MASTER

FINAL REPORT
CRYOGEN SYSTEM ANALYSIS
FOR THE
MIRROR FUSION TEST FACILITY

BY
R. T. Parmley, R. F. Hausman and L. G. Naes

JUNE 1979

PALO ALTO RESEARCH LABORATORY
LOCKHEED MISSILES & SPACE COMPANY, INC.

PREPARED FOR
UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
LIVERMORE, CA 94550
PURCHASE ORDER 1025609

LMSC-D673326

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ABSTRACT

The Mirror Fusion Test Facility being designed and constructed at the Lawrence Livermore Laboratory requires a liquid helium liquefaction, storage, distribution, and recovery system and a liquid nitrogen storage and distribution system. To provide a powerful analytical tool to aid in the design evolution of this system through hardware, a thermodynamic fluid flow model was developed. This model allows the Lawrence Livermore Laboratory to verify that the design meets desired goals and to play "what if?" games during the design evolution. For example, what if the helium flow rate is changed in the magnet liquid helium flow loop; how does this affect the temperature, fluid quality, and pressure?

This final report defines the cryogen system that was analyzed (consisting of the LHe subsystem, the GHe recovery subsystem and the LN₂ subsystem). It details the program assumptions, the theoretical basis for the analysis and limitations of the output. Several parametric runs were performed to illustrate the use of the program. Special detailed analyses were also performed on components such as the recuperator in the helium gas recovery system.

Recommendations for future work complete the final report.

FOREWORD

The Final Report, LMSC-D673326 and the Program Users Manual LMSC-D673325 (under separate cover) were prepared for the Lawrence Livermore Laboratory (LLL), University of California, under Purchase Order No. 1025609. Mr. W. H. Sterbentz and R. L. Nelson of LLL were Technical Monitors for the program.

The Lockheed Palo Alto Research Laboratory conducted the program within the Thermophysics Group of the Materials Sciences Laboratory. R. T. Parnley was Program Manager. Key individuals who contributed to the success of this program and their contributions are as follows:

- o R. F. Hausman - Developed the program for the liquid helium distribution subsystem and prepared the Program Users Manual.
- o L. G. Naes - Developed the program for the liquid nitrogen subsystem and helium gas recovery subsystem and analyzed in detail the recuperator used in the helium recovery subsystem.

Information concerning detailed use of the program is provided in the Program Users Manual. A complete description of the cryogen systems that were modeled and the mathematical basis for the models are given in the Final Report.

CONTENTS

<u>Section</u>	<u>Page</u>
ABSTRACT	i
FOREWORD	iii
1.0 INTRODUCTION	1
2.0 CRYOGEN SYSTEM DESCRIPTION	4
2.1 Liquid Helium Liquefaction Storage and Distribution Subsystem	4
2.2 Gaseous Helium Recovery Subsystem	26
2.3 Liquid Nitrogen Storage and Distribution Subsystem	29
3.0 PROGRAM DESCRIPTION	38
3.1 Subroutine C MPCAL	38
3.1.1 Input Requirements	40
3.1.2 Major C MPCAL Math Model Equations	42
3.2 Subroutine GASRCV	45
3.2.1 Subroutine DPLINE	46
3.2.2 Subroutine DPVALV	47
3.2.3 Subroutine C MPDP	48
3.3 Subroutine LIQNIT	49
4.0 PARAMETRIC ANALYSES	58
4.1 Liquid Helium Dewar/Magnet Flow Loop Analyses	58
4.2 Gaseous Helium Recovery Subsystem Analyses	58
4.3 Liquid Nitrogen Supply Subsystem Analyses	62
5.0 RECOMMENDATIONS	67

FIGURES

<u>Figure</u>		<u>Page</u>
1	Isometric View of Cryogen System	5
2	Site Plan for the Cryogen System	6
3	Plan View of the Cryogen System	7
4	Elevation Drawing of the Cryogen System	8
5	Legend for Schematics in Figs. 6, 10 and 11.	9
6	Liquid Helium Subsystem Schematic	10
7	Magnets/Dewar Flow Loop	11
8	Cryopanel/Dewar Flow Loop	14
9	Refrigerator/Liquefier Flow Loop	17
10	Gaseous Helium Recovery Subsystem Schematic	27
11	Liquid Nitrogen Subsystem Schematic	30
12	Effect of Flow Rate on Magnet/Dewar Quality	59
13	Helium Flow Velocity Between the Gas Bag and the Compressor	63

TABLES

<u>Table</u>		<u>Page</u>
1	Magnet Supply Subsystem Components	12
2	Cryopanel Supply Subsystem Components	15
3	Refrigerator/Liquefier Components	21
4	Gaseous Helium Recovery Subsystem Components	28
5	Liquid Nitrogen Subsystem Components	31
6	Results of Recuperator Analyses	60
7	Flow Analysis Results for the Gaseous Helium Recovery Subsystem	64
8	Effect of Line Size on Liquid Nitrogen Temperature and Quality	65

Section 1

INTRODUCTION

A Mirror Fusion Test Facility (MFTF) is being constructed at the Lawrence Livermore Laboratory of the University of California. This facility is one of a number of projects being funded by the Department of Energy to demonstrate fusion power as a potential commercial energy source by the end of this century. The large electromagnet system located within a high-vacuum chamber is required to confine the energetically charged plasma necessary to achieve the extremely high temperatures needed for fusion. To dramatically reduce power requirements for the electromagnet, the magnet temperature must be reduced to the superconducting range, ~ 4.35 K.

In addition, cryopanel at both liquid helium and liquid nitrogen temperatures are required as cryopumps to maintain the desired low vacuum pressure during fusion operation. Consequently, a cryogen liquefaction, storage and distribution system is required to support the test facility. This system can be subdivided into three subsystems.

- (1) The liquid helium liquefaction, storage, and distribution subsystem
- (2) The gaseous helium recovery subsystem (used during cooldown, warmup, and emergency magnet quench conditions)
- (3) The liquid nitrogen storage and distribution subsystem

To ensure the cryogen system can maintain the temperatures required plus meet other engineering specifications such as heat rates, pressures, and fluid quality, a thermodynamic fluid flow computer model was developed. This program provides a powerful analytical tool for rapid analysis of the design and variations on the design as it evolves to the hardware stage.

This Final Report is subdivided into four sections, exclusive of the Introduction. The first section provides a detailed description of the three cryogen subsystems that make up the total cryogen system. These are the:

- o Liquid helium liquefaction, storage and distribution subsystem
- o Gaseous helium recovery subsystem
- o Liquid nitrogen storage and distribution subsystem

This description includes schematics plan layouts and component descriptions when applicable. The system description was put in a document separate from the Program Users Manual to allow the user to reference a schematic in the Final Report at the same time he reads through the applicable section in the Program Users Manual.

The second section of this report provides a description of the computer program and the mathematical models used to calculate the system fluid flow and thermodynamic properties including assumptions used and limitations where applicable.

The third section provides examples of parametric analyses that can be performed using this program.

Recommendations on areas where future work can provide additional useful information concludes the report.

Section 2

CRYOGEN SYSTEM DESCRIPTION

A description of the cryogen system supporting the Mirror Fusion Test Facility that was modelled in this program is provided in this section. The three dimensional view of the facility (Fig. 1), Site Plan (Fig. 2), Plan View (Fig. 3), and Elevation Drawing (Fig. 4) were used to estimate line lengths, number of elbows and hydraulic head elevations for use in the computer model. Detailed identification of components are shown in the following sections, grouped into three subsystems that comprise the total cryogen system. Fig. 5 provides the legend identification for the schematics that follow.

2.1 LIQUID HELIUM LIQUEFACTION, STORAGE AND DISTRIBUTION SUBSYSTEM

The major schematic for this subsystem is shown in Fig. 6. The schematic was further subdivided into three groupings.

	Schematic Fig. No.	Component Des- cription Table No.
Magnets/Dewar Flow Loop	7	1
Cryopanel/Dewar Flow Loop	8	2
Refrigerator/Liquefier Flow Loop	9	3

REVISION					SYNOPSIS	
REV.	DATE	BY	CHKD	APPD	DESCRIPTION	REMARKS

2

Fig. 1 Isometric

Fig. 1 Isometric View of Cryogen System

3

Fig. 2 Site Plan 1

NOTES:
 SEE DWG AAR 78-105219, FOR MORE DETAIL OF THIS AREA.

LMSC-D673326

Fig. 2 Site Plan for the Cryogen System

38.14
(ELEVATION)
HELIUM G. S. TWO

HELIUM G. S. TWO
(ELEVATION)

HELIUM G. S. TWO
LEADS FROM
2 PLCS.

VAULT FLOOR
EL. - 6.44

VAULT

NOTES: UNLESS OTHERWISE NOTED.

1. CRYO-EQUIPMENT HOUSINGS, ON THE FOURTH FLOOR, WILL BE PROVIDED BY L.L.L. & WILL BE ERECTED AFTER FINAL INSTALLATION OF EQUIPMENT.
2. 100 LBS PER SQ. FT., MAX. ALLOWABLE LOAD ON THE FOURTH FLOOR.
3. COLD BOX MAY EXTEND THRU THE FOURTH FLOOR TO OBTAIN A COMMON AVERAGE HEIGHT OVER EQUIPMENT.
4. HELIUM GAS BAG, CROSS SECTION MAY INCREASE COMPENSATE FOR REDUCED LENGTH. (1695)

NOTES: UNLESS OTHERWISE NOTED.

1. CRYO-EQUIPMENT HOUSINGS, ON THE FOURTH FLOOR, WILL BE PROVIDED BY L.L.L. & WILL BE ERECTED AFTER FINAL INSTALLATION OF EQUIPMENT.
2. 150 LBS PER SQ FT, MAX ALLOWABLE LOADING ON THE FOURTH FLOOR.
3. COLD BOX MAY EXTEND THRU THE FOURTH FLOOR, IN ORDER TO OBTAIN A COMMON LIFT/GEAR SYSTEM WITH OTHER EQUIPMENT.
4. HELIUM GAS LIFT CROSS SECTION MAY INCREASE TO COMPENSATE FOR REDUCED LENGTH. (1600 SQ CM, 1500)

LMSC-D673326

Fig. 3 Plan View of the Cryogen System

2

Fig. 4 Elevation Draw1

REVISIONS				
NO.	DATE	BY	APPV	DESCRIPTION
A	10/20/60	JAN		ORIGINATED LETTER OF IDENTITY AND INSTR & VALVE NOS
				REVISED 3-WAY SOLENOID VALVES @ ADDED FLOW ARROW UNDER MISC
B	11/16/60	HW		ADDED 10 TO 12 TP VALVE NOS & 1-2 TRANSMITTER @ MISC
C	11/16/60	HW		ADDED 5TH OUTSIDE BALLON, AN TO LETTERS OF IDENTITY

LETTERS OF IDENTIFICATION

DEFINITION & PERMISSIBLE POSITIONS IN ANY COMBINATION

UPPER CASE LETTER	FIRST LETTER PROCESS VARIABLE OR ACTION	SECOND LETTER TYPE READING OR OTHER FUNCTION	THIRD LETTER ADDITIONAL FUNCTION
A	AIR	ALARM	ALARM
An	ANALYZER	ANALYZER	ANALYZER
C	CONTROL	CONTROL OR CONTROLLER	CONTROL OR CONTROLLER
D			
E		ELEMENT (PRIMARY SENSING)	
F	FLOW		
G		GLASS (VISUAL OBSERVATION)	
H	HAND		
I		INDICATOR OR INDICATING	INDICATOR
J			
K			
L	LEVEL		
M	MOTOR		
N			
O		OPERATED	
P	PRESSURE		
P	DIFF PRESSURE		
Q			
R		RECORDER OR RECORDING	RECORDER OR RECORDING
S	SOLENOID	SAFETY	SWITCH
S _p	SPEED		
T	TEMPERATURE	TRANSMITTER OR TRANSMITTING	TRANSMITTER OR TRANSMITTING
AT	DIFF TEMP		
U			
V	VACUUM	VALVE	VALVE
W	WEIGHT	TEST POINT OR WELL	
X			
Y			
Z			

SYMBOLS USED OUTSIDE BALLON WITH ANALYZERS

C₂H₆ - CHEMICAL ELEMENTS
I-131 - A SPECIFIC ISOTOPE
PART - PARTICULATE MATTER
FIS - FISSION PRODUCTS
GAS - FISSION GAS
RAD - RADIO GAS

1 (ANY S'W) RADIOACTIVE

MISCELLANEOUS

INSTRUMENTS & VALVE NUMBERS	
NO SERIES	UNIT DESCRIPTION
A1 → UP	HE REFRIGERATOR & COMPRESSOR
B1 → UP	LN ₂ SUBCOOLER
C1 → UP	RELIQUEFIER
D1 → UP	THERMAL CYCLE
E1 → UP	FACILITY VACUUM
F1 → UP	FACILITY WATER
G1 → UP	FACILITY HELIUM
H1 → UP	FACILITY NITROGEN
J1 → UP	FACILITY AIR
K1 → UP	WARM-UP CYCLE
L1 → UP	COLD GAS REFRIGERATOR
M1 → UP	PURIFIER
N1 → UP	GAS LIQUEFACTION PLANT
P1 → UP	VAPORIZER
R1 → UP	RECIPROCAL PUMP
S1 → UP	RECIPROCAL PUMP STATION
T1 → UP	CENTRIFUGAL PUMP
U1 → UP	FILTER SYSTEM

SYMBOLS USED, BUT NOT SHOWN ON THIS
LEGEND ARE TO BE NOTED ON THE SCHEMATIC
WHERE USED.

GENERAL NOTES:

VALVES

SPECIAL VALVES

```
TS B VALVE AL-WEERS  
UNIT DESCRIPTION  
REFRIGERATOR & COMPRESSOR  
UBCCOLEP  
USER ER  
MAL CYCLE  
TY VAL M  
TY KATL  
TY HS M  
TY KATL-FIN  
TY F  
UP-CYCLE  
DRAIN COMPRESSOR  
ER  
CLEANING PLANT  
IZER  
ROCK PUMP  
LOCAL PUMP STATION  
REFUGAL PUMP  
R SYSTEM
```

PIPING

Fig. 5 Leg-

Fig. 5 Legend for Schematics in Figs. 6, 10 and 11

212A

25112
5-22

7424

5
10

101

2113 17411
19

200
21145 242 147

TO
LESS
15.5

2

11 (P11) ALV. VALVE, P11C & INSTRUMENTATION NAMEP. 1-102
EXAMPLE
A-100-CH-143 (VALVE)
A-100-LIN-144 (PIPE)

GENERAL NOTES

3

Fig. 6 Liquid Helium Subsystem Schematic

Fig. 7 Magnet/Dewar Flow Loop

LMSC-D673326

TABLE 1 MAGNET SUPPLY SUBSYSTEM COMPONENTS

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
GAS	HC-L10	1	2	-0.00	1	.00000000	-0.00	-0.00	0	-0.00	-0.00
TANK	HC-SV2	0	1	-0.00	6	.00000000	-0.00	-0.00	0	-0.00	-0.00
LINE	MS-100	10	1	1.48	6	.70000000-02	-0.23	-0.15	0	-0.00	-0.00
TEE	FS-101	31	1	-0.00	6	.70000000-02	60.00	-0.00	0	-0.00	-0.00
LINE	MS-102	10	1	-0.00	6	.70000000-02	1.07	-0.15	0	-0.00	-0.00
VALVE	CV-135	31	1	-0.00	6	.70000000-02	400.00	-0.00	0	-0.00	-0.00
LINE	MS-103	10	1	-0.00	6	.70000000-02	1.05	-0.15	0	-0.00	-0.00
ELBOW	FS-104	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-105	10	1	2.59	6	.70000000-02	2.52	-0.15	0	-0.00	-0.00
ELBOW	FS-106	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-107	10	1	-0.00	6	.70000000-02	12.40	-0.00	0	-0.00	-0.00
ELBOW	FS-108	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-109	10	1	17.25	6	.70000000-02	17.25	-0.15	0	-0.00	-0.00
ELBOW	FS-110	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-111	10	1	-0.00	6	.70000000-02	.80	-0.15	0	-0.00	-0.00
ELBOW	FS-112	21	1	-0.00	6	.70000000-02	8.60	-0.00	0	-0.00	-0.00
LINE	MS-113	10	1	-0.00	6	.70000000-02	5.00	-0.15	0	-0.00	-0.00
ELBOW	FS-114	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-115	10	1	-3.00	6	.70000000-02	3.00	-0.15	0	-0.00	-0.00
ELBOW	FS-116	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MS-117	10	1	-0.00	6	.70000000-02	4.00	-0.15	0	-0.00	-0.00
ELBOW	FS-118	21	1	-0.00	6	.70000000-02	8.60	-0.00	0	-0.00	-0.00
LINE	MS-119	10	1	-1.64	6	.70000000-02	.90	-0.15	0	-0.00	-0.00
MAGNET	MAG-01	0	1	-4.21	6	.70000000-02	10.96	-0.15	0	-0.00	-0.00
LINE	MH-101	10	1	-1.64	6	.70000000-02	.90	-0.15	0	-0.00	-0.00
ELBOW	FR-102	21	1	-0.00	6	.70000000-02	8.60	-0.00	0	-0.00	-0.00
LINE	MH-103	10	1	-0.00	6	.70000000-02	4.00	-0.15	0	-0.00	-0.00
ELBOW	FR-104	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MR-105	10	1	-4.00	6	.70000000-02	4.00	-0.15	0	-0.00	-0.00
ELBOW	FR-106	21	1	-0.00	6	.70000000-02	8.60	-0.00	0	-0.00	-0.00
LINE	MR-107	10	1	-4.75	6	.70000000-02	7.27	-0.15	0	-0.00	-0.00
ELBOW	FR-108	21	1	-0.00	6	.70000000-02	8.60	-0.00	0	-0.00	-0.00
LINE	MR-109	10	1	-0.00	6	.70000000-02	12.40	-0.15	0	-0.00	-0.00
ELBOW	FR-110	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MR-111	10	1	-2.59	6	.70000000-02	2.59	-0.15	0	-0.00	-0.00
ELBOW	FR-112	31	1	-0.00	6	.70000000-02	13.00	-0.00	0	-0.00	-0.00
LINE	MR-113	10	1	-0.00	6	.70000000-02	.61	-0.15	0	-0.00	-0.00
VALVE	CV-145	31	1	-0.00	6	.70000000-02	400.00	-0.00	0	-0.00	-0.00
LINE	MH-114	10	1	-0.00	6	.70000000-02	1.99	-0.15	0	-0.00	-0.00
TEE	FR-115	31	1	-0.00	6	.70000000-02	60.00	-0.00	0	-0.00	-0.00
LINE	MH-116	10	1	-1.48	6	.70000000-02	1.52	-0.15	0	-0.00	-0.00
TANK	HC-SV2	0	1	-0.00	6	.00000000	-0.00	-0.00	0	-0.00	-0.00
GAS	HC-L10	1	2	-0.00	2	.00000000	-0.00	-0.00	0	-0.00	-0.00
LINE	MS-202	10	1	-0.00	6	.70000000-02	1.07	-0.15	0	-0.00	-0.00

LMS-C-D673326

TABLE 1. MAGNET SUPPLY SUBSYSTEM COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW COEFFICIENT	FRICTION OR L-OVER-D	LINE LENGTH	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
VALVE	CV-136	31	1	-1.00	6	.70000000-02		400.00	-1.00	0	-1.00	-1.0
LINE	MS-203	10	1	-1.00	6	.70000000-02		1.00	.15	0	-1.00	-1.0
ELBOW	FS-204	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-205	10	1	2.59	6	.70000000-02		2.59	.15	0	-1.00	-1.0
ELBOW	FS-206	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-207	10	1	-1.00	6	.70000000-02		12.40	.15	0	-1.00	-1.0
ELBOW	FS-208	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-209	10	1	17.25	6	.70000000-02		17.25	.15	0	-1.00	-1.0
ELBOW	FS-210	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-211	10	1	-1.00	6	.70000000-02		.00	.15	0	-1.00	-1.0
ELBOW	FS-212	21	1	-1.00	6	.70000000-02		0.60	-1.00	0	-1.00	-1.0
LINE	MS-213	10	1	-1.00	6	.70000000-02		5.00	.15	0	-1.00	-1.0
ELBOW	FS-214	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-215	10	1	-3.00	6	.70000000-02		3.00	.15	0	-1.00	-1.0
ELBOW	FS-216	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MS-217	10	1	-1.00	6	.70000000-02		0.30	.15	0	-1.00	-1.0
ELBOW	FS-218	21	1	-1.00	6	.70000000-02		0.60	-1.00	0	-1.00	-1.0
LINE	MS-219	10	1	-1.64	6	.70000000-02		.90	.15	0	-1.00	-1.0
MAGNET	MAG-02	0	1	-4.24	6	.70000000-02		10.96	.15	0	-1.00	-1.0
LINE	MR-200	10	1	-1.64	6	.70000000-02		.90	.15	0	-1.00	-1.0
ELBOW	FR-201	21	1	-1.00	6	.70000000-02		0.60	-1.00	0	-1.00	-1.0
LINE	MR-202	10	1	-1.00	6	.70000000-02		0.30	.15	0	-1.00	-1.0
ELBOW	FR-203	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MR-204	10	1	-4.00	6	.70000000-02		4.00	.15	0	-1.00	-1.0
ELBOW	FR-205	21	1	-1.00	6	.70000000-02		0.60	-1.00	0	-1.00	-1.0
LINE	MR-206	10	1	-4.75	6	.70000000-02		7.27	.15	0	-1.00	-1.0
ELBOW	FR-207	21	1	-1.00	6	.70000000-02		0.60	-1.00	0	-1.00	-1.0
LINE	MR-208	10	1	-1.00	6	.70000000-02		12.40	.15	0	-1.00	-1.0
ELBOW	FR-209	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MR-210	10	1	-2.59	6	.70000000-02		2.59	.15	0	-1.00	-1.0
ELBOW	FR-211	31	1	-1.00	6	.70000000-02		13.00	-1.00	0	-1.00	-1.0
LINE	MR-212	10	1	-1.00	6	.70000000-02		.61	.15	0	-1.00	-1.0
VALVE	CV-146	31	1	-1.00	6	.70000000-02		400.00	-1.00	0	-1.00	-1.0
LINE	MR-213	10	1	-1.00	6	.70000000-02		1.90	.15	0	-1.00	-1.0
END		0	0	-1.00	0	.00000000		-1.00	-1.00	0	-1.00	-1.0

LMSC-D673326

LMSC-D673326

Fig. 8 Cryopanel/Dewar Flow Loop

TABLE 2 CRYOPANEL SUPPLY SUBSYSTEM COMPONENTS

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
ELBOW	FS-216	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-217	10	1	- .00	6	.70000000-02	10.00	- .10	0	- .00	- .00
ELBOW	FS-218	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-219	10	1	-9.25	6	.70000000-02	9.00	- .10	0	- .00	- .00
ELBOW	FS-220	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-221	10	1	- .00	6	.70000000-02	.20	- .10	0	- .00	- .00
CRYSPAN	CR-21	1	1	-3.0460006		.70000000-02	12.50	- .10	0	- .00	- .00
LINE	CR-200	10	1	- .00	6	.70000000-02	.20	- .10	0	- .00	- .00
TAP	TR-103	31	1	- .00	6	.70000000-02	15.50	- .00	0	- .00	- .00
GAS	HE-L10	1	2	- .00	3	- .00000000	- .00	- .00	0	- .00	- .00
LINE	CS-302	10	1	1.48	6	.70000000-02	1.12	- .05	0	- .00	- .00
VALVE	CV-143	31	1	- .00	6	.70000000-02	400.00	- .00	0	- .00	- .00
LINE	CS-303	10	1	- .00	6	.70000000-02	.86	- .05	0	- .00	- .00
ELBOW	FS-304	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-305	10	1	2.59	6	.70000000-02	2.59	- .05	0	- .00	- .00
ELBOW	FS-306	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-307	10	1	- .00	6	.70000000-02	12.30	- .05	0	- .00	- .00
ELBOW	FS-308	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-309	10	1	17.75	6	.70000000-02	17.75	- .05	0	- .00	- .00
ELBOW	FS-310	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-311	10	1	- .00	6	.70000000-02	.00	- .05	0	- .00	- .00
ELBOW	FS-312	21	1	- .00	6	.70000000-02	8.60	- .00	0	- .00	- .00
LINE	CS-313	10	1	- .00	6	.70000000-02	5.00	- .05	0	- .00	- .00
ELBOW	FS-314	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-315	10	1	-1.50	6	.70000000-02	1.50	- .05	0	- .00	- .00
ELBOW	FS-316	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-317	10	1	- .00	6	.70000000-02	11.00	- .05	0	- .00	- .00
ELBOW	FS-318	41	1	- .00	6	.70000000-02	18.00	- .00	0	- .00	- .00
LINE	CS-319	10	1	- .25	6	.70000000-02	.25	- .05	0	- .00	- .00
TAP	TR-320	31	1	- .00	6	.70000000-02	15.00	- .00	0	- .00	- .00
LINE	CS-321	10	1	- .20	6	.70000000-02	.20	- .05	0	- .00	- .00
CRYSPAN	CYP-23	3	1	-1.5230006		.70000000-02	6.00	- .05	0	- .00	- .00
LINE	CR-300	10	1	- .20	6	.70000000-02	.20	- .05	0	- .00	- .00
ELBOW	FR-301	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CR-302	10	1	- .00	6	.70000000-02	10.00	- .05	0	- .00	- .00
TAP	TR-103	31	1	- .00	6	.70000000-02	60.00	- .00	0	- .00	- .00
GAS	HE-L10	1	2	- .00	4	- .00000000	- .00	- .00	0	- .00	- .00
LINE	CS-401	10	1	- .00	6	.70000000-02	10.00	- .05	0	- .00	- .00
ELBOW	FS-402	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CS-403	10	1	- .20	6	.70000000-02	.20	- .05	0	- .00	- .00
CRYSPAN	CYP-24	4	1	-1.5230006		.70000000-02	6.00	- .05	0	- .00	- .00
LINE	CR-401	10	1	- .20	6	.70000000-02	.20	- .05	0	- .00	- .00
ELBOW	FR-402	31	1	- .00	6	.70000000-02	13.00	- .00	0	- .00	- .00
LINE	CR-403	10	1	- .50	6	.70000000-02	.50	- .05	0	- .00	- .00

LMSC-D-67326

TABLE 2 CRYOPANEL SUPPLY SUBSYSTEM COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
TAP	1P-103	31	1	-1.00	6	.70000000-02	60.00	-1.00	0	-1.00	1.0
GAS	HE-110	1	2	-1.00	5	-1.00000000	1.00	-1.00	0	-1.00	1.0
TAP	1P-103	31	1	-1.00	6	.70000000-02	15.50	-1.00	0	-1.00	1.0
LINE	CR 104	10	1	-1.50	6	.70000000-02	1.50	.15	0	-1.00	1.0
ELBOW	FR 105	21	1	-1.00	6	.70000000-02	8.60	-1.00	0	-1.00	1.0
LINE	CR 106	10	1	-4.75	6	.70000000-02	7.27	.15	0	-1.00	1.0
ELBOW	FR 107	21	1	-1.00	6	.70000000-02	8.60	-1.00	0	-1.00	1.0
LINE	CR 108	10	1	-1.00	6	.70000000-02	12.30	.15	0	-1.00	1.0
ELBOW	FR 109	31	1	-1.00	6	.70000000-02	13.00	-1.00	0	-1.00	1.0
LINE	CR 110	10	1	-2.59	6	.70000000-02	2.59	.15	0	-1.00	1.0
ELBOW	FR 111	31	1	-1.00	6	.70000000-02	13.00	-1.00	0	-1.00	1.0
LINE	CR 112	10	1	-1.00	6	.70000000-02	.53	.15	0	-1.00	1.0
VALVE	CV-144	31	1	-1.00	6	.70000000-02	400.00	-1.00	0	-1.00	1.0
LINE	CR 113	10	1	-1.00	6	.70000000-02	2.21	.15	0	-1.00	1.0
ELBOW	FR 114	31	1	-1.00	6	.70000000-02	13.00	-1.00	0	-1.00	1.0
LINE	CR 115	10	1	-1.48	6	.70000000-02	1.48	.15	0	-1.00	1.0
TANK	HE-SV1	0	1	-1.00	6	-1.00000000	1.00	-1.00	0	-1.00	1.0
END		0	0	-1.00	0	-1.00000000	1.00	-1.00	0	-1.00	1.0

Fig. 9 Refrigerator/Liquefier Flow Loop

Fig. 9A. Plumbing for Magnet/Cryopanel Dewars

Fig. 9B. Cold Box Connections.

TABLE 3 REFRIGERATOR/LIQUEFIER COMPONENTS

REFRIGERATOR-LIQUEFIER HEAD-END CONDITIONS:

	TEMP. (DEG.K)	PRESS. (KPA)	FLOW (GM/SEC)	ENTHALPY (J/MOL)
UPPER HEX-LN2 BOILER ASSY.:				
WARM HELIUM INLET (T1,P1,W1)	300.00	1215.9	474.1	6310.4
WARM HELIUM OUTLET (T2,P1,W1)	80.00	1215.9	474.1	1731.6
COLD HELIUM INLET (T3,P2,W2)	80.00	113.8	TBD	1727.6
COLD HELIUM OUTLET (T4,P2,W2)	290.00	113.8	TBD	6088.1
LN2-BOILER INLET (T5,P3,W3)	77.35	101.3	TBD	-3504.3
GH2 TOP-HEX OUTLET (T6,P3,W3)	290.00	101.3	TBD	8426.2
TURBINE EXPANDERS:				
WARM TURBINE INLET	30.00	1215.9	72.6	845.8
WARM TURBINE OUTLET	23.00	113.8	72.6	534.8
COLD TURBINE INLET	13.00	1215.9	155.1	277.3
COLD TURBINE OUTLET	7.00	113.8	155.1	191.9
REF-LIQ BOTTOM-END CONDITIONS:				
J-T VALVE - INLET	4.80	1215.9	246.4	66.4
J-T VALVE - OUTLET	4.35	113.8	246.4	41.5
COLD HE-VAPOR INLET	5.00	113.8	TBD	142.0
COMPRESSOR-PURIFIER ASSY:				
LOW-PRES. HELIUM INLET	290.00	113.8	474.1	6088.1
HIGH-PRES. HELIUM OUTLET	300.00	1215.9	474.1	6310.4

** TBD VALUES ARE COMPUTED IN PROGRAM **

COMPRESSOR

N2-VENT

MAKE-UP

LMSC-D-673326

TABLE 3 REFRIGERATOR/LIQUEFIER COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
GAS	HE-GAS	1	1	.00	1	.00000000	.00	.00	0	.00	.0
TANK	HE-SV1	0	1	.00	6	.00000000	.00	.00	0	.00	.0
LINE	CGV301	10	1	.00	6	.60000000-02	.91	.00	10	.00	.0
ELBOW	FGV302	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	CGV303	10	1	.00	6	.60000000-02	.46	.00	10	.00	.0
ELBOW	FGV304	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	CGV305	10	1	.00	6	.60000000-02	.05	.00	10	.00	.0
VALVE	AV-121	41	1	.00	6	.10000000-01	400.00	.00	10	.00	.0
LINE	CGV306	10	1	.00	6	.60000000-02	.08	.00	10	.00	.0
ELBOW	FGV307	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	CGV308	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
FITING	FGV309	41	1	.00	6	.60000000-02	8.00	.00	10	.00	.0
LINE	CGV310	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
ELBOW	FGV311	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	CGV312	10	1	.00	6	.60000000-02	5.94	.00	10	.00	.0
GAS	HE-GAS	1	1	.00	2	.00000000	.00	.00	0	.00	.0
TANK	HE-SV2	0	1	.00	6	.00000000	.00	.00	0	.00	.0
LINE	MSV401	10	1	.00	6	.60000000-02	.91	.00	10	.00	.0
ELBOW	FGV402	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	MSV403	10	1	.00	6	.60000000-02	.46	.00	10	.00	.0
ELBOW	FGV404	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	MSV405	10	1	.00	6	.60000000-02	.05	.00	10	.00	.0
VALVE	AV-122	41	1	.00	6	.10000000-01	400.00	.00	10	.00	.0
LINE	MSV406	10	1	.00	6	.60000000-02	.08	.00	10	.00	.0
ELBOW	FGV407	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	MSV408	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
FITING	FGV409	41	1	.00	6	.70000000-02	8.00	.00	10	.00	.0
LINE	MSV410	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
TEE	FGV313	31	1	.00	6	.70000000-02	60.00	.00	10	.00	.0
LINE	MSV411	10	1	.00	6	.60000000-02	1.03	.00	10	.00	.0
ELBOW	FGV412	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	MSV413	10	1	.00	6	.60000000-02	3.96	.00	10	.00	.0
GAS	HE-GAS	1	1	.00	3	.00000000	.00	.00	0	.00	.0
TANK	HE-SV3	0	1	.00	6	.00000000	.00	.00	0	.00	.0
LINE	SGV501	10	1	.00	6	.60000000-02	.91	.00	10	.00	.0
ELBOW	FGV502	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	SGV503	10	1	.00	6	.60000000-02	.05	.00	10	.00	.0
VALVE	CV-123	41	1	.00	6	.10000000-01	400.00	.00	10	.00	.0
LINE	SGV504	10	1	.00	6	.60000000-02	.08	.00	10	.00	.0
ELBOW	FGV505	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	SGV506	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
FITING	FGV507	41	1	.00	6	.70000000-02	8.00	.00	10	.00	.0
LINE	SGV508	10	1	.00	6	.60000000-02	.61	.00	10	.00	.0
ELBOW	FGV509	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0

LMS-C-0673326

TABLE 3 REFRIGERATOR/LIQUEFIER COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
LINE	SGV510	10	1	.00	6	.60000000-02	6.09	.08	10	.00	.0
ELBOW	FGV511	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	SGV512	10	1	.00	6	.60000000-02	1.22	.08	10	.00	.0
TEE	FGV513	31	1	.00	6	.70000000-02	15.50	.00	10	.00	.0
LINE	CH1101	10	1	.00	6	.60000000-02	1.22	.08	10	.00	.0
GAS	HE-GAS	1	1	.00	4	-.00000000	-.00	-.00	0	-.00	-.0
REFLIQ	RT-LQ1	0	1	.00	6	.70000000-02	.00	.00	10	.00	.0
LINE	CH1101	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
FITTING	FHD102	41	1	.00	6	.90000000-02	8.00	.00	10	.00	.0
LINE	CH1103	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
TEE	FHD104	31	1	.00	6	1.00000000-01	60.00	.00	10	.00	.0
GAS	HE-GAS	1	1	.00	5	-.00000000	-.00	-.00	0	-.00	-.0
REFLIQ	RT-LQ2	0	1	.00	6	.70000000-02	100.00	.03	10	.00	.0
LINE	SHPG01	10	1	.00	6	.90000000-02	1.22	.10	10	.00	.0
ELBOW	FHPG02	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	SHPG03	10	1	.00	6	.90000000-02	5.79	.10	10	.00	.0
ELBOW	FHPG04	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	SHPG05	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
FITTING	FHPG06	41	1	.00	6	.90000000-02	8.00	.00	10	.00	.0
LINE	SHPG07	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
ELBOW	FHPG08	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	SHPG09	10	1	.00	6	.90000000-02	.30	.10	10	.00	.0
VALVE	CV-104	51	1	.00	6	.00000000-02	422.00	.00	10	.00	.0
LINE	SHPG10	10	1	.00	6	.70000000-02	.15	.10	10	.00	.0
ELBOW	FHPG11	31	1	.00	6	.70000000-02	13.00	.00	10	.00	.0
LINE	SHPG12	10	1	.00	6	.70000000-02	2.44	.10	10	.00	.0
TANK	HE-SV3	0	1	.00	6	.00000000	.00	.00	0	.00	.0
GAS	HE-GAS	1	1	.00	6	-.00000000	-.00	-.00	0	-.00	-.0
LINE	CHP701	10	1	.00	6	.90000000-02	4.26	.10	10	.00	.0
ELBOW	FHP702	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	CHP703	10	1	.00	6	.90000000-02	1.22	.10	10	.00	.0
TEE	FHP704	31	1	.00	6	.90000000-02	60.00	.00	10	.00	.0
LINE	CHP705	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
FITTING	FHP706	41	1	.00	6	.90000000-02	8.00	.00	10	.00	.0
LINE	CHP707	10	1	.00	6	.90000000-02	.61	.10	10	.00	.0
ELBOW	FHP708	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	CHP709	10	1	.00	6	.90000000-02	.05	.10	10	.00	.0
VALVE	CV-105	41	1	.00	6	.90000000-02	400.00	.00	10	.00	.0
LINE	CHP710	10	1	.00	6	.90000000-02	.05	.10	10	.00	.0
ELBOW	FHP711	31	1	.00	6	.90000000-02	13.00	.00	10	.00	.0
LINE	CHP712	10	1	.00	6	.90000000-02	.60	.10	10	.00	.0
VALVE	AV-129	51	1	.00	6	.90000000-02	422.00	.00	10	.00	.0
LINE	CHP713	10	1	.00	6	.70000000-02	.91	.10	10	.00	.0
TANK	HE-SV1	0	1	.00	6	.00000000	.00	.00	0	.00	.0

LMSG-D673326

TABLE 3 REFRIGERATOR/LIQUEFIER COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
GAS	HE-GAS	1	1	.00	7	.00000000	.00	.00	0	.00	.0
LINE	MHP001	10	1	.00	6	.00000000-02	6.24	.10	10	.00	.0
ELBOW	FHP002	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	MHP003	10	1	.00	6	.00000000-02	.61	.10	10	.00	.0
FITTING	FHP004	41	1	.00	6	.00000000-02	8.00	.00	10	.00	.0
LINE	MHP005	10	1	.00	6	.00000000-02	.61	.10	10	.00	.0
ELBOW	FHP006	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	MHP007	10	1	.00	6	.00000000-02	.05	.10	10	.00	.0
VALVE	CV-106	41	1	.00	6	.00000000-02	400.00	.00	10	.00	.0
LINE	MHP008	10	1	.00	6	.00000000-02	.05	.10	10	.00	.0
ELBOW	FHP009	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	MHP010	10	1	.00	6	.00000000-02	.60	.10	10	.00	.0
VALVE	AV-128	51	1	.00	6	.00000000-02	422.00	.00	10	.00	.0
LINE	MHP011	10	1	.00	6	.00000000-02	.91	.10	10	.00	.0
TANK	HE-SV2	0	1	.00	6	.00000000	.00	.00	0	.00	.0
GAS	HE-GAS	1	1	.00	8	.00000000	.00	.00	0	.00	.0
REFL JO	RF-103	0	1	.00	6	.00000000-02	.00	.00	10	.00	.0
LINE	CLP101	10	1	.00	6	.00000000-02	.30	.15	10	.00	.0
ELBOW	FLP102	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP103	10	1	.00	6	.00000000-02	7.92	.15	10	.00	.0
ELBOW	FLP104	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP105	10	1	.00	6	.00000000-02	3.95	.15	10	.00	.0
ELBOW	FLP106	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP107	10	1	.00	6	.00000000-02	9.74	.15	10	.00	.0
ELBOW	FLP108	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP109	10	1	.00	6	.00000000-02	8.22	.15	10	.00	.0
ELBOW	FLP110	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP111	10	1	.00	6	.00000000-02	8.00	.15	10	.00	.0
ELBOW	FLP112	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP113	10	1	.00	6	.00000000-02	7.00	.15	10	.00	.0
ELBOW	FLP114	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP115	10	1	.00	6	.00000000-02	6.00	.15	10	.00	.0
ELBOW	FLP116	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CLP117	10	1	.00	6	.00000000-02	.50	.15	10	.00	.0
COMPUR	CPU-01	0	1	.00	6	.00000000-02	.00	.00	10	.00	.0
LINE	CHP101	10	1	.00	6	.00000000-02	.50	.00	10	.00	.0
ELBOW	FHP102	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CHP103	10	1	.00	6	.00000000-02	6.00	.00	10	.00	.0
ELBOW	FHP104	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CHP105	10	1	.00	6	.00000000-02	8.00	.00	10	.00	.0
ELBOW	FHP106	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CHP107	10	1	.00	6	.00000000-02	8.22	.00	10	.00	.0
ELBOW	FHP108	31	1	.00	6	.00000000-02	13.00	.00	10	.00	.0
LINE	CHP109	10	1	.00	6	.00000000-02	9.74	.00	10	.00	.0

TABLE 3 REFRIGERATOR/LIQUEFIER COMPONENTS (CONT)

COMP NAME	COMP CODE	FUNC. TYPE	NUMB. OPER.	NHEAD (M)	MATRL. TYPE	FLOW FRICTION COEFFICIENT	LINE LENGTH OR L-OVER-D	LINE DIAMETER	INSULATION TYPE	INSULATION THICKNESS	NO. LAYERS INSULATION
ELBOW	FHP110	31	1	.00	6	.80000000-02	13.00	.00	10	.00	.0
LINE	FHP111	10	1	.00	6	.80000000-02	3.96	.00	10	.00	.0
ELBOW	FHP112	31	1	.00	6	.80000000-02	13.00	.00	10	.00	.0
LINE	FHP113	10	1	.00	6	.80000000-02	7.92	.00	10	.00	.0
VALVE	AV-041	41	1	.00	6	.80000000-02	422.00	.00	10	.00	.0
LINE	FHP114	10	1	.00	6	.80000000-02	.05	.00	10	.00	.0
ELBOW	FHP115	31	1	.00	6	.80000000-02	13.00	.00	10	.00	.0
LINE	FHP116	10	1	.00	6	.80000000-02	.30	.00	10	.00	.0
REFLIQ	RF-LQ4	0	1	.00	6	.70000000-02	.00	.00	10	.00	.0
END		0	0	.00	0	.00000000	.00	.00	0	.00	.0

This breakout was necessary to provide the added detail necessary to characterize the system for analysis. Since the line insulation system was not yet defined, the insulation thickness in Tables 1 to 3 was specified as zero for this run.

2.2 GASEOUS HELIUM RECOVERY SUBSYSTEM

The schematic for this subsystem is shown in Fig. 10. The heavy line represents the flow-path modelled for the program. For redundant, parallel flow components, i.e., the blower, dryer and purifier, one leg of the flow path is valved off for purposes of analyses.

The flow path is divided into the following three sequential sections.

	Schematic Fig. No.	Component Description Table No.
o Magnet to Recuperator to Gas Bag (9)	10	-
o Gas Bag (9) to Compressor (20) Low Pressure Section)	10	4
o Compressor (21) to Clean Gas Storage (46) (High Pressure Section)	10	4

The transient analysis for magnet quench flow to the gas bag through the recuperator was performed using a proprietary Lockheed Thermal Analyzer Program. The results of this analysis are presented in Section 4, Table 6 of this report.

TABLE 4 GASEOUS HELIUM RECOVERY SUBSYSTEM COMPONENTS

LOW PRESSURE SECTION:	LINE LENGTH	NUM.-ELBOWS	L/D OF COMP.	MAJOR COMP.
	48.000	1.0	.0	-.0
	.000	.0	340.0	-.0
	5.000	2.0	.0	-.0
	.000	.0	340.0	-.0
	1.000	.0	.0	-.0
	.000	.0	.0	1.0
	1.000	.0	.0	-.0
	.000	.0	340.0	-.0
	12.000	2.0	.0	-.0
	.000	.0	340.0	-.0
	1.000	.0	.0	-.0
HIGH PRESSURE SECTION:				
	1.000	.0	.0	-.0
	.000	.0	340.0	-.0
	1.000	.0	.0	-.0
	.000	.0	77.0	-.0
	3.000	4.0	.0	-.0
	7.000	3.0	.0	-.0
	.000	.0	170.0	-.0
	2.000	1.0	.0	-.0
	.000	.0	.0	2.0
	2.000	1.0	.0	-.0
	.000	.0	.0	3.0
	2.000	.0	.0	-.0
	.000	.0	170.0	-.0
	5.000	3.0	.0	-.0
	.000	.0	340.0	-.0
	1.000	1.0	.0	-.0
	.000	.0	.0	4.0
	1.000	1.0	.0	-.0
	.000	.0	340.0	-.0
	1.000	1.0	.0	-.0
	.000	.0	340.0	-.0
	2.000	2.0	.0	-.0
	.000	.0	340.0	-.0
	99.000	5.0	.0	-.0
	.000	.0	340.0	-.0

LMSC-D/673326

2.3 LIQUID NITROGEN STORAGE AND DISTRIBUTION SUBSYSTEM

The schematic for the liquid distribution subsystem is shown in Fig. 11. A listing of the components that comprise the six major lines are shown in Table 5. The nomenclature used in Fig. 11 to identify components shows the major line no. first, separated by a dash from the appropriate line section number. For example, 2-44 refers to line 2, line section No. 44. Going to Table 5, Line 2, shows that component No. 44 is a bayonet.'

Line 1 provides liquid nitrogen from the storage tank for distribution throughout the system. Four of the lines, which service the helium purifier, external vacuum system, magnet heat exchanger and refrigerator cold box, are shown as open loop systems in Fig. 11. To account for the reduction in the available mass flow to remaining closed loop lines, the program reduces the mass flow at the end of line 1 by an amount that is input to the program. The closed loop lines 2 through 5 recombine into line 6 at the exit valve box. Line 6 is routed back to a location near the liquid storage tank where the excess vapor is vented to the atmosphere. The remaining liquid nitrogen is transferred back into the storage tank.

S PREFIX PIPE VALVE AND INSTRUMENT NUMBERS WITH L-00
 EXAMPLE: L-00-S0V-10 (VALVE)
 L-00-LH₂-10 (PIPE)
 GENERAL NOTES

Fig. 11 Liquid Nitrogen Subsystem Schematic

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS

LINE DESCRIPTION FOR LINE NUMBER 1

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	-LINE TYPE-				
						LINE	ELBOW	VALVE	BAYONET	-T-
1	3.06	2.06	-1.00	.0	3.47	X				
2	.00	-1.00	-1.00	31.0	.00		X			
3	18.00	-1.00	-1.00	.0	20.42	X				
4	.00	-1.00	-1.00	31.0	.00		X			
5	54.50	-1.00	-1.00	.0	61.83	X				
6	.00	-1.00	-1.00	31.0	.00		X			
7	7.90	-1.00	6.90	.0	8.96	X				
8	.00	6.90	6.90	31.0	.00		X			
9	18.50	6.90	6.90	.0	20.99	X				
10	.00	6.90	6.90	31.0	.00		X			
11	0.50	6.90	15.40	.0	9.64	X				
12	.00	15.40	15.40	31.0	.00		X			
13	26.00	15.40	15.40	.0	29.50	X				

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 2

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	LINE	-LINE TYPE- ELBOW VALVE BAYONET	-T-
1	.00	15.40	15.40	340.0	.00		X	
2	2.00	15.40	15.40	.0	.57	X		
3	.00	15.40	15.40	.0	2.72			X
4	1.00	15.40	15.40	.0	.20	X		
5	.00	15.40	15.40	31.0	.00		X	
6	.60	15.40	16.08	.0	.19	X		
7	.00	16.08	16.08	31.0	.00		X	
8	.50	16.08	16.08	.0	.14	X		
9	.00	16.08	16.08	.0	2.72			X
10	.00	16.08	16.08	31.0	.00		X	
11	6.36	16.08	16.08	.0	10.05	X		
12	.00	16.08	16.08	31.0	.00		X	
13	.50	16.08	16.08	.0	.14	X		
14	.00	16.08	16.08	.0	2.72			X
15	.00	16.08	16.08	31.0	.00		X	
16	8.72	16.08	17.45	.0	280.00	X		
17	.00	17.45	17.45	31.0	.00		X	
18	1.37	17.45	16.08	.0	.39	X		
19	.00	16.08	16.08	31.0	.00		X	
20	.00	16.08	16.08	.0	2.72			X
21	.50	16.08	16.08	.0	.14	X		
22	.00	16.08	16.08	31.0	.00		X	
23	12.72	16.08	16.08	.0	20.10	X		
24	.00	16.08	16.08	31.0	.00		X	
25	.50	16.08	16.08	.0	.14	X		
26	.00	16.08	16.08	.0	2.72			X
27	.00	16.08	16.08	31.0	.00		X	
28	17.37	16.08	18.81	.0	576.00	X		
29	.00	18.81	18.81	31.0	.00		X	
30	2.73	18.81	16.08	.0	.77	X		
31	.00	16.08	16.08	31.0	.00		X	
32	.00	16.08	16.08	.0	2.72			X
33	.50	16.08	16.08	.0	.14	X		
34	.00	16.08	16.08	31.0	.00		X	
35	12.72	16.08	16.08	.0	20.10	X		
36	.00	16.08	16.08	31.0	.00		X	
37	.50	16.08	16.08	.0	.14	X		
38	.00	16.08	16.08	.0	2.72			X

LMSC-D673326

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 2

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	LINE	-LINE TYPE- ELBOW VALVE BAYONET -T-
39	.00	16.00	16.00	31.0	.00		
40	17.37	16.00	10.81	.0	576.00	X	
41	.00	10.81	10.81	31.0	.00		X
42	2.73	10.81	16.00	.0	6.77	X	
43	.00	16.00	16.00	31.0	.00		X
44	.00	16.00	16.00	.0	0.72		
45	.50	16.00	16.00	.0	6.14	X	
46	.00	16.00	16.00	31.0	.00		X
47	12.72	16.00	14.00	.0	20.10	X	
48	.00	14.00	14.00	31.0	.00		X
49	09.07	14.00	14.00	.0	140.69	X	
50	.00	14.00	14.00	31.0	.00		X
51	119.61	14.00	-4.72	.0	180.92	X	
52	.00	-4.72	-4.72	31.0	.00		X
53	46.44	-4.72	-4.72	.0	73.36	X	
54	.00	-4.72	-4.72	31.0	.00		X
55	13.36	-4.72	-2.62	.0	21.10	X	
56	11.94	-2.62	9.32	.0	3.39	X	
57	30.20	9.32	14.00	.0	47.83	X	
58	.00	14.00	14.00	31.0	.00		X
59	46.44	14.00	14.00	.0	73.36	X	
60	14.00	14.00	14.00	.0	3.97	X	
61	.00	14.00	14.00	31.0	.00		X
62	2.00	14.00	16.00	.0	.57	X	
63	.00	16.00	16.00	31.0	.00		X
64	5.00	16.00	16.00	.0	1.42	X	
65	.00	16.00	16.00	31.0	.00		X
66	.00	16.00	16.00	.0	2.72		
67	.50	16.00	16.00	.0	.14	X	
68	.00	16.00	16.00	31.0	.00		X
69	.60	16.00	15.40	.0	.19	X	
70	.00	15.40	15.40	31.0	.00		X
71	1.00	15.40	15.40	.0	.28	X	
72	.00	15.40	15.40	.0	2.72		X
73	2.00	15.40	15.40	.0	.57	X	

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 3

LINE SECTION NUMBER	LENGTH (FEET)	INLET HEIGHT (FEET)	EXIT HEIGHT (FEET)	EFFECTIVE L/D	HEAT RATE (WATTS)	LINE	-LINE TYPE- ELBOW VALVE BAYONET -T-
1	.00	15.40	15.40	340.0	.00		X
2	2.00	15.40	15.40	.0	1.13	X	
3	.00	15.40	15.40	.0	6.39		
4	1.00	15.40	15.40	.0	.57	X	X
5	.00	15.40	15.40	31.0	.00		
6	1.32	15.40	14.08	.0	.75	X	X
7	.00	14.08	14.08	31.0	.00		X
8	14.00	14.08	14.08	.0	7.94	X	
9	.00	14.08	14.08	31.0	.00		X
10	5.00	14.08	9.00	.0	2.88	X	
11	.00	9.00	9.00	31.0	.00		X
12	3.00	9.00	9.00	.0	1.75	X	
13	.00	9.00	9.00	31.0	.00		X
14	1.00	9.00	0.00	.0	.57	X	
15	.00	0.00	0.00	.0	6.39		X
16	.50	0.00	7.50	.0	.20	X	
17	.50	7.50	7.00	.0	.28	X	
18	.00	7.00	7.00	90.0	.00		X
19	.50	7.00	6.50	.0	.20	X	
20	6.30	6.50	.20	.0	7500.00	X	
21	1.50	.20	-1.30	.0	.85	X	
22	1.00	-1.30	-2.30	.0	.57	X	
23	.00	-2.30	-2.30	31.0	.00		X
24	3.00	-2.30	-2.30	.0	1.75	X	
25	.00	-2.30	-2.30	31.0	.00		X
26	11.30	-2.30	9.00	.0	6.41	X	
27	.00	9.00	9.00	31.0	.00		X
28	5.00	9.00	14.08	.0	2.88	X	
29	.00	14.08	14.08	31.0	.00		X
30	14.00	14.08	14.08	.0	7.94	X	
31	.00	14.08	14.08	31.0	.00		X
32	1.32	14.08	15.40	.0	.75	X	
33	.00	15.40	15.40	31.0	.00		X
34	1.00	15.40	15.40	.0	.57	X	
35	.00	15.40	15.40	.0	6.39		X
36	2.00	15.40	15.40	.0	1.13	X	

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 4

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	LINE	-LINE TYPE-			
							ELBOW	VALVE	SAYONET	-T-
1	.00	15.40	15.40	340.0	.00				X	
2	2.00	15.40	15.40	.0	1.13	X				
3	.00	15.40	15.40	.0	6.39				X	
4	1.00	15.40	15.40	.0	.57	X				
5	.00	15.40	15.40	31.0	.00		X			
6	1.32	15.40	14.08	.0	.75	X				
7	.00	14.08	14.08	31.0	.00		X			
8	14.00	14.08	14.08	.0	7.94	X				
9	.00	14.08	14.08	31.0	.00		X			
10	5.08	14.08	9.00	.0	2.88	X				
11	.00	9.00	9.00	31.0	.00		X			
12	3.08	9.00	9.00	.0	1.75	X				
13	.00	9.00	9.00	31.0	.00		X			
14	9.70	9.00	9.00	.0	5.50	X				
15	.00	9.00	9.00	31.0	.00		X			
16	1.00	9.00	8.00	.0	.57	X				
17	.00	8.00	8.00	.0	6.39				X	
18	.00	8.00	8.00	90.0	.00					X
19	1.00	8.00	7.00	.0	.57	X				
20	.00	7.00	7.00	31.0	.00		X			
21	.00	7.00	7.00	.0	320.00	X				
22	.00	7.00	7.00	31.0	.00		X			
23	1.00	7.00	8.00	.0	.57	X				
24	.00	8.00	8.00	.0	6.39				X	
25	1.00	8.00	9.00	.0	.57	X				
26	.00	9.00	9.00	31.0	.00		X			
27	9.70	9.00	9.00	.0	5.50	X				
28	.00	9.00	9.00	31.0	.00		X			
29	3.08	9.00	9.00	.0	1.75	X				
30	.00	9.00	9.00	31.0	.00		X			
31	5.08	9.00	14.08	.0	2.88	X				
32	.00	14.08	14.08	31.0	.00		X			
33	14.00	14.08	14.08	.0	7.94	X				
34	.00	14.00	14.08	31.0	.00		X			
35	1.32	14.08	15.40	.0	.75	X				
36	.00	15.40	15.40	31.0	.00		X			
37	1.00	15.40	15.40	.0	.57	X				
38	.00	15.40	15.40	.0	6.39				X	
39	2.00	15.40	15.40	.0	1.13	X				

LMSC-D673226

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 5

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	-LINE TYPE-				
						LINE	ELBOW	VALVE	BAYONET	-T-
1	.00	15.40	15.40	340.0	.00				X	
2	2.00	15.40	15.40	.0	1.13	X				
3	.00	15.40	15.40	.0	6.39				X	
4	1.00	15.40	15.40	.0	.57	X				
5	.00	15.40	15.40	31.0	.00		X			
6	1.32	15.40	14.08	.0	.75	X				
7	.00	14.08	14.08	31.0	.00		X			
8	14.00	14.08	14.08	.0	7.94	X				
9	.00	14.08	14.08	31.0	.00		X			
10	5.00	14.08	9.00	.0	2.80	X				
11	.00	9.00	9.00	31.0	.00		X			
12	2.00	9.00	9.00	.0	1.13	X				
13	.00	9.00	9.00	31.0	.00		X			
14	9.70	9.00	9.00	.0	5.50	X				
15	.00	9.00	9.00	31.0	.00		X			
16	5.50	9.00	3.50	.0	3.12	X				
17	.00	3.50	3.50	.0	6.39				X	
18	.50	3.50	3.00	.0	.28	X				
19	.00	3.00	3.00	90.0	.00					X
20	.50	.00	2.50	.0	.28	X				
21	.00	2.50	2.50	31.0	.00		X			
22	.00	2.50	2.50	.0	.00	X				
23	.00	2.50	2.50	31.0	.00		X			
24	1.00	2.50	3.50	.0	.57	X				
25	.00	3.50	3.50	.0	6.39				X	
26	5.50	3.50	9.00	.0	3.12	X				
27	.00	9.00	9.00	31.0	.00		X			
28	9.70	9.00	9.00	.0	5.50	X				
29	.00	9.00	9.00	31.0	.00		X			
30	2.00	9.00	9.00	.0	1.13	X				
31	.00	9.00	9.00	31.0	.00		X			
32	5.00	9.00	14.08	.0	2.80	X				
33	.00	14.08	14.08	31.0	.00		X			
34	14.00	14.08	14.08	.0	7.94	X				
35	.00	14.08	14.08	31.0	.00		X			
36	1.32	14.08	15.40	.0	.75	X				
37	.00	15.40	15.40	31.0	.00		X			
38	1.00	15.40	15.40	.0	.57	X				
39	.00	15.40	15.40	.0	6.39				X	
40	2.00	15.40	15.40	.0	1.13	X				

TABLE 5 LIQUID NITROGEN SUBSYSTEM COMPONENTS (CONT)

LINE DESCRIPTION FOR LINE NUMBER 6

LINE SECTION NUMBER	LENGTH (METER)	INLET HEIGHT (METER)	EXIT HEIGHT (METER)	EFFECTIVE L/D	HEAT RATE (WATTS)	-LINE TYPE-				
						LINE	ELBOW	VALVE	BAYONET	-T-
1	.00	15.40	15.40	90.0	340.65				X	
2	26.00	15.40	15.40	.0	29.50	X				
3	.00	15.40	15.40	31.0	.00		X			
4	0.50	15.40	6.90	.0	9.64	X				
5	.00	6.90	6.90	31.0	.00		X			
6	10.50	6.90	6.90	.0	20.99	X				
7	.00	6.90	6.90	31.0	.00		X			
8	7.90	6.90	-1.00	.0	8.96	X				
9	.00	-1.00	-1.00	31.0	.00		X			
10	54.50	-1.00	-1.00	.0	61.83	X				
11	.00	-1.00	-1.00	31.0	.00		X			
12	18.00	-1.00	-1.00	.0	20.42	X				
13	.00	-1.00	-1.00	31.0	.00		X			

Section 3

PROGRAM DESCRIPTION

A description of the major calculational subroutines and associated sub-programs is presented here along with the necessary equations and procedural techniques used to compute fluid flow and thermodynamic properties throughout the cryogen system.

First, the major subroutine CMPCAL used in the liquid helium subsystem calculations is discussed followed in order by GASRCV for the helium gas recovery subsystem and LIQNIT for the liquid nitrogen subsystem.

3.1 SUBROUTINE CMPCAL

Subroutine CMPCAL provides, in one package, the necessary equations, constants, and procedural techniques for the computation of the fluid flow and thermodynamic conditions existing in the various circuit segments of the liquid helium subsystem. The subroutine makes use of several sub-programs which supply specific computations for the helium coolant fluid thermodynamic properties.

The manner in which CMPCAL is programmed to carry through its calculation is illustrated in the following sketch and explanation.

Subroutine CMPCAL begins with the identification of the cryogen fluid and its state (liquid helium in this instance) and then proceeds to consider each component in the fluid circuit starting with the magnet dewar. Each component in its proper sequence, supply line segments, fittings, tees, valves, magnet segment, and return line segments, are considered, ending with the return line sparger at the magnet dewar. For each component item, the fluid condition is evaluated as the flow characteristics and thermodynamic state. CMPCAL performs the computations for each fluid subsystem loop separately, treating first the entire primary loop and then, in turn, each secondary loop.

For the magnet system there are two loops, with the secondary loop running from the supply line tee to the return line tee. The subroutine maintains a running account of all flow partitioning and recombination.

Data transfer to and from subroutine CMPCAL is effected through the use of INCLUDE statements which bring in the appropriate PDF element defining the required labeled COMMON storage areas for the variables involved.

3.1.1 Input Requirements

All input data requirements needed for CMPCAL for the processing of:

Magnet Subsystem Configurations

Cryopanel Subsystem Configurations

Refrigerator-Liquefier Configurations

are transferred to CMPCAL via the "PDP CMAG" common statements, and are invoked by the INCLUDE CMAG statement. The input data variables and previously computed value variables required here are defined in Subroutines MAGNET, CRYOPAN and HTMKUP.

Input Required from Configuration Data

<u>NAME</u>	<u>DESCRIPTION</u>
ICNF	Number of Configuration Data Cards Input
IDX	Configuration Item Index
ISIGN	Analysis Directional Index
CFUNCT	Integer Corresponding to Configuration Item Function
CFTYPE	Integer Corresponding to Function Type
CITYPE	Integer Corresponding to Insulation Type
CNOPER	Number of Units Operating
CHHEAD	Relative Fluid Head Height for Unit
FRCTDEF	Characteristic Friction Factor for Flow Region
LDD	Length over Diameter (Length only for Lines)
DIAM	Diameter

<u>NAME</u>	<u>DESCRIPTION</u>
ITHIK	Insulation Thickness
NBAR	Number of Layers of Insulation per Inch
CODE	Identification Code for Config. Unit

Major Variables Employed in Model Equations

<u>NAME</u>	<u>DESCRIPTION</u>
IGAS	Integer Corresponding to Fluid Kind
GSTATE	Integer Corresponding to Fluid State
PRES	Fluid Pressure at Each Point in System
TEMP	Fluid Temp at each Point in System
WDOTN	Fluid Flowrate at each Point in System
WDOTI	Branch Flowrate in Magnet Circuits
WDOTL	Liquid Mass Flow at each Point in System
WDOTG	Gaseous Mass Flow at each Point in System
FLD	$\frac{FL}{D}$ for Configuration Unit Considered
IDV	Integer Pointer for Control Volume Index
LDV	Integer Pointer for Fitting and Tap Configuration
RHD or RDENS	Fluid Density at any Point in System
DELP	Fluid Pressure Drop across Component
A	Cross Sectional Area of Flow Region
GLOPP	Integer Specifying Current Subsystem Loop
CMPVOL	Volume of Component Being Considered
CPNU	C_p of Fluid at Current Point Condition
DELH or DH	Enthalpy Change (ΔH)
DLPTOT	Pressure Drop Summing Variable
MUHE	Viscosity of Helium at Given Point.

<u>NAME</u>	<u>DESCRIPTION</u>
QIN	Thermal Energy Input
QXFER	Thermal Energy Transfer
QUAL	Fluid Quality at Point Considered
SVLIN	Fluid Specific Volume at Entering Condition
SVLMIX	Fluid Specific Volume (Gas + Liquid)
SVLNEW	Recomputed Sp. Vol. for New Condition
SYSVØL	System Volume Summing Variable
WDGSTØ	Mass Flow of Gas from Storage Dewar
WDGMAG	Mass Flow of Gas from Magnet Dewar
WDGCRY	Mass Flow of Gas from Cryopanel Dewar
WDTXS	Mass Flow of Make up Gas added to System
SFAREA	Surface Area of Component being Considered
VELØ	Fluid Velocity at point being Considered
REYNØ	Reynolds Number of Fluid at Point Considered

Constants Required

$$PI = 3.14159265$$

$$\text{Gravity} = G = 4.4482152 \text{ (Kg-M/Sec}^2\text{)}$$

$$CI = 1.5134E-09 / (G * PI * PI)$$

3.1.2 Major CMPCAL Math Model Equations

Much of the coding in subroutine CMPCAL is required for setting-up component sequencing indices, temperatures, pressures, component identity and dimensions, as well as fluid identity and state. Most of this coding is obvious as to its meaning by simple inspection and tracking at the branching variable; therefore, only the more significant equations will be treated.

Pressure drop and fluid state calculations are performed by CMPCAL for all lines, fittings, taps and valves. A typical line calculation will serve to illustrate the computation procedure, taking the first line encountered after a major heat source, which will be assumed to be a magnet.

Determine the frictional length

$$FLD = f * \frac{L}{D}$$

Determine the surface area and volume of line segment

$$SFAREA = \pi * DIAM(i) * L(i)$$

$$CMFVOL(i) = (\pi/4) * DIAM(i) * DIAM(i) * L(i)$$

Assign correct heat leak to line

$$QUSE = QLEAKI$$

Calculate inlet conditions

$$\dot{w}_N(i) = \dot{w}_N(i-1) \quad \text{Flow rate}$$

$$T(i) = T(i-1) \quad \text{Temperature}$$

$$P(i) = P(i-1) \quad \text{Pressure}$$

$$RH\emptyset = RH\emptyset (Li\emptyset + \text{Gas Mix}) \text{ from Magnet}$$

$$RDENS(i) = RH\emptyset$$

Calculate pressure drop

$$DELP(i) = C1 * FLD * \dot{w}_N(i-1)^2 / (RH\emptyset * DIAM(i)^4)$$

Calculate helium head change

$$HDLP = RH\emptyset * CHEAD(i) * 0.00980665$$

Calculate new pressure

$$P(i) = P(i) + HDLP - DELP(i)$$

Compute new temperature using predicted heat leak

$$C_p = f(P(i), T(i), \text{Liq. State}) \text{ (He Thermo Program)}$$

$$QXFER = QLEAK1 * 3600 * SFAREA$$

$$TNEW = T(i) + (QXFER / (C_p * \dot{w}_N(i)))$$

Compute new fluid properties for line exit

Liquid Enthalpy Entering Line

$$H1 = f(P(i-1), T(i-1), \text{Liq. State}) \text{ (He Thermo Program)}$$

Obtain liquid and vapor saturated properties at TNEW from Helium

Thermo Program

$$HESATD = f(P(i), TNEW, \text{Sat. Condition})$$

HESATD contains:

H2(L) - Liq. Enthalpy

H2(V) - Vap. Enthalpy

TSAT - Sat. Temp.

SVL - Sp. Vol. of Liquid

SVV - Sp. Vol. of Vapor

VISCL - Viscosity of Liquid

VISCV - Viscosity of Vapor

Calculate enthalpy change, inlet-to-outlet liquid

$$\Delta H1 = H1 - H2(L)$$

Calculate enthalpy change, liquid to vapor

$$\Delta H2 = H2(V) - H2(L)$$

Calculate new fluid temperature

$$T(i) = TSAT$$

Calculate energy available to generate state change

$$\Delta Q = ((\dot{w}_L(i-1) * \Delta H1) / \text{HEMWT}) * 1000 \quad (\text{J/Hr})$$

Calculate new vapor generated

$$\dot{w}_G X = (\Delta Q * \text{HEMWT}) / (\Delta H2 * 1000) \quad (\text{Kg/Hr})$$

Calculate new mass flow rates - liquid and gas

$$\dot{w}_G(i) = \dot{w}_G(i-1) + \dot{w}_G X$$

$$\dot{w}_L(i) = \dot{w}_L(i-1) - \dot{w}_G X$$

Calculate new quality at line exit .

$$QUAL(i) = \dot{w}_G(i) / \dot{w}_L(i)$$

Calculate specific volume of fluid (mix) at line outlet

$$SVLNEW = (1-QUAL(i)) * SVL + QUAL(i) * 3VG$$

Compute velocity of fluid at line outlet

$$VELO(i) = \dot{w}_N(i) * SVLNEW * (1.0/HEMWT) * (1.0/(0.7854 * Diam(i)^2))$$

Calculate density at line outlet

$$RH\emptyset (Liq + Gas) = (1.0/SVLNEW) * HEMWT$$

$$RDENS(i) = RH\emptyset (Liq + Gas)$$

Calculate viscosity of fluid mix at line outlet

$$MUHE = (1.0 - QUAL(i)) * VISCL + QUAL(i) * VISCV * 0.00001$$

Compute Reynolds Number at line outlet

$$REYN\emptyset(i) = (DIAM(i) * VELO(i))/3600. * RDENS(i))/MUHE$$

At this point CMPCAL adds the computed DELP(i) to DLPTOT (Summing for total pressure drop) and adds CMVVL(i) to SYSVVL (Summing for total system volume) and then prints out a line of computed LINE values in the Summary of Computed Configuration Parameters table. The program then obtains the I.D. of the next component from the Configuration Table and continues the calculations until the END card in the Configuration Table is reached.

3.2 SUBROUTINE GASRCV

GASRCV is a subroutine for analyzing the gaseous helium recovery subsystem; it is accessed by the main subroutine CCTRL; however, its function and output is independent of the MFTF*CSA helium program.

Each line section is analyzed in sequence by branching to one of three subroutines included within the program, DPLINE, DPVALV, or COMPDP. These subroutines determine the pressure drop across the line section for the case of a plumbing line, valve or major component respectively. In all cases, the flow is assumed to be isothermal at the local ambient temperature so that once the pressure drop across the line section is determined, the thermodynamic state of the helium is completely specified. The assumption of isothermal flow breaks down if detailed analysis of the purifier system is included in this analysis. After discussion with LLL personnel, however, it was decided that the purifier system could be treated as an equivalent isothermal blackbox since a heat exchanger is provided internal to the purifier system to insure that the gas exit temperature is at, or at least near, the local ambient temperature.

3.2.1 Subroutine DPLINE

A one dimensional isothermal frictional flow gas dynamic analysis was used to determine the pressure drop through the plumbing lines of the helium recovery system. Referring to the listing for subroutine DPLINE, the maximum length to diameter ratio (given the inlet Mach number) is determined from:

$$X_{LMAX} = \left[\frac{1 - \gamma M_1^2}{\gamma M_1^2} + \ln(\gamma M_1^2) \right] \frac{1}{4f}$$

f = friction factor

γ = ratio of specific heats (1.667)

M_1 = Mach number at inlet

The value of XLD_{MAX} is compared with the effective length to diameter ratio determined for the line section, XLD (which includes effects of elbows or bends). If XLD is greater than XLD_{MAX} , then the pressure drop is flagged to indicate choked flow for the particular line section. If XLD is less than XLD_{MAX} , then the program continues forward to solve for the exit pressure, p_2 from the relationship

$$4f(XLD) = \frac{1 - \left(\frac{p_2}{p_1}\right)^2}{\gamma M_1^2} + \ln \left(\frac{p_2}{p_1}\right)^2$$

when p_1 is the inlet pressure.

The accuracy of this calculational method depends on how closely the properties of a real gas approaches that of an ideal gas over the conditions analyzed. Checks were made which show calculated pressures differed less than 0.01% between the two calculational methods for both the low pressure section and the high pressure section (when pressure gradients are small). To avoid any cumulative errors, the density of the real gas is recomputed at the exit pressure and ambient temperature after each pressure drop calculation is performed. This density value is then used to determine the gas mach number within the line for use in the next iteration.

3.2.2 Subroutine DPVALV

The pressure drop experienced through valves is computed from the standard engineering frictional flow pressure drop relationship:

$$\Delta p = \frac{32}{T^2} \times 10^{-3} \frac{f(L/D) (\dot{m}^2)}{(\rho) D^4}$$

where

f = friction factor

L/D = effective L/D ratio for valve

340 for globe valve

170 for angle valve

77 for check valve

$\dot{m}$ = mass flow rate (kg/sec)

D = diameter (meter)

ρ = density (kg/meter³)

and

Δp = pressure drop (kPa)

the factor of 1.0×10^{-3} converts pressure units from n/m^2 to kPa.

3.2.3 Subroutine COMPDP

Subroutine COMPDP provides access where the pressure drop across the major system components can be inserted. At the present time, no specific data on these components exists; hence, no routines were developed. Instead, a constant worst case pressure drop of 13.8 kPa (2 psia) across the recovery blowers and 172.0 kPa (25.0 psia) across all remaining components was assumed. These values should be updated or routines be developed when sufficient data becomes available.

3.3 SUBROUTINE LIQNIT

LIQNIT is a subroutine for analyzing the liquid nitrogen distribution system; it is accessed by the main subroutine CCTRL; however, its function and output is independent of the MFTF*CSA helium program.

When control is transferred from subroutine CCTRL to LIQNIT, subroutine N2MAIN is accessed. Within subroutine N2MAIN, all required system input data and parameters are specified.

Identification of the flow geometry is first defined for each of the six flow lines. The line number is specified as the variable LINE, followed in sequential order by the line section length (XLEN), inlet height (ZIN), exit height (ZOUT), effective L/D ratio (EFF), three line section heat rate terms (Q0, Q1 and Q2), the line section line type identifier (TYPE), and the number of branches incurred for "T" sections (TNUM). One data card is used for definition of these variables for each line section using a FORMAT (7F10.3, 2F5.1) field specification. The program is currently set up to read 100 different line sections for each of the six line numbers. Provision is made to accept fewer line sections by inputting a negative value for XLEN in the card following the last line section to be defined. The total number of line sections contained in each line number, I, is stored as the variable JMAX(I).

Once the line geometry has been defined, analysis parameters which are fixed for each calling of LIQNIT are specified. These parameters include the storage tank delivery pressure (PST[R]), and initial cryogen quality (QUAL) -

FØRMAT (F10.2, F10.6), the number of layers of multilayer insulation to be used over the insulated line sections (RNLAYR) and the hot boundary temperature (THØT) - FØRMAT(2F10.3), as well as the fluid flow losses to each of the four open loop nitrogen systems (WLN14, WLN16, WLN17 and WLN19) - FØRMAT (4F10.7). Once having the hot boundary temperature, initial pressure and number of insulation layers, the effective multilayer conductivity can be determined for use in determining line section heat loads.

$$CØNMLI = 5.329E-10*(THØT + TCØLD) - (3.684E-13*(THØT**3 - TCØLD**3)/(THØT-TCØLD)) + (1.4941E-16*(THØT**4.67 - TCØLD**4.67)/(THØT-TCØLD))$$

where CØNMLI is in w/cm-°K

Up to ten parametric runs are possible for each calling of LJQNT, varying line diameters and flow rates. As part of a DØ loop, the flow rate in m²/sec (FLØW) and line section diameters (DIA) are specified - FØRMAT(F10.7, 6F10.5) for each case. Fewer than 10 cases may be considered by specifying a negative flow rate after the last case of interest.

The heat rates to each line section, QNET, are evaluated using the line diameter and three each heat rate terms, Q0, Q1 and R2. Depending on the type of line section, the function of each heat rate term may vary slightly. The Q0 term represents an additive constant heat flux term which is used to identify known heat loads in line sections such as the cryopanel, dewar shields, etc. Heat loads for valves and bayonet fittings are sized relative to a typical line element, in proportion to the line diameter. The Q1 term is a multiplier which multiplies

the proportional heat load by either zero or one. If one, the Q0 additive term is then set to zero. At a later date, when a specified component is selected with known thermal resistance, that value may be input as the Q0 term and Q1 made equal to zero. Heat loads to "T" sections and line elbows are set equal to zero.

In the cryogen plumbing lines, the heat load is assumed to be that load through the insulation blanket. The Q1 term is again a multiplier which can be set to zero if measured or known values can be used in the Q0 term. Support heat loads were not included here, but may also be included in the Q0 term once they are defined at a later time.

For shielded lines, the Q1 and Q2 terms represent the effective cold shield diameter and length which define the cold shield surface area. Q0 is again an additive constant which, if non-zero, represent additional structural heat loads or specific line heat loads. If the latter is the case, the Q1 or Q2 or(both) should be set to zero.

Once the heat loads to each line section are determined, an image of the configuration geometry is output for each line number. The length, inlet and exit height, effective L/D, computed line section heat load and definition of the line type are shown. At this point, subroutine LNSYST is called when analysis of the defined system is begun.

Within subroutine LNSYST, the thermodynamic state of nitrogen is determined at each line section for all lines. LINE 1 is analyzed first.

From the storage tank pressure and quality, the initial cryogen state is determined. Subroutine N2PROP is called which first determines the cryogen temperature from the vapor pressure-nitrogen temperature relationship. Once the vapor pressure temperature is determined, the liquid and vapor viscosity, density, enthalpy, as well as the heat of vaporization and change in liquid enthalpy with respect to pressure is computed within N2PROP. The Reynolds Number and friction factor are computed from

$$REYN = 4.0 * WDOT / (3.14159 * DIAM * VL1)$$

$$FRICT = 0.00560 + 0.500 * (REYN ** (-0.32))$$

for use in the pressure drop calculation.

where WDOT - total mass flow rate (kg/s)

DIAM - line diameter (m)

VL1 - inlet liquid viscosity (kg/m·s)

The line section length (XLEN), inlet height (ZIN), exit height (ZOUT), effective L/D ratio (EFF), line section computed heat load (QNET), line type identifier (TYPE) and number of branches indexed for "T" sections (TNUM) are defined as part of a DØ loop. At each line section, subroutine DPCAL (which is described later) is called to evaluate both the pressure drop within the line section as well as the change in thermodynamic state of the cryogen. The nitrogen properties at the exit of the line section are stored for use as the inlet nitrogen properties at the next line section. The procedure is repeated until the last line section in LINE 1 is reached at the liquid nitrogen inlet valve box, where branching to the several open and closed loop

lines occurs. The flow required by the open loop lines reduces that available to the closed loop lines by the variable $WLOST$ where

$$WLOST = WLN14 + WLN16 + WLN17 + WLN19$$

To determine the flow through each of the remaining four, parallel flow, closed loop lines, the line pressure drop as a function of mass flow rate is determined for three different flow rates between 0 and $WTOT$ when $WTOT = WDOT - WLOST$. A quadratic least squares curve fit of the data is generated for each line which is used to generate a probable line flow rate consistent with an equal pressure drop at the exit of each line and a total mass flow rate in all lines equal to $WTOT$. The line pressure drops are re-evaluated, checking to insure the actual pressure drop in each line is within 100 n/m^2 of the average pressure drop in all lines. Should further iterations be necessary, the data from the last pressure drop vs. flow rate computation is added to the set of data points to be curve-fit and a new curve-fit relationship is generated. Separate curve fit relationships are generated in each line for the case where 1) the quality equals 1 and 2) the quality is less than 1.

If all pressure drops are within 100 n/m^2 of the average, then the analysis continues by recombining the total mass flow from lines 2-5 and initiates the pressure drop analysis through line 6. Initial pressure at the inlet to line 6 is set equal to the average of the exit pressure in lines 2-5 and the quality is evaluated taking into account the possibility of 100% gas flow in any of the lines at a temperature higher than the vapor pressure temperature.

Once the thermodynamic state of the nitrogen is determined at the entrance to line 6, the pressure drop and change in thermodynamic state of the nitrogen is determined for each line section using subroutine DPCAL. In subroutine DPCAL, the pressure drop and change in thermodynamic state of the nitrogen at each line section is evaluated. For those cases where the nitrogen quality is less than one, pressure drop incurred during two-phase diabatic flow is determined from:

$$\Delta p_f = \left(\frac{dp}{dL} \right)_0 \int_0^L (1-x)^{1.8} \phi_L^2 dL$$

where

ϕ_L is the Martinelli-Nelson correlation for two-phase adiabatic flow

x is fluid quality

$(dp/dL)_0$ is the pressure gradient that would be exhibited by liquid flow only, i.e. $x = 1.0$

L is the effective length of the line section

For use in this relationship, the variables XTT and XLOCK are defined as:

$$XTT = \left(\frac{1-x}{x} \right)^{1.8} \left(\frac{\mu_k}{\mu_v} \right)^{0.2} \left(\frac{\rho_v}{\rho_k} \right) \quad \text{and} \quad XLOCK = (XTT)^{1/3.6}$$

where μ and ρ are the cryogen viscosity and density respectively. The Lockhart-Nelson correction was then approximated by

$$\phi = 1.0 + (1.703/XLOCK) + (1.269/(XLOCK^{**2}))$$

Once a frictional pressure drop is defined, a first approximation to the exit quality is made from an energy balance on a closed section of tubing,

$$\Delta p = \frac{(x_2 h_2 - x_1 h_1) - \dot{Q}/\dot{m} + g(z_2 - z_1)}{(dh/dp)_{SAT}}$$

where

$$\Delta p = \Delta p_f + \Delta p_{\text{head}} \quad (\text{diabatic flow})$$

h = heat of vaporization

$\dot{Q}$ = heat flux

$\dot{m}$ = mass flow rate

g = acceleration constant

z = head height

Properties at the inlet of the line section are known from either initial input or from previous calculations. At the line exit, z_2 is defined as input and h_2 is determined from N2PRØP using $p_2 = p_1 - \Delta p$.

Once the exit quality is defined, the pressure drop relationship is refined to include a diabatic momentum pressure drop defined by

$$\Delta p = \frac{\phi \left(\dot{m}_v + \dot{m}_l \right)^2}{\rho_l A^2}$$

where

$$\phi = \left[\frac{(1-x_2)^2}{R_{l2}} - \frac{(1-x_1)^2}{R_{l1}} \right] + \left[\frac{x_2^2}{R_{v2}} - \frac{x_1^2}{R_{v1}} \right] \frac{\rho_l}{\rho_v}$$

and R_l , R_v are the volume fraction of liquid and vapor phases respectively. This momentum pressure drop term is added to the net diabatic pressure drop which in turn is used to recalculate an exit quality, this time including momentum effects in the quality relationship.

$$\Delta p = \frac{(x_2 h_2 - x_1 h_1) + \frac{v_2^2 - v_1^2}{2} - Q/\dot{m} + g(z_2 - z_1)}{(dh/dp)_{\text{SAT}}}$$

where V = flow velocity

This process is repeated, each time improving the accuracy of the exit quality computation, until finally the change in the exit quality is within 0.1% of the previous calculation. Because the momentum effect is of second order, the number of iterations is usually quite small (between 2-3).

In the case where a transition occurs from quality less than 1.0 to a quality equal to 1.0, the pressure drop required to bring the cryogen to a quality of 1.0 is first determined and that relative location within the line is determined. At that point, the remaining pressure drop within the line is computed, as are all remaining calculations for quality equal to one, using the standard gas dynamic relationship for frictional flows within a constant area duct with heat interaction. Specifically, the change in Mach number is determined from

$$\frac{dM}{M} = \frac{(1 + \gamma M^2) (1 + \frac{\gamma-1}{2} M^2)}{2(1-M^2)} \frac{dT_0}{T_0} + \frac{(\gamma M^2) (1 + \frac{\gamma-1}{2} M^2)}{2(1-M^2)} \frac{4fL}{D}$$

where

M = inlet Mach number

T_0 = stagnation temperature of the gas

γ = ratio of specific heats

f = friction factor

L, D = line length and diameter

and $dT_0 = \dot{Q}/C_p$

Knowing the change in Mach number in the line, the exit Mach number is determined from which the exit gas temperature is derived.

$$T = T_0 / \left[\left(\frac{\gamma-1}{2} \right) M^2 \right]$$

Using the equation of state, the density of the gas at the exit of the line section is determined, using the inlet line section pressure. The line pressure drop is evaluated assuming both a frictional and head pressure drop:

$$\Delta p = (4.0 fL/D/2 \rho_{avg}) \left[(\dot{m}/0.7854 D^2)^2 + 9.8066(z_2 - z_1) \rho_{avg} \right]$$

The computed exit pressure is again input to the equation of state and a refined gas density at the exit of the line section is determined. This density is used to determining the final line pressure drop using the above relationship.

Section 4

PARAMETRIC ANALYSES

To illustrate the type of design information that can be generated by the MFTF*CSA program, typical parametric analyses were performed for selected cryogen subsystems.

4.1 LIQUID HELIUM DEWAR/MAGNET FLOW LOOP ANALYSIS

The magnets are cooled from a 4000 liter Dewar using a liquid helium natural convection flow loop as shown previously in Fig. 7. Consequently, it is of interest to see if the helium quality remains below the desired value of 0.10 within the magnet for projected flow rates of interest (and whether a forced convection flow system may be required). Fig. 12 shows the flow rate must exceed 6750 liters/hour to keep the quality in the magnet at or below 0.10. It is recommended a detailed fluid flow analysis be made of the magnet to see if natural convection forces are sufficient to maintain this flow rate.

4.2 GASEOUS HELIUM RECOVERY SYSTEM ANALYSIS

The Gaseous Helium Recovery subsystem analysis is divided into two parts

- 1) the flow from the magnet through the recuperator to the gas bag and
- 2) the flow from the gas bag through various processing steps to high pressure gas storage. The first part of the program handles transient flow conditions, i.e., a magnet quench and subsequent dump of the liquid helium through the recuperator where it is vaporized and warmed to near ambient temperature. Table 6 summarizes the results of transient parametric analyses

Fig. 12 Effect of Flow Rate on Magnet/Dewar Quality

TABLE 6. RESULTS OF RECUPERATOR ANALYSES

RECUPERATOR CONFIGURATION DIMENSIONS, M	RECUPERATOR GAS PLENUM		VOL OF LHe VENTED, LITERS	INITIAL BLOWDOWN PRESSURE FROM MAGNET TO RECUPERATOR, KPa	AMB TEMP., K	AMB TEMP MINUS RECUPERATOR GAS EXIT TEMPERATURE ΔK_{MAX}
	INLET	EXIT				
A <p>.68 SOLID FRACTION .025 DIA. S.S. BALLS</p> <p>.254 DIA. INLET AND OUTLET</p>	1 Yes	Yes	3000	345	290	~ 0
B <p>.68 SOLID FRACTION .025 DIA. S.S. BALLS</p> <p>50% OPEN AREA</p> <p>.254 DIA. INLET AND OUTLET</p>	2 No	No	3000	345	316.5	19
	No	No	3000	689	316.5	25.5
	No	No	3000	1034	316.5	28.5
	3 No	No	3000	345	266.5	19.5
	No	No	3000	689	266.5	25.5
	No	No	3000	1034	266.5	28.5
	4 No	Yes	3000	689	273	7
	No	Yes	4500	689	273	8.8*
	No	Yes	6000	689	273	9.0*
* When Gas Bag is Filled to 100% Capacity						

LMSC-D673326

performed on the flow loop from the magnet through the recuperator to the gas bag (see Fig. 10). Recuperator configuration A was initially selected for analysis by LLL. This heat exchanger tank, filled with stainless steel balls, had gas plenums both at the inlet and outlet providing uniform axial fluid flow. The outlet gas temperature for this recuperator was essentially ambient (as desired) as shown in Table 6, case 1. Based on the availability of another tank suitable for use as a recuperator (configuration B), the analyses were repeated for 1) no gas plenums at the inlet or outlet, i.e., the tank is filled to 100% with the stainless steel balls, 2) different initial inlet blowdown pressures, 3) a gas plenum at the outlet (made by filling the tank with stainless steel balls to the top of the cylindrical section) and 4) different quantities of vented liquid helium (with a gas plenum still at the outlet). Note for case 2, when the tank is filled to the 100% level with stainless steel balls, the exit gas temperature is as much as 28.5K below the ambient temperature due to channel flow through the center of the tank. Almost no flow occurs in the tank outer periphery. Dropping the ambient temperature 50K (case 3, 316.5 to 266.5K) does not affect the drop in gas exit temperature below ambient, i.e., up to 28.5K. When a gas plenum is provided at the outlet, the additional fluid radial flow in the tank drops the exit ΔT below ambient to 7 to 9K, depending on the mass of helium to be vented. It should be noted that the gas bag is not sized to hold 100% of the blowdown helium gas. The ΔT for the temperatures below ambient shown in Table 6 takes this into account and in two cases represent the outlet gas temperature from the recuperator when the gas bag is just filled to 100% capacity. (The remainder is dumped to the atmosphere.)

For the other cases, the maximum ΔT condition is reached before the gas bag is filled to 100% capacity.

From the gas bag, the ambient temperature helium gas flows through a recovery blower to a recovery compressor as shown previously in Fig. 10. Choked flow can occur in this low-pressure line section as illustrated by the rapidly rising curves in Fig. 13 and the tabular listing in Table 7. On the downstream (high pressure) side of the compressor, no choked flow conditions were found anywhere in the system for line sizes down to .02 m diameter and flow rates up 0.1 kg/sec. (A flow rate of 0.05 kg/sec is nominal.)

4.3 LIQUID NITROGEN SUPPLY SUBSYSTEM ANALYSIS

The liquid nitrogen flow loop is split into four parallel flow paths downstream of the pump as shown previously in Fig. 11. Some liquid nitrogen flow is also diverted to expendable users before entering the parallel flow paths. Two cases were analyzed where 1) the pump pressure plus inlet (line 1) and outlet (line 6) diameters were kept constant and 2) the parallel line diameters were varied as shown in Table 8. For the first case (where lines 2-5 all had the same diameter) the liquid quality was highest in line 3 (0.79) but in all lines liquid/gas flow was present in each parallel leg. When lines 3-5 were increased in diameter, the quality in line 3 dropped to 0.48 from 0.79, but increased in line 2 from 0.52 to 1.00. These types of analyses show the necessity for accurately sizing the parallel flow legs and having active fluid flow control valves on all four parallel legs on the downstream

Fig. 13 Helium Flow Velocity Between the Gas Bag and the Compressor

TABLE 7 FLOW ANALYSIS RESULTS FOR THE GASEOUS HELIUM RECOVERY SUBSYSTEM

DIA(METER)		MOOT(KG/SEC)		REYNOLDS NUMBER		F-FACTOR	
.050		.050		66703.2		.004905	
TG= 273.15		PBAG= 101.325		PCOMP= 16542.86			
LINE	END NODES	DP {KPA}	DP/L(GEOM) {KPA/M}	MACH NO.	PRESSURE {KPA}	DENSITY {KG/M**3}	
LOW PRESSURE LINE ANALYSIS							
			AT RECOVERY BAG EXIT				
L 1	9 - 10	50.4149	1.0175	.14676	101.3250	.178	
L 2	10 - 11	24.1250		.29198	50.9101	.090	
L 3	11 - 12			.55480	26.7851	.047	
FLOW IS CHOKED IN THIS LINE SECTION FOR THIS FLOW RATE AND DIAMETER							
HIGH PRESSURE LINE ANALYSIS							
			AT COMPRESSOR EXIT				
H 1	21 - 22	-.0000	-.0000	.00099	16542.8601	26.374	
H 2	22 - 23	-.0820	-.0000	.00099	16542.8601	26.374	
H 3	23 - 24	-.0000	-.0000	.00099	16542.7783	26.373	
H 4	24 - 25	-.0186	-.0000	.00099	16542.7783	26.374	
H 5	25 - 26	-.0000	-.0000	.00099	16542.7598	26.374	
H 6	26 - 27	-.0000	-.0000	.00099	16542.7598	26.374	
H 7	27 - 28	-.0418	-.0000	.00099	16542.7190	26.374	
H 8	28 - 29	-.0000	-.0000	.00099	16542.7190	26.374	
H 9	29 - 30	172.0000	-.0000	.00100	16370.7190	26.125	
H 10	30 - 31	-.0000	-.0000	.00100	16370.7190	26.125	
H 11	31 - 32	172.0000	-.0000	.00101	16198.7190	25.875	
H 12	32 - 33	-.0000	-.0000	.00101	16198.7190	25.875	
H 13	33 - 34	-.0418	-.0000	.00101	16198.6772	25.875	
H 14	34 - 35	-.0000	-.0000	.00101	16198.6772	25.875	
H 15	35 - 36	-.0836	-.0000	.00101	16198.5937	25.875	
H 16	36 - 37	-.0000	-.0000	.00101	16198.5937	25.875	
H 17	37 - 38	172.0000	-.0000	.00102	16026.5937	25.625	
H 18	38 - 39	-.0000	-.0000	.00102	16026.5937	25.625	
H 19	39 - 40	-.0844	-.0000	.00102	16026.5094	25.625	
H 20	40 - 41	-.0000	-.0000	.00102	16026.5094	25.625	
H 21	41 - 42	-.0844	-.0000	.00102	16026.4250	25.625	
H 22	42 - 43	-.0000	-.0000	.00102	16026.4250	25.625	
H 23	43 - 44	-.0844	-.0000	.00102	16026.3407	25.625	
H 24	44 - 45	-.0000	-.0000	.00102	16026.3407	25.625	
H 25	45 - 46	.0844	-.0000	.00102	16026.2563	25.625	

TABLE 8. EFFECT OF LINE SIZE ON LIQUID NITROGEN TEMPERATURE AND QUALITY

CASE 1 Line I.D., M Temp, K Quality	LOCATION						
	A	B	C	D	E	F	G
	.102	.102	.025	.025	.025	.025	.102
	88.2	88.1	86.6	86.3	86.7	86.6	86.4
	0	.001	.52	.79	.027	.020	.193
CASE 2 Line I.D., M Temp, K Quality	LOCATION						
	A	B	C	D	E	F	G
	.102	.102	.025	.051	.051	.051	.102
	88.2	88.1	132.5	88.0	88.1	88.1	88.0
	0	.001	1.00	.48	.014	.0035	.168

LMSC-D673326

exit to ensure balanced flow and adequate cooling in all four legs, simultaneously.

SECTION 5

RECOMMENDATIONS

The MFTF*CSA computer program was developed concurrently with the preliminary design phase of the Mirror Fusion Test Facility. Consequently, the design layouts which were modeled may change as the program moves toward the hardware phase and the design becomes firm. In addition, design details for system components were not always available or available only in preliminary form. For these reasons, it is desirable to update the program as more design details become available. Since the program is modular in construction, this update can be accomplished readily.

Areas where future work may prove profitable are as follows:

- o Review the system schematics and update the model using detailed component specification data.
- o Add in any flow circuitry that is not now covered, i.e., the LN_2 storage dewar to pool boiling heat exchanger,
- o Insert heat exchanger routines for the cryopanel to handle non-uniform heat loads.
- o Analyze the flow processes inside the magnet with non-uniform heating sources. Make an assessment whether natural convection provides sufficient flow to maintain temperatures below 4.35K at all locations within the magnet.
- o Add a transient analysis capability to the program for startup and shutdown modes of operation.

- o Model the transient thermal response of the magnet when quench starts in the coil. The response depends on the energy release rate, the thermal capacity of the structure and the amount of liquid helium in the magnet.

NOTICE

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