSC refrigeration system. We have been asked by system planners to address the following questions:

> Are there new techniques or hardware which might have an impact on refrigerators for SSC?
>
> What R&D might industry undertake to improve efficiencies of machinery? And under what funding conditions?
>
> Are there ideas for reduction of capital acquisition costs?
>
> What are current thoughts about capital cost vs. refrigerator size?

<u>January 17, 1984 (3:00 to 5:00)</u>

Introductions

Operating experience with present large helium refrigerator systems:

- -- Fermilab Central Liquefier - R. Walker
- -- Brookhaven CBA Refrigerator - R. Gibbs, A. Schlafke
- -- Lawrence Livermore MFTF Refrigerator - W. Chronis
- -- APCI Panhandle Liquefier - J. Stoltz
- -- Airco KRH Liquefier - J. Stiff (tentative)

Summary of "Study of Refrigeration System for Superconducting Power Transmission Line" (Component Type vs. Size, Reliability, Business Factors) - R. Longsworth

<u>January 18, 1984 (8:30 to 12:45)</u>

Open discussion of components for both 1.8 K and 4.6 K refrigerators. Consider efficiency, reliability, maintenance, cost, transient response, etc.

1. Compressors
   - oil lubricated screw
   - oil lubricated reciprocating
   - centrifugal
2. Oil removal equipment and intrumentation
3. Sealing of compressors for ^{3}He use
4. Expanders
   - oil bearing
   - gas bearing
   - reciprocating

SSC REFRIGERATION EQUIPMENT WORKSHOP
SUMMARY REPORT

References:

Agenda
List of Participants
Studies of Refrigeration for Power Transmission

Superconducting - ERDA Report 00-02552-6, 1976
Cryoresistive - GE, Adv. CE Vol. 25, 1979
Refrigerator Survey - NBS Tech. Note 655, 1974

General Comments

1. A reliable refrigeration system operating at 4.2 K can be built with present technology.

2. System cost is dependent on reliability which needs to be defined.

3. Costs should be evaluated on basis of "present value" which capitalizes power and maintenance costs.

4. Heat loads are typically 50% greater than design.

5. Refrigerator should be designed to operate efficiently at turndown conditions, e.g., 60% of maximum load.

6. Need to define transient loading of refrigerator cooldown, warm-up, quenches, loss of vacuum, start-up of system in segments, etc.

7. Need to study dynamic response of refrigerator to transient loads.

8. It is desirable to buffer refrigerator from load with liquid storage or heat exchanger.

9. Historically, plant operators have learned how to live with problems.

10. Reliability is enhanced with liquid helium and liquid nitrogen storage, interconnection of system components, redundancy and bulk transport of refrigeration by pipeline or truck.

11. Redundant components can be used to help cool plant down.

12. Dummy loads (calorimeters) are desirable on refrigerator heat stations.

13. Consider means to control helium losses.

14. Refrigeration cost is strongly dependent on the total number of refrigerators.

15. NBS (Strobridge) refrigerator survey may be high on efficiency because of inconsistencies in accounting for LN_2 cost and high on equipment cost if multiple identical units are built. Use of screw compressors will result in reduced efficiency.

16. This project will require refrigerators that are relatively small, i.e., they fall in the range studied by Strobridge. Equipment can be shop-fabricated.

17. Studies of refrigeration systems for power transmission lines contain much information that can be applied to the present system studies including reliability data, analysis of cost vs. reliability, and considerations of private investment.

18. Consider having enough thermal inertia in the system to permit power to be interrupted during peak loads.

19. The refrigerator must be able to handle moisture getting into the helium. Adsorbers and redundant parallel warm heat exchangers are being used successfully.

20. A neon refrigerator may be used to subcool nitrogen for shield cooling.

21. Helium refrigerators are going through a transition from laboratory-type units to industrial plants. This implies more thought being given to life cycle cost, reliability, safety, maintainability, quality control, and use of experienced operators.

Discussion on Components

1. Compressor - Compressors represent a major cost item and have the greatest impact on operating cost. There was an extensive discussion on oil-flooded screw compressors vs. oil-lubricated reciprocating compressors.

   Two plants now have oil-lubricated recips. It is estimated that their initial cost may be more than screws, including foundation maintenance costs are slightly higher and outage time is slightly greater. These disadvantages tend to be offset by better efficiency resulting in reduced power cost.

   A large number of screw compressors are now in operation and are still preferred by most designers. They have accumulated good reliability records. Motor failures are abnormally high. Work needs to be done to study motor-compressor interactions on helium screw compressors, especially during transients. Motor specification needs to include more attention to quality and quality assurance. Consideration needs to be given to off-design and transient operation.

   More consideration needs to be given to the reliability of auxiliary equipment.

A wide range of efficiencies are reported. With special manufacturing control BNL hopes to achieve 57% isothermal efficiency. Work is being done to improve efficiency by putting a slide valve in the discharge to eliminate over- and under-compression. Specification and cost incentives can encourage careful fabrication to improve efficiency. It was recommended that compressor efficiencies be compared on an isothermal basis.

Screw compressors or recips will probably be used on the SSC. The system will probably be too small to consider a centrifugal machine. Redundancy in the compressors favors screw compressors because of their lower capital cost.

2. Oil Removal - All users were satisfied that effective oil removal systems are available. Oil mist detectors, PPM and Climate seem to be adequate for detecting oil mist.

   The effectiveness of charcoal and molecular sieve downstream of the compressor is questionable and needs to be studied.

3. Sealing of Compressors for ^{3}He use - not discussed.

4. Expanders

   Figure 4.3 of report COO-02552-5 is still valid for selecting turbine type and estimating efficiency.

   Oil-bearing expanders are generally considered to be more tolerant to transients than gas bearings, however, the following developments are improving gas bearing turbines.

   Magnetic bearings for speeds less than 40,000 rpm - Sulzer
   Radial self-acting bearings - Mafie-Trench
   Improved thrust bearings - Creare

   The system, including controls, needs to be designed to protect the turbo expanders.

   Reciprocating expanders are favored for wet expansion and small sizes. They are reasonably efficient and are very tolerant of pressure and temperature transients.

5. Cold Components

   Use of cold pump to circulate helium might permit greater spacing between refrigerators, thus fewer refrigerators.

   Efficiency is reduced from conventional data by 5 to 15% due to heat leak. The cold pump and cold compressor in the CBA refrigerator seem viable but need to be tested.

   Ejectors are only economical in small refrigerators.

6. Heat Exchangers

The SCC refrigerators are of a size that is good for plate-fin type heat exchangers. Dust problems reported by FNAL were due to an unusual problem in the salt bath during brazing. Trane now vacuum brazes in the U.S. Advantages are a) cleanliness, b) can braze more complex geometries, and c) maximum pressure increased to 1,400 psi.

70% of cores are leak-free in vacuum. Balance of units can be easily sealed at customer facility.

Plate fin exchangers do not tolerate thermal shocks very well. System must be designed to avoid freezing LN_2 when cold gas is dumped into the warm exchanger.

Horizontal orientation is desirable for fabrication and service but has a small efficiency penalty.

Answers to Questions

1. Are there new techniques which might impact an SSC refrigerator.

   Use of cold circulating pumps and compressors.

2. What R&D might industry undertake to improve efficiency of machinery. Under what funding conditions?

3. Are there ideas for reduction of capital acquisition cost?

   Private investment in refrigerators (sale of refrigeration) will be encouraged by:

   a) Use of a few large units
   b) Buffers to help isolate the refrigerators from the load

4. What are current thoughts about capital cost vs refrigeration size?

   Strobridge related that cost is proportional to power exp. 6.8 is valid for one-of-a-kind systems but the exponent is greater if multiple identical systems are built.

Recommendations

1. Test cold pump and cold compressor on CBA refrigerator.

2. Update '76 refrigerator survey with emphasis on compressor efficiency and reliability.

3. Update '74 refrigerator survey to clarify overall system efficiency.

4. Perform a system analysis to determine optimum refrigerator size and cost reliability tradeoffs.

5. Give a lot of thought to non-steady state operation.

6. Give more thought to operating cost and maintainability.

SIMULATION, CONTROLS AND INSTRUMENTATION

G.T. Mulholland

Fermilab

Computer Process Control Systems for accelerator cryogenics dominated the discussion. Two of the four source cryogenic systems represented were developed, distributed CPCS, one an extension of accelerator controls and the other a commercial stand-alone unit. Commercial units complete with software to the applications level are aggressively priced and increasingly broadly available. The questions peculiar to the distributed nature of application raised questions of communication architecture that will require further study. Early simulation, Fermilab Saver careful test and measurement, and instrumentation experience should aid the convergence of the CPCS requirements. The pilot control system should be up and running before the pilot magnet system or individual magnet test.

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WORKSHOP ON CRYOGENICS FOR THE SUPERCONDUCTING SUPER COLLIDER

January 17-19, 1984

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