VOLUME II ATTACHMENTS

ATTACHMENT 4

LIGO-C960964-01-V

2. VACUUM AND PROCESS CALCULATIONS

TITLE	DOCUMENT NO.	REVISION
I. Vacuum Calculations		
Pressure Drop in Vacuum Header	V049-1-006	2
Turbomolecular Pump Intermediate Pumpdown	V049-1-007	2
Flange Annulus Conductance	V049-1-012	1
Main TMP Port Conductance	V049-1-044	0
Station Pumpdown & Ultimate Pressure	V049-1-078	0
II. 80K Pumps		
80K Pumps - Heat Load Calculations	V049-1-033	2
80K Pumps - Heat Steady State LN_2 Consumption	V049-1-037	1
80K Pumps - Roughdown Pressure Drop Analysis	V049-1-072	0
80K Pumps - Regeneration System Pressure Drop Analysis	V049-1-092	0
80K Pumps - Relief Valve Sizing	V049-1-094	1
80K Pumps - Regeneration System Process Calculations	V049-1-096	0
80K Pumps - Control Valve Sizing	V049-1-116	0
III. Bakeout System		
Bakeout System Heat Transfer Analysis	V049-1-065	0
Bakeout Control System Functionality	V049-1-086	0
IV. Utilities		
Cooling Water Requirements	V049-1-010	1
Cooling Water Line Sizing	V049-1-034	1
Instrument Air Requirements	V049-1-043	1
Equipment Power Requirements	V049-1-047	0
Instrument Air Line Sizing	V049-1-093	0

3. SAFETY AND RELIABILITY ANALYSIS

TITLE	DOCUMENT NO.	REVISION
V. Safety		
Hazards Analysis	V049-2-093	0
Failure Modes, Effects and Cricticality Analysis	V049-2-094	1

PROCESS SYSTEMS INTERNATIONAL, INC.	ENGINEERING CALCULATIONS	NO: V049-1-006
WESTBOROUGH, MA		PAGE 1 OF 14

REV	DEO#	DATE	BY:	CHECK
0	0007	10/26/95	R. Than	DMW
1		10/31/95	R. Than	
2	0127	04/16/96	R.Than	D.MW

TITLE:
PRESSURE DROP VACUUM HEADER LINES
ROUGHING PUMPS EDWARDS' EDP200
with EH2600 ROOTS BLOWER

BY: R. THAN	DEPT: 744
PROJECT: LIGO	PROJECT NO: V59049

PURPOSE:
To determine the intermediate header size required to operate one (1) roughing pump set

METHOD:
Viscous Regime
Turbulent flow: Colebrook formula, "Moody chart"
Laminar flow: Hagen-Poiseuille Flow
Free molecular regime: Long tube formula

ASSUMPTIONS:
See calculations

INPUTS:
Pumping speed curves: EDP-200 / EH2600 COMBO
Equipment layout drawing V049-5-001

REFERENCE:
Theory and Practice of vacuum Technology, ISBN 3-528-08908-3
Perry's Chemical Engineers handbook, 6th edition, McGrawHill, 1984

CALCULATIONS:

see Attachments

CONCLUSIONS: 6" line is required for a single pump in order to operate the roots blower to a suction pressure of 0.05 mbar.

NOTES:

PROJECT: LIGO BY: R.THAN DEPT: 744

PROJECT NO: V59049 DATE: 10/31/95

TITLE: PRESSURE DROP VACUUM HEADERS PAGE : 2 OF 14

A 6 inch (150 mm) line is required to operate the roots blower EH2600 at a suction of 0.05 mbar. The compression ratio required will be about 10. Pressure drop at higher pressures is less than a few percent with this configuration. At a header pressure of 0.1 mbar, the ultimate pressure of the backing pump is being approach, with the roots blower operating at a suction of 0.01 mbar. But at this point the chamber pressure is low enough for the turbo to operate at sufficient capacity.

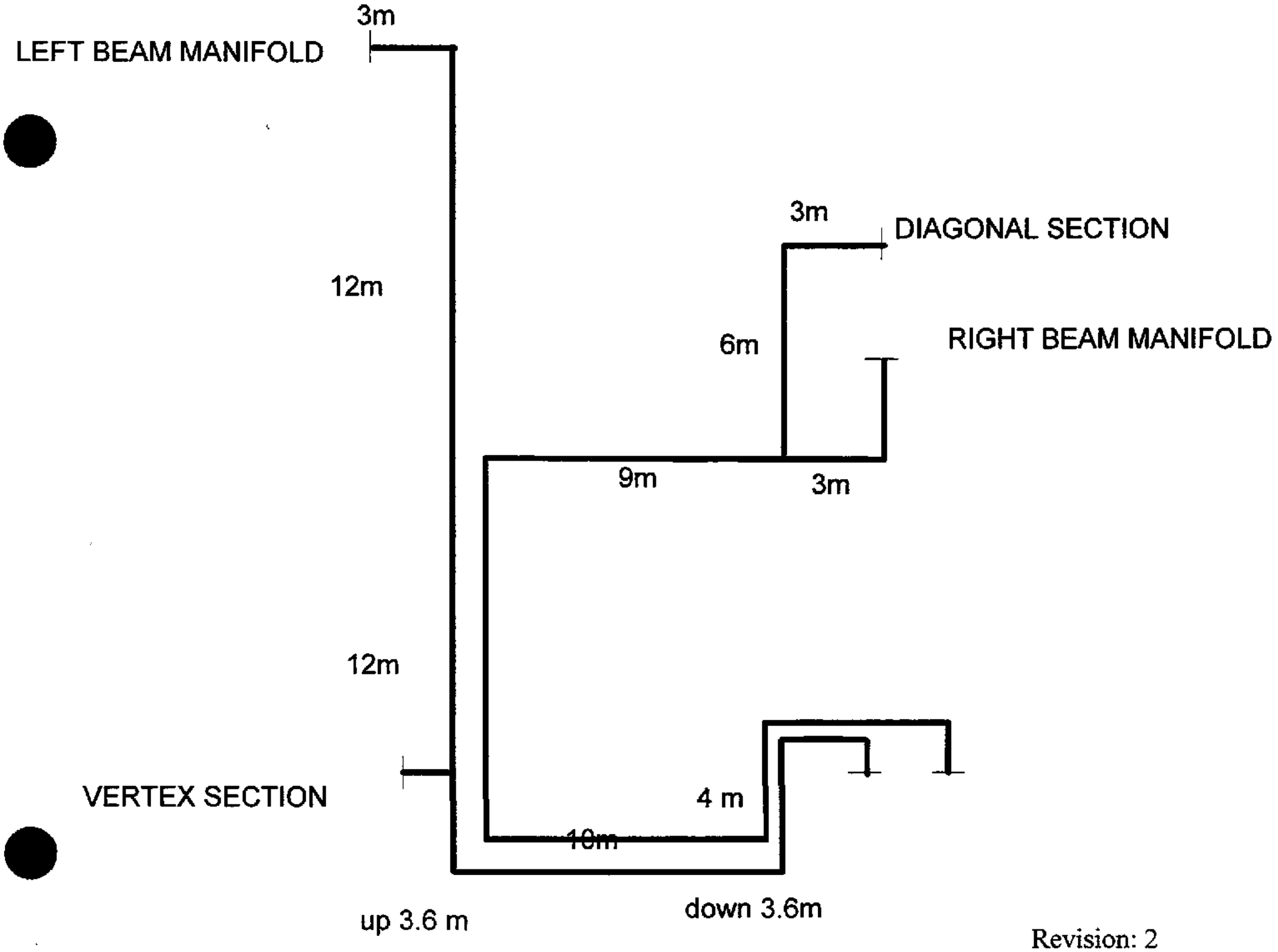
Pump	Chamber	Header	Header			
operating	Pressure	Pressure	Flow rate	ΔP	$\Delta P/P$	
	mbar	mbar	m^3/hr	mbar		
EDP200+EH2600	1000	~1000	300	5	0.5%	
EDP200+EH2600	100	~140	300	0.8	0.8%	
EDP200+EH2600	10	~40	290	0.4	1.0%	
EDP200+EH2600	1	9	286	0.23	2.3%	
EDP200+EH2600	0.1	1	180	0.15	14.5%	
EDP200+EH2600	0.05	0.5	107	0.09	17.4%	
EDP200+EH2600	0.02	0.2	28	0.02	11%	

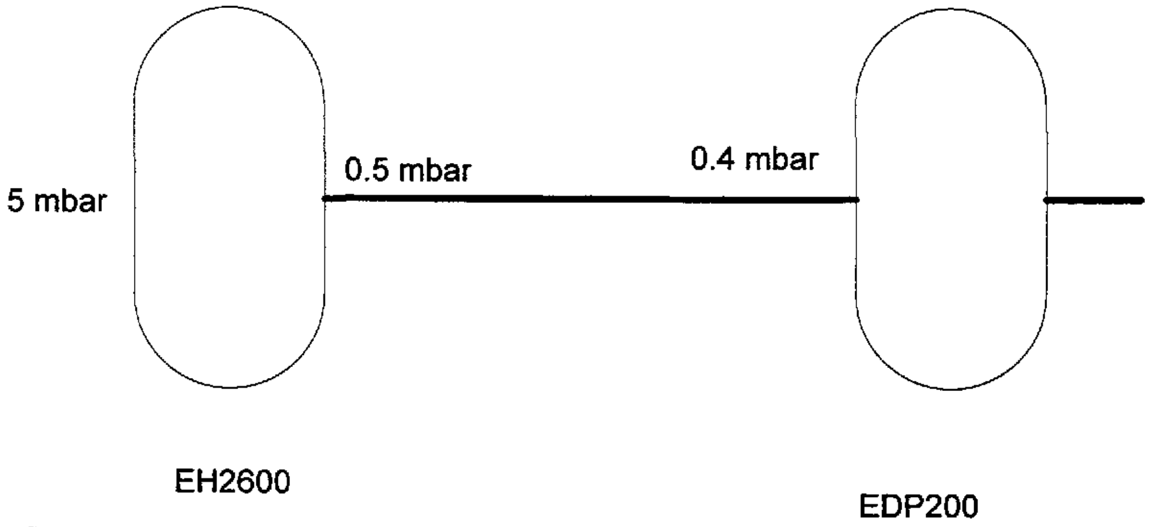
The current piping configuration allows at least one pump to pump on any beam-manifold, vertex or diagonal section.

PROJECT: LIGO
PROJECT NO: V59049
TITLE: VACUUM HEADER
ROUGHING LINE ROUTES

BY: R. THAN
DATE:
PAGE of

ROUGHING LINE




5 mbar
0.5 mbar
0.4 mbar
EH2600
EDP200

PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 1000mbar

PRESSURE: 100000.0 Pa   1.000 BAR
TEMPERATURE: 293.000 K   293.000 K
DENSITY : 1.150 KG/M^3   0.115E+01 KG/M^3
QUALITY : 1.000

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.954E-01	0.100			15.0	99793.9	0.00	0.00	206.05	0.00	206.05	206.05	0.115E+01	0.69E+05	0.65E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99790.8	0.00	0.00	3.11	0.00	3.11	209.16	0.115E+01			
6" ELBOW LR-90	0.954E-01	0.146	0.220			99787.7	0.00	0.00	3.11	0.00	3.11	212.27	0.115E+01			
6" FLEX LINE,3M	0.954E-01	0.146			15.0	99755.3	0.00	0.00	32.40	0.00	32.40	244.67	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" PIPE LENGTH	0.954E-01	0.146			3.0	99748.8	0.00	0.00	6.48	0.00	6.48	251.15	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99745.7	0.00	0.00	3.11	0.00	3.11	254.26	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			6.0	99732.8	0.00	0.00	12.96	0.00	12.96	267.23	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" TEE BRANCH	0.954E-01	0.146	0.650			99723.6	0.00	0.00	9.20	0.00	9.20	276.42	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			9.0	99704.1	0.00	0.00	19.45	0.00	19.45	295.87	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" PIPE LENGTH	0.954E-01	0.146			9.0	99684.7	0.00	0.00	19.45	0.00	19.45	315.33	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" TEE BRANCH	0.954E-01	0.146	0.650			99675.5	0.00	0.00	9.20	0.00	9.20	324.53	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			12.0	99649.5	0.00	0.00	25.95	0.00	25.95	350.47	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" TEE LINE	0.954E-01	0.146	0.220			99646.4	0.00	0.00	3.11	0.00	3.11	353.59	0.115E+01			
6" ELBOW LR-90	0.954E-01	0.146	0.220			99643.3	0.00	0.00	3.11	0.00	3.11	356.70	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			3.6	99595.0	0.00	3.60	7.79	40.48	48.27	404.97	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99591.9	3.60	3.60	3.12	0.00	3.12	408.08	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			10.0	99570.3	3.60	3.60	21.64	0.00	21.64	429.72	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99567.2	3.60	3.60	3.12	0.00	3.12	432.84	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			3.6	99599.8	3.60	0.00	7.79	-40.45	-32.66	400.18	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99596.7	0.00	0.00	3.12	0.00	3.12	403.30	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			3.0	99590.2	0.00	0.00	6.49	0.00	6.49	409.79	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99587.1	0.00	0.00	3.12	0.00	3.12	412.91	0.115E+01			
6" PIPE LENGTH	0.954E-01	0.146			10.0	99565.4	0.00	0.00	21.64	0.00	21.64	434.55	0.115E+01	0.47E+05	0.45E-06	VISCOUS
6" ELBOW LR-90	0.954E-01	0.146	0.220			99562.3	0.00	0.00	3.12	0.00	3.12	437.67	0.115E+01			
6" FLEX LINE,2M	0.954E-01	0.146			10.0	99540.7	0.00	0.00	21.65	0.00	21.65	459.31	0.115E+01	0.47E+05	0.45E-06	VISCOUS
								TOTAL	459.2829	0.0309		459.3138				

EH2600 DISCHARGE PRESSURE:100000.000 Pa   FORELINE SPEED : 0.0826 M^3/S   PUMP PRESSURE : 99562.332 Pa   PUMP SPEED : 0.0830 M^3/S

PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 100mbar

PRESSURE:	10000.0 Pa	0.100 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.115 KG/M^3	0.115E+00 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.961E-02	0.100			15.0	9966.1	0.00	0.00	33.91	0.00	33.91	33.91	0.115E+00	0.69E+04	0.65E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9965.8	0.00	0.00	0.32	0.00	0.32	34.23	0.115E+00			
6" ELBOW LR-90	0.961E-02	0.146	0.220			9965.5	0.00	0.00	0.32	0.00	0.32	34.54	0.115E+00			
6" FLEX LINE,3M	0.961E-02	0.146			15.0	9959.8	0.00	0.00	5.66	0.00	5.66	40.20	0.115E+00	0.48E+04	0.45E-05	VISCOUS
6" PIPE LENGTH	0.961E-02	0.146			3.0	9958.7	0.00	0.00	1.13	0.00	1.13	41.33	0.115E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9958.3	0.00	0.00	0.32	0.00	0.32	41.65	0.115E+00			
6" PIPE LENGTH	0.961E-02	0.146			6.0	9956.1	0.00	0.00	2.26	0.00	2.26	43.92	0.115E+00	0.48E+04	0.45E-05	VISCOUS
6" TEE BRANCH	0.961E-02	0.146	0.650			9955.1	0.00	0.00	0.94	0.00	0.94	44.85	0.115E+00			
6" PIPE LENGTH	0.961E-02	0.146			9.0	9951.8	0.00	0.00	3.40	0.00	3.40	48.25	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" PIPE LENGTH	0.961E-02	0.146			9.0	9948.4	0.00	0.00	3.40	0.00	3.40	51.65	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" TEE BRANCH	0.961E-02	0.146	0.650			9947.4	0.00	0.00	0.94	0.00	0.94	52.59	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			12.0	9942.9	0.00	0.00	4.53	0.00	4.53	57.12	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" TEE LINE	0.961E-02	0.146	0.220			9942.6	0.00	0.00	0.32	0.00	0.32	57.44	0.114E+00			
6" ELBOW LR-90	0.961E-02	0.146	0.220			9942.2	0.00	0.00	0.32	0.00	0.32	57.75	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			3.6	9936.8	0.00	3.60	1.36	4.04	5.40	63.15	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9936.5	3.60	3.60	0.32	0.00	0.32	63.47	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			10.0	9932.7	3.60	3.60	3.78	0.00	3.78	67.25	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9932.4	3.60	3.60	0.32	0.00	0.32	67.57	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			3.6	9935.1	3.60	0.00	1.36	-4.03	-2.67	64.90	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9934.8	0.00	0.00	0.32	0.00	0.32	65.22	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			3.0	9933.6	0.00	0.00	1.14	0.00	1.14	66.35	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9933.3	0.00	0.00	0.32	0.00	0.32	66.67	0.114E+00			
6" PIPE LENGTH	0.961E-02	0.146			10.0	9929.5	0.00	0.00	3.78	0.00	3.78	70.45	0.114E+00	0.48E+04	0.45E-05	VISCOUS
6" ELBOW LR-90	0.961E-02	0.146	0.220			9929.2	0.00	0.00	0.32	0.00	0.32	70.77	0.114E+00			
6" FLEX LINE,2M	0.961E-02	0.146			10.0	9925.4	0.00	0.00	3.79	0.00	3.79	74.56	0.114E+00	0.48E+04	0.45E-05	VISCOUS
								TOTAL	74.5533	0.0040		74.5573				

EH2600 DISCHARGE PRESSURE: 10000.000 Pa   FORELINE SPEED : 0.0839 M^3/S   PUMP PRESSURE : 9929.229 Pa   PUMP SPEED : 0.0845 M^3/S

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DOC NO: V049-1-006
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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 10mbar

PRESSURE:	1000.0 Pa	0.010 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.012 KG/M^3	0.115E-01 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.882E-03	0.100			15.0	991.7	0.00	0.00	8.25	0.00	8.25	8.25	0.115E-01	0.64E+03	0.65E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			991.5	0.00	0.00	0.25	0.00	0.25	8.51	0.114E-01			
6" ELBOW LR-90	0.882E-03	0.146	2.091			991.2	0.00	0.00	0.25	0.00	0.25	8.76	0.114E-01			
6" FLEX LINE,3M	0.882E-03	0.146			15.0	989.4	0.00	0.00	1.83	0.00	1.83	10.59	0.114E-01	0.44E+03	0.45E-04	VISCOUS
6" PIPE LENGTH	0.882E-03	0.146			3.0	989.0	0.00	0.00	0.37	0.00	0.37	10.96	0.114E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			988.8	0.00	0.00	0.25	0.00	0.25	11.21	0.114E-01			
6" PIPE LENGTH	0.882E-03	0.146			6.0	988.1	0.00	0.00	0.73	0.00	0.73	11.95	0.114E-01	0.44E+03	0.45E-04	VISCOUS
6" TEE BRANCH	0.882E-03	0.146	2.091			987.8	0.00	0.00	0.26	0.00	0.26	12.20	0.114E-01			
6" PIPE LENGTH	0.882E-03	0.146			9.0	986.7	0.00	0.00	1.10	0.00	1.10	13.31	0.114E-01	0.44E+03	0.45E-04	VISCOUS
6" PIPE LENGTH	0.882E-03	0.146			9.0	985.6	0.00	0.00	1.10	0.00	1.10	14.41	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" TEE BRANCH	0.882E-03	0.146	2.091			985.3	0.00	0.00	0.26	0.00	0.26	14.67	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			12.0	983.9	0.00	0.00	1.47	0.00	1.47	16.14	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" TEE LINE	0.882E-03	0.146	2.091			983.6	0.00	0.00	0.26	0.00	0.26	16.40	0.113E-01			
6" ELBOW LR-90	0.882E-03	0.146	2.091			983.3	0.00	0.00	0.26	0.00	0.26	16.65	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			3.6	982.5	0.00	3.60	0.44	0.40	0.84	17.50	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			982.2	3.60	3.60	0.26	0.00	0.26	17.75	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			10.0	981.0	3.60	3.60	1.23	0.00	1.23	18.99	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			980.8	3.60	3.60	0.26	0.00	0.26	19.24	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			3.6	980.7	3.60	0.00	0.44	-0.40	0.05	19.29	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			980.5	0.00	0.00	0.26	0.00	0.26	19.55	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			3.0	980.1	0.00	0.00	0.37	0.00	0.37	19.92	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			979.8	0.00	0.00	0.26	0.00	0.26	20.17	0.113E-01			
6" PIPE LENGTH	0.882E-03	0.146			10.0	978.6	0.00	0.00	1.24	0.00	1.24	21.41	0.113E-01	0.44E+03	0.45E-04	VISCOUS
6" ELBOW LR-90	0.882E-03	0.146	2.091			978.3	0.00	0.00	0.26	0.00	0.26	21.67	0.113E-01			
6" FLEX LINE,2M	0.882E-03	0.146			10.0	977.1	0.00	0.00	1.24	0.00	1.24	22.90	0.113E-01	0.44E+03	0.46E-04	VISCOUS
								TOTAL	22.9025	0.0011		22.9035				

EH2600 DISCHARGE PRESSURE: 1000.000 Pa   FORELINE SPEED : 0.0795 M^3/S   PUMP PRESSURE : 978.334 Pa   PUMP SPEED : 0.0813 M^3/S

REVISION : 2
DOC NO: V049-1-006
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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 1mbar

PRESSURE:	100.0 Pa	0.001 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.001 KG/M^3	0.115E-02 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.573E-04	0.100			15.0	94.6	0.00	0.00	5.36	0.00	5.36	5.36	0.115E-02	0.41E+02	0.65E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			94.6	0.00	0.00	0.08	0.00	0.08	5.44	0.109E-02			
6" ELBOW LR-90	0.573E-04	0.146	14.980			94.5	0.00	0.00	0.08	0.00	0.08	5.52	0.109E-02			
6" FLEX LINE,3M	0.573E-04	0.146			15.0	93.2	0.00	0.00	1.25	0.00	1.25	6.77	0.109E-02	0.28E+02	0.47E-03	VISCOUS
6" PIPE LENGTH	0.573E-04	0.146			3.0	93.0	0.00	0.00	0.25	0.00	0.25	7.02	0.107E-02	0.28E+02	0.48E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			92.9	0.00	0.00	0.08	0.00	0.08	7.11	0.107E-02			
6" PIPE LENGTH	0.573E-04	0.146			6.0	92.4	0.00	0.00	0.51	0.00	0.51	7.61	0.107E-02	0.28E+02	0.48E-03	VISCOUS
6" TEE BRANCH	0.573E-04	0.146	14.980			92.3	0.00	0.00	0.08	0.00	0.08	7.70	0.106E-02			
6" PIPE LENGTH	0.573E-04	0.146			9.0	91.5	0.00	0.00	0.77	0.00	0.77	8.46	0.106E-02	0.28E+02	0.48E-03	VISCOUS
6" PIPE LENGTH	0.573E-04	0.146			9.0	90.8	0.00	0.00	0.77	0.00	0.77	9.24	0.105E-02	0.28E+02	0.49E-03	VISCOUS
6" TEE BRANCH	0.573E-04	0.146	14.980			90.7	0.00	0.00	0.08	0.00	0.08	9.32	0.104E-02			
6" PIPE LENGTH	0.573E-04	0.146			12.0	89.6	0.00	0.00	1.04	0.00	1.04	10.36	0.104E-02	0.28E+02	0.49E-03	VISCOUS
6" TEE LINE	0.573E-04	0.146	14.980			89.6	0.00	0.00	0.09	0.00	0.09	10.45	0.103E-02			
6" ELBOW LR-90	0.573E-04	0.146	14.980			89.5	0.00	0.00	0.09	0.00	0.09	10.53	0.103E-02			
6" PIPE LENGTH	0.573E-04	0.146			3.6	89.1	0.00	3.60	0.32	0.04	0.35	10.88	0.103E-02	0.28E+02	0.50E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			89.0	3.60	3.60	0.09	0.00	0.09	10.97	0.102E-02			
6" PIPE LENGTH	0.573E-04	0.146			10.0	88.1	3.60	3.60	0.88	0.00	0.88	11.85	0.102E-02	0.28E+02	0.50E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			88.1	3.60	3.60	0.09	0.00	0.09	11.94	0.101E-02			
6" PIPE LENGTH	0.573E-04	0.146			3.6	87.8	3.60	0.00	0.32	-0.04	0.29	12.23	0.101E-02	0.28E+02	0.51E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			87.7	0.00	0.00	0.09	0.00	0.09	12.31	0.101E-02			
6" PIPE LENGTH	0.573E-04	0.146			3.0	87.4	0.00	0.00	0.27	0.00	0.27	12.58	0.101E-02	0.28E+02	0.51E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			87.3	0.00	0.00	0.09	0.00	0.09	12.67	0.101E-02			
6" PIPE LENGTH	0.573E-04	0.146			10.0	86.4	0.00	0.00	0.90	0.00	0.90	13.57	0.100E-02	0.28E+02	0.51E-03	VISCOUS
6" ELBOW LR-90	0.573E-04	0.146	14.980			86.3	0.00	0.00	0.09	0.00	0.09	13.66	0.994E-03			
6" FLEX LINE,2M	0.573E-04	0.146			10.0	85.4	0.00	0.00	0.91	0.00	0.91	14.57	0.993E-03	0.28E+02	0.52E-03	VISCOUS
								TOTAL	14.5689	0.0006		14.5695				

EH2600 DISCHARGE PRESSURE: 100.000 Pa   FORELINE SPEED   :   0.0501 M^3/S   PUMP PRESSURE   :   86.341 Pa   PUMP SPEED   :   0.0580 M^3/S

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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 0.5mbar

PRESSURE:	50.0 Pa	0.001 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.001 KG/M^3	0.575E-03 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.170E-04	0.100			15.0	46.8	0.00	0.00	3.18	0.00	3.18	3.18	0.575E-03	0.12E+02	0.13E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			46.8	0.00	0.00	0.04	0.00	0.04	3.22	0.538E-03			
6" ELBOW LR-90	0.170E-04	0.146	43.411			46.7	0.00	0.00	0.04	0.00	0.04	3.27	0.538E-03			
6" FLEX LINE,3M	0.170E-04	0.146			15.0	46.0	0.00	0.00	0.75	0.00	0.75	4.02	0.537E-03	0.84E+01	0.95E-03	VISCOUS
6" PIPE LENGTH	0.170E-04	0.146			3.0	45.8	0.00	0.00	0.15	0.00	0.15	4.17	0.529E-03	0.84E+01	0.97E-03	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			45.8	0.00	0.00	0.04	0.00	0.04	4.21	0.527E-03			
6" PIPE LENGTH	0.170E-04	0.146			6.0	45.5	0.00	0.00	0.31	0.00	0.31	4.52	0.527E-03	0.84E+01	0.97E-03	VISCOUS
6" TEE BRANCH	0.170E-04	0.146	43.411			45.4	0.00	0.00	0.04	0.00	0.04	4.56	0.523E-03			
6" PIPE LENGTH	0.170E-04	0.146			9.0	45.0	0.00	0.00	0.46	0.00	0.46	5.02	0.523E-03	0.84E+01	0.98E-03	VISCOUS
6" PIPE LENGTH	0.170E-04	0.146			9.0	44.5	0.00	0.00	0.47	0.00	0.47	5.49	0.517E-03	0.84E+01	0.99E-03	VISCOUS
6" TEE BRANCH	0.170E-04	0.146	43.411			44.5	0.00	0.00	0.04	0.00	0.04	5.53	0.512E-03			
6" PIPE LENGTH	0.170E-04	0.146			12.0	43.8	0.00	0.00	0.63	0.00	0.63	6.16	0.511E-03	0.84E+01	0.10E-02	VISCOUS
6" TEE LINE	0.170E-04	0.146	43.411			43.8	0.00	0.00	0.04	0.00	0.04	6.21	0.504E-03			
6" ELBOW LR-90	0.170E-04	0.146	43.411			43.7	0.00	0.00	0.04	0.00	0.04	6.25	0.504E-03			
6" PIPE LENGTH	0.170E-04	0.146			3.6	43.5	0.00	3.60	0.19	0.02	0.21	6.46	0.503E-03	0.84E+01	0.10E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			43.5	3.60	3.60	0.04	0.00	0.04	6.51	0.501E-03			
6" PIPE LENGTH	0.170E-04	0.146			10.0	43.0	3.60	3.60	0.54	0.00	0.54	7.04	0.500E-03	0.84E+01	0.10E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			42.9	3.60	3.60	0.05	0.00	0.05	7.09	0.494E-03			
6" PIPE LENGTH	0.170E-04	0.146			3.6	42.7	3.60	0.00	0.20	-0.02	0.18	7.27	0.494E-03	0.84E+01	0.10E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			42.7	0.00	0.00	0.05	0.00	0.05	7.31	0.491E-03			
6" PIPE LENGTH	0.170E-04	0.146			3.0	42.5	0.00	0.00	0.16	0.00	0.16	7.48	0.491E-03	0.84E+01	0.10E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			42.5	0.00	0.00	0.05	0.00	0.05	7.52	0.489E-03			
6" PIPE LENGTH	0.170E-04	0.146			10.0	41.9	0.00	0.00	0.55	0.00	0.55	8.07	0.489E-03	0.84E+01	0.10E-02	VISCOUS
6" ELBOW LR-90	0.170E-04	0.146	43.411			41.9	0.00	0.00	0.05	0.00	0.05	8.12	0.482E-03			
6" FLEX LINE,2M	0.170E-04	0.146			10.0	41.3	0.00	0.00	0.56	0.00	0.56	8.68	0.482E-03	0.84E+01	0.11E-02	VISCOUS
								TOTAL	8.6759	0.0003		8.6762				

EH2600 DISCHARGE PRESSURE: 50.000 Pa   FORELINE SPEED : 0.0298 M^3/S   PUMP PRESSURE : 41.881 Pa   PUMP SPEED : 0.0356 M^3/S

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PROCESS SYSTEMS INTERNATIONAL, INC 20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: ROOTS PUMP,BACKING PUMP VACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:EH2600 DISCHARGE 0.2mbar

PRESSURE:	20.0 Pa	0.000 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.000 KG/M^3	0.230E-03 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
4" FLEX LINE,3M	0.177E-05	0.100			15.0	19.2	0.00	0.00	0.83	0.00	0.83	0.83	0.230E-03	0.13E+01	0.33E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			19.2	0.00	0.00	0.01	0.00	0.01	0.84	0.221E-03			
6" ELBOW LR-90	0.177E-05	0.146	366.549			19.2	0.00	0.00	0.01	0.00	0.01	0.85	0.220E-03			
6" FLEX LINE,3M	0.177E-05	0.146			15.0	19.0	0.00	0.00	0.19	0.00	0.19	1.04	0.220E-03	0.88E+00	0.23E-02	VISCOUS
6" PIPE LENGTH	0.177E-05	0.146			3.0	18.9	0.00	0.00	0.04	0.00	0.04	1.07	0.218E-03	0.88E+00	0.24E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.9	0.00	0.00	0.01	0.00	0.01	1.08	0.218E-03			
6" PIPE LENGTH	0.177E-05	0.146			6.0	18.8	0.00	0.00	0.08	0.00	0.08	1.16	0.218E-03	0.88E+00	0.24E-02	VISCOUS
6" TEE BRANCH	0.177E-05	0.146	366.549			18.8	0.00	0.00	0.01	0.00	0.01	1.17	0.217E-03			
6" PIPE LENGTH	0.177E-05	0.146			9.0	18.7	0.00	0.00	0.12	0.00	0.12	1.29	0.217E-03	0.88E+00	0.24E-02	VISCOUS
6" PIPE LENGTH	0.177E-05	0.146			9.0	18.6	0.00	0.00	0.12	0.00	0.12	1.40	0.215E-03	0.88E+00	0.24E-02	VISCOUS
6" TEE BRANCH	0.177E-05	0.146	366.549			18.6	0.00	0.00	0.01	0.00	0.01	1.41	0.214E-03			
6" PIPE LENGTH	0.177E-05	0.146			12.0	18.4	0.00	0.00	0.16	0.00	0.16	1.57	0.214E-03	0.88E+00	0.24E-02	VISCOUS
6" TEE LINE	0.177E-05	0.146	366.549			18.4	0.00	0.00	0.01	0.00	0.01	1.58	0.212E-03			
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.4	0.00	0.00	0.01	0.00	0.01	1.59	0.212E-03			
6" PIPE LENGTH	0.177E-05	0.146			3.6	18.4	0.00	3.60	0.05	0.01	0.05	1.64	0.212E-03	0.88E+00	0.24E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.3	3.60	3.60	0.01	0.00	0.01	1.65	0.211E-03			
6" PIPE LENGTH	0.177E-05	0.146			10.0	18.2	3.60	3.60	0.13	0.00	0.13	1.78	0.211E-03	0.88E+00	0.24E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.2	3.60	3.60	0.01	0.00	0.01	1.79	0.209E-03			
6" PIPE LENGTH	0.177E-05	0.146			3.6	18.2	3.60	0.00	0.05	-0.01	0.04	1.83	0.209E-03	0.88E+00	0.24E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.2	0.00	0.00	0.01	0.00	0.01	1.84	0.209E-03			
6" PIPE LENGTH	0.177E-05	0.146			3.0	18.1	0.00	0.00	0.04	0.00	0.04	1.88	0.209E-03	0.88E+00	0.25E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.1	0.00	0.00	0.01	0.00	0.01	1.89	0.208E-03			
6" PIPE LENGTH	0.177E-05	0.146			10.0	18.0	0.00	0.00	0.13	0.00	0.13	2.03	0.208E-03	0.88E+00	0.25E-02	VISCOUS
6" ELBOW LR-90	0.177E-05	0.146	366.549			18.0	0.00	0.00	0.01	0.00	0.01	2.04	0.207E-03			
6" FLEX LINE,2M	0.177E-05	0.146			10.0	17.8	0.00	0.00	0.14	0.00	0.14	2.17	0.207E-03	0.88E+00	0.25E-02	VISCOUS
								TOTAL	2.1729	0.0001		2.1730				

EH2600 DISCHARGE PRESSURE: 20.000 Pa FORELINE SPEED : 0.0078 M^3/S PUMP PRESSURE : 17.962 Pa PUMP SPEED : 0.0086 M^3/S

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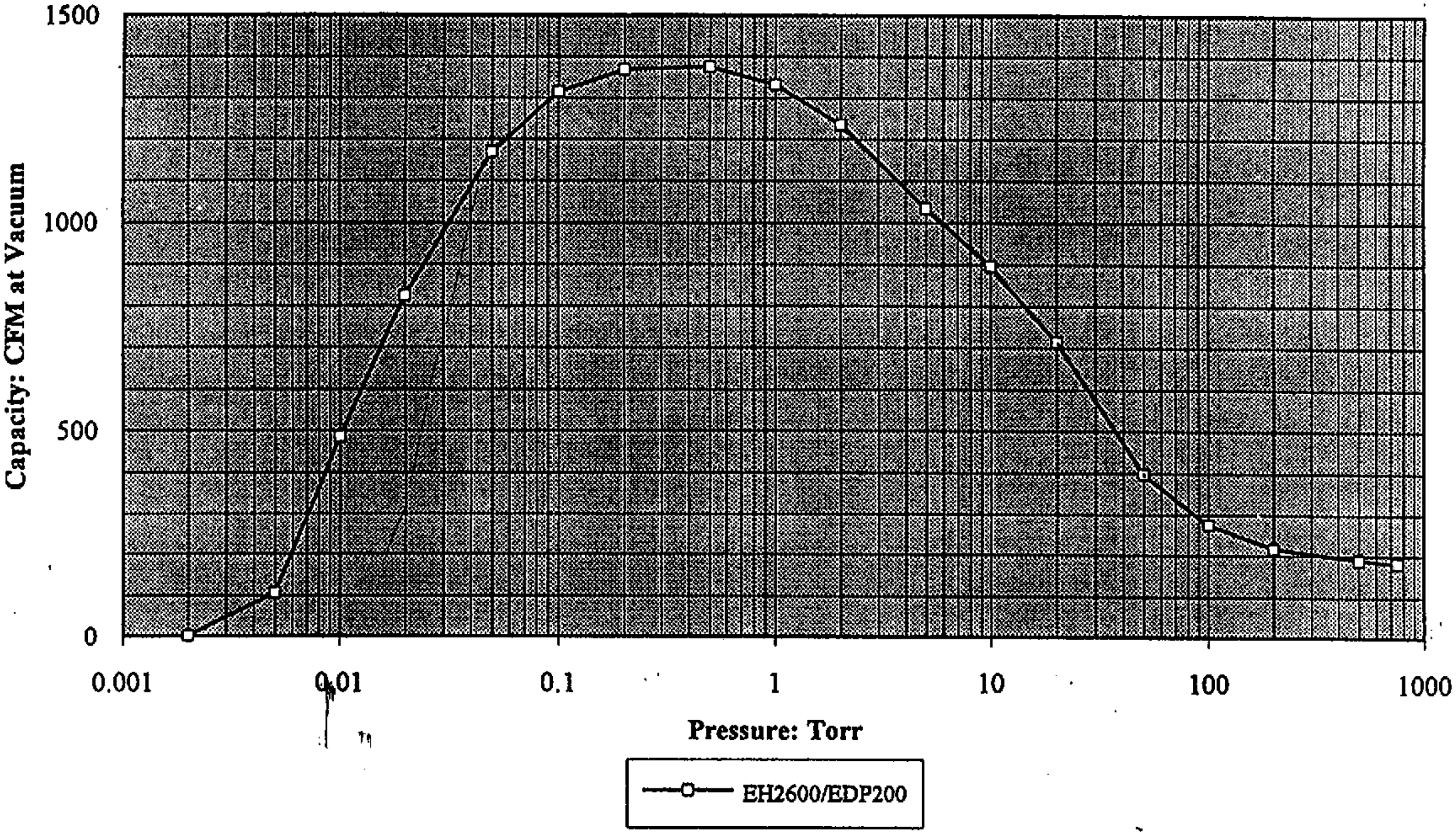
EDP200/Booster Combinations



	EDP100	[illegible]200	EDP300
Nominal pumping speed, ACFM	80	190	250
Maximum sound level, dB(A)	75*	80	80
Ultimate pressure, Torr	0.1	0.1	0.1
Motor size, HP	10	20	30
Motor power at vacuum, HP	5	9	12
Cooling water, GPM	0.7	1	1
Inlet connection	3" ANSI	3" ANSI	3" ANSI
Outlet connection	1½" ANSI	2" ANSI	2" ANSI
Weight with motor and frame, lb.	620	1700	1800

* EDP100 fitted with acoustic enclosure

- Protective instrumen[illegible]
- Facilities for liquid flush or gas purge
- Seals and bearings in cartridges for simple replacement
- Short gas path for enhanced pumping of entrained liquids and solids
- Compact footprint for ease of installation

PERFORMANCE DATA

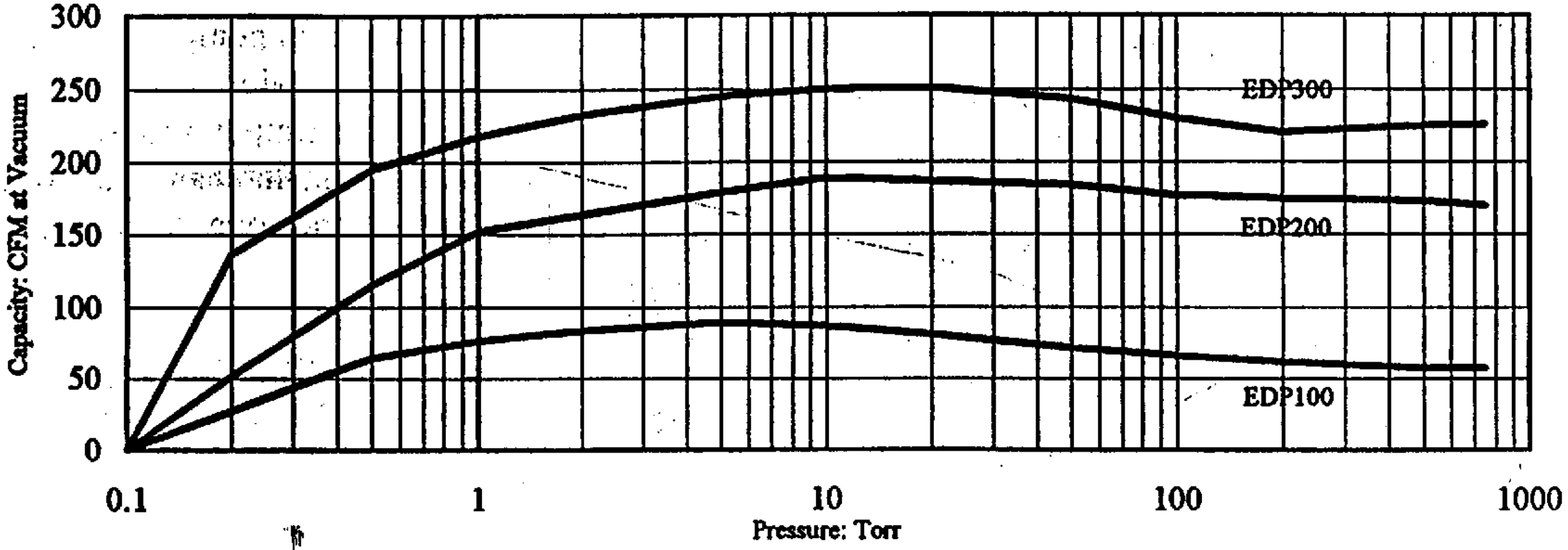


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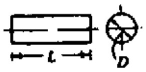
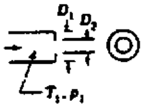
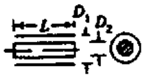
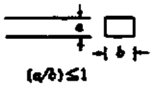
Table 5.3 **Calculation of the pumping speed S for a combination of a Roots pump type RUWAC WA 1000 with the rotary plunger pumps E250 and E75. Theoretical pumping speed of the Roots pump from which a 2.5% slip must be subtracted: $S_{th} = 1000\ \mathrm{m^3h^{-1}}\ (1 - 0.025) = 975\ \mathrm{m^3h^{-1}}$. Pumping speed of the rotary plunger pumps are taken from their pumping speed curves with closed gas ballast valve. See also fig. 5.45 for comparison.**

p_v in mbar	S_v in $\mathrm{m^3 \cdot h^{-1}}$	$K_{th} = \frac{S_{th}}{S_v} = \frac{975\ \mathrm{m^3h^{-1}}}{S_v}$	K_0 (measured)	$\frac{K_0}{K_{th}}$	$\eta_V = \frac{\frac{K_0}{K_{th}}}{1 + \frac{K_0}{K_{th}}}$	$S = \eta_V \cdot S_{th}$	$p_A = \frac{p_v \cdot S_v}{S}$ in mbar
		equ. (5.59)	fig. 5.41		equ. (5.60)	equ. (5.61)	equ. (5.58)
E250							
133	250	3.9	13	3.34	0.77	750	44.3
53	250	3.9	16.5	4.23	0.81	789	16.8
13	250	3.9	27	6.93	0.874	851	3.82
7	250	3.9	34	8.72	0.898	875	2
1	250	3.9	52	13.3	0.93	906	0.276
$7 \cdot 10^{-1}$	245	3.98	49.5	12.4	0.929	905	0.189
$1 \cdot 10^{-1}$	185	5.26	27	5.14	0.838	817	$2.3 \cdot 10^{-2}$
$5 \cdot 10^{-2}$	105	9.28	19	2.05	0.673	656	$8 \cdot 10^{-3}$
E75							
100	74	13.2 *)	13	0.985	0.496	484	15.3
40	74	13.2	16.5	1.25	0.556	542	5.5
10	74	13.2	27	2.04	0.673	656	1.13
5	74	13.2	34	2.58	0.722	704	0.53
1	74	13.2	52	3.94	0.798	778	$9.5 \cdot 10^{-2}$
$5 \cdot 10^{-1}$	71	13.7	49.5	3.61	0.784	764	$4.7 \cdot 10^{-2}$
$1 \cdot 10^{-1}$	52	18.7	27	1.44	0.59	575	$9 \cdot 10^{-3}$
$4 \cdot 10^{-2}$	27	36.1 *)	19	0.53	0.35	341	$3 \cdot 10^{-3}$
$p_{v,\mathrm{end}} = 2 \cdot 10^{-}$			$K_{0,\mathrm{end}} = 14.0$				$p_e = 1.5 \cdot 10^{-3}$

* theoretical value, since we must *not* have $K_{th} > K_0$ since then we would have $\eta_V < 0.5$

Table 8.1. Conductance equations for vacuum systems. μ = gas viscosity, $\bar{p}$ = mean pressure, g_c = conversion factor in Newton's Law, R_u = universal gas constant, M = molecular weight, γ = specific heat ratio, L = tube length, D = tube diameter

Element	Sketch of Element	Flow Regime	
		Continuum (Laminar Flow)	Free Molecular
1. Long tube, $L/D > 30$		$C = \frac{\pi D^4 g_c \bar{p}}{128\mu L}$	$C = \left(\frac{\pi g_c R_u T}{18M}\right)^{1/2} \frac{D^3}{L}$
2. Short tube, $L/D < 30$ D_1 = larger diameter D_2 = smaller diameter	Same as (1)	$C = \frac{\pi D^4 g_c \bar{p}}{128\mu L}\left(1 + \frac{m}{22\mu L}\right)^{-1}$	$C = \frac{(\pi g_c R_u T/18M)^{1/2} D^3}{L/D + (4/3)[1 - (D_2/D_1)^2]}$
3. Orifice or aperture D_1 = tube diameter D_2 = orifice diameter $r_p = p_2/p_1$		$C = KD^2\left[\frac{\gamma\pi^2 g_c R_u T_1}{8(\gamma - 1)M}\right]^{1/2}$ (a) For $r_p \geq [2/(\gamma + 1)]^{\gamma/(\gamma-1)}$ $K = \frac{1 - r_p^{(\gamma-1)/\gamma}}{r_p^{2/\gamma}(1 - r_p)^2}$ (b) For $r_p < [2/(\gamma + 1)]^{\gamma/(\gamma-1)}$ $K = \frac{[(\gamma - 1)/(\gamma + 1)]^{1/2}}{[2/(\gamma + 1)]^{1/(\gamma-1)}(1 - r_p)}$	$C = \frac{(\pi g_c R_u T/32M)^{1/2} D^2}{1 - (D_2/D_1)^2}$
4. Annular flow passage D_1 = larger diameter D_2 = smaller diameter		$C = \frac{\pi g_c \bar{p}}{128\mu L}\left[(D_1^4 - D_2^4) - \frac{(D_1^2 - D_2^2)^2}{\ln(D_1/D_2)}\right]$	$C = \left(\frac{\pi g_c R_u T}{18M}\right)^{1/2} \frac{(D_1 - D_2)^2(D_1 - D_2)K}{L + (4/3)(D_1 - D_2)}$ where K is given as follows: D_2/D_1 0 0.259 0.500 K 1 1.072 1.154 D_2/D_1 0.707 0.866 0.966 K 1.254 1.430 1.675
5. Rectangular tube $a/b \leq 1$		$C = \frac{\pi g_c a^2 b^2 \bar{p} K}{87.4\mu L}$ where K is given as follows: a/b 1.00 0.90 0.80 0.70 0.60 K 1.00 0.99 0.98 0.95 0.90 a/b 0.50 0.40 0.30 0.20 0.10 K 0.82 0.71 0.58 0.42 0.23	$C = \left(\frac{32 g_c R_u T}{9\pi M}\right)^{1/2} \frac{a^2 b^2 K}{(a + b)L + (8/3)ab}$ where K is given as follows: a/b 1.000 0.667 0.500 0.333 K 1.108 1.126 1.151 1.198 a/b 0.200 0.125 0.100 0.000 K 1.297 1.400 1.444 1.667
6. 90° elbow r = mean radius		$C = \frac{\pi g_c K D^3 \bar{p}}{128\mu}$ where K is given as follows: r/D 0.000 1.000 2.000 3.000 4.000 K 0.017 0.050 0.083 0.083 0.073 r/D 6.0 8.0 10 12 14 K 0.056 0.042 0.034 0.029 0.026	$C = \left(\frac{2 g_c R_u T}{9\pi M}\right)^{1/2} \frac{D^3}{r}$

$$\Delta P = \frac{\rho \cdot \dot{V}}{C} \quad [Pa]$$

PROCESS SYSTEMS INTERNATIONAL, INC.	ENGINEERING	NO: V049-1-007
WESTBOROUGH, MA	CALCULATIONS	PAGE 1 OF 13

REV	DEO#	DATE	BY:	CHECK
0	0007	10/28/95	R. Than	DMW
1		10/31/95	R. Than	
2	0127	04/16/96	R.Than	D.W.

TITLE:
TURBO PUMP INTERMEDIATE HEADER
PRESSURE DROP ANALYSIS

BY: R. THAN

DEPT: 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: Pressure drop calcs for vacuum header for 1400 L/s Main turbo molecular pumps with QDP80 dry backing pump.

METHOD:
Viscous Regime: Turbulent flow: Colebrook formula, "Moody chart"
Laminar flow: hagen-Poiseuille flow
Free molecular regime: Long tube formula

ASSUMPTIONS:
Operation of one main TurboMolecular Pump into header

INPUTS:
Per equipment layout, 4 inch header

REFERENCE:
Theory and Practice of vacuum Technology, ISBN 3-528-08908-3
Perry's Chemical Engineers handbook, 6th edition, McGrawHill, 1984

CALCULATIONS:

see Attachments

CONCLUSIONS: 4 inch pipe header is adequate to handle flow of 90 m^3/hr
(Edwards' QDP80 dry backing pump)

NOTES:

PROJECT: LIGO BY: R.THAN DEPT: 744

PROJECT NO: _V59049 DATE: 04/17/96

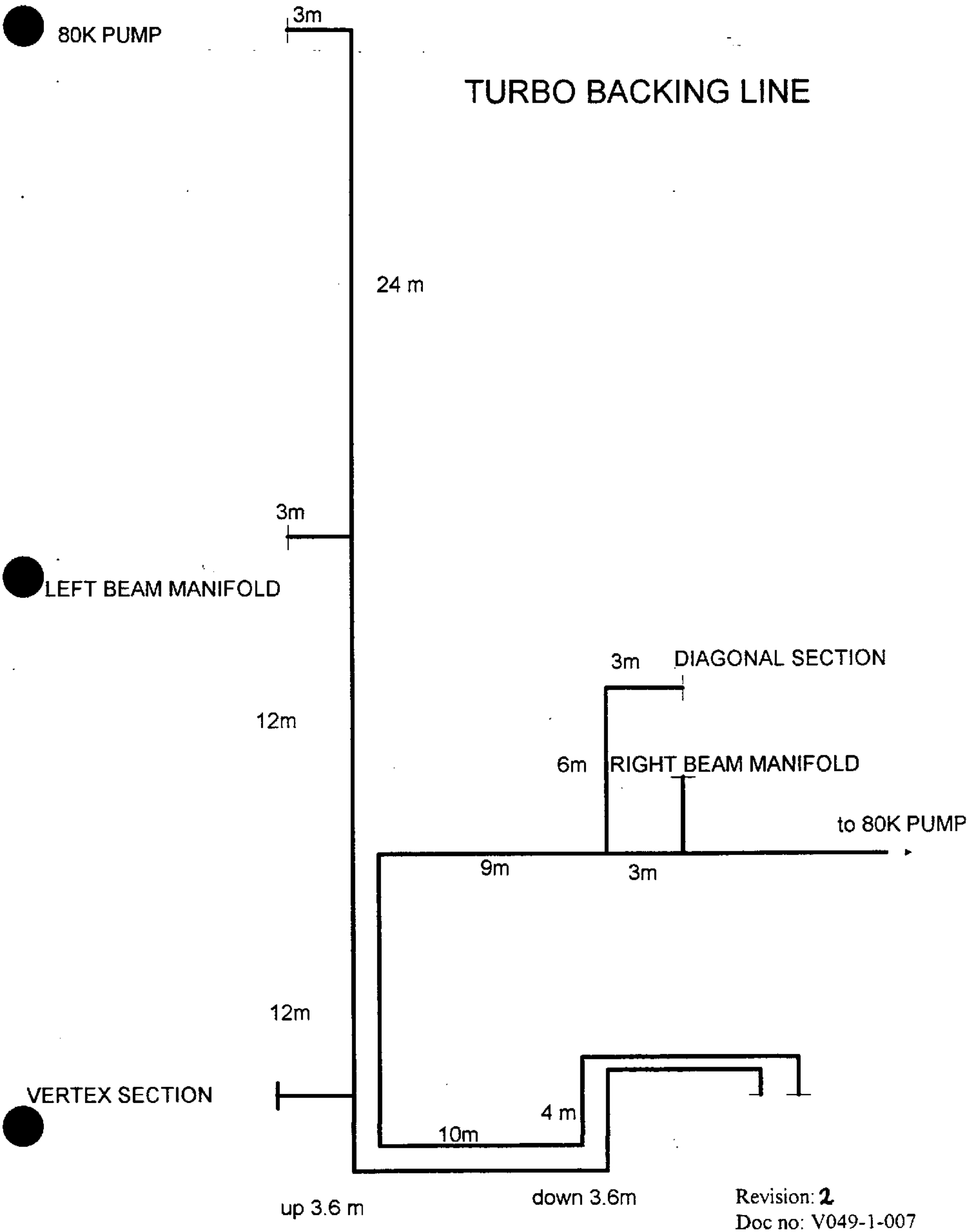
TITLE: MAIN TMP VACUUM HEADER DP PAGE : 2 OF 13

Pressure drop calculations were done with the current piping layout using 4 inch headers, 2.5 inch flexline from the turbo discharge to the header.

The pressure drop in the 1 mbar range is about 0.33 mbar. To meet the through put of 5 Torr-L/s or 6.5 mbar-L/s at a backing pressure of 1 Torr (1.3 mbar), the backing pump needs to have a capacity of 6.5 L/s or 24 m^3/hr at a suction pressure of 1 mbar.

The pressure drop through the lines at a header inlet pressure of 1 mbar is 0.33 mbar at a through put 11 mbar-L/s. Pumping speed curves of the QDP80 indicates that the pump has a speed of 61 m^3/hr at suction pressure of 0.66 mbar.

TURBO BACKING LINE



PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: TURBO PUMPVACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:TURBO BACKING PUMP QDP80

PRESSURE: 100000.0 Pa 1.000 BAR
TEMPERATURE: 293.000 K 293.000 K
DENSITY : 1.150 KG/M^3 0.115E+01 KG/M^3
QUALITY : 1.000

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
1.5" BYPASS	0.218E-01	0.038			4.0	99569.8	0.00	0.00	430.25	0.00	430.25	430.25	0.115E+01	0.41E+05	0.17E-05	VISCOUS
2.5"ELBOW LR-90	0.218E-01	0.063	1.000			99548.4	0.00	0.00	21.34	0.00	21.34	451.59	0.115E+01			
2.5" FLEX LINE,2M	0.218E-01	0.063			10.0	99459.1	0.00	0.00	89.33	0.00	89.33	540.92	0.115E+01	0.25E+05	0.10E-05	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99455.7	0.00	0.00	3.37	0.00	3.37	544.28	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			3.0	99452.8	0.00	0.00	2.87	0.00	2.87	547.15	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99449.5	0.00	0.00	3.37	0.00	3.37	550.52	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			24.0	99426.5	0.00	0.00	22.95	0.00	22.95	573.47	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" TEE LINE	0.218E-01	0.100	1.000			99423.2	0.00	0.00	3.37	0.00	3.37	576.84	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			12.0	99411.7	0.00	0.00	11.48	0.00	11.48	588.32	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" TEE BRANCH	0.218E-01	0.100	1.000			99408.3	0.00	0.00	3.37	0.00	3.37	591.69	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			10.0	99398.7	0.00	0.00	9.57	0.00	9.57	601.25	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" TEE LINE	0.218E-01	0.100	1.000			99395.4	0.00	0.00	3.37	0.00	3.37	604.62	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			2.0	99393.5	0.00	0.00	1.91	0.00	1.91	606.54	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99390.1	0.00	0.00	3.37	0.00	3.37	609.90	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			3.6	99346.3	0.00	3.60	3.45	40.38	43.82	653.73	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99342.9	3.60	3.60	3.37	0.00	3.37	657.10	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			10.0	99333.3	3.60	3.60	9.57	0.00	9.57	666.67	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99330.0	3.60	3.60	3.37	0.00	3.37	670.04	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			3.6	99366.9	3.60	0.00	3.45	-40.35	-36.91	633.14	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99363.5	0.00	0.00	3.37	0.00	3.37	636.50	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			3.0	99360.6	0.00	0.00	2.87	0.00	2.87	639.38	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99357.3	0.00	0.00	3.37	0.00	3.37	642.75	0.114E+01			
4" PIPE LENGTH	0.218E-01	0.100			10.0	99347.7	0.00	0.00	9.57	0.00	9.57	652.32	0.114E+01	0.16E+05	0.66E-06	VISCOUS
4" ELBOW LR-90	0.218E-01	0.100	1.000			99344.3	0.00	0.00	3.37	0.00	3.37	655.69	0.114E+01			
4" FLEX LINE,3M	0.218E-01	0.100			10.0	99334.7	0.00	0.00	9.57	0.00	9.57	665.26	0.114E+01	0.16E+05	0.66E-06	VISCOUS
								TOTAL	665.2391	0.0244		665.2635				

CHAMBER PRESSURE:100000.000 Pa   CHAMBER SPEED : 0.0190 M^3/S   PUMP PRESSURE : 99334.736 Pa   PUMP SPEED : 0.0191 M^3/S

PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: TURBO PUMPVACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:TURBO BACKING PUMP QDP80

PRESSURE:	10000.0 Pa	0.100 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.115 KG/M^3	0.115E+00 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
1.5" BYPASS	0.271E-02	0.038			4.0	9899.1	0.00	0.00	100.88	0.00	100.88	100.88	0.115E+00	0.52E+04	0.17E-04	VISCOUS
2.5"ELBOW LR-90	0.271E-02	0.063	1.000			9895.8	0.00	0.00	3.33	0.00	3.33	104.21	0.114E+00			
2.5" FLEX LINE,2M	0.271E-02	0.063			10.0	9872.7	0.00	0.00	23.11	0.00	23.11	127.32	0.114E+00	0.31E+04	0.10E-04	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9872.1	0.00	0.00	0.53	0.00	0.53	127.85	0.114E+00			
4" PIPE LENGTH	0.271E-02	0.100			3.0	9871.6	0.00	0.00	0.51	0.00	0.51	128.37	0.114E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9871.1	0.00	0.00	0.53	0.00	0.53	128.90	0.114E+00			
4" PIPE LENGTH	0.271E-02	0.100			24.0	9867.0	0.00	0.00	4.12	0.00	4.12	133.02	0.114E+00	0.20E+04	0.66E-05	VISCOUS
4" TEE LINE	0.271E-02	0.100	1.016			9866.5	0.00	0.00	0.53	0.00	0.53	133.55	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			12.0	9864.4	0.00	0.00	2.06	0.00	2.06	135.61	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" TEE BRANCH	0.271E-02	0.100	1.016			9863.9	0.00	0.00	0.53	0.00	0.53	136.14	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			10.0	9862.1	0.00	0.00	1.72	0.00	1.72	137.86	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" TEE LINE	0.271E-02	0.100	1.016			9861.6	0.00	0.00	0.53	0.00	0.53	138.39	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			2.0	9861.3	0.00	0.00	0.34	0.00	0.34	138.74	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9860.7	0.00	0.00	0.53	0.00	0.53	139.27	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			3.6	9856.1	0.00	3.60	0.62	4.01	4.62	143.89	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9855.6	3.60	3.60	0.53	0.00	0.53	144.43	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			10.0	9853.9	3.60	3.60	1.72	0.00	1.72	146.15	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9853.3	3.60	3.60	0.53	0.00	0.53	146.68	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			3.6	9856.7	3.60	0.00	0.62	-4.00	-3.38	143.30	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9856.2	0.00	0.00	0.53	0.00	0.53	143.83	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			3.0	9855.7	0.00	0.00	0.52	0.00	0.52	144.35	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9855.1	0.00	0.00	0.53	0.00	0.53	144.88	0.113E+00			
4" PIPE LENGTH	0.271E-02	0.100			10.0	9853.4	0.00	0.00	1.72	0.00	1.72	146.60	0.113E+00	0.20E+04	0.66E-05	VISCOUS
4" ELBOW LR-90	0.271E-02	0.100	1.016			9852.9	0.00	0.00	0.53	0.00	0.53	147.13	0.113E+00			
4" FLEX LINE,3M	0.271E-02	0.100			10.0	9851.1	0.00	0.00	1.72	0.00	1.72	148.85	0.113E+00	0.20E+04	0.66E-05	VISCOUS
								TOTAL	148.8497	0.0030		148.8527				

CHAMBER PRESSURE: 10000.000 Pa   CHAMBER SPEED   :   0.0237 M^3/S   PUMP PRESSURE   : 9851.147 Pa   PUMP SPEED   :   0.0240 M^3/S

REVISION : 2
DOC NO: V049-1-007
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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: TURBO PUMPVACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:TURBO BACKING PUMP QDP80

PRESSURE:	1000.0 Pa	0.010 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.012 KG/M^3	0.115E-01 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
1.5" BYPASS	0.230E-03	0.038			4.0	972.5	0.00	0.00	27.50	0.00	27.50	27.50	0.115E-01	0.44E+03	0.17E-03	VISCOUS
2.5"ELBOW LR-90	0.230E-03	0.063	2.835			971.8	0.00	0.00	0.69	0.00	0.69	28.19	0.112E-01			
2.5" FLEX LINE,2M	0.230E-03	0.063			10.0	962.4	0.00	0.00	9.37	0.00	9.37	37.56	0.112E-01	0.26E+03	0.11E-03	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			962.3	0.00	0.00	0.15	0.00	0.15	37.71	0.111E-01			
4" PIPE LENGTH	0.230E-03	0.100			3.0	961.8	0.00	0.00	0.45	0.00	0.45	38.15	0.111E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			961.7	0.00	0.00	0.15	0.00	0.15	38.30	0.111E-01			
4" PIPE LENGTH	0.230E-03	0.100			24.0	958.1	0.00	0.00	3.58	0.00	3.58	41.88	0.111E-01	0.17E+03	0.68E-04	VISCOUS
4" TEE LINE	0.230E-03	0.100	3.846			958.0	0.00	0.00	0.15	0.00	0.15	42.03	0.110E-01			
4" PIPE LENGTH	0.230E-03	0.100			12.0	956.2	0.00	0.00	1.80	0.00	1.80	43.83	0.110E-01	0.17E+03	0.68E-04	VISCOUS
4" TEE BRANCH	0.230E-03	0.100	3.846			956.0	0.00	0.00	0.15	0.00	0.15	43.98	0.110E-01			
4" PIPE LENGTH	0.230E-03	0.100			10.0	954.5	0.00	0.00	1.50	0.00	1.50	45.48	0.110E-01	0.17E+03	0.68E-04	VISCOUS
4" TEE LINE	0.230E-03	0.100	3.846			954.4	0.00	0.00	0.15	0.00	0.15	45.63	0.110E-01			
4" PIPE LENGTH	0.230E-03	0.100			2.0	954.1	0.00	0.00	0.30	0.00	0.30	45.93	0.110E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			953.9	0.00	0.00	0.15	0.00	0.15	46.08	0.110E-01			
4" PIPE LENGTH	0.230E-03	0.100			3.6	953.0	0.00	3.60	0.54	0.39	0.93	47.00	0.110E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			952.8	3.60	3.60	0.15	0.00	0.15	47.15	0.110E-01			
4" PIPE LENGTH	0.230E-03	0.100			10.0	951.3	3.60	3.60	1.50	0.00	1.50	48.66	0.110E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			951.2	3.60	3.60	0.15	0.00	0.15	48.81	0.109E-01			
4" PIPE LENGTH	0.230E-03	0.100			3.6	951.0	3.60	0.00	0.54	-0.39	0.16	48.97	0.109E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			950.9	0.00	0.00	0.15	0.00	0.15	49.12	0.109E-01			
4" PIPE LENGTH	0.230E-03	0.100			3.0	950.4	0.00	0.00	0.45	0.00	0.45	49.57	0.109E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			950.3	0.00	0.00	0.15	0.00	0.15	49.72	0.109E-01			
4" PIPE LENGTH	0.230E-03	0.100			10.0	948.8	0.00	0.00	1.51	0.00	1.51	51.23	0.109E-01	0.17E+03	0.68E-04	VISCOUS
4" ELBOW LR-90	0.230E-03	0.100	3.846			948.6	0.00	0.00	0.15	0.00	0.15	51.38	0.109E-01			
4" FLEX LINE,3M	0.230E-03	0.100			10.0	947.1	0.00	0.00	1.51	0.00	1.51	52.89	0.109E-01	0.17E+03	0.69E-04	VISCOUS
								TOTAL	52.8895	0.0011		52.8907				

CHAMBER PRESSURE: 1000.000 Pa   CHAMBER SPEED : 0.0201 M^3/S   PUMP PRESSURE : 947.109 Pa   PUMP SPEED : 0.0212 M^3/S

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DOC NO: V049-1-007
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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: TURBO PUMPVACUUM HEADER

BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:TURBO BACKING PUMP QDP80

PRESSURE:	100.0 Pa	0.001 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.001 KG/M^3	0.115E-02 KG/M^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
1.5" BYPASS	0.132E-04	0.038			4.0	84.2	0.00	0.00	15.80	0.00	15.80	15.80	0.115E-02	0.25E+02	0.17E-02	VISCOUS
2.5"ELBOW LR-90	0.132E-04	0.063	25.697			84.0	0.00	0.00	0.24	0.00	0.24	16.04	0.968E-03			
2.5" FLEX LINE,2M	0.132E-04	0.063			10.0	77.7	0.00	0.00	6.23	0.00	6.23	22.26	0.966E-03	0.15E+02	0.12E-02	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			77.7	0.00	0.00	0.06	0.00	0.06	22.33	0.894E-03			
4" PIPE LENGTH	0.132E-04	0.100			3.0	77.4	0.00	0.00	0.32	0.00	0.32	22.64	0.893E-03	0.95E+01	0.84E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			77.3	0.00	0.00	0.06	0.00	0.06	22.71	0.890E-03			
4" PIPE LENGTH	0.132E-04	0.100			24.0	74.7	0.00	0.00	2.56	0.00	2.56	25.26	0.889E-03	0.95E+01	0.84E-03	VISCOUS
4" TEE LINE	0.132E-04	0.100	38.768			74.7	0.00	0.00	0.06	0.00	0.06	25.33	0.860E-03			
4" PIPE LENGTH	0.132E-04	0.100			12.0	73.4	0.00	0.00	1.32	0.00	1.32	26.65	0.859E-03	0.95E+01	0.87E-03	VISCOUS
4" TEE BRANCH	0.132E-04	0.100	38.768			73.3	0.00	0.00	0.06	0.00	0.06	26.71	0.844E-03			
4" PIPE LENGTH	0.132E-04	0.100			10.0	72.2	0.00	0.00	1.12	0.00	1.12	27.84	0.843E-03	0.95E+01	0.89E-03	VISCOUS
4" TEE LINE	0.132E-04	0.100	38.768			72.1	0.00	0.00	0.07	0.00	0.07	27.90	0.830E-03			
4" PIPE LENGTH	0.132E-04	0.100			2.0	71.9	0.00	0.00	0.23	0.00	0.23	28.13	0.829E-03	0.95E+01	0.90E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			71.8	0.00	0.00	0.07	0.00	0.07	28.20	0.827E-03			
4" PIPE LENGTH	0.132E-04	0.100			3.6	71.4	0.00	3.60	0.41	0.03	0.44	28.64	0.826E-03	0.95E+01	0.91E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			71.3	3.60	3.60	0.07	0.00	0.07	28.71	0.821E-03			
4" PIPE LENGTH	0.132E-04	0.100			10.0	70.1	3.60	3.60	1.16	0.00	1.16	29.86	0.820E-03	0.95E+01	0.91E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			70.1	3.60	3.60	0.07	0.00	0.07	29.93	0.807E-03			
4" PIPE LENGTH	0.132E-04	0.100			3.6	69.7	3.60	0.00	0.42	-0.03	0.39	30.33	0.806E-03	0.95E+01	0.93E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			69.6	0.00	0.00	0.07	0.00	0.07	30.39	0.801E-03			
4" PIPE LENGTH	0.132E-04	0.100			3.0	69.3	0.00	0.00	0.35	0.00	0.35	30.75	0.801E-03	0.95E+01	0.93E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			69.2	0.00	0.00	0.07	0.00	0.07	30.82	0.796E-03			
4" PIPE LENGTH	0.132E-04	0.100			10.0	68.0	0.00	0.00	1.19	0.00	1.19	32.01	0.796E-03	0.95E+01	0.94E-03	VISCOUS
4" ELBOW LR-90	0.132E-04	0.100	38.768			67.9	0.00	0.00	0.07	0.00	0.07	32.08	0.782E-03			
4" FLEX LINE,3M	0.132E-04	0.100			10.0	66.7	0.00	0.00	1.21	0.00	1.21	33.29	0.781E-03	0.95E+01	0.96E-03	VISCOUS
								TOTAL	33.2902	0.0007		33.2909				

CHAMBER PRESSURE:	100.000 Pa	CHAMBER SPEED :	0.0115 M^3/S	PUMP PRESSURE :	66.709 Pa	PUMP SPEED :	0.0172 M^3/S

REVISION : 2
DOC NO: V049-1-007

PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: TURBO PUMPVACUUM HEADER

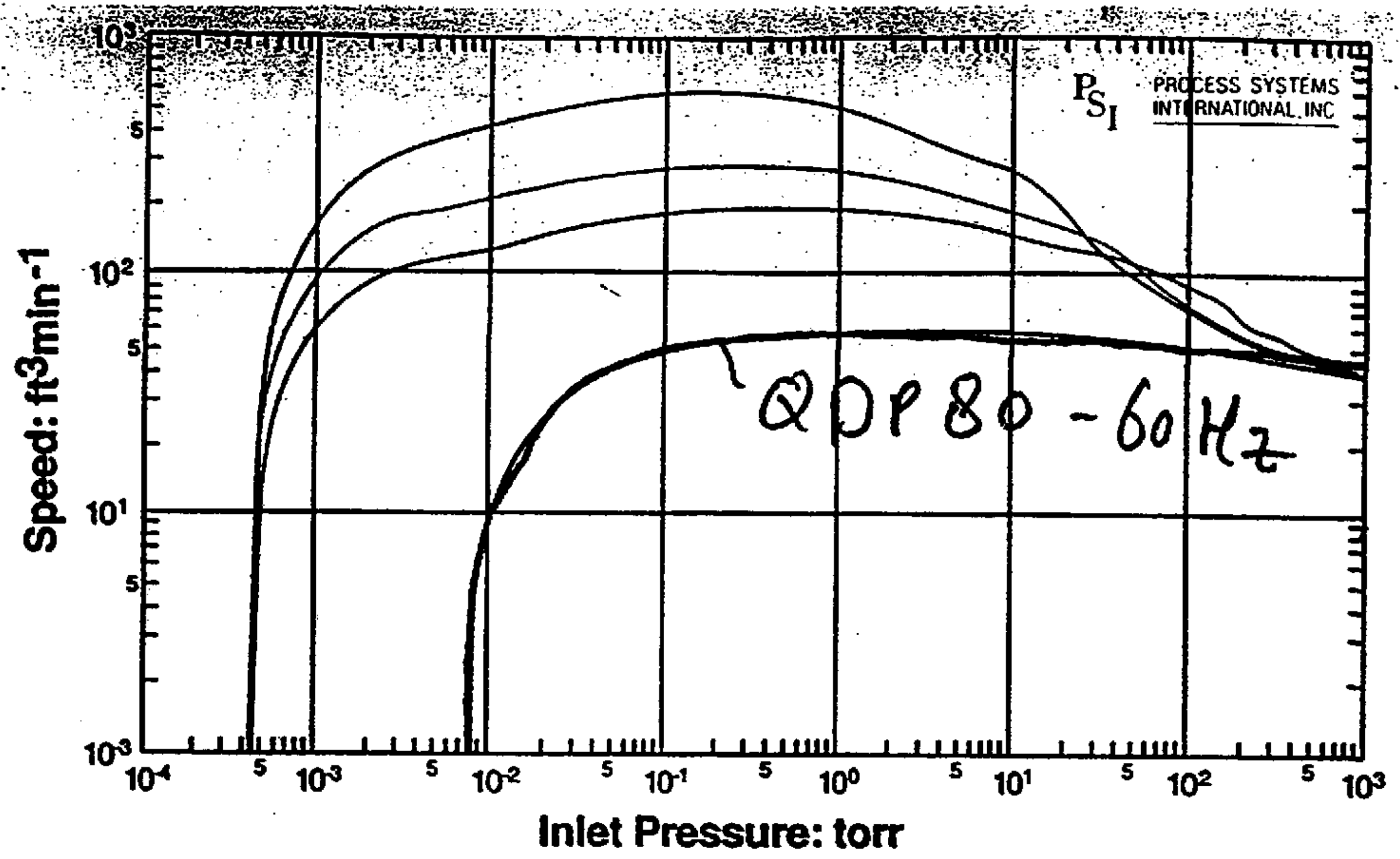
BY: R. THAN
DATE: 4/17/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:TURBO BACKING PUMP QDP80

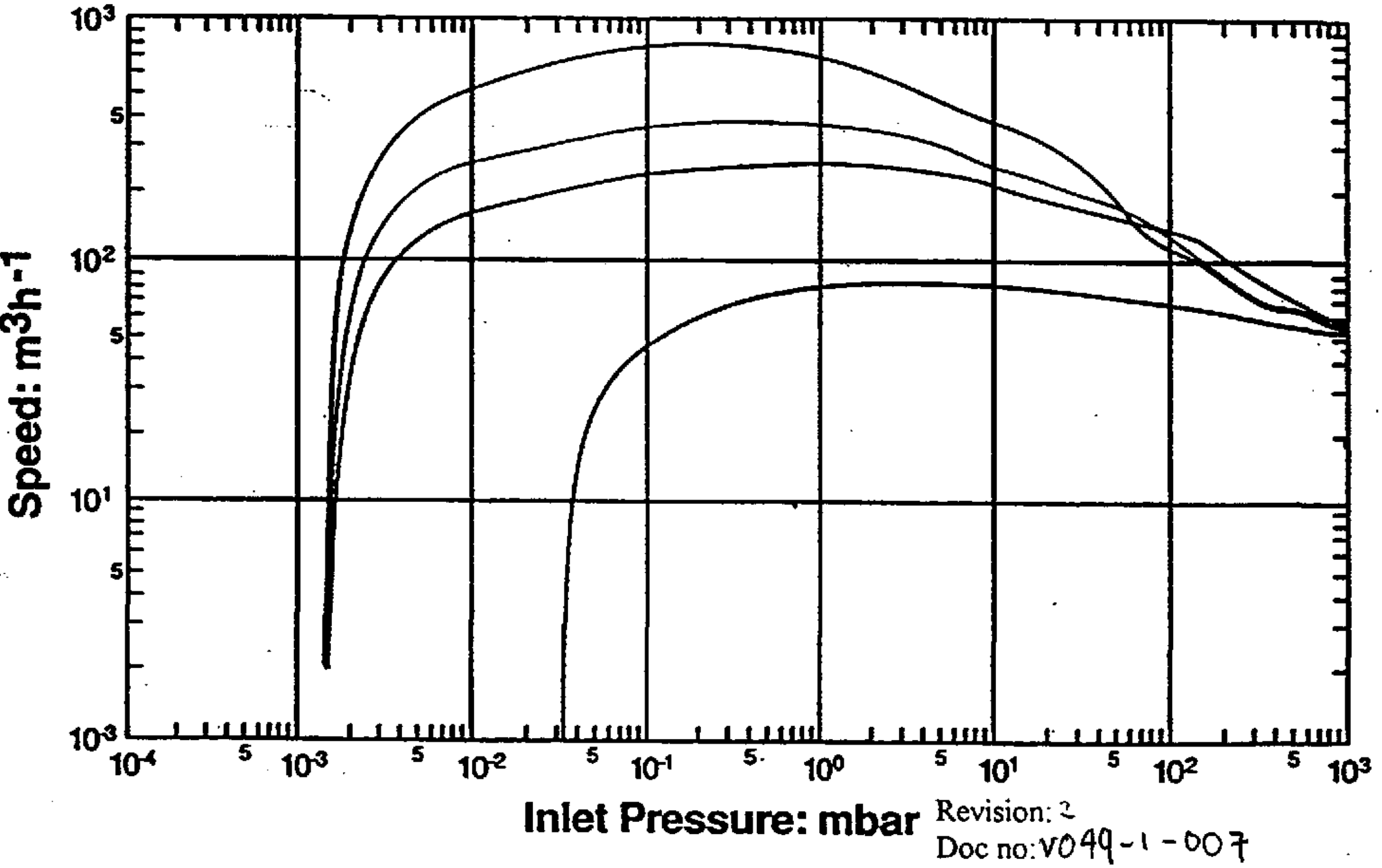
PRESSURE:	10.0 Pa	0.000 BAR
TEMPERATURE:	293.000 K	293.000 K
DENSITY :	0.000 KG/M^3	0.115E-03 KG/M^3
QUALITY :	1.000	

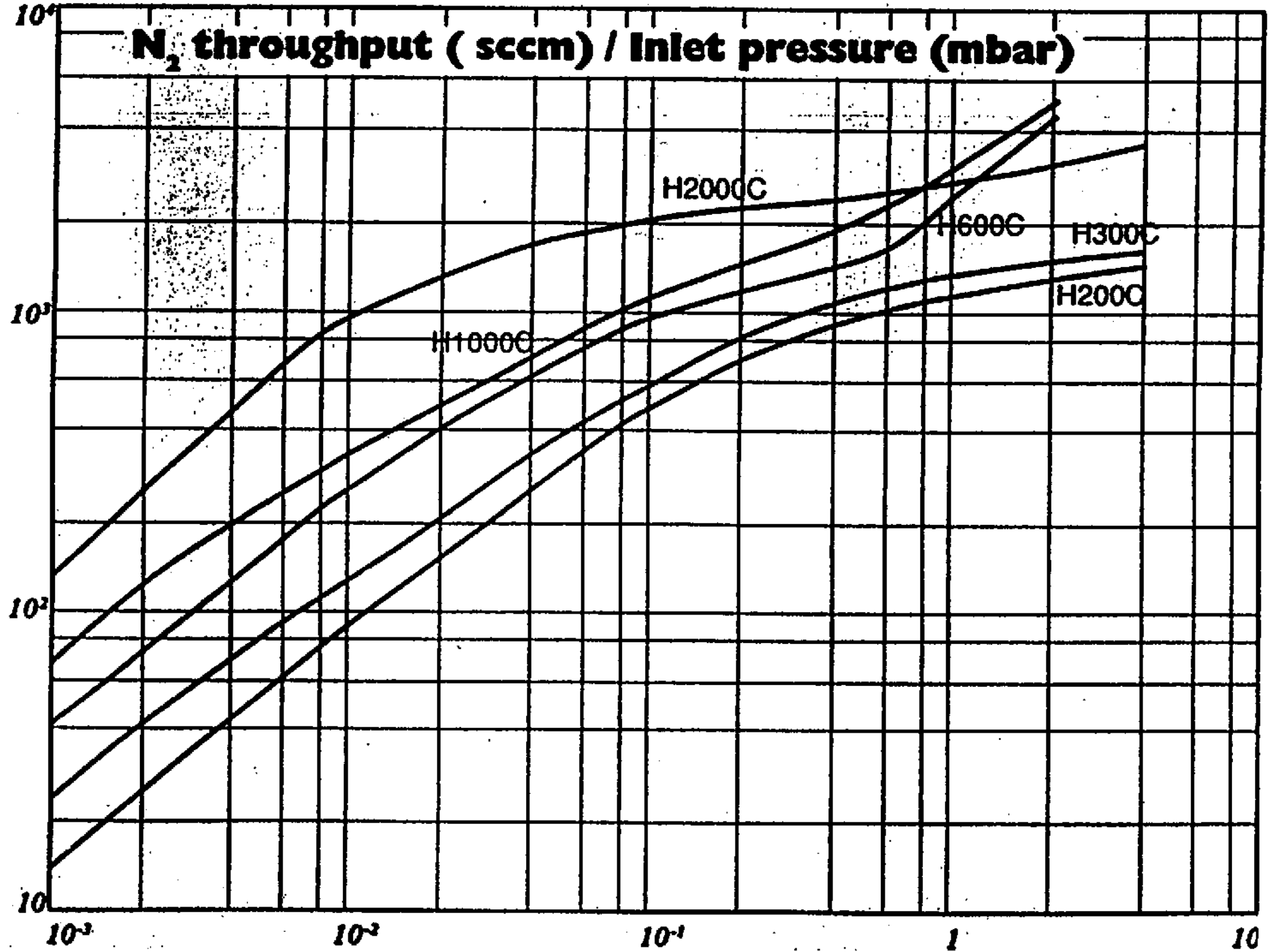
ITEMNAME	FLOWRATE KG/S	I.D. METER	K / DO	CV	LENGTH M	PRESSURE Pa	Z1 METER	Z2 METER	DP-F Pa	DP-Z Pa	DP-T Pa	DP-SUM Pa	DENSITY KG/M^3	RE NO	Knunsen	Regime
1.5" BYPASS	0.237E-06	0.038			4.0	7.2	0.00	0.00	2.84	0.00	2.84	2.84	0.115E-03	0.45E+00	0.17E-01	SLIP
2.5"ELBOW LR-90	0.237E-06	0.063	1144.091			7.1	0.00	0.00	0.04	0.00	0.04	2.88	0.823E-04			
2.5" FLEX LINE,2M	0.237E-06	0.063			10.0	5.8	0.00	0.00	1.32	0.00	1.32	4.20	0.819E-04	0.27E+00	0.15E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.388			5.8	0.00	0.00	0.01	0.00	0.01	4.21	0.667E-04			
4" PIPE LENGTH	0.237E-06	0.100			3.0	5.7	0.00	0.00	0.08	0.00	0.08	4.29	0.665E-04	0.17E+00	0.11E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.388			5.7	0.00	0.00	0.01	0.00	0.01	4.30	0.657E-04			
4" PIPE LENGTH	0.237E-06	0.100			24.0	5.1	0.00	0.00	0.62	0.00	0.62	4.93	0.655E-04	0.17E+00	0.11E-01	SLIP
4" TEE LINE	0.237E-06	0.100	1802.388			5.1	0.00	0.00	0.01	0.00	0.01	4.94	0.583E-04			
4" PIPE LENGTH	0.237E-06	0.100			12.0	4.7	0.00	0.00	0.35	0.00	0.35	5.29	0.582E-04	0.17E+00	0.13E-01	SLIP
4" TEE BRANCH	0.237E-06	0.100	1802.387			4.7	0.00	0.00	0.02	0.00	0.02	5.31	0.541E-04			
4" PIPE LENGTH	0.237E-06	0.100			10.0	4.4	0.00	0.00	0.32	0.00	0.32	5.62	0.540E-04	0.17E+00	0.14E-01	SLIP
4" TEE LINE	0.237E-06	0.100	1802.387			4.4	0.00	0.00	0.02	0.00	0.02	5.64	0.503E-04			
4" PIPE LENGTH	0.237E-06	0.100			2.0	4.3	0.00	0.00	0.07	0.00	0.07	5.71	0.502E-04	0.17E+00	0.15E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.387			4.3	0.00	0.00	0.02	0.00	0.02	5.72	0.494E-04			
4" PIPE LENGTH	0.237E-06	0.100			3.6	4.2	0.00	3.60	0.12	0.00	0.13	5.85	0.492E-04	0.17E+00	0.15E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.387			4.1	3.60	3.60	0.02	0.00	0.02	5.87	0.477E-04			
4" PIPE LENGTH	0.237E-06	0.100			10.0	3.8	3.60	3.60	0.36	0.00	0.36	6.23	0.475E-04	0.17E+00	0.16E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.387			3.8	3.60	3.60	0.02	0.00	0.02	6.24	0.434E-04			
4" PIPE LENGTH	0.237E-06	0.100			3.6	3.6	3.60	0.00	0.14	0.00	0.14	6.38	0.432E-04	0.17E+00	0.17E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.386			3.6	0.00	0.00	0.02	0.00	0.02	6.40	0.416E-04			
4" PIPE LENGTH	0.237E-06	0.100			3.0	3.5	0.00	0.00	0.12	0.00	0.12	6.53	0.413E-04	0.17E+00	0.18E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.386			3.5	0.00	0.00	0.02	0.00	0.02	6.55	0.399E-04			
4" PIPE LENGTH	0.237E-06	0.100			10.0	3.0	0.00	0.00	0.43	0.00	0.43	6.98	0.397E-04	0.17E+00	0.19E-01	SLIP
4" ELBOW LR-90	0.237E-06	0.100	1802.386			3.0	0.00	0.00	0.02	0.00	0.02	7.00	0.348E-04			
4" FLEX LINE,3M	0.237E-06	0.100			10.0	2.5	0.00	0.00	0.49	0.00	0.49	7.50	0.345E-04	0.17E+00	0.22E-01	SLIP
								TOTAL	7.4952	0.0002		7.4954				

CHAMBER PRESSURE: 10.000 Pa   CHAMBER SPEED : 0.0021 M^3/S   PUMP PRESSURE : 2.505 Pa   PUMP SPEED : 0.0084 M^3/S

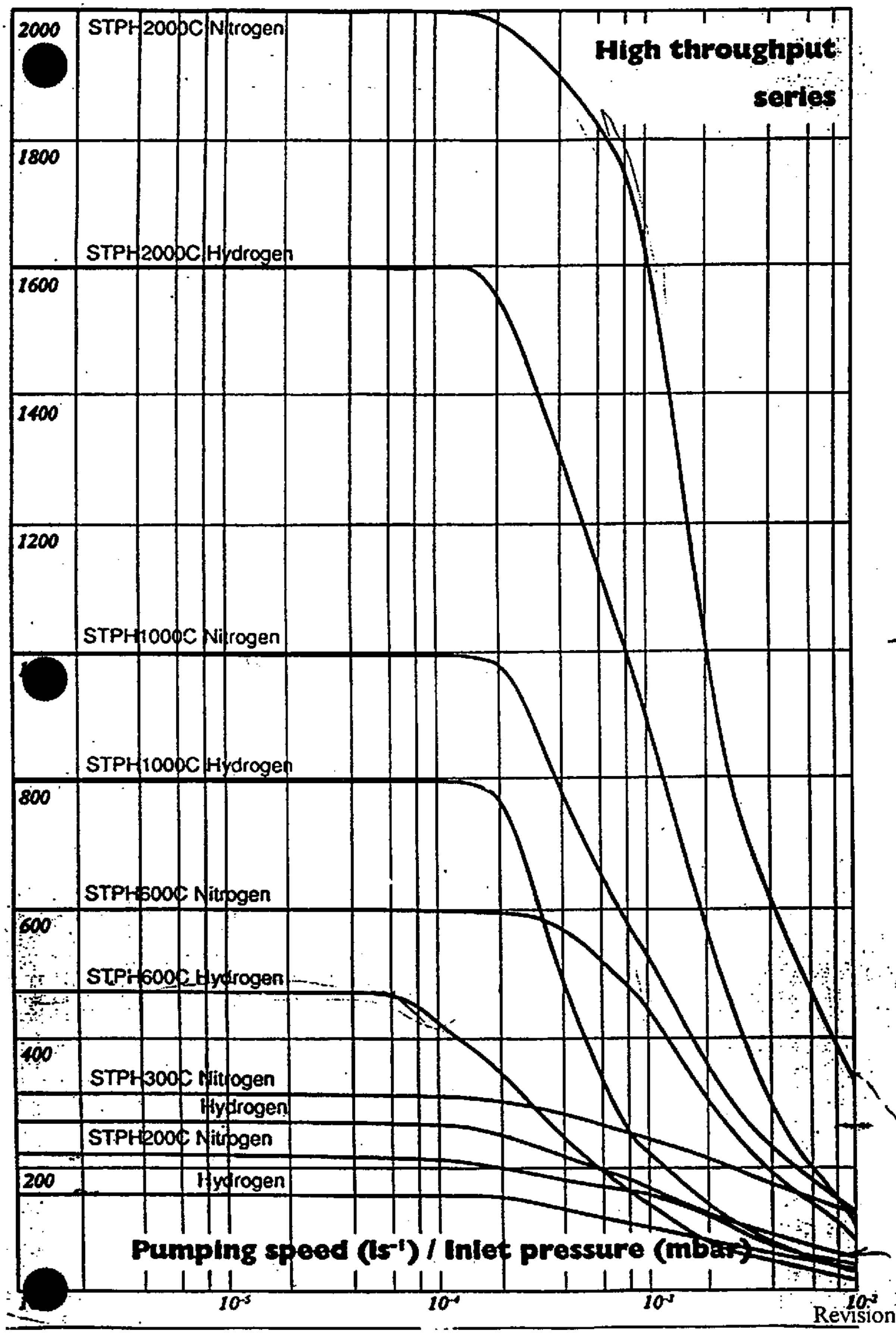


QMB1200 + QDP80 50Hz QMB500 + QDP80 50Hz
QMB250 + QDP80 50Hz QDP80 50Hz





H200C and H300C used with $14 m^3h^{-1}$ rotary pump, H600C and H100(H2000C used with $30 m^3h^{-1}$ rotary pump.


High throughput series
STPH2000C Nitrogen
STPH2000C Hydrogen
STPH1000C Nitrogen
STPH1000C Hydrogen
STPH600C Nitrogen
STPH600C Hydrogen
STPH300C Nitrogen
Hydrogen
STPH200C Nitrogen
Hydrogen
2000
1800
1600
1400
1200
800
600
400
200
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Pumping speed (ls⁻¹) / Inlet pressure (mbar)

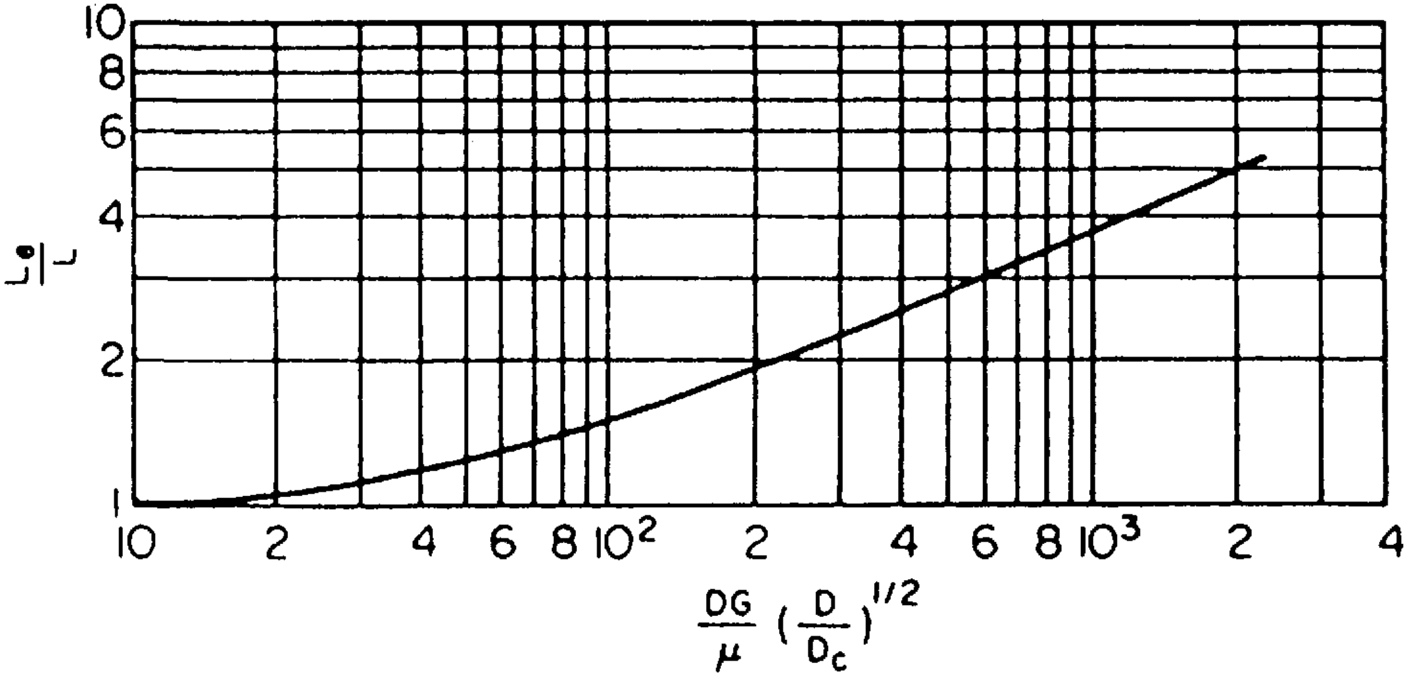


FIG. 5-46 Equivalent length for curved pipe in laminar flow. $Le/L = 1$ for $(DG/\mu)(D/D_c)^{1/2} < 10$ [*White*, Proc. R. Soc. (London), *A123, 645 (1929)*

PROJECT: LIGO BY: R.THAN DEPT: 744

PROJECT NO: V59049 DATE:

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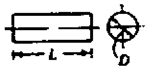
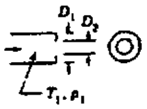
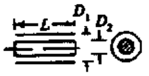
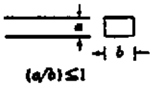
PROCESS SYSTEMS
INTERNATIONAL INC

Table 8.1. Conductance equations for vacuum systems. μ = gas viscosity, $\bar{p}$ = mean pressure, g_c = conversion factor in Newton's Law, R_0 = universal gas constant, M = molecular weight, γ = specific heat ratio, L = tube length, D = tube diameter

Element	Sketch of Element	Flow Regime: Continuum (Laminar Flow)	Flow Regime: Free Molecular
1. Long tube, $L/D > 30$		$C = \frac{\pi D^4 g_c \bar{p}}{128\mu L}$	$C = \left(\frac{\pi g_c R_0 T}{18M}\right)^{1/2} \frac{D^3}{L}$
2. Short tube, $L/D < 30$ D_1 = larger diameter D_2 = smaller diameter	Same as (1)	$C = \frac{\pi D^4 g_c \bar{p}}{128\mu L}\left(1 + \frac{m}{22\mu L}\right)^{-1}$	$C = \frac{(\pi g_c R_0 T/18M)^{1/2} D^3}{L/D + (\frac{4}{3})[1 - (D_2/D_1)^2]}$
3. Orifice or aperture D_1 = tube diameter D_2 = orifice diameter $r_p = p_2/p_1$		$C = KD^2\left[\frac{\gamma\pi^2 g_c R_0 T_1}{8(\gamma - 1)M}\right]^{1/2}$ (a) For $r_p \geq [2/(\gamma + 1)]^{\gamma/(\gamma-1)}$ $K = \frac{1 - r_p^{(\gamma-1)/\gamma}}{r_p^{2/\gamma}(1 - r_p)^2}$ (b) For $r_p < [2/(\gamma + 1)]^{\gamma/(\gamma-1)}$ $K = \frac{[(\gamma - 1)/(\gamma + 1)]^{1/2}}{[2/(\gamma + 1)]^{1/(\gamma-1)}(1 - r_p)}$	$C = \frac{(\pi g_c R_0 T/32M)^{1/2} D^2}{1 - (D_2/D_1)^2}$
4. Annular flow passage D_1 = larger diameter D_2 = smaller diameter		$C = \frac{\pi g_c \bar{p}}{128\mu L}\left[(D_1^4 - D_2^4) - \frac{(D_1^2 - D_2^2)^2}{\ln(D_1/D_2)}\right]$	$C = \left(\frac{\pi g_c R_0 T}{18M}\right)^{1/2} \frac{(D_1 - D_2)^2(D_1 - D_2)K}{L + (\frac{4}{3})(D_1 - D_2)}$ where K is given as follows: D_2/D_1 0 0.259 0.500 K 1 1.072 1.154 D_2/D_1 0.707 0.866 0.966 K 1.254 1.430 1.675
5. Rectangular tube $a/b \leq 1$		$C = \frac{\pi g_c a^2 b^2 \bar{p} K}{87.4\mu L}$ where K is given as follows: a/b 1.00 0.90 0.80 0.70 0.60 K 1.00 0.99 0.98 0.95 0.90 a/b 0.50 0.40 0.30 0.20 0.10 K 0.82 0.71 0.58 0.42 0.23	$C = \left(\frac{32 g_c R_0 T}{9\pi M}\right)^{1/2} \frac{a^2 b^2 K}{(a + b)L + \frac{8}{3}ab}$ where K is given as follows: a/b 1.000 0.667 0.500 0.333 K 1.108 1.126 1.151 1.198 a/b 0.200 0.125 0.100 0.000 K 1.297 1.400 1.444 1.667
6. 90° elbow r = mean radius		$C = \frac{\pi g_c K D^3 \bar{p}}{128\mu}$ where K is given as follows: r/D 0.000 1.000 2.000 3.000 4.000 K 0.017 0.050 0.083 0.083 0.073 r/D 6.0 8.0 10 12 14 K 0.056 0.042 0.034 0.029 0.026	$C = \left(\frac{2 g_c R_0 T}{9\pi M}\right)^{1/2} \frac{D^3}{r}$

$$\Delta P = \frac{\rho \cdot \dot{V}}{C} \quad [Pa]$$

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PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-012
PAGE 1 OF 20

REV	DEO#	DATE	BY:	CHECK
0	0106	3/29/96	R. Than	SM
1	0389	12/16/96	R.Than	D.McW

TITLE:
ANNULUS CHANNEL SIZING

ANNULI MANIFOLDING, ION PUMP

BY: R. THAN
DEPT: 744

PROJECT: LIGO
PROJECT NO: V59049

PURPOSE: Sizing: Annulus channel, External Tubing, Manifold, Beamtube-Manifold Annuli header

METHOD:
Long tube formula: Circular section, Rectangular section.

ASSUMPTIONS:
Minimum **0.20 L/s** pumping speed at any location in annulus
75 L/s Ion pump per chamber
25 L/s Large gate valves

INPUTS:

REFERENCE:
Theory and Practice of vacuum Technology
ISBN 3-528-08908-3

CALCULATIONS:

see Attachments

CONCLUSIONS: Some flange annuli requires multiport pumpout configuration (104") to meet pumping speed in annulus and to keep annulus channel at reasonable size. A 0.687 inch X 0.500 inch or a 0.687 X 0.375 inch annulus channel size is used, depending on flange sizes.

NOTES:

Revision History

Rev 0	Initial release
Rev 1	Update BSC annulus configuration to ion pump location on the top dome of BSC and changed the size of vent grooves and number of vent grooves on flanges.

TITLE: ANNULUS CHANNEL, MANIFOLDING

FLANGE ANNULI

Annulus Channels

To minimize diffusion of gasses from atmosphere through the double Viton o-ring seal, the space between the two o-rings is pumped out and maintained at a certain vacuum pressure using an ion pump. There are 7 sizes of flange connections which require a double Viton o-ring seal:

inches	cm
30	76
44	112
48	122
60	152
72	183
84	213
104	264

Diffusion rate

A diffusion rate of 2 x 10^{-6} [Torr - L/s]·[m/m^2 $^-$bar] is used for diffusion of air through Viton. A nominal o-ring diameter of 1/4 inch (6.35 mm) was assumed in the calculation of the amount of gas diffused through the o-rings.

Annulus Pressure and Pumping Speed

To achieve a diffusion rate into the ultra-high vacuum (UHV) side, which does not require a significant pumping speed on the UHV side, a certain pressure must be maintained in the annulus space. A diffusion rate per o-ring on the order of 1 x 10^{-5} Torr - L/s is expected from the atmospheric side. The annulus channel was sized to meet the specified pumping speed of 0.20 L/s anywhere in the annulus channel. With a pumping speed of 0.20 L/s and a difussion rate of 1 x 10^{-5} Torr - L/s, the annulus pressure will be on the order of 5 x 10^{-5} Torr. This gives a diffusion rate into the UHV section on the order of 1 x 10^{-12} Torr - L/s. The high pumping speed in the channel would allow a leak rate from the atmosphere of 1 x 10^{-4} Torr - L/s and still maintain a rate into the UHV side on the order of 1 x 10^{-11} Torr - L/s.

PROJECT NO: _V59049_DATE: ___12/16/96

TITLE: ANNULUS CHANNEL, MANIFOLDING

Annulus Channel Size

The annulus channel was sized for a pumping speed of 0.20 L/s anywhere in the annulus.

Annulus port

The diameter of the annulus pump out port must be large enough to allow a pumping speed of over 1 L/s. The port is sized at 0.62 inch diameter, the same size as the jumper.

Annulus Interconnecting jumper to header

Because of the location of the annulus channel the the interconnecting jumper tube to the header cannot be too large to allow space for welding. A 0.75 tube jumper is used with an ID of 0.620 inch, the allowable length should be no longer than 6 inches.

Annulus Pumpout Interconnecting tubing / Pump Manifold

A typical vessel is about 2.8 m diameter. Because of space limitations the pump may need to be located away from the chamber. The length of the tube from the annuli ports to the manifold could therefore be a longer than 5 m. The size of the tube that runs from the annulus pump out port to the manifold where the auxiliary turbo pump and ion pump are connected will need to be approximately 1 to 1.5 inch diameter (25 mm - 38 mm) to prevent the conductance of this path from dominating the overall conductance. In order to have an effective speed at the annulus port the pumping speed at the pumpmanifold needs to be 10 L/s. A 2.5 inch manifold is proposed.

Pump Size and Capacity

A 75 L/s pump is proposed for each manifolded annuli group: BSC, TMC, HAM, 183 Beam manifold. A separate 25 liters/s Ion pump is proposed for the 122 / 111 cm Gate valve's gate-seals and flange annuli. This would give a pump life of about 40,000 hours with an average gas load of 1 x 10^{-5} Torr - L/s per annulus. With a higher gas load due to high leakage, the pump life will be shortened.

Valving

Each manifolded annuli group has an single roughing port 63 mm HV valve for pumpout using the auxilliary pumping cart. An isolation valve separates the Ion pump from the pump manifold. A separate roughing valve is provided for the ion pump, either on the pump housing or off the spool piece.

TITLE: ANNULUS CHANNEL, MANIFOLDING

Annulus Speed

The net speed / conductance is calculated for a point that is midway between two exit ports. This will give the minimum conductance between this point and the pump. All gas molecules at other points in the annulus will have an equal or higher probability. In the case of a single port this point would be located 180 degrees across from the exit port.

The probability (conductance) that a gas molecule from this point reaches the pump is determined by all possible gas path back to the pump. So for the BSC 104" annulus the conductance calculated from the midpoint between two exitports back to pump via one port is about 0.12 L/s.
But gas molecules at this point has twice the probability of reaching the pump, because of the other parallel path through the other 60" flange. The effective speed for a point in the 104 inch annulus is therefor 0.24 L/s. Note that for a point closer to the port, the effective speed would remain almost unchanged because for one path the probability has increased (approximately linearly, long tube formula) for the other path the probabilty has decreased.

For the flanges with a single port, the parallel path is only for the section of the path in the flange until the molecule reaches the exit port, where it becomes a single path to the pump.

TITLE: ANNULUS CHANNEL, MANIFOLDING

Annulus channels sizes for flanges

	Annulus Width inch (mm)	Annulus Height *inch (mm)*	No ports	Annulus Speed L/s	Interconnecting Piping I.D. inch
BSC 60" *	0.6875 (17.5)	0.500 (12.7)	1 (2)	0.2	1.37
BSC 104" *	0.6875 (17.5)	0.375 (12.7)	4	0.14 x2=0.28	1.37
HAM 84"	0.6875 (17.5)	0.500 (12.7)	1	0.21	1.37
HAM 60"	0.6875 (17.5)	0.500 (12.7)	1	0.25	1.37
HAM 30"	0.6875 (17.5)	0.375 (9.53)	1	0.25	1.37
B-M 72"	0.6875 (17.5)	0.500 (12.7)	1	0.23	1.20 (tube) 2.37" (header) (header10m long)
GATE-VALVE 48"	0.6875 (17.5)	0.375 (9.53)	1	0.26	1.12
GATE VALVE 44"	0.6875 (17.5)	0.375 (9.53)	1	0.27	1.12
GATE Bonnet	0.3750 (9.53)	0.410 (10.41)	2	0.18	1.12
GATE Seal	0.3125 (7.9)	0.500 (12.7)	2	0.22	1.12

* BSC 104" flange in series with 60" flange

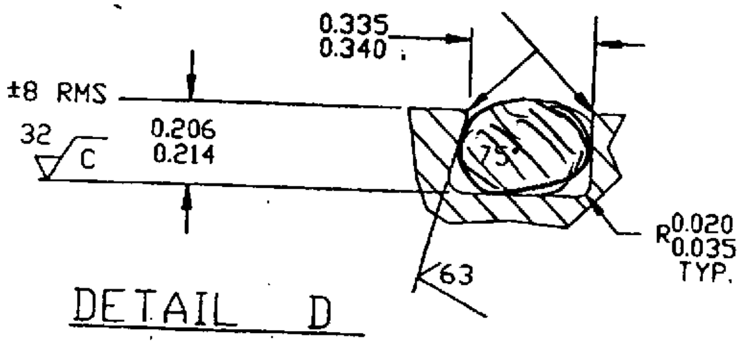
Terminology used in tables:

Lo	Orifice conductance
Li	Effective conductance
So	Orifice speed
Si	Effective Speed
P	Tranmission Probability

O-ring grooves vents

To ensure that there are no trapped volumes that could serve as virtual leaks, the O-ring grooves needs to be vented. The vents need to be sized such that they can allow the trapped O-ring volumes to be evacuated to the same pressures during the roughing cycle.

The cross sectional area of the trapped O-ring channel (on the UHV side, dovetail side) is approximately 0.005 in^2 or 0.03 cm^2.



DETAIL D

For the corner station there is about 300 m of o-ring length. The total trapped o-ring volume is therefore about 2.1 liters.

The ratio of trapped o-ring volume ($2.1\text{x}10^{-3}$ m^3) to corner station volume ($196m^3$) is approximately $1\text{x}10^{-5}$.

The required pumping speed is about $1\text{x}10^{-5}$ X 2000 L/s = 0.02 L/s for total trapped volume.

Per meter length of o-ring the required speed is 0.02/300= $7\text{X}10^{-5}$ L/s per meter o-ring.
For efficient pumping the conductance should be about 10 times the required speed or $7\text{X}10^{-4}$ L/s per meter o-ring.

Conductance of trapped o-ring channel.

The hydraulic diameter of the trapped channel is about 6 mm.
The conductance of this channel is approximately 0.0008 L/s for one meter length of o-ring.
The requirements for venting based on roughing of the trapped volume is a vent every 1.5 to 2 m of o-ring length.

The proposed vent dimension of 0.15 inches high by 0.500 inches wide has a conductance of about 1 L/s which is sufficient compared to the trapped channel conductance.

Outgassing.

The outgassing of the o-ring is on the order of $1x10^{-8}$ Torr-L/s-cm^2 .
With about 3 m of o-ring length the outgassing rate would $300x10^{-8}$ Torr-L/s-cm^2
The pressure in the channel at the vent location would be in 10^{-5} Torr range and at the far end between vents the pressure in the channel would be in the 10^{-3} Torr range.

The same size vent is used for the vent for the trapped volume of the annulus side of the UHV o-ring. The same size vent is also used for the annulus side of the atmospheric o-ring. A vent for the atmospheric side of the atmospheric o-ring is not required.

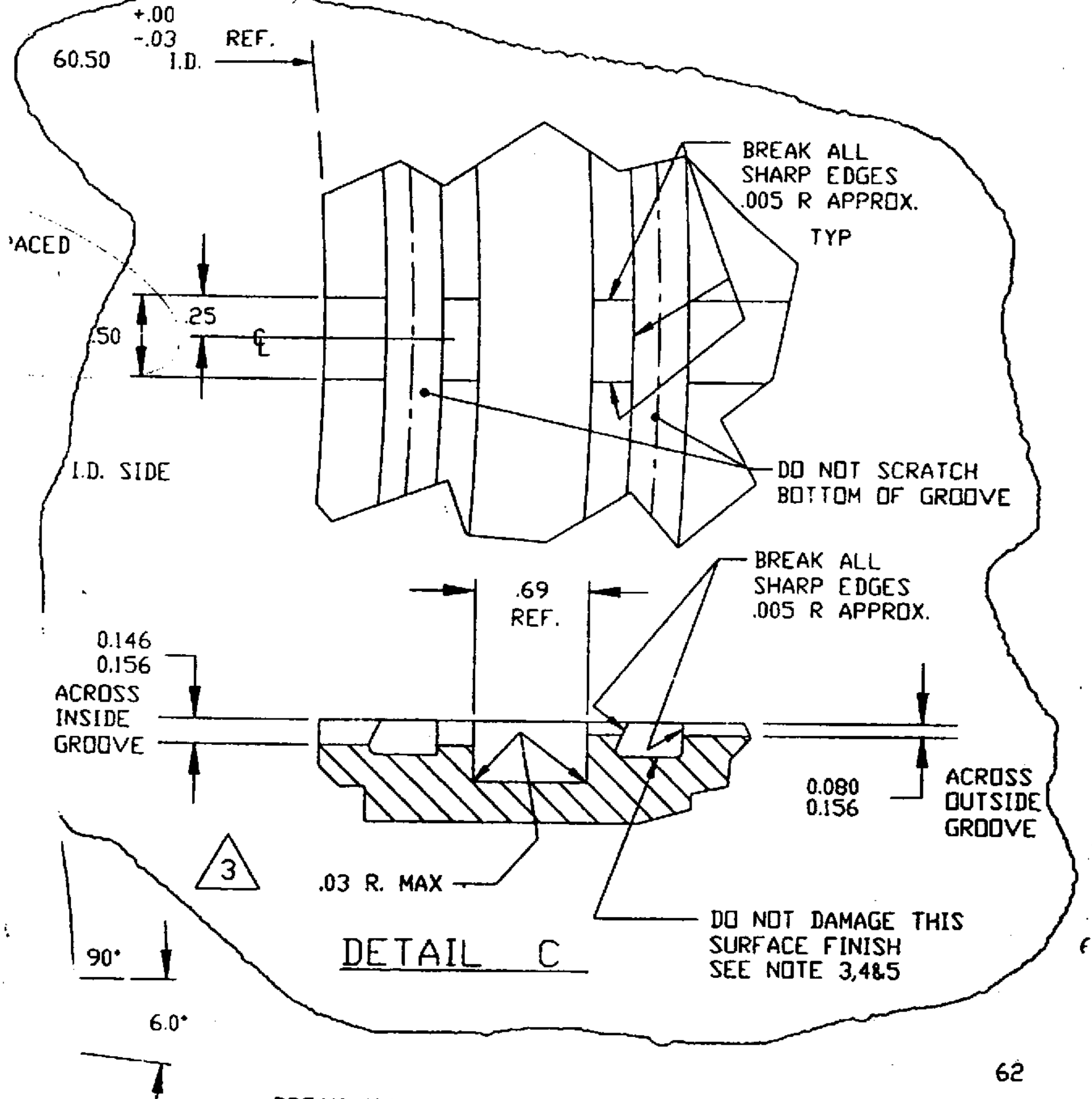
Flange size inches	Flange size m	Circumference m	No vents
44	1.12	3.52	3
48	1.22	3.83	4
60	1.52	4.78	6
72	1.83	5.75	6
84	2.13	6.69	6
104	2.64	8.29	8

PROJECT: __LIGO_____ BY: R.THAN DEPT: _744__

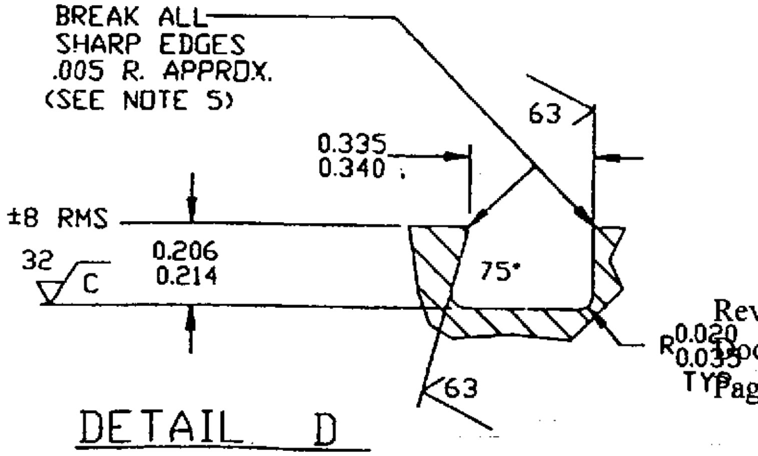
PROCESS SYSTEMS
INTERNATIONAL, INC.

PROJECT NO: _V59049_DATE: ___12/16/96

TITLE: ANNULU~~S CHANNEL,~~ MANIFOLDING



DETAIL C



DETAIL D

Revision: 1
Doc no: V049-1-012

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: BSC FLANGES, ANNULI CONFIGURATION

60 INCH FLANGE TO PUMP														Temp	293							
		Flange		No.			Annulus Channel							Mol W	29							
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	
		m	in		m	in	in	in	mm	in	in	mm	m*2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	s/L
ANNULUS	RECT	1.6	63	1	2.51	98.85	11/16	0.6875	17.5	1/2	0.5000	12.7	2.22E-04	0.344	115,628	25.6	0.009	0.23	4.414	2.00	2.207	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.08	3.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.2160	4.87	0.206	1.00	0.206	
INTERCONN	TUBE				1.42	55.98	67/77	0.8700	22.1				3.84E-04	0.594	115,628	44.3	0.0203	0.90	1.111	1.00	1.111	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.08	3.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.2160	4.87	0.206	1.00	0.206	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.17	6.50	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1129	2.54	0.393	1.00	0.393	
INTERCONN	TUBE				*3.50*	*137.80*	*1 10/27*	*1.3700*	34.8				9.51E-04	1.474	115,628	110.0	0.0131	1.44	0.695	1.00	0.695	
																				1/L tot =	5.11	
																				ANNULUS SPEED		0.192
																				PUMP MANIFOLD SPEED		10

		Flange		No.			Annulus Channel							Mol W	29							
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	s/L
104 INCH FLANGE TO PUMP																						
ANNULUS	RECT	2.74	108	2	2.15	84.72	11/16	0.6875	17.5	3/8	0.3750	9.5	1.66E-04	0.258	115,628	19.2	0.009	0.17	5.873	1.00	5.873	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.17	6.69	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1099	2.48	0.404	1.00	0.404	
INTERCONN	TUBE				3.50	137.80	1 10/27	1.3700	34.8				9.51E-04	1.474	115,628	110.0	0.0131	1.44	0.695	1.00	0.695	
																				1/L tot =	7.07	
																				ANNULUS SPEED		0.139
																				PUMP MANIFOLD SPEED		10
																				2 nd PATH		0.28

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: HAM FLANGES ANNULI CONFIGURATION

		Flange		No.			Annulus Channel							Mol W	29							SI
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-I	L/s
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	2.21	87	2	1.74	68.34	11/16	0.6875	17.5	5/8	0.6250	15.9	2.77E-04	0.430	115,628	32.1	0.014	0.45	2.214	1.00	2.214	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1211	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				0.61	24.00	67/77	0.8700	22.1				3.84E-04	0.594	115,628	44.3	0.0461	2.04	0.489	1.00	0.489	
JUMPER	TUBE				0.08	3.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.2160	4.87	0.206	1.00	0.206	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
ANNULUS	RECT	1.6	63	1	2.51	98.95	11/16	0.6875	17.5	1/2	0.5000	12.7	2.22E-04	0.344	115,628	25.6	0.009	0.22	4.453	2.00	2.23	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1211	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				0.61	24.00	67/77	0.8700	22.1				3.84E-04	0.594	115,628	44.3	0.0461	2.04	0.489	1.00	0.489	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1211	2.73	0.367	1.00	0.367	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
ANNULUS	RECT	2.21	87	2	1.74	68.34	11/16	0.6875	17.5	5/8	0.6250	15.9	2.77E-04	0.430	115,628	32.1	0.014	0.45	2.245	1.00	2.24	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1211	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				3.00	118.11	1 10/27	1.3700	34.8				9.51E-04	1.474	115,628	110.0	0.0152	1.67	0.597	1.00	0.597	
																		1/L tot =			10.42	
																					ANNULUS SPEED	0.095
																					PUMP MANIFOLD SPEED	10

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: BEAM MANIFOLD FLANGES, ANNULI CONFIGURATION

		BEAM MANIFOLD, 72 INCH FLANGE																				
														Temp	293							
		Flange		No.					Annulus Channel					Mol W	29							Si
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia				channel Height		Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	L/s
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	1.905	76	1	2.99	117.81	11/16	0.6875	17.5	1/2	0.5000	12.7	2.22E-04	0.344	115,628	25.6	0.007	0.19	5.256	2.00	2.628	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1210	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				2.00	78.74	1 1/8	1.1250	28.6				6.41E-04	0.994	115,628	74.2	0.0187	1.39	0.721	1.00	0.721	
HEADER	TUBE				10.00	393.70	2 10/27	2.3700	60.2				*2.85E-03*	*4.412*	115,628	329.1	0.0080	2.62	0.382	1.00	0.382	
																		1/L tot =			4.20	
																					ANNULUS SPEED	0.23
																					PUMP MANIFOLD HEADER SPEED	10

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: LARGE GATE VALVE FLANGES ANNULI / BONNET GATE SEAL CONFIGURATION

GATE VALVE, 44 INCH FLANGE

														Temp	293							
		Flange		No.			Annulus Channel							Mol W	29							SI
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube I.D			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	L/s
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	1.194	47	1	1.88	73.84	11/16	0.6875	17.5	3/8	0.3750	9.5	1.66E-04	0.258	115,628	19.2	0.010	0.20	5.073	2.00	2.536	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1210	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				2.50	98.43	1 3/25	1.1200	28.4				6.36E-04	0.985	115,628	73.5	0.0149	1.10	0.910	1.00	0.910	
																		1/L tot =			3.91	
																					ANNULUS SPEED	0.25
																					PUMP MANIFOLD SPEED	10

GATE VALVE, 48 INCH FLANGE

														Temp	293							
		Flange		No.			Annulus Channel							Mol W	29							SI
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube I.D			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	L/s
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	1.295	51	1	2.03	80.09	11/16	0.6875	17.5	3/8	0.3750	9.5	1.66E-04	0.258	115,628	19.2	0.009	0.18	5.502	2.00	2.751	
PORT	TUBE				0.03	1.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.4526	10.19	0.098	1.00	0.098	
JUMPER	TUBE				0.15	6.00	31/50	0.6200	15.7				1.95E-04	0.302	115,628	22.5	0.1210	2.73	0.367	1.00	0.367	
INTERCONN	TUBE				2.50	98.43	1 1/8	1.1250	28.6				6.41E-04	0.994	115,628	74.2	0.0150	1.11	0.898	1.00	0.898	
																		1/L tot =			4.11	
																					ANNULUS SPEED	0.24
																					PUMP MANIFOLD SPEED	10

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: LARGE GATE VALVE FLANGES ANNULI / BONNET GATE SEAL CONFIGURATION

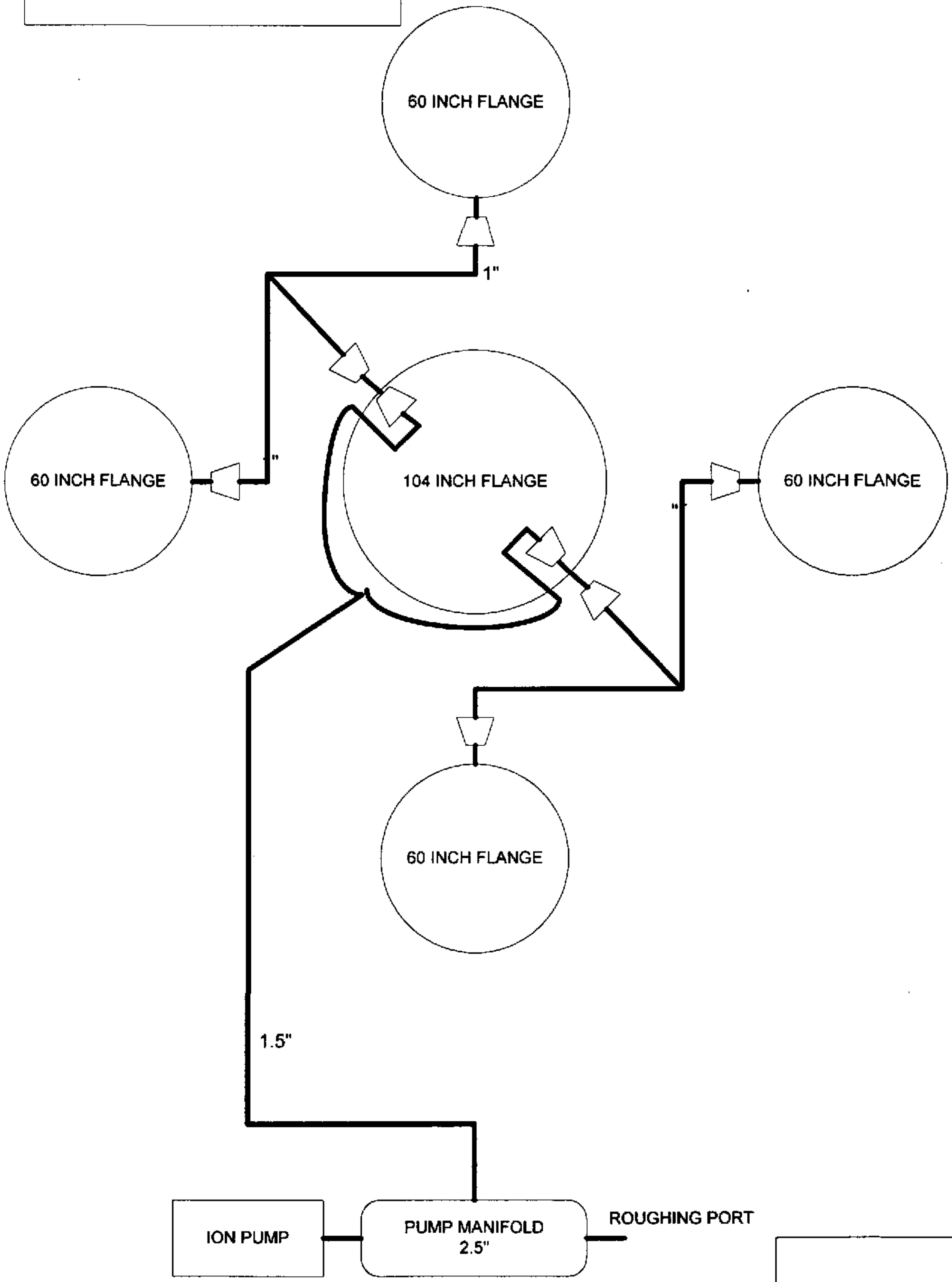
BONNET FLANGE ANNULUS

														Temp	293							
		Flange		No.			Annulus Channel							Mol W	29							Si
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	L/s
		m	in		m	in	in	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	1.4	55	2	1.10	43.29	3/8	0.3750	9.5	16/39	0.4100	10.4	9.92E-05	0.154	115,628	11.5	0.013	0.15	6.698	2.00	3.349	
PORT	PORT				0.01	0.38	3/8	0.3750	9.5				7.13E-05	0.110	115,628	8.2	0.5714	4.71	0.212	2.00	0.106	
JUMPER	JUMPER				0.09	3.54	3/7	0.4300	10.9				9.37E-05	0.145	115,628	10.8	0.1393	1.51	0.663	2.00	0.331	
INTERCONN	*TUBE*				4.00	157.48	67/77	0.8700	22.1				3.84E-04	0.594	115,628	44.3	0.0073	0.32	3.084	1.00	3.084	
																		1/L tot =			6.87	
																					ANNULUS SPEED	**0.14**
																					PUMP MANIFOLD SPEED	5

GATE SEAL ANNULUS

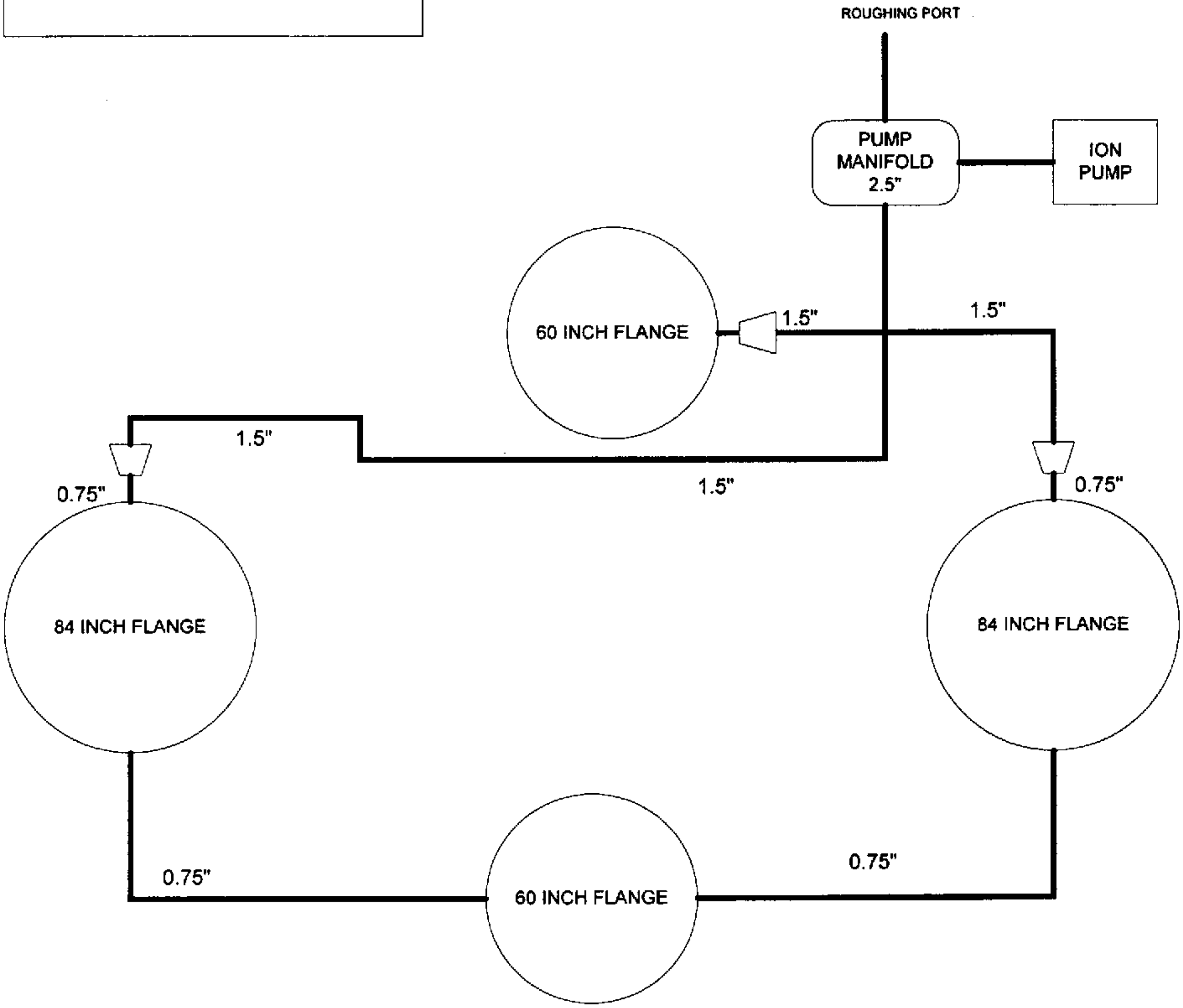
														Temp	293							
		Flange		No.			Annulus Channel							Mol W	29							Si
DESCRIPTION	TYPE	Diameter		Ports	Circ Section Length		channel Width or tube dia			channel Height			Channel Area		Vol Vel	Lo	P	Li	1/Li	parallel	1/Li-t	L/s
		m	in		m	in	In	in	mm	in	in	mm	m^2	in^2	l/s	L/s		L/s	s/L	circuit	s/L	
ANNULUS	RECT	1.14	45	2	0.90	35.25	5/16	0.3125	7.9	1/2	0.5000	12.7	1.01E-04	0.156	115,628	11.7	0.015	0.17	5.733	2.00	2.867	
PORT	TUBE				0.10	3.94	3/8	0.3750	9.5				7.13E-05	0.110	115,628	8.2	0.1127	0.93	1.077	2.00	0.539	
JUMPER	TUBE				0.08	3.00	3/7	0.4300	10.9				9.37E-05	0.145	115,628	10.8	0.1604	1.74	0.575	2.00	0.288	
INTERCONN	TUBE				2.00	78.74	67/77	0.8700	22.1				3.84E-04	0.594	115,628	44.3	0.0145	0.64	1.563	1.00	1.553	
																		1/L tot =			5.25	
																					ANNULUS SPEED	**0.19**
																					PUMP MANIFOLD SPEED	10

PROJECT: LIGO
PROJECT NO: V59049 DATE: 12/16/96
TITLE: BSC ANNULI CONFIGURATION



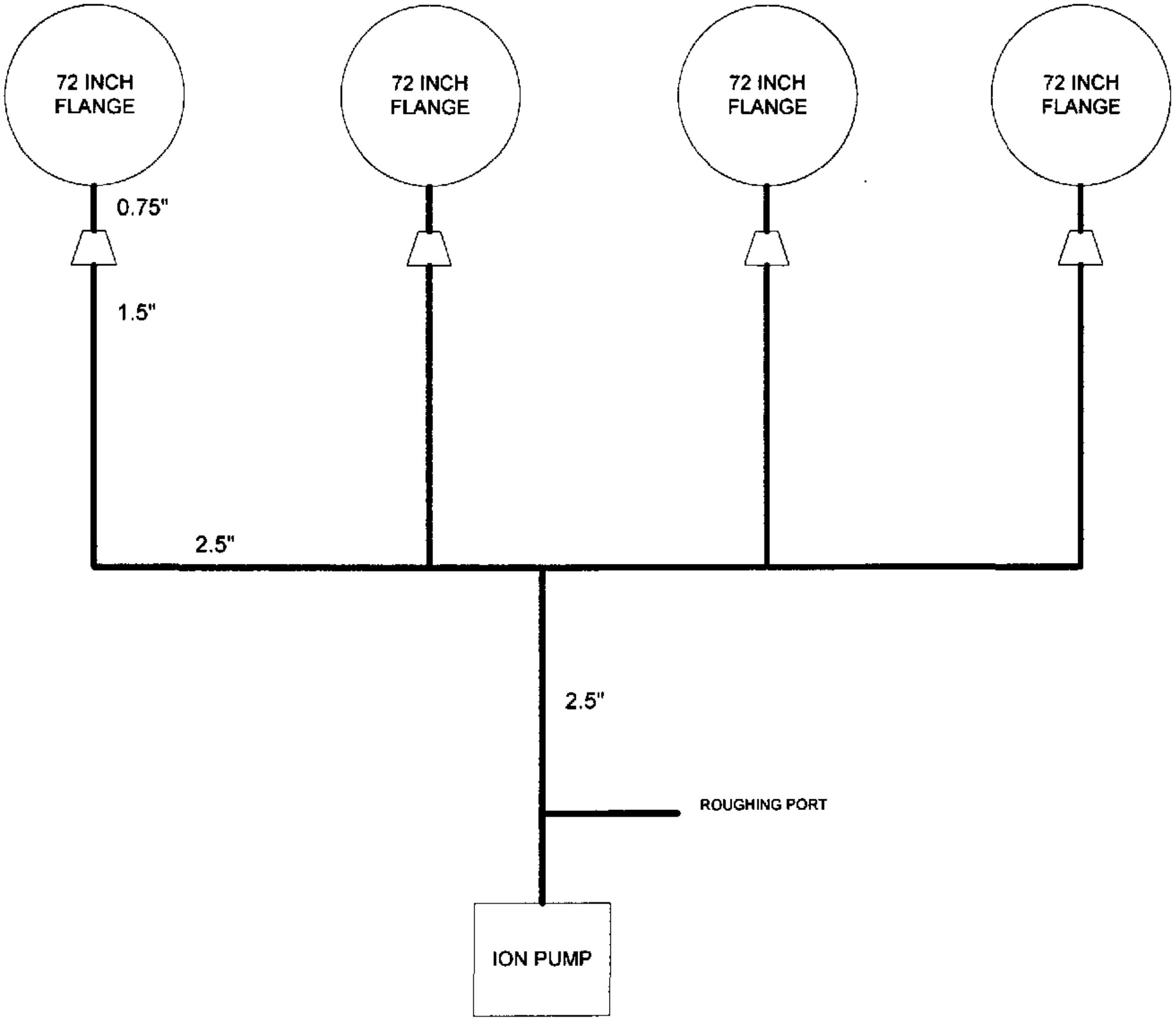
REVISION: 1
DOC NO: V049-1-012
PAGE 15 OF 20

PROJECT: LIGO
PROJECT NO: V59049 DATE: 12/16/96
TITLE: HAM ANNULI CONFIGURATION



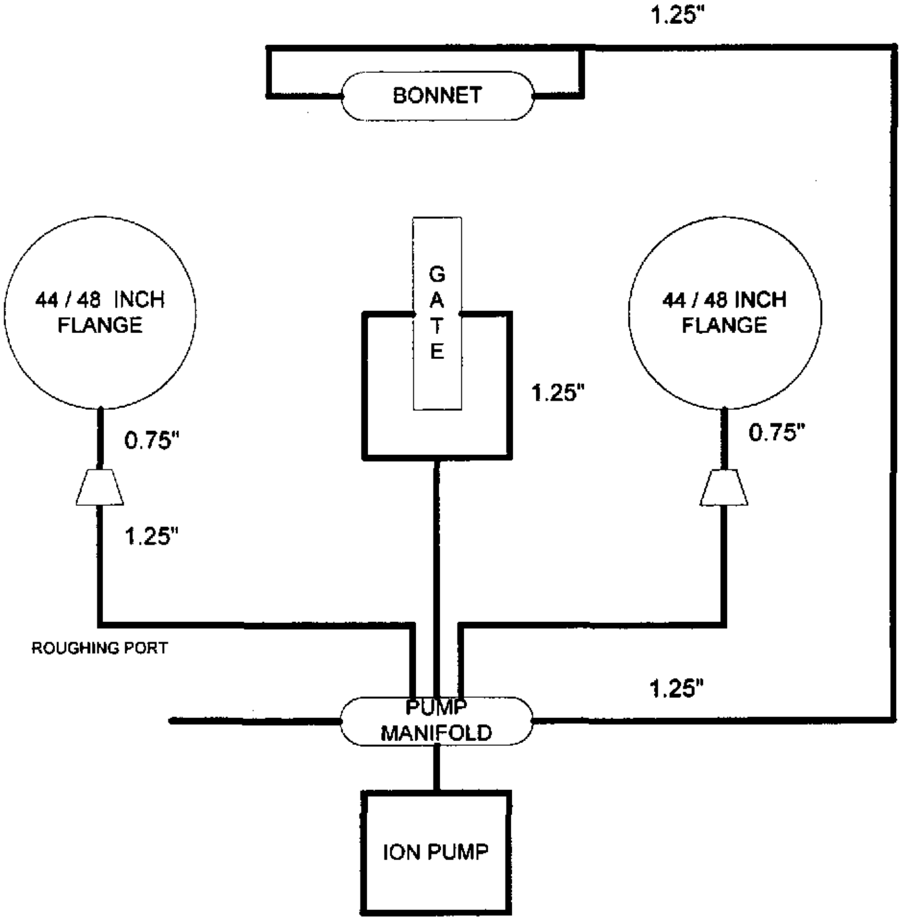
REVISION: 1
DOC NO: V049-1-012
PAGE 16 OF 20

PROJECT: LIGO
PROJECT NO: V59049 DATE: 12/16/96
TITLE: BEAM MANIFOLD ANNULI CONFIGURATION



REVISION: 1
DOC NO: V049-1-012
PAGE 17 OF 20

PROJECT: LIGO
PROJECT NO: V59049 DATE: 12/16/96
TITLE: 48" / 44" GATE VALVES ANNULI CONFIGURATION



REVISION: 1
DOC NO: V049-1-012

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: DIFFUSION, UHV O-RING

DIFFUSION: UHV O-RING

Permeability Viton	O-ring dia		Flange dia		Diffusion Area	Differential pressure	Diffusion Rate	
(mbar-L/s)(m/m^2-bar)	m	in	m	in	m^2	bar	mbar-L/s	Torr-L/s
2.00E-06	0.00635	1/4	0.76	30	0.015161	1.00E-07	**4.78E-13**	**3.58E-13**
2.00E-06	0.00635	1/4	1.12	44	0.022343	1.00E-07	**7.04E-13**	**5.28E-13**
2.00E-06	0.00635	1/4	1.22	48	0.024338	1.00E-07	**7.67E-13**	**5.75E-13**
2.00E-06	0.00635	1/4	1.52	60	0.030323	1.00E-07	**9.55E-13**	**7.16E-13**
2.00E-06	0.00635	1/4	1.83	72	0.036507	1.00E-07	**1.15E-12**	**8.62E-13**
2.00E-06	0.00635	1/4	2.13	84	0.042492	1.00E-07	**1.34E-12**	**1E-12**
2.00E-06	0.00635	1/4	2.64	104	0.052666	1.00E-07	**1.66E-12**	**1.24E-12**
2.00E-06	0.00635	1/4	0.35	14	0.006982	1.00E-07	**2.20E-13**	**1.65E-13**
2.00E-06	0.001588	1/16	0.152	5.98	0.000758	1.00E-07	**9.55E-14**	**7.16E-14**

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 12/16/96
TITLE: DIFFUSION, UHV O-RING

DIFFUSION ATMOSPHERIC O-RING

Permeability Viton (mbar-L/s)(m/m^2-bar)	O-ring dia m	O-ring dia in	Flange dia m	Flange dia in	Diffusion Area m^2	Differential pressure bar	Diffusion Rate mbar-L/s	Diffusion Rate Torr-L/s	Ion-pump Speed for 40,000 hrs life L/s
2.00E-05	0.00635	1/4	0.76	30	0.015161	1	**4.78E-05**	**3.58E-05**	35.81
2.00E-05	0.00635	1/4	1.12	44	0.022343	1	**7.04E-05**	**5.28E-05**	52.78
2.00E-05	0.00635	1/4	1.22	48	0.024338	1	**7.67E-05**	**5.75E-05**	57.49
2.00E-05	0.00635	1/4	1.52	60	0.030323	1	**9.55E-05**	**7.16E-05**	71.63
2.00E-05	0.00635	1/4	1.83	72	0.036507	1	**1.15E-04**	**8.62E-05**	86.24
2.00E-05	0.00635	1/4	2.13	84	0.042492	1	**1.34E-04**	**0.0001**	100.37
2.00E-05	0.00635	1/4	2.64	104	0.052666	1	**1.66E-04**	**0.000124**	124.41
2.00E-05	0.00635	1/4	0.35	14	0.006982	1	**2.20E-05**	**1.65E-05**	16.49
2.00E-05	0.001588	1/16	0.152	5.98	0.000758	1	**9.55E-06**	**7.16E-06**	7.16

PROCESS SYSTEMS INTERNATIONAL, INC.					ENGINEERING	NO: V049-1-044
WESTBOROUGH, MA					CALCULATIONS	PAGE 1 OF 5
REV	DEO#	DATE	BY:	CHECK	TITLE:	
0	01216	4/17/96	R. Than	D.McW	MAIN TURBO MOLECULAR PUMP PORT 250 mm (10")	
					BY: R. THAN	DEPT: 744
PROJECT: LIGO					PROJECT NO: V59049	

PURPOSE:
Determine allowable length for 250 mm (10") main turbo port, for Turbo pump STPH2000, with vibration isolator, gate valve, by-pass / gauge spool piece

METHOD:
Free molecular regime: Long tube formula / short tube formula
Monte Carlo simulations

ASSUMPTIONS:
1400 L/s speed for N2

INPUTS:

REFERENCE:
Theory and Practice of vacuum Technology, ISBN 3-528-08908-3

CALCULATIONS:
see Attachments

CONCLUSIONS: A overall length of no more than 21 inches is allotted to meet the net speed of 1000 L/s for nitrogen through the 10" port. This include the nozzle, gate valve, vibration isolation spool, and by-pass/gauge spool.

NOTES:

Pumping speed

To meet the required pumping speed of 1000 L/s for the turbo, the allowable length of the pumpout port configuration needs to be less than 21 inches.

The by-pass / gauge spool is required at the end and mid stations for roughing of the vacuum volume with the QDP80 backing pump.

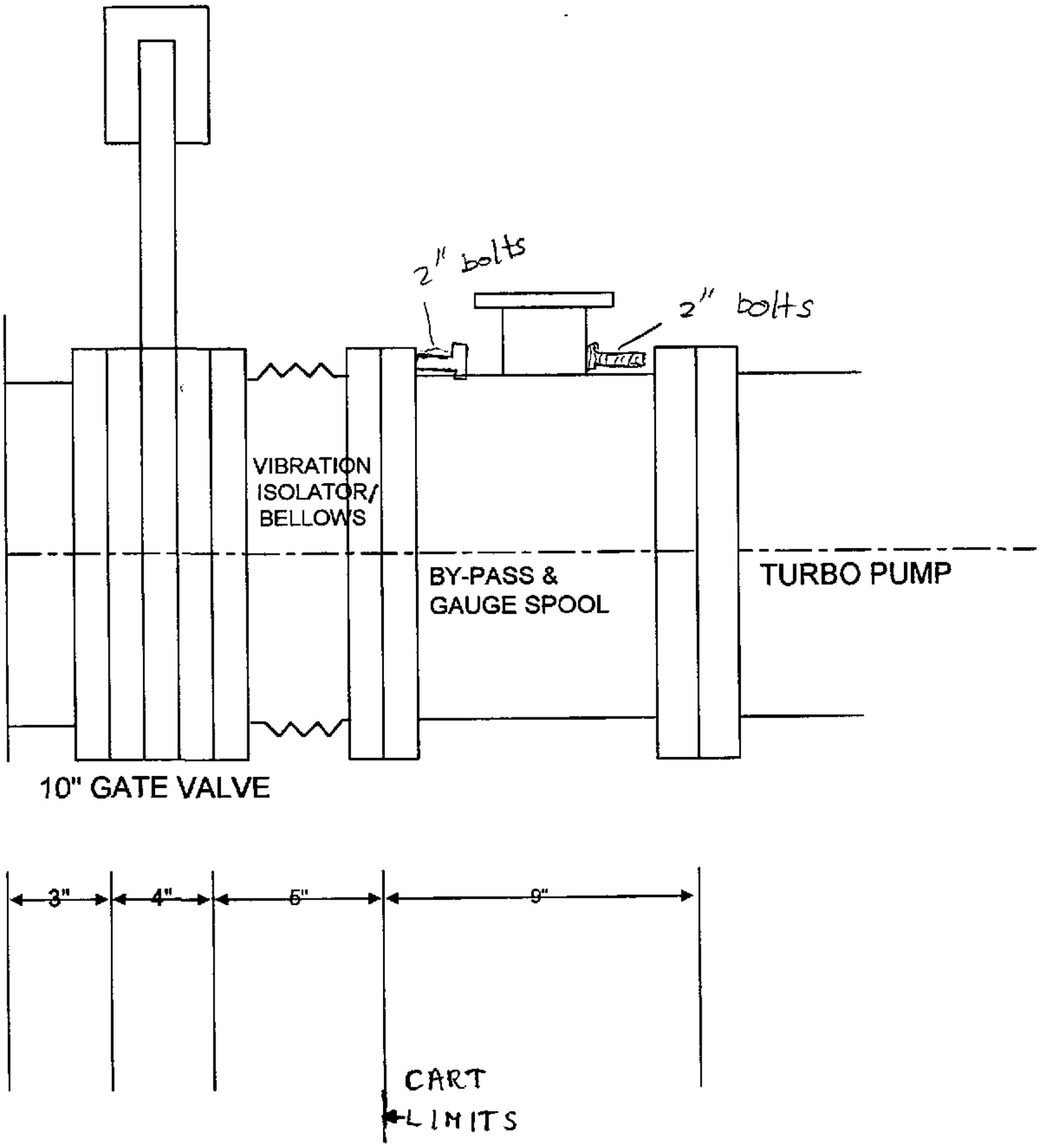
Vibration isolation bellows

The allowable length for the vibration isolation bellows is about 5 inches.

PROJECT: LIGO
PROJECT NO: V59049
TITLE:MAIN TURBO PORT, 250mm

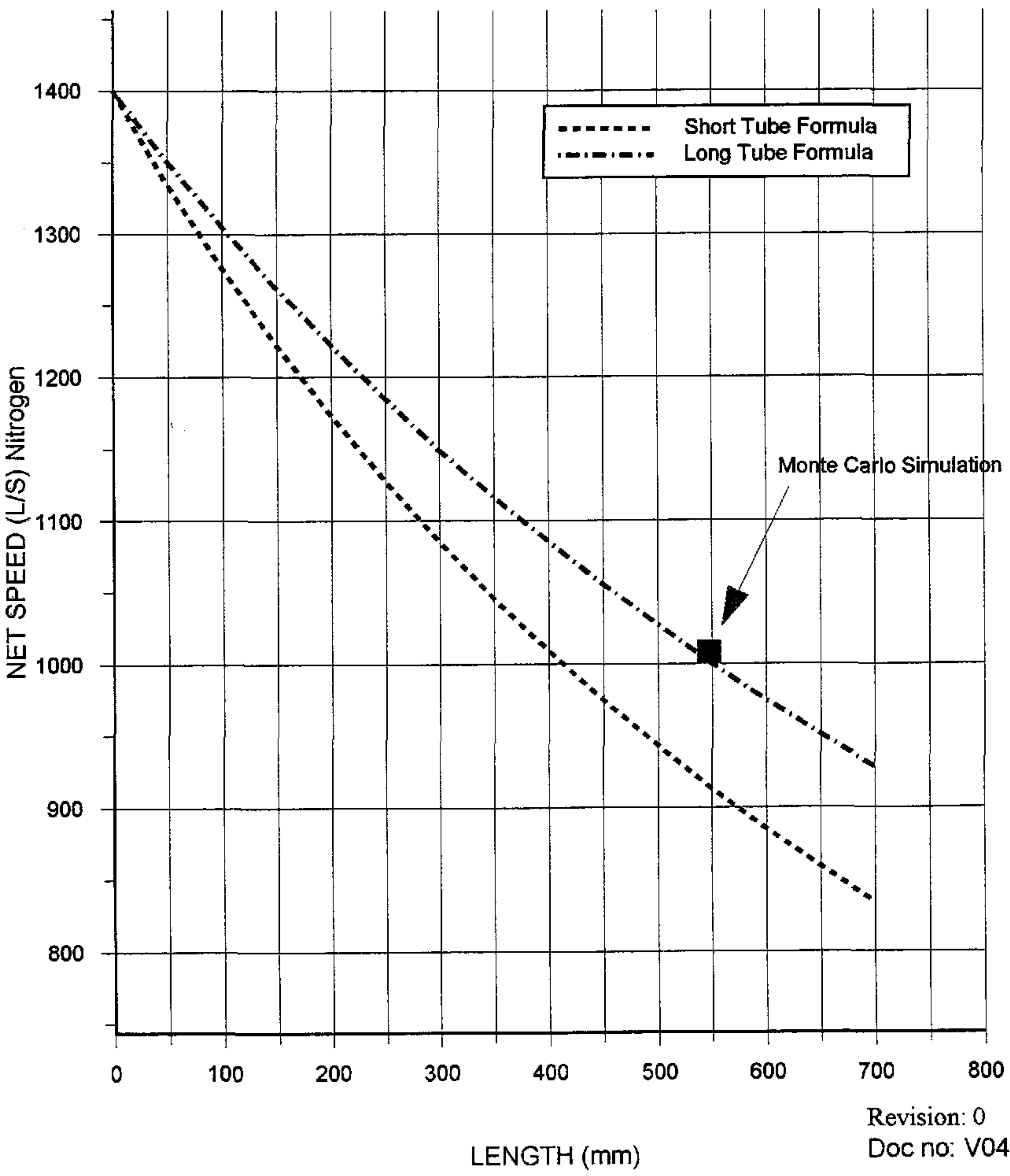
BY: R. THAN
DATE: 02/08/96
PAGE of

6" GATE VALVE: WEIGHT: 40-65 Lbs
10" GATE VALVE: WEIGHT: 100 - 130 Lbs
BELLOWS: WEIGHT: 50 Lbs
Turbo Pump will be supported vertically to take weight off nozzles, but axially will be supported with the bellows onto nozzle / chamber wall.



PROJECT: LIGO BY: R. THAN
PROJECT NO: V59049 DATE: 2/8/96
TITLE: MAIN TURBO PORT

MAIN TURBO PORT 250 mm Diameter



Revision: 0
Doc no: V049-1-044
Page 4 of 5

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MONTE CARLO SIMULATION

TURBO PORT 250 MM DIAMETER, 550 MM LONG

ENTER NUMBER OF TRIALS             30000

              NUMBER    FRACTION     90% ERROR LIMIT
REFLECTED      24711    .8244695      3.603708E-03
CAPTURED       5261     .1755305      3.603708E-03
THROUGH        0        0             0
TOTAL  TRIALS       30000
NO CONTACT TRIALS   28

PRINT BOUNCE TABLE ?  Y/N
BOUNCES   THROUGH       CAPTURED      REFLECTED                   BOUNCES   THROUGH       CAPTURED      REFLECTED
0         0             487           0                           41        0             0             6
1         0             327           7118                        42        0             3             5
2         0             446           3693                        43        0             2             8
3         0             440           2364                        44        0             3             5
4         0             429           1861                        45        0             5             10
5         0             381           1378                        46        0             0             3
6         0             328           1129                        47        0             3             6
7         0             295           949                         48        0             5             3
8         0             255           809                         49 +      0             10            17
9         0             226           713
10        0             202           577                         RUN TIME    0           6.555338
11        0             178           529
12        0             171           462                         TURBO NITROGEN SPEED    : 1400 L/S
13        0             128           413
14        0             130           319                         PUMP CAPTURE FRACTION   : 0.243
15        0             100           311
16        0             92            244                         VOLUMETRIC SPEED        : 5773 L/S
17        0             94            235
18        0             73            224                         NET CAPTURE FRACTION    : 0.1755
19        0             66            179
20        0             54            166                         NET SPEED               : 1013 L/S
21        0             41            155
22        0             32            92
23        0             28            109
24        0             41            87
25        0             34            80
26        0             20            77
27        0             20            58
28        0             20            39
29        0             13            38
30        0             14            44
31        0             11            32
32        0             8             31
33        0             8             19
34        0             4             25
35        0             10            24
36        0             10            20
37        0             0             7
38        0             2             13
39        0             8             11
40        0             4             14
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P 5 OF 5

PROCESS SYSTEMS INTERNATIONAL, INC.	ENGINEERING	NO:V049-1-078
WESTBOROUGH, MA	CALCULATIONS	PAGE 1 OF 44

REV	DEO#	DATE	BY:	CHECK
0	133	04/22/96	R. Than	D. Mcw

TITLE:
STATIONS
PUMPDOWN & ULTIMATE PRESSURES

BY: R. THAN
DEPT: 744

PROJECT: LIGO
PROJECT NO: V59049

PURPOSE:
Pumpdown of the End Station
Pumpdown of the Mid Station
Pumpdown of Vertex & Beam manifold isolatable section WA Corner station
Pumpdown of Vertex isolatable section WA Corner station with only 1 roughing and 1 main turbo system.
Pumpdown of Vertex & Beam manifold isolatable section LA Corner station
with selected vacuum system.

METHOD:
Computer simulation
Standard calcs

ASSUMPTIONS:
See calculations

INPUTS:

REFERENCE: See page 9

CALCULATIONS: see Attachments

CONCLUSIONS: Pumpdown of stations isolatable sections to a total pressure of less than 2X10^{-8} Torr

NOTES:

PRESSURE MEASUREMENT

Partial pressure of gasses will vary depending where the pressure gauge / RGA is located relative to the pumps. Partial pressures will be measured at the ion pumps. Because the attainable partial pressure of water is based on the pumping speed of water at the cryopump, the partial pressure of water at other locations will be higher. Thus measurement of the partial pressure of water at the ion pumps may not be representative of the outgassing rates for water. Rather measurements at two locations one at the ion pumps and one at the cryopump is recommended.

OUTGASSING RATES

Outgassing from Viton O-rings

The available data on outgassing of unbaked and baked O-ring material is limited.

The following table contains selected outgassing data for Viton-A from W.G. Perkins' "Permeation and Outgassing of Vacuum Materials," *Journal of Vacuum Science & Technology*, Vol. 10, No.4, 1973. Outgassing experiments were also done by L. de Csernatony with o-rings in their grooves and outside their grooves, see article: L. de Csernatony, "The properties of Viton "A" elastomers III", *Vacuum*, Vol. 16, No.5, 1967.

	Pumpdown time hours	Outgassing Rate Torr-L/s-cm^2	Dominant Species
Unbaked samples			
Unbaked Pumpdown Viton-A	51	1×10^{-7}	H_2O, H_2, O_2, N_2
Baked Pumpdown (200 °C) Viton-A	24	20×10^{-10}	H_2O

	Pumpdown time hours	Outgassing Rate Torr-L/s-cm^2	Dominant Species
Pre-baked samples air-exposed for 0.5 hr			
Unbaked pumpdown Viton-A	5	1.5×10^{-8}	H_2O
Baked Pumpdown (200 °C) Viton-A	12	1×10^{-10}	H_2O

The total outgassing rate of a Viton o-ring can be reduced to 1 X 10^{-10} Torr-L/s-cm^2 through baking under vacuum. Since the vacuum system needs to be re-opened, the total outgassing rate will vary depending on the amount of time the o-ring is re-exposed to air. The outgassing of a baked Viton o-ring which has been re-exposed to normal air will be dominated by water. Since the vacuum system is purged with dry air when open for service, the re-adsorption of moisture can be minimized; however the readsorption of other gasses will be dictated by exposure time. For short exposure times to air, the amount of gases other than water that are readsorbed is minimal. Water outgassing dominates for short exposure times, such as 0.5 hour. However, since in practice the O-rings are re-exposed to air for a longer period than 0.5 hour, the actual amount of gasses readsorbed can only be determined from further experiments.

If re-exposure is limited to a short time the outgassing rate of a baked O-ring will be about 1.5 X 10^{-8} Torr-L/s-cm^2, mostly water, after 5 hours. Assuming the outgassing is dictated by diffusion, i.e. the decay behaves as function of time to the -0.5 power, the outgassing rate for water will be about 3 X 10^{-9} Torr-L/s-cm^2 after 100 hours of pumping. Since the outgassing rate for short term re-exposure is dominated by water, assuming that the total outgassing rate for the other gasses is no more than 10% of that of water, the outgassing rate of the other gasses will be approximately 3 X 10^{-10} Torr-L/s-cm^2.

L. de Csernàtony (Ref.13,14) experiments with baked o-ring without re-exposure gives a rate of 2 X 10^{-10} Torr-L/s-cm^2 after 25 hours for an o-ring in the chamber and 8 X 10^{-9} Torr-L/s-cm^2 after 25 hours with the o-ring in the groove.

The o-ring grooves are designed with vents to vent the trap volume in the o-ring groove. This will prevent the outgassing of the o-ring to retard and allow the outgassing rate to approach that of an o-ring inside a chamber.

Outgassing from Stainless Steel.

Various sources provide data on outgassing of hydrogen from stainless steel for unbaked and baked specimens.

G.Moraw and R. Dobrozemsky report a total outgassing rate of about 8×10^{-12} Torr-L/s-cm^2 after a 20-hour vacuum bakeout at 100 °C, with H_2 dominating at a rate of 7×10^{-12} Torr-L/s-cm^2 ,and CO outgassing at a rate of less than 4×10^{-13} Torr-L/s-cm^2 , and CO_2, CH_4, and water each at less than 1×10^{-13} Torr-L/s-cm^2.

Calder and Lewin report a total outgassing rate of 1.4×10^{-11} Torr-L/s-cm^2 after 40 hours of pumping for a specimen bake in vacuum at 350 °C for 2 days and re-expose to air for 3 hours.

Barton and Govier report a total outgassing of 7×10^{-12} Torr-L/s-cm^2 after a 100 hours of pumping for a specimen that has been prebaked in vacuum at 400°C and re-exposed to air for 24 hours with water being the predominant outgassing specie.
For an unbaked vapor degreased specimen the total outgassing rate was about 1×10^{-11} Torr-L/s-cm^2 after 100 hours of pumping, with water being the predominant outgassing specie. Partial pressure measurements after 70 hours indicated that about 60% was water and about 30% CO and CO_2.

Dylla et al. report outgassing rates of between 6×10^{-11} to 1×10^{-11} Torr-L/s-cm^2
after 100 hours of pumping for specimens baked at 150 °C for 48 hours and re-exposed to air. The predicted decay and outgassing rates at the end of 100 hours vary depending on exposure time to air, and dew point of the air. Analysis of species after 100 minutes into pumpdown indicates that the outgassing rate is dominated by water, with CO, CO_2, and CH_4 contributing less than 10% to the outgassing rate (5%,3%, and 2% respectively).

S. Rezaie-Serej and R.A. Outlaw report for a baked stainless steel specimen the amount of hydrogen desorbed is about 38 times the amount of CO desorbed. No outgassing rates were given.

Okamura, Miyauchi, and Hisatsugu report a total outgassing rate approaching 5×10^{-13} Torr-L/s-cm^2 for finely polished stainless steel surface and a 1×10^{-12} Torr-L/s-cm^2
for a standard electropolished surface after 100 hours of pumping preceded by an 80-hour vacuum bakeout at 250 °C. H_2 dominates with water being the next dominant specie, and with CO and CO_2 contributing less than 20% to the outgassing rate.
(2×10^{-13} Torr-L/s-cm^2).

Santeler predicts an outgassing rate of stainless steel based on a diffusion model of about 2×10^{-11} Torr-L/s-cm^2, with a 200 hour, 150 °C bake, and 6×10^{-12} Torr-L/s-cm^2, with a 20 hour, 250 °C bake.

Outgassing rates:

Stainless steel

H2: 1.0X 10^{-11} Torr-L/s-cm^{2}

H2O:

Re-exposure to air	
Time	Q
min.	Torr-L/s-cm^{2}
10	7X 10^{-8}
100	5X 10^{-9}
1000	3.5X 10^{-10}
1440	2.4X 10^{-10}
6000	5X 10^{-11}

No Re-exposure	
Time	Q
min.	Torr-L/s-cm^{2}
10	2.8X 10^{-9}
100	5.6X 10^{-10}
1000	1.1X 10^{-10}
1440	8.6X 10^{-11}
6000	3.0X 10^{-11}

Other gasses: 10% of water rate.

Viton:

H2O:

Short Re-exposure to air. (Ref.1)	
Time	Q
min.	Torr-L/s-cm^{2}
300	1.5X 10^{-8}
6000	3X 10^{-9}

No Re-exposure (Ref.1)	
Time	Q
min.	Torr-L/s-cm^{2}
720	1X 10^{-10}
6000	4X 10^{-11}

Other gasses: 10% of water rate.

END STATION / MID STATION PUMPDOWN

Pumpdown of the End station section using one the QDP80 dry pump set, and one main turbomolecular pump and 1 Main ion pump.

Roughing pump

The QDP80 pump is used to rough down the end or mid stations. It also serves as the backing pump to the main turbo: STPH2000.

Turbo pump

The main turbo, STPH2000, is turned on when a pressure of 1 mbar has been reached using the QDP80. The bypass is closed across the turbo pump and the turbo pump starts pumping. The STPH2000 is a wide range turbo which has a drag stage to pump at high inlet pressures. The backing pump of the main turbo is located in the mechanical room.

Main Ion pump

The main ion pump is a 2500 L/s (N2) Varian Ion Pump with a 350 mm inlet tube, which can be isolated by a 350 mm (14 inch) gate valve. The End Station and Mid Station are each equipped with one Main ion pump.

CORNER STATION PUMPDOWN

Pumpdown of the corner station sections is accomplished using two the EDP200/EH2600 dry pump set, and two main turbomolecular pump and several Main ion pumps.

WA CORNER STATION

The WA corner station has two roughing cart sets, two turbomolecular pump sets, and 8 main ion pumps. 4 Main ion pumps are on the Vertex section, one each on the beam manifold sections, and two on the diagonal (offset) section.

LA CORNER STATION

The LA corner station has two roughing cart sets, two turbomolecular pump sets, and 4 main ion pumps. 4 Main ion pumps are on the Vertex section.

Roughing pump

The roughing system is separated in two skids. The EDP200 is located in the mechanical room, and the EH2600 Roots blower is move around the detector building. Two 6 inch headers runs in the detector building back to the mechanical room.

Turbo pump

The main turbo, STPH2000C, is turned on when a pressure of 0.1 Torr has been reached. The backing pump of the main turbo is located in the mechanical room.

Main Ion pump

The main ion pump is a 2500 L/s (N2) Varian Ion Pump with a 350 mm inlet tube, which can be isolated by a 350 mm (14 inch) gate valve.

Pumpdown curves:

END STATION PUMPDOWN

Figure V049-1-078-1a: 0-100 hours
Figure V049-1-078-1b 0-32 hours

MID STATION PUMPDOWN

Figure V049-1-078-2a 0-100 hours
Figure V049-1-078-2b 0-32 hours

WA. CORNER STATION PUMPDOWN

Figure V049-1-078-3a 0-100 hours
Figure V049-1-078-3b 0-32 hours

LA. CORNER STATION PUMPDOWN

Figure V049-1-078-4a 0-100 hours
Figure V049-1-078-4b 0-32 hours

WA. VERTEX ISOLATABLE SECTION . CORNER STATION PUMPDOWN

Figure V049-1-078-5 0-24 hours

References

1. W.G. Perkins' "Permeation and Outgassing of Vacuum Materials," *Journal of Vacuum Science & Technology*, Vol. 10, No.4, 1973.

2. R.S. Barton and R.P. Govier. "The effect of cleaning technique on the outgassing rate of 18/9/1 stainless steel," *Vacuum*, Vol. 20, No.1, 1970.

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4. H.F. Dylla, D.M. Manos, P.H. LaMarche, "Correlation of outgassing of stainless steel and aluminum with various surface treatments." *Journal of Vacuum Science & Technology*, Vol. A11, No.5, 1993.

5. M. Li and H.F. Dylla, "Model for outgassing from metal surfaces II." *Journal of Vacuum Science & Technology*, Vol. A12, No.4, 1994.

6. S. Okamura, E. Miyauchi, and T. Hisatsugu, "Outgassing measurements of finely polished stainless steel." *Journal of Vacuum Science & Technology*, Vol. A 9, No.4, 1991.

7. R. Calder and G. Lewin, " Reduction of stainless steel outgassing in ultra-high vacuum," *Journal of Applied Physics,* Vol 18, 1967.

8. D. J. Santeler, " Estimating the gas partial pressure due to diffusive outgassing" *Journal of Vacuum Science & Technology*, Vol. A10, No.4, 1992.

9. D. Wu, R.M.Stephens, R.A. Outlaw, and P. Hopson, "An Auger Electron Spectroscopy Study of Surface-Preparation Contaminants", *NASA Technical Paper 2972*, Feb. 1990

10. S. Rezaie-Serej, R.A. Outlaw, "Thermal desorption of CO and H2 from degassed 304 and 347 stainless steel", *Journal of Vacuum Science & Technology*, Vol. A12, No.5, 1994.

11. J.D Herbert, A.E. Groome, "Study of cleaning agents for stainless steel for ultrahigh vacuum use", *Journal of Vacuum Science & Technology*, Vol. A12, No.4, 1994.

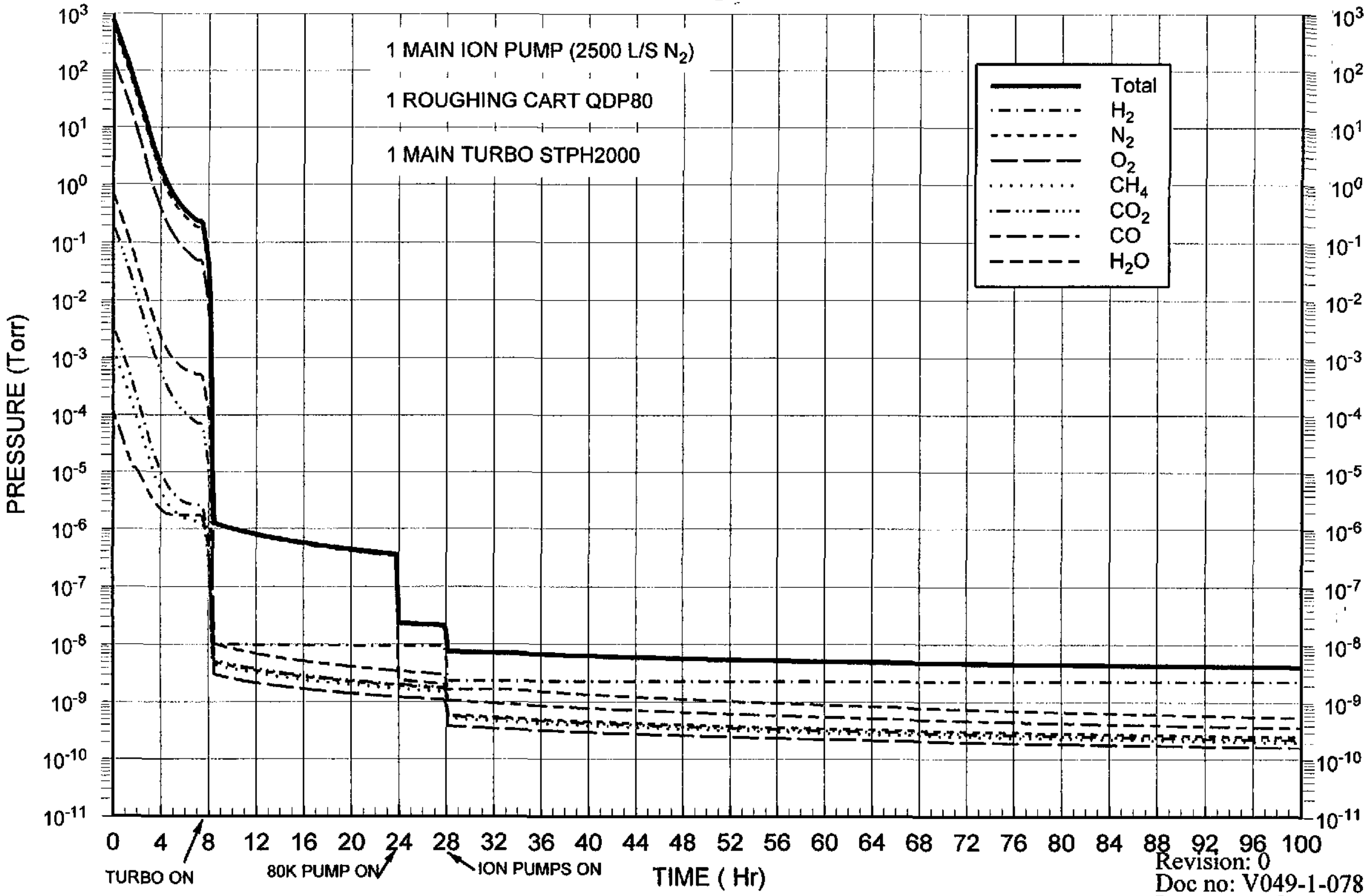
12. B.C Moore, "Recombination limited outgassing of stainless steel", *Journal of Vacuum Science & Technology*, Vol. A13, No.3, 1995, pp. 545-548

13. L. de Csernatony, "The properties of Viton "A" elastomers II", *Vacuum*, Vol. 16, No.3, 1966.

PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-1a, END STATION PUMPDOWN

STEEL AREA: 119 m^2, Volume: 56 m^3, $H_2=1X10^{-11}$ Torr-L/s-cm^2, $H_2O=1X10^{-6}*t^{-1.15}$, t=min, OTHER GASSES: 10%

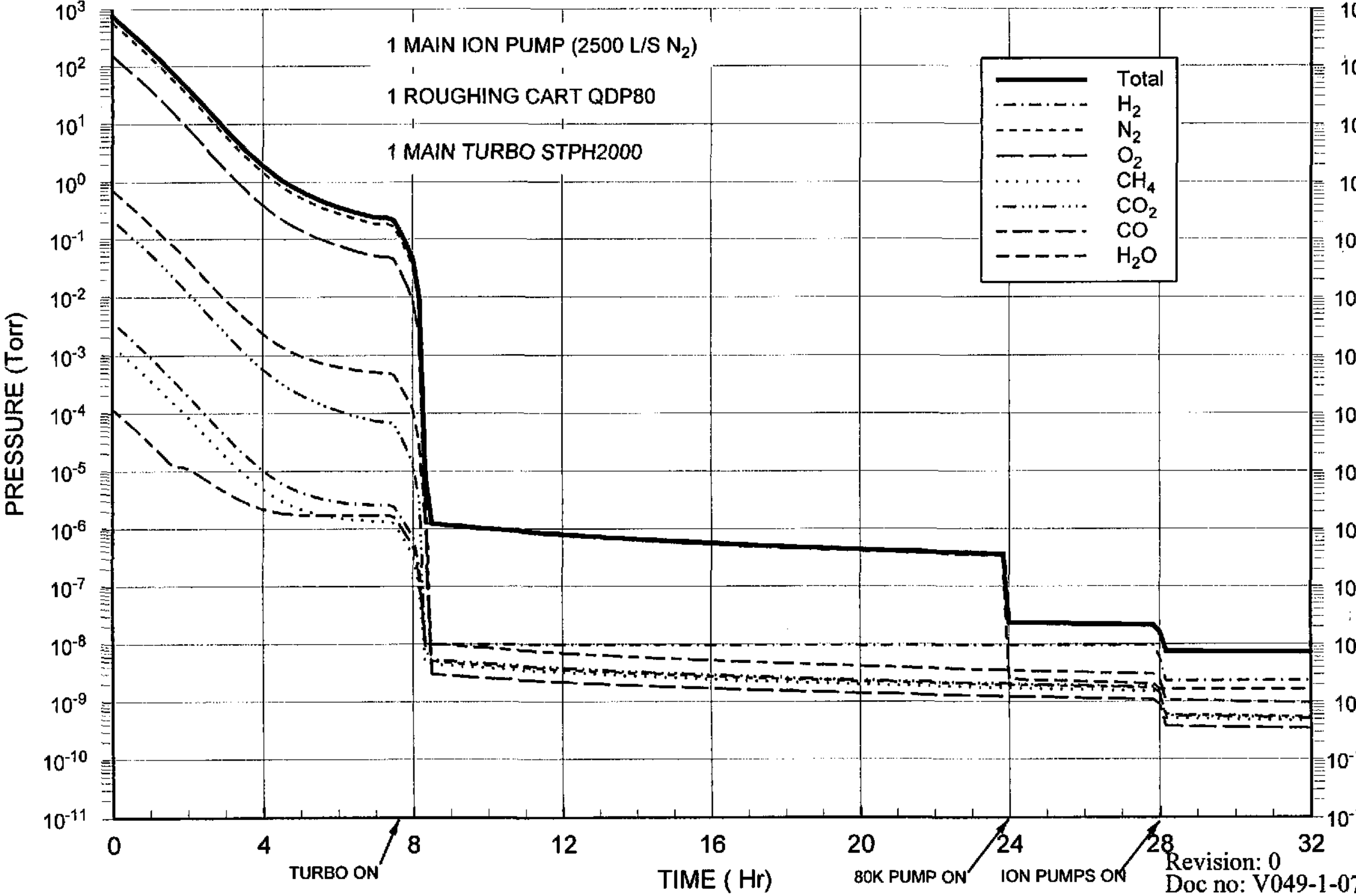
VITON AREA: 0.77m^2, Baked, re-exposed to air 0.5 hr, 100 hr: $H_2O=3X10^{-9}$ Torr-L/s-cm^2, OTHER GASSES=$3X10^{-10}$ Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-1b, END STATION PUMPDOWN

STEEL AREA: 119 m^2, Volume: 56 m^3, H_2=1X10^{-11} Torr-L/s-cm^2, H_2O=1X10^{-6}*$t^{-1.15}$, t=min, OTHER GASSES: 10%

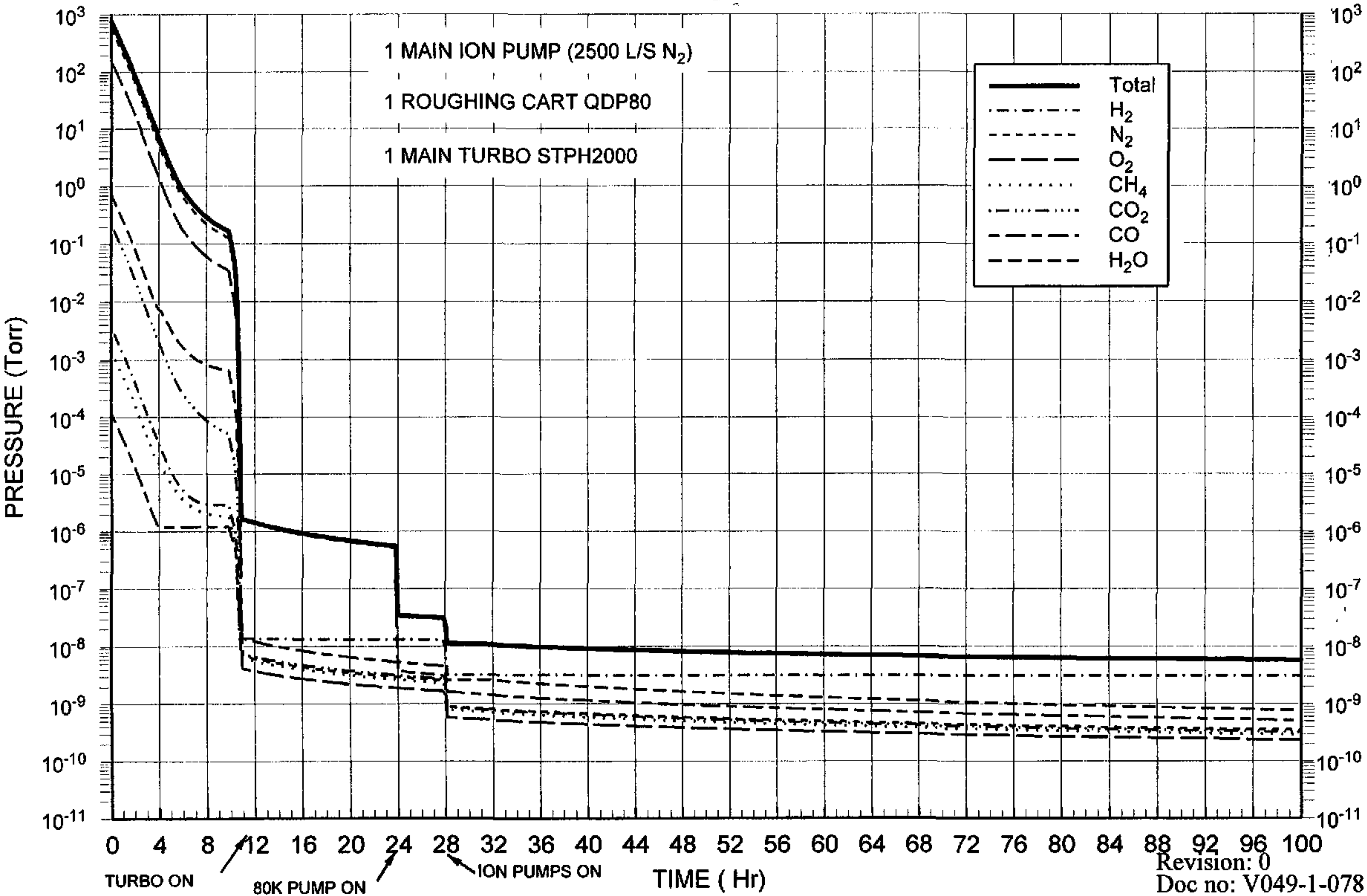
VITON AREA: 0.77m^2, Baked, re-exposed to air 0.5 hr, 100 hr: H_2O=3X10^{-9} Torr-L/s-cm^2, OTHER GASSES=3X10^{-10} Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-2a, MID STATION PUMPDOWN

STEEL AREA: 162 m^2, Volume: 72 m^3, H_2=1X10^{-11} Torr-L/s-cm^2, H_2O=1X10^{-6}*t$^{-1.15}$, t=min, OTHER GASSES: 10%

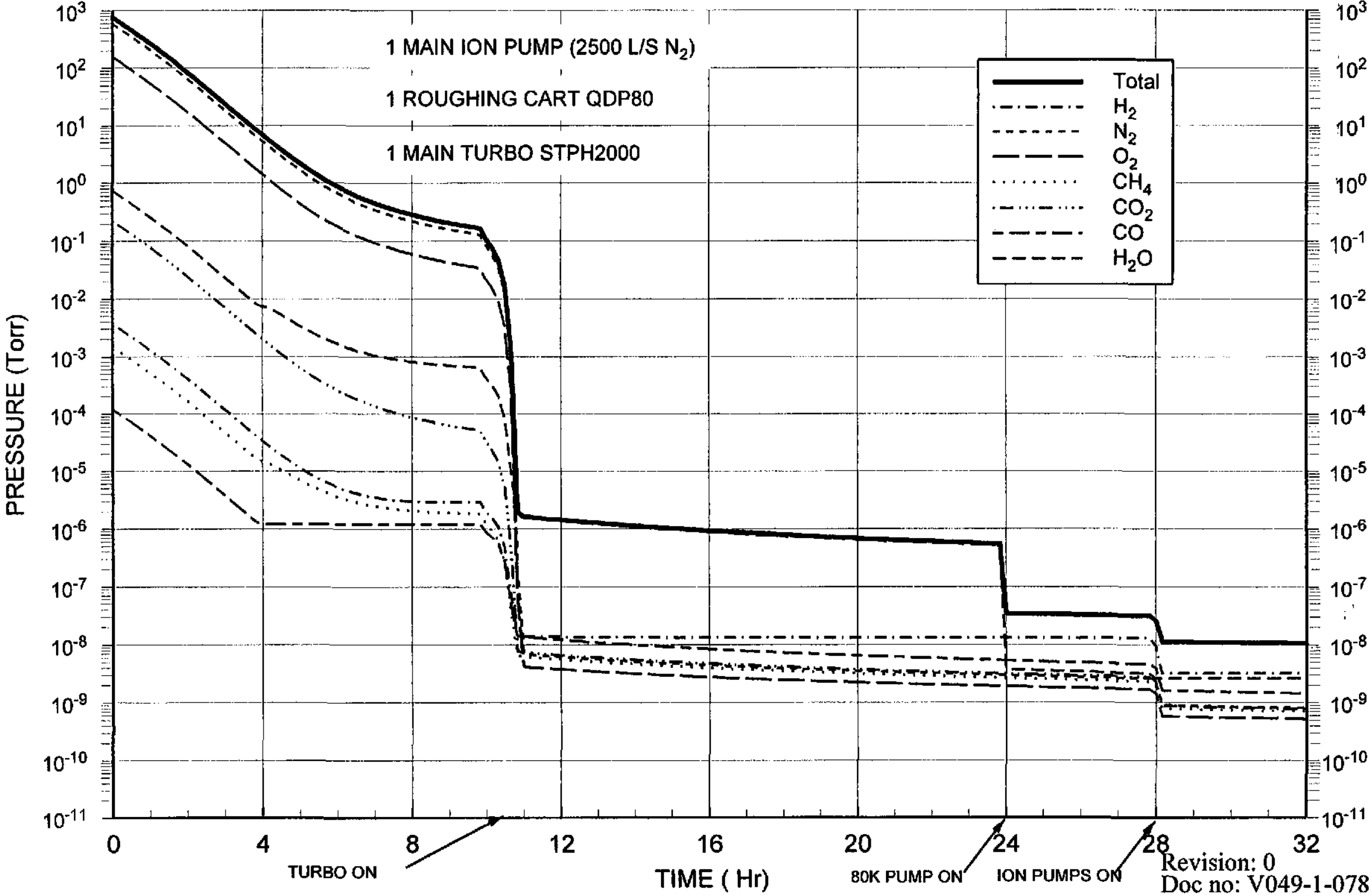
VITON AREA: 1.17m^2, Baked, re-exposed to air 0.5 hr, 100 hr: H_2O=3X10^{-9} Torr-L/s-cm^2, OTHER GASSES=3X10^{-10} Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-2b, MID STATION PUMPDOWN

STEEL AREA: 162 m^2, Volume: 72 m^3, H_2=1X10^{-11} Torr-L/s-cm^2, H_2O=1X10^{-6}*t$^{-1.15}$, t=min, OTHER GASSES: 10%

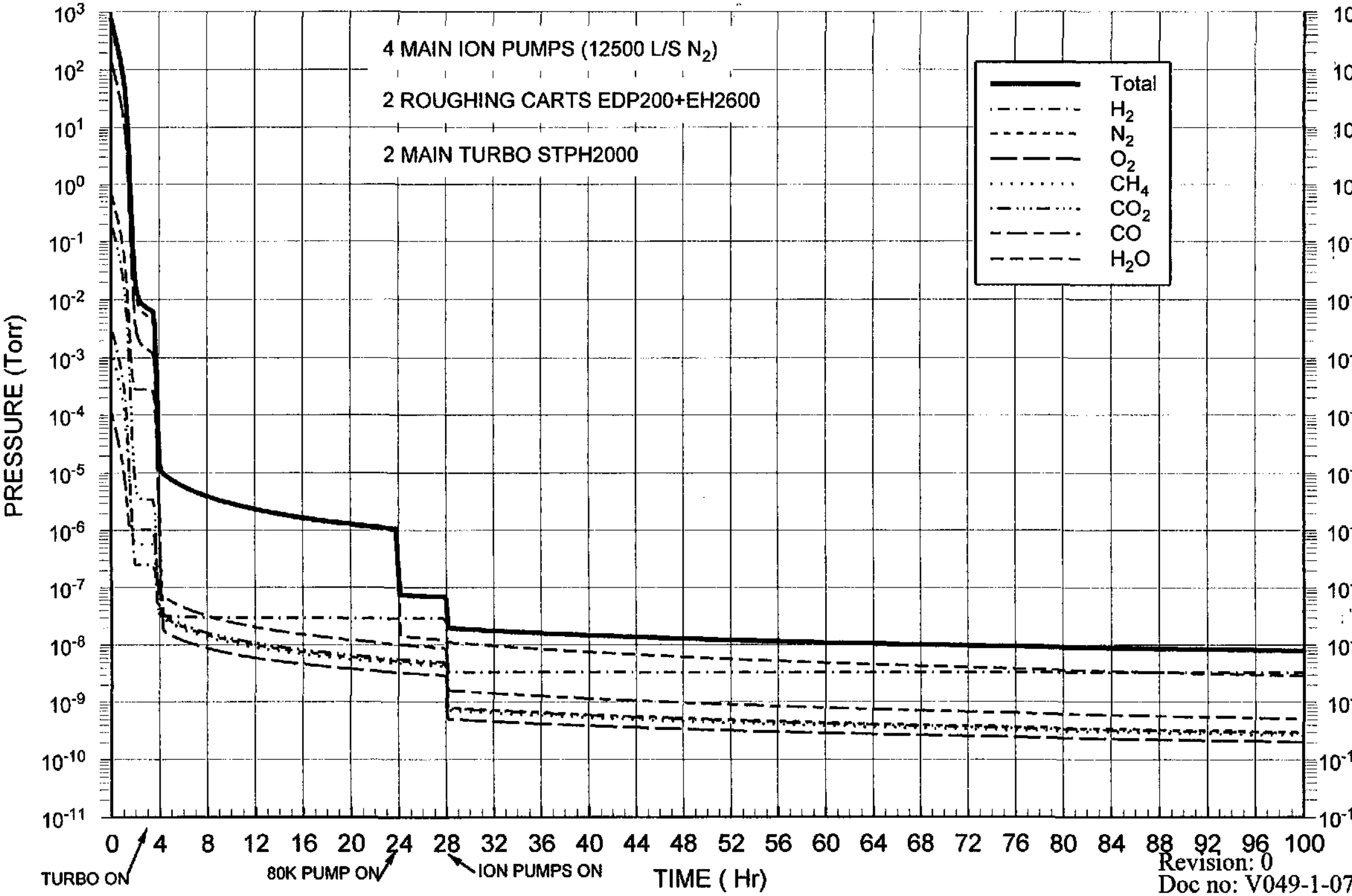
VITON AREA: 1.17m^2, Baked, re-exposed to air 0.5 hr, 100 hr: H_2O=3X10^{-9} Torr-L/s-cm^2, OTHER GASSES=3X10^{-10} Torr-L/s-cm^2



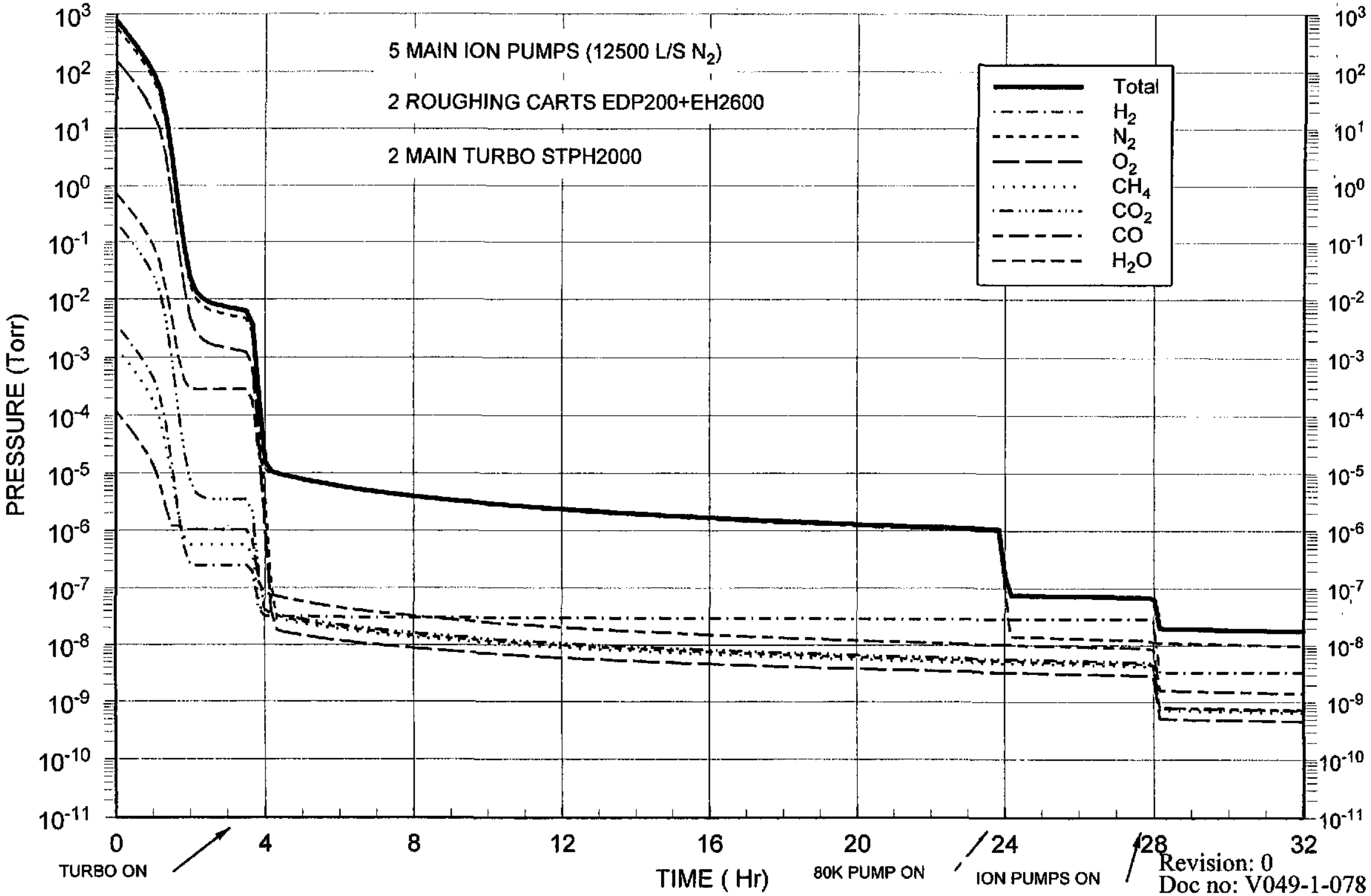
PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-3a, VERTEX & BEAM MANIFOLD-CORNER STATION PUMPDOWN, WA

STEEL AREA: 732 m^2, Volume: 316 m^3, $H_2=1X10^{-11}$ Torr-L/s-cm^2, $H_2O=1X10^{-6}*t^{-1.15}$, t=min, OTHER GASSES: 10%

VITON AREA: 3.7m^2, Baked, re-exposed to air 0.5 hr, 100 hr: $H_2O=3X10^{-9}$ Torr-L/s-cm^2, OTHER GASSES=$3X10^{-10}$ Torr-L/s-cm^2



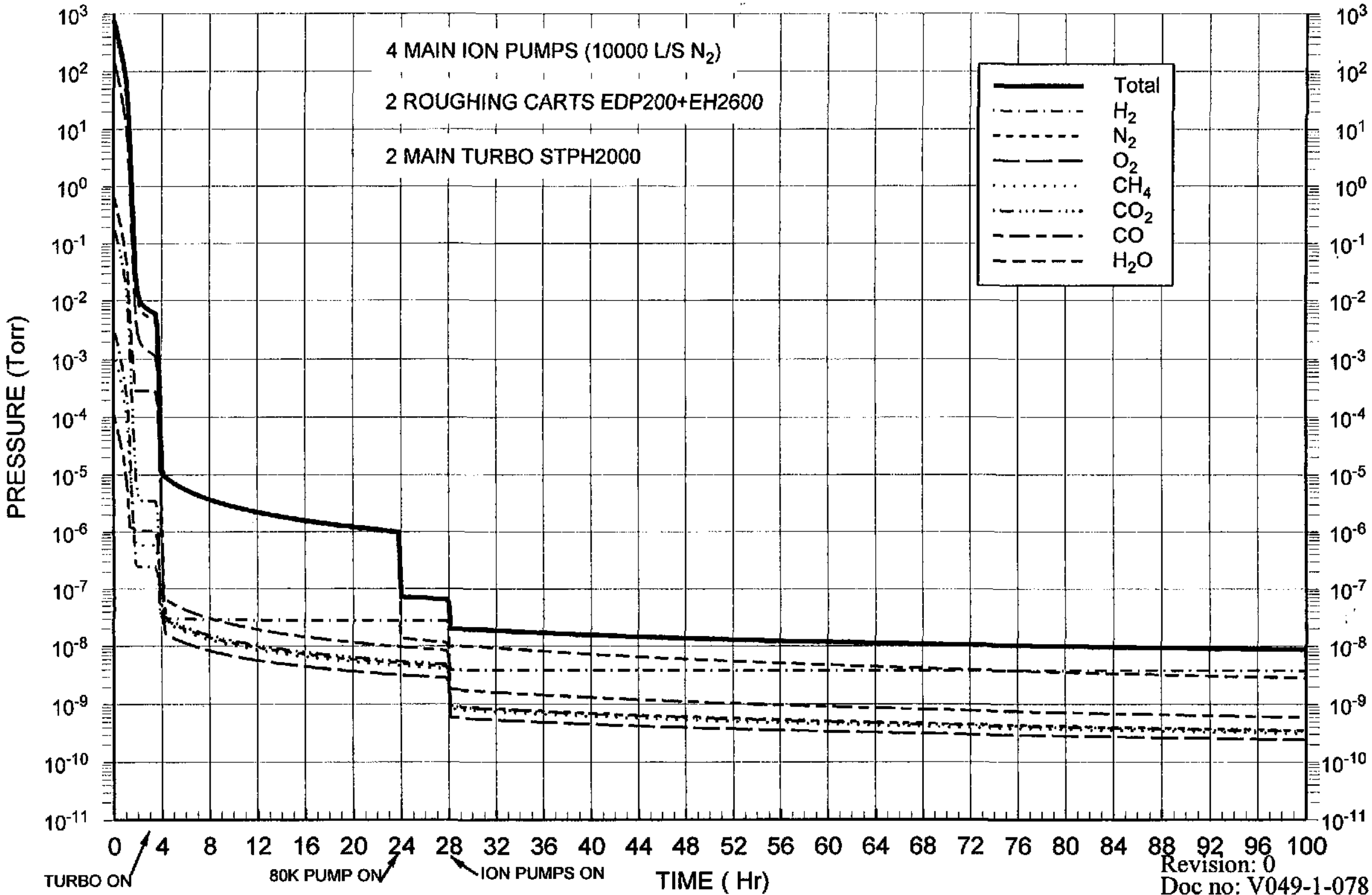
PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-3b, VERTEX & BEAMMANIFOLD-CORNER STATION PUMPDOWN, WA
STEEL AREA: 732 m^2, Volume: 316 m^3, H_2=1X10^{-11} Torr-L/s-cm^2, H_2O=1X10^{-6}*$t^{-1.15}$, t=min, OTHER GASSES: 10%
VITON AREA: 3.7m^2, Baked, re-exposed to air 0.5 hr, 100 hr: H_2O=3X10^{-9} Torr-L/s-cm^2, OTHER GASSES=3X10^{-10} Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-4a, VERTEX & BEAM MANIFOLD-CORNER STATION PUMPDOWN, LA

STEEL AREA: 695 m^2, Volume: 298 m^3, H_2=1X10^{-11} Torr-L/s-cm^2, H_2O=1X10^{-6}*$t^{-1.15}$, t=min, OTHER GASSES: 10%

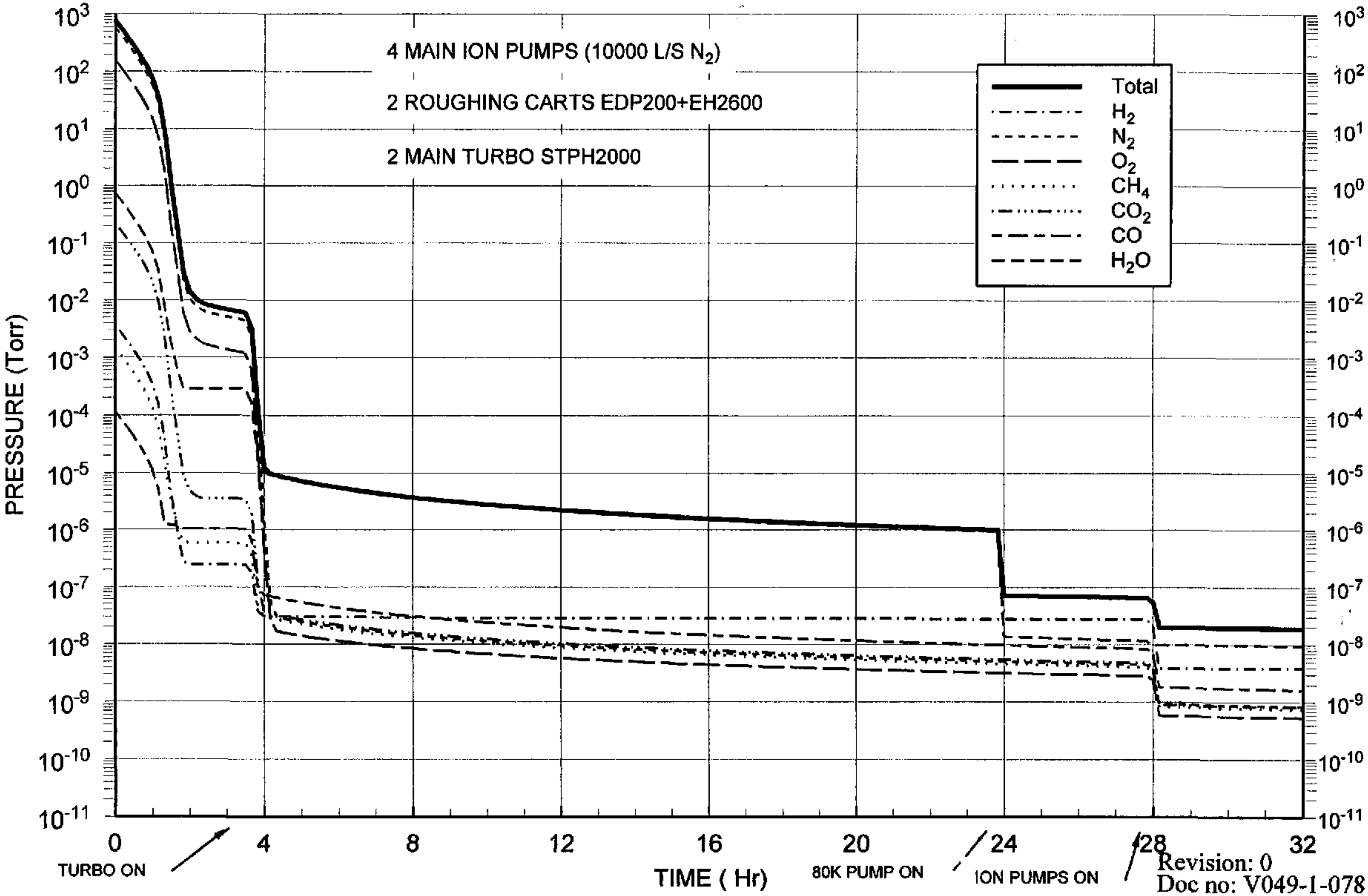
VITON AREA: 3.7m^2, Baked, re-exposed to air 0.5 hr, 100 hr: H_2O=3X10^{-9} Torr-L/s-cm^2, OTHER GASSES=3X10^{-10} Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-4b, VERTEX & BEAMMANIFOLD-CORNER STATION PUMPDOWN, LA

STEEL AREA: 695 m^2, Volume: 298 m^3, $H_2=1X10^{-11}$ Torr-L/s-cm^2, $H_2O=1X10^{-6}*t^{-1.15}$, t=min, OTHER GASSES: 10%

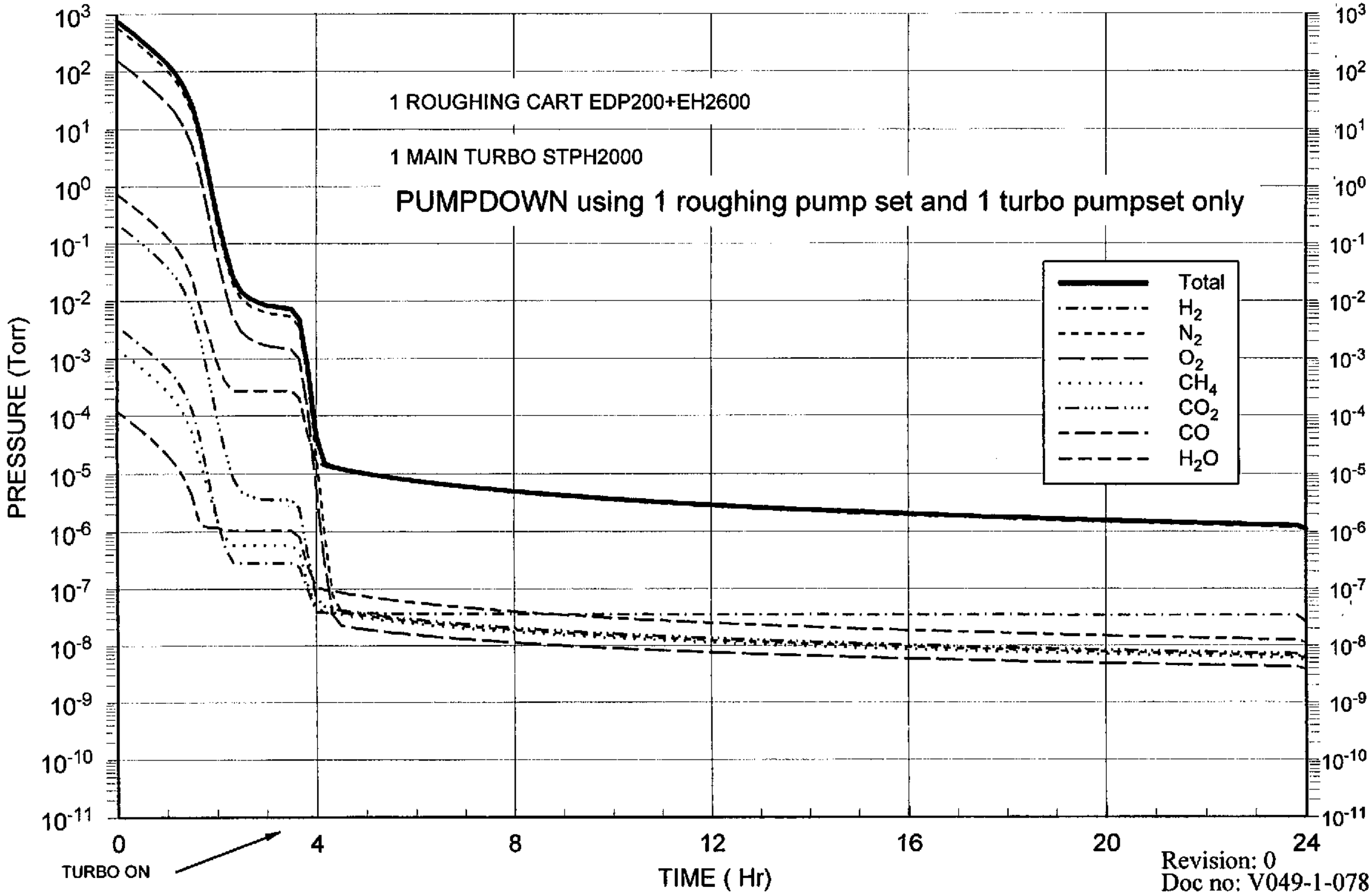
VITON AREA: 3.7m^2, Baked, re-exposed to air 0.5 hr, 100 hr: $H_2O=3X10^{-9}$ Torr-L/s-cm^2, OTHER GASSES=$3X10^{-10}$ Torr-L/s-cm^2



PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:
TITLE:FIGURE V049-1-078-5, VERTEX SECTION, CORNER STATION PUMPDOWN, WA

STEEL AREA: 430 m^2, Volume: 187 m^3, $H_2=1X10^{-11}$ Torr-L/s-cm^2, $H_2O=1X10^{-6}*t^{-1.15}$, t=min, OTHER GASSES: 10%

VITON AREA: 2.5m^2, Baked, re-exposed to air 0.5 hr, 100 hr: $H_2O=3X10^{-9}$ Torr-L/s-cm^2, OTHER GASSES=$3X10^{-10}$ Torr-L/s-cm^2



PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: END STATION PRESSURES

END STATION PARAMETERS

END STATIONS with 80K Pump										
						Viton				
Outgassing area	119	M^2				7757	cm^2			
						3.00E-09	Torr-L/s-cm^2			
Gas species	Partial pressure		Final Outgassing rates					Partial pressure		
	Goals	Ion Pump	80K pump	Vacuum Vessel Metal		O-rings	Total	Metal	O-ring	Total
	100 hrs of pumping	peed (1 pumps)						contribution	contribution	
	Torr	L/s	L/s	Torr-L/s-cm^2	Torr-L/s	Torr-L/s	Torr-L/s	Torr	Torr	Torr
		1								
N2	5.00E-10	2,000		2.00E-13	2.38E-07	3.88E-07	6.26E-07	1.19E-10	1.94E-10	3.13E-10
CO	5.00E-10	1,900		5.00E-13	5.96E-07	3.88E-07	9.84E-07	3.14E-10	2.04E-10	5.18E-10
CO2	2.00E-10	2,150		2.00E-13	2.38E-07	3.88E-07	6.26E-07	1.11E-10	1.80E-10	2.91E-10
CH4	2.00E-10	2,200		2.00E-13	2.38E-07	3.88E-07	6.26E-07	1.08E-10	1.76E-10	2.85E-10
Others	5.00E-10	1,700		2.00E-13	2.38E-07	3.88E-07	6.26E-07	1.40E-10	2.28E-10	3.68E-10
H2	5.00E-09	4,200		1.00E-11	1.19E-05	3.88E-07	1.23E-05	2.84E-09	9.23E-11	2.93E-09
H2O	5.00E-09		142,000	5.00E-11	5.96E-05	2.33E-05	8.29E-05	4.20E-10	1.64E-10	5.8349E-10
TOTAL gasses	1.90E-09				1.55E-06	2.33E-06	3.88E-06	7.92E-10	9.83E-10	1.78E-09
TOTAL with H2	6.40E-09				1.35E-05	2.33E-06	1.58E-05	3.63E-09	1.08E-09	4.70E-09
TOTAL with H2O,H2	1.90E-09				7.31E-05	2.56E-05	9.86E-05	4.05E-09	1.24E-09	5.29E-09

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: END STATION PRESSURES

END STATION PARAMETERS

END STATIONS with 80K Pump							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
Short 80K cryopump chamber	1	2.5		16.59		9.95	915.33
Short 80K cryopump surface	1	1.2		9.80		0.00	
183 cm beam manifold		3.3		18.97		8.68	1046.91
157 cm intercon spool		1		4.93		1.94	272.17
116 cm intercon spool		3.2		11.66		3.74	643.50
BSC	1	1.5		57.21		31.67	3157.10
Total		12.70		***119***		**56**	**6035**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	1	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	1	2500	2000	2500	2000	35.73	**16.78**
CO	1	2350	1900	2350	1900	33.94	**15.94**
CO2	1	2940	2150	2940	2150	38.41	**18.04**
CH4	1	2650	2200	2650	2200	39.30	**18.46**
O2	1	2100	1700	2100	1700	30.37	**14.27**
He	1	295	290	295	290	5.18	**2.43**
Ar	1	590	550	590	550	9.83	**4.62**
H2	1	4700	4200	4700	4200	75.03	**35.24**
H2O	1	2940	2400				
TURBO MOLECULAR *	1	1500	1000	1500	1000	17.86	8.39
* Nitrogen speed							
DRY PUMP QDP80	1	22	18	22	18	0.32	0.15
80K CRYOPUMP **	1	142000	142000	142000	142000	2536.68	**1191.59**
** Water speed							

PROJECT: LIGO BY: R.THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: VITON O-RING AREA END STATION

FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	1	8.54	937
84	0	6.94	0
72	1	5.98	657
60	4	5.03	2206
48	0	4.07	0
44	4	3.75	1646
Bonnet/Gate	6	3.51	2311
			7757

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: MID STATION PRESSURES

MID STATION
PARAMETERS

MID STATIONS with 80K Pumps										
						Viton				
Outgassing area	162	M^2				11715	cm^2			
						3.00E-09	Torr-L/s-cm^2			
Gas species	Partial pressure		Final Outgassing rates					Partial pressure		
	Goals	Ion Pump	80K pump	Vacuum Vessel Metal		O-rings	Total	Metal	O-ring	Total
	100 hrs of pumping	Speed						contribution	contribution	
	Torr	L/s	L/s	Torr-L/s-cm^2	Torr-L/s	Torr-L/s	Torr-L/s	Torr	Torr	Torr
		1								
N2	5.00E-10	2,000		2.00E-13	3.25E-07	5.86E-07	9.10E-07	1.62E-10	2.93E-10	4.55E-10
CO	5.00E-10	1,900		5.00E-13	8.11E-07	5.86E-07	1.40E-06	4.27E-10	3.08E-10	7.35E-10
CO2	2.00E-10	2,150		2.00E-13	3.25E-07	5.86E-07	9.10E-07	1.51E-10	2.72E-10	4.23E-10
CH4	2.00E-10	2,200		2.00E-13	3.25E-07	5.86E-07	9.10E-07	1.48E-10	2.66E-10	4.14E-10
Others	5.00E-10	1,700		2.00E-13	3.25E-07	5.86E-07	9.10E-07	1.91E-10	3.45E-10	5.35E-10
H2	5.00E-09	4,200		1.00E-11	1.62E-05	5.86E-07	1.68E-05	3.86E-09	1.39E-10	4.00E-09
H2O	5.00E-09		284,000	5.00E-11	8.11E-05	3.51E-05	1.16E-04	2.86E-10	1.24E-10	4.0945E-10
TOTAL gasses	1.90E-09				2.11E-06	3.51E-06	5.62E-06	1.08E-09	1.48E-09	2.56E-09
TOTAL with H2	6.40E-09				1.83E-05	3.51E-06	2.19E-05	4.94E-09	1.62E-09	6.57E-09
TOTAL with H2O,H2	1.19E-08				9.95E-05	3.87E-05	1.38E-04	5.23E-09	1.75E-09	6.98E-09

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: MID STATION PRESSURES

MID STATION
PARAMETERS

MID STATIONS with 80K Pumps							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	Approx
Short 80K cryopump chamber	2	2.5		33.18		19.91	1830.66
Short 80K cryopump surface	2	1.2		19.60		0.00	
183 cm beam manifold		3.8		21.85		9.99	1205.53
116 cm intercon spool		7		25.51		8.18	1407.67
157 cm intercon spool		1		4.93		1.94	272.17
BSC	1	3.5		57.21		31.67	3157.10
Total		19.00		***162***		**72**	**7873**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	1	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	1	2500	2000	2500	2000	27.90	**12.32**
CO	1	2350	1900	2350	1900	26.50	**11.71**
CO2	1	2940	2150	2940	2150	29.99	**13.25**
CH4	1	2650	2200	2650	2200	30.69	**13.56**
O2	1	2100	1700	2100	1700	23.71	**10.48**
He	1	295	290	295	290	4.05	**1.79**
Ar	1	590	550	590	550	7.67	**3.39**
H2	1	4700	4200	4700	4200	58.59	**25.88**
H2O	1	2940	2400	2940	2400	33.48	**14.79**
TURBO MOLECULAR *	1	1500	1000	1500	1000	**13.95**	6.16
* Nitrogen speed							
DRY PUMP QDP80	1	22	18	22	18	**0.25**	0.11
80K CRYOPUMP **	2	142000		284000		3961.58	**1750.06**
** Water speed							

PROJECT: LIGO BY: R.THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: VITON O-RING AREA MID STATION

FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	1	8.54	937
84	0	6.94	0
72	1	5.98	657
60	4	5.03	2206
48	0	4.07	0
44	8	3.75	3292
Bonnet/Gate	12	3.51	4623
			11715

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: CORNER STATION PRESSURES

CORNER STATION, WA
PARAMETERS

CORNER STATION (WA) VERTEX & ARM ISOLATABLE SECTION with 80K Pump										
						VITON				
Outgassing area	732	M^2				37639	cm^2			
						3.00E-09	Torr-L/s-cm^2			
Gas species	Partial pressure				Final Outgassing rates				Partial pressure	
	Goals	Ion Pump	80K pump	Vacuum Vessel Metal		O-rings	Total	Metal	O-ring	**Total**
	100 hrs of pumping	speed						contribution	contribution	
	Torr	L/s	L/s	Torr-L/s-cm^2	Torr-L/s	Torr-L/s	Torr-L/s	Torr	Torr	Torr
N2	5.00E-10	10000		2.00E-13	1.46E-06	1.88E-06	3.35E-06	1.46E-10	1.88E-10	**3.35E-10**
CO	5.00E-10	9500		5.00E-13	3.66E-06	1.88E-06	5.54E-06	3.85E-10	1.98E-10	**6.83E-10**
CO2	2.00E-10	10750		2.00E-13	1.46E-06	1.88E-06	3.35E-06	1.36E-10	1.75E-10	**3.11E-10**
CH4	2.00E-10	11000		2.00E-13	1.46E-06	1.88E-06	3.35E-06	1.33E-10	1.71E-10	**3.04E-10**
Others	5.00E-10	8500		2.00E-13	1.46E-06	1.88E-06	3.35E-06	1.72E-10	2.21E-10	**3.94E-10**
H2	5.00E-09	21000		1.00E-11	7.32E-05	1.88E-06	7.50E-05	3.48E-09	8.96E-11	**3.57E-09**
H2O	5.00E-09		142,000	5.00E-11	3.66E-04	1.13E-04	4.79E-04	2.58E-09	7.95E-10	**3.3712E-09**
TOTAL gasses	1.90E-09				9.51E-06	1.13E-05	2.08E-05	9.73E-10	9.54E-10	**1.93E-09**
TOTAL with H2	6.40E-09				8.27E-05	1.13E-05	9.40E-05	4.46E-09	1.04E-09	**5.50E-09**
TOTAL with H2O,H2	1.90E-09				4.48E-04	1.24E-04	5.73E-04	7.03E-09	1.84E-09	**8.87E-09**

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: CORNER STATION PRESSURES

CORNER STATION, WA
PARAMETERS

CORNER STATION (WA) VERTEX & ARM ISOLATABLE SECTION with 80K Pump							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
Long 80K Cryopump chamber	1	4.2	m	31.67		19.00	1747.45
Long 80K Cryopump surface	1	3.7	m	30.22			
183 cm beam manifold		25.6	m	147.18		67.33	8121.47
157m intercon spool		6.7	m	33.05		12.97	1823.55
122 cm intercon spool		7.3	m	27.98		8.53	1543.92
116 cm intercon spool		3	m	10.93		3.17	603.29
BSC	4	4	m	228.85		126.68	12628.40
HAM	6		m	164.40		67.53	9071.65
76 cm cleaner tube		24	m	57.30		*10.89*	*3162.05*
Total		78.50	m	***732***		**316**	**38702**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	5	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	5	2500	2000	12500	10000	31.63	**13.67**
CO	5	2350	1900	11750	9500	30.05	**12.99**
CO2	5	2940	2150	14700	10750	34.01	**14.69**
CH4	5	2650	2200	13250	11000	34.80	**15.04**
O2	5	2100	1700	10500	8500	26.89	**11.62**
He	5	295	290	1475	1450	4.59	**1.98**
Ar	5	590	550	2950	2750	8.70	**3.76**
	5						
H2	5	4700	4200	23500	21000	66.43	**28.71**
H2O	5	2940	2400				
TURBO MOLECULAR *	1	1500	1000	1500	1000	3.16	1.37
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	2	600	438	1200	876	2.77	1.20
Claw&Root 760 Torr - 10 Torr	2	83	78	166	156	0.49	0.21
80K CRYOPUMP **	1	142000	142000	142000	142000	449.21	**194.10**
** Water speed							

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: CORNER STATION PRESSURES

CORNER STATION, WA
PARAMETERS

CORNER STATION (WA) BEAM MANIFOLD with 80K Pump							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
Long 80K Cryopump chamber	1	4.2	m	31.67		19.00	1747.45
Long 80K Cryopump surface	1	3.7	m	30.22			
183 cm beam manifold		25.6	m	147.18		67.33	8121.47
157 cm intercon spool		1.2	m	5.92		2.32	326.61
122 cm intercon spool		4.9	m	18.78		5.73	1036.33
116 cm intercon spool	0	3	m	10.93		3.17	603.29
BSC	1	4	m	57.21		31.67	3157.10
HAM	0		m	0.00		0.00	0.00
76 cm cleaner tube		0	m	0.00		0.00	0.00
Total		46.60	m	***302***		**129**	**14992**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	1	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	1	2500	2000	2500	2000	15.48	**6.62**
CO	1	2350	1900	2350	1900	14.70	**6.29**
CO2	1	2940	2150	2940	2150	16.64	**7.12**
CH4	1	2650	2200	2650	2200	17.02	**7.29**
O2	1	2100	1700	2100	1700	13.16	**5.63**
He	1	295	290	295	290	2.24	**0.96**
Ar	1	590	550	590	550	4.26	**1.82**
	1			0	0	0.00	**0.00**
H2	1	4700	4200	4700	4200	32.50	**13.91**
H2O	1	2940	2400				
TURBO MOLECULAR *	1	1500	1000	1500	1000	7.74	3.31
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	2	600	438	1200	876	6.78	2.90
Claw&Root 760 Torr - 10 Torr	2	83	78	166	156	1.21	0.52
80K CRYOPUMP **	1	142000	142000	142000	142000	**1098.86**	**470.34**
** Water speed							

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: CORNER STATION PRESSURES

CORNER STATION, WA
PARAMETERS

DIAGONAL (OFFSET) SECTION, WA							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
183 cm beam manifold		0	m	*0.00*		0.00	0.00
157 cm intercon spool		2.2	m	10.85		4.26	598.78
122 cm intercon spool		6.7	m	25.68		7.83	1417.03
116 cm intercon spool	0	0	m	0.00		0.00	0.00
BSC	1	4	m	57.21		31.67	3157.10
HAM	6			164.40		67.53	9071.65
76 cm cleaner tube		24	m	57.30		10.89	3162.05
Total		36.90	m	***315***		**122**	**17407**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	2	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	2	2500	2000	5000	4000	32.74	**12.68**
CO	2	2350	1900	4700	3800	31.10	**12.05**
CO2	2	2940	2150	5880	4300	35.19	**13.63**
CH4	2	2650	2200	5300	4400	36.01	**13.95**
O2	2	2100	1700	4200	3400	27.83	**10.78**
He	2	295	290	590	580	4.75	**1.84**
Ar	2	590	550	1180	1100	9.00	**3.49**
	2			0	0	0.00	**0.00**
H2	2	4700	4200	9400	8400	68.75	**26.63**
H2O	2	2940	2400				
TURBO MOLECULAR *	1	1500	1000	1500	1000	8.18	3.17
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	1	600	438	600	438	3.58	1.39
Claw&Root 760 Torr - 10 Torr	1	83	78	83	78	0.64	0.25
80K CRYOPUMP **	1	142000	142000	142000	142000	1162.21	**450.16**
** Water speed							

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: CORNER STATION PRESSURES

CORNER STATION, WA
PARAMETERS

VERTEX SECTION, WA							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
183 cm beam manifold		0	m	0.00		0.00	0.00
157 cm intercon spool		5.5	m	27.13		10.65	1496.94
122 cm intercon spool		2.4	m	9.20		2.81	507.59
116 cm intercon spool	0	0	m	0.00		0.00	0.00
BSC	3	4	m	171.64		95.01	9471.30
HAM	6			164.40		67.53	9071.65
76 cm cleaner tube		24	m	57.30		10.89	3162.05
Total		35.90	m	***430***		**187**	**23710**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	4	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N_2	4	2500	2000	10000	8000	65.48	**25.36**
CO	4	2350	1900	9400	7600	62.20	**24.09**
CO_2	4	2940	2150	11760	8600	70.39	**27.26**
CH_4	4	2650	2200	10600	8800	72.02	**27.90**
O_2	4	2100	1700	8400	6800	55.65	**21.56**
He	4	295	290	1180	1160	9.49	**3.68**
Ar	4	590	550	2360	2200	18.01	**6.97**
	4			0	0	0.00	**0.00**
H_2	4	4700	4200	18800	16800	137.50	**53.26**
H_2O	4	2940	2400				
TURBO MOLECULAR *	1	1500	1000	1500	1000	8.18	3.17
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	1	600	438	600	438	3.58	1.39
Claw&Root 760 Torr - 10 Torr	1	83	78	83	78	0.64	0.25
80K CRYOPUMP **	1	142000	142000	142000	142000	1162.21	**450.16**
** Water speed							

PROJECT: LIGO BY: R.THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: VITON O-RING AREA CORNER STATION ,WA

RIGHT/LEFT BEAM MANIFOLD			
FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	1	8.54	937
84	0	6.94	0
72	5	5.98	3283
60	4	5.03	2206
48	3	4.07	1340
Bonnet/Gate	7	3.51	2697
44	4	3.75	1646
		TOTAL	***12109***
VERTEX			
FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	3	8.54	2810
84	12	6.94	9141
72	0	5.98	0
60	23	5.03	12686
48	2	4.07	893
44	0	3.75	0
		TOTAL	**25530**
DIAGONAL			
FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	1	8.54	937
84	12	6.94	9141
72	0	5.98	0
60	15	5.03	8274
48	4	4.07	1786
Bonnet	2	3.51	770
44	0	3.75	0
		TOTAL	**20908**
DIAGONAL			***20908***
VERTEX			***25530***
RIGHT BEAM MANIFOLD			***12109***
LEFT BEAM MANIFOLD			***12109***
			70655

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: LA. CORNER STATION PRESSURES

CORNER STATION, LA
PARAMETERS

CORNER STATION (LA) VERTEX & BEAM MANIFOLD ISOLATABLE SECTION with 80K Pump										
Outgassing area	695	M^2				36746	cm^2			
						3.00E-09	Torr-L/s-cm^2			
Gas species	Partial pressure		Final Outgassing rates					Partial pressure		
	Goals	Ion Pump	80K pump	Vacuum Vessel Metal		O-rings **	Total	Metal	O-ring	Total
	100 hrs of pumping	peed (1 pumps)						contributio	contributio	
	Torr	L/s	L/s	Torr-L/s-cm^2	Torr-L/s	Torr-L/s	Torr-L/s	Torr	Torr	Torr
		1								
N2 *	5.00E-10	8,000		2.00E-13	1.39E-06	1.84E-06	3.23E-06	1.74E-10	2.30E-10	**4.03E-10**
CO	5.00E-10	7,600		5.00E-13	3.47E-06	1.84E-06	5.31E-06	4.57E-10	2.42E-10	**6.99E-10**
CO2	2.00E-10	8,600		2.00E-13	1.39E-06	1.84E-06	3.23E-06	1.62E-10	2.14E-10	**3.75E-10**
CH4	2.00E-10	8,800		2.00E-13	1.39E-06	1.84E-06	3.23E-06	1.58E-10	2.09E-10	**3.67E-10**
Others	5.00E-10	6,800		2.00E-13	1.39E-06	1.84E-06	3.23E-06	2.04E-10	2.70E-10	**4.74E-10**
H2	5.00E-09	16,800		1.00E-11	6.95E-05	1.84E-06	7.13E-05	4.13E-09	1.09E-10	**4.24E-09**
H2O	5.00E-09		142,000	5.00E-11	3.47E-04	1.10E-04	4.58E-04	2.45E-09	7.76E-10	**3.222E-09**
TOTAL gasses	1.90E-09				9.03E-06	1.10E-05	2.01E-05	1.15E-09	1.16E-09	**2.32E-09**
TOTAL with H2	6.40E-09				7.85E-05	1.10E-05	8.95E-05	5.29E-09	1.27E-09	**6.56E-09**
TOTAL with H2O,H2	1.90E-09				4.26E-04	1.21E-04	5.47E-04	7.73E-09	2.05E-09	**9.78E-09**

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: LA. CORNER STATION PRESSURES

CORNER STATION, LA
PARAMETERS

CORNER STATION (LA) VERTEX & BEAM MANIFOLD ISOLATABLE SECTION with 80K Pump							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
Long 80K Cryopump chamber	1	4.2	m	31.67		19.00	1747.45
Long 80K Cryopump surface	1	3.7	m	30.22			
183 cm beam manifold		37	m	212.72		97.32	11738.06
122 cm intercon spool		6	m	23.00		7.01	1268.98
116 cm intercon spool		1	m	3.64		1.06	201.10
BSC	3	4	m	171.64		95.01	9471.30
HAM	6		m	164.40		67.53	9071.65
76 cm cleaner tube		24	m	57.30		10.89	3162.05
Total		79.90	m	**695**		**298**	**36661**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	4	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	4	2500	2000	10000	8000	26.86	**11.52**
CO	4	2350	1900	9400	7600	25.52	**10.94**
CO2	4	2940	2150	11760	8600	28.88	**12.38**
CH4	4	2650	2200	10600	8800	29.55	**12.67**
O2	4	2100	1700	8400	6800	22.83	**9.79**
He	4	295	290	1180	1160	3.89	**1.67**
Ar	4	590	550	2360	2200	7.39	**3.17**
	4						
H2	4	4700	4200	18800	16800	56.41	**24.19**
H2O	4	2940	2400			0.00	
TURBO MOLECULAR *	1	1500	1000	1500	1000	3.36	1.44
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	2	600	438	1200	876	2.94	1.26
ROTARY 760 Torr - 10 Torr	2	138	100	276	200	0.67	0.29
80K CRYOPUMP **	1	142000	142000	142000	142000	476.80	**204.44**
** Water speed							

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: LA. CORNER STATION PRESSURES

CORNER STATION, LA
PARAMETERS

CORNER STATION (LA) entire station with 80K Pumps										
Outgassing area	898	M^2				47961	cm^2			
						3.00E-09	Torr-L/s-cm^2			
Gas species	Partial pressure				Final Outgassing rates				Partial pressure	
	Goals	Ion Pump	80K pump	Vacuum Vessel Metal		O-rings **	Total	Metal	O-ring	Total
	100 hrs of pumping	peed (1 pumps)						contributio	contributio	
	Torr	L/s	L/s	Torr-L/s-cm^2	Torr-L/s	Torr-L/s	Torr-L/s	Torr	Torr	Torr
N2 *	5.00E-10	8,000		2.00E-13	1.80E-06	2.40E-06	4.19E-06	2.25E-10	3.00E-10	**5.24E-10**
CO	5.00E-10	7,600		5.00E-13	4.49E-06	2.40E-06	6.89E-06	5.91E-10	3.16E-10	**9.07E-10**
CO2	2.00E-10	8,600		2.00E-13	1.80E-06	2.40E-06	4.19E-06	2.09E-10	2.79E-10	**4.88E-10**
CH4	2.00E-10	8,800		2.00E-13	1.80E-06	2.40E-06	4.19E-06	2.04E-10	2.73E-10	**4.77E-10**
Others	5.00E-10	6,800		2.00E-13	1.80E-06	2.40E-06	4.19E-06	2.64E-10	3.53E-10	**6.17E-10**
H2	5.00E-09	16,800	16800	1.00E-11	8.98E-05	2.40E-06	9.22E-05	5.35E-09	1.43E-10	**5.49E-09**
H2O	5.00E-09		284,000	5.00E-11	4.49E-04	1.44E-04	5.93E-04	1.58E-09	5.07E-10	**2.0885E-09**
TOTAL gasses	1.90E-09				1.17E-05	1.44E-05	2.61E-05	1.49E-09	1.52E-09	**3.01E-09**
TOTAL with H2	6.40E-09				1.02E-04	1.44E-05	1.16E-04	6.84E-09	1.66E-09	**8.50E-09**
TOTAL with H2O,H2	1.90E-09				5.51E-04	1.58E-04	7.09E-04	8.42E-09	2.17E-09	**1.06E-08**

PROJECT: LIGO BY: R. THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE: LA. CORNER STATION PRESSURES

CORNER STATION, LA
PARAMETERS

CORNER STATION (LA) entire station with 80K Pumps							
	Qty'	Length		Area		Volume	Weight
		m		m^2		m^3	kg
Long 80K Cryopump chamber	2	4.2	m	63.33		38.00	3494.89
Long 80K Cryopump surface	2	3.7	m	60.44			
183 cm beam manifold		60	m	344.95		157.81	19034.69
122 cm intercon spool		9.5	m	36.41		11.11	2009.22
116 cm intercon spool	0	9.5	m	0.00		0.00	0.00
BSC	3	4	m	171.64		*95.01*	*9471.30*
HAM	6		m	164.40		67.53	9071.65
76 cm cleaner tube		24	m	57.30		10.89	3162.05
Total		114.90	m	***898***		**380**	**46244**
VACUUM SYSTEM		Pump		Total	Total	Specific	Specific
	Qty'	Speed	Net Speed	Speed	Net Speed	speed/ Vol	speed/ Area
ION PUMPS , 0.5m intercon	4	l/s	l/s	l/s	l/s	l/s-m^3	l/s-m^2
N2	4	2500	2000	10000	8000	21.03	**8.90**
CO	4	2350	1900	9400	7600	19.98	**8.46**
CO2	4	2940	2150	11760	8600	22.61	**9.57**
CH4	4	2650	2200	10600	8800	23.14	**9.79**
O2	4	2100	1700	8400	6800	17.88	**7.57**
He	4	295	290	1180	1160	3.05	**1.29**
Ar	4	590	550	2360	2200	5.78	**2.45**
	4						
H2	4	4700	4200	18800	16800		**18.70**
H2O	4	2940	2400			0.00	
TURBO MOLECULAR *	1	1500	1000	1500	1000	2.63	1.11
* Nitrogen speed							
ROOTS 10 Torr - 0.01 Torr	2	600	438	1200	876	2.30	0.97
ROTARY 760 Torr - 10 Torr	2	138	100	276	200	0.53	0.22
80K CRYOPUMP **	2	142000	142000	284000	284000	746.68	**316.09**
** Water speed							

PROJECT: LIGO BY: R.THAN DEPT: 744
PROJECT NO: V59049 DATE:
TITLE VITON O-RING AREA, CORNER STATION ,LA

RIGHT/LEFT BEAM MANIFOLD			
FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	1	8.54	937
84	0	6.94	0
72	5	5.98	3283
60	0	5.03	0
48	1	4.07	447
Bonnet/Gate	7	3.51	2697
44	4	3.75	1646
		TOTAL	**9009**
VERTEX			
FLANGE SIZE		Length	Area
INCH	Qty'	m	cm^2
104	3	8.54	2810
84	12	6.94	9141
72	0	5.98	0
60	23	5.03	12686
48	2	4.07	893
44	0	3.75	0
		TOTAL	**25530**
VERTEX			***25530***
RIGHT BEAM MANIFOLD			***9009***
LEFT BEAM MANIFOLD			***9009***
			43549

Table 1

VIT 142	(E.H.V.) O-ring
Section	0.353 cm
ID	3.769 cm
Surface area	14.3 cm²
Length	13 cm
L/A	0.91 cm⁻¹
Volume	1.26 cm³

Initial gas content (estimated) 5.7 cm³ air at NTP

Table 2

Curve No	Position of O-ring	Baking time (h)	Baking temperature °C
1	In chamber	—	—
2	In groove	—	—
3	In groove	16	100
4	In chamber	16	100

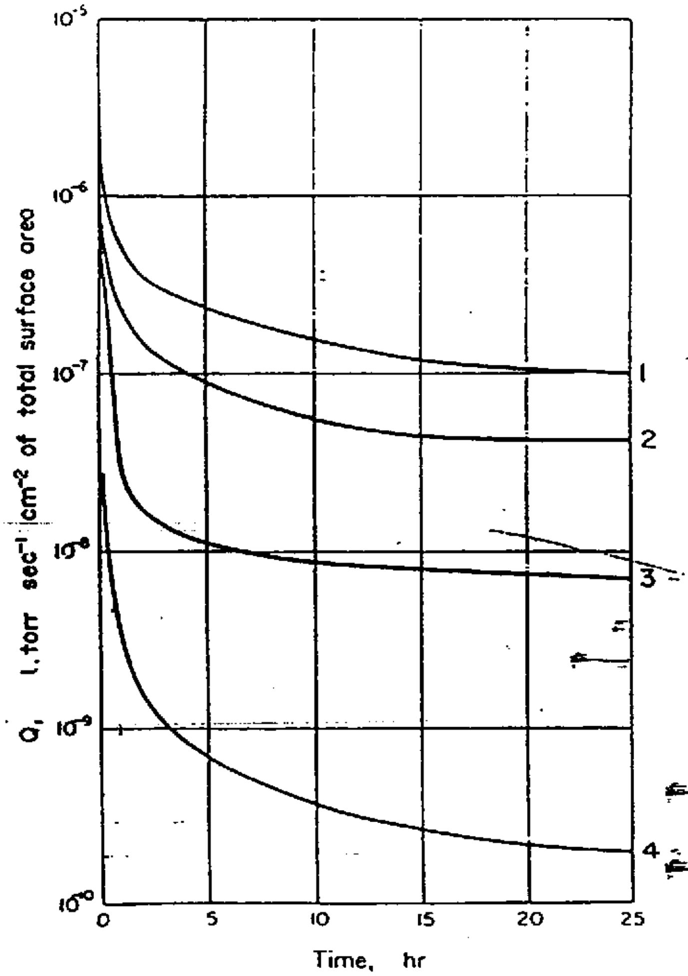


Figure 1. Gas evolution rates in litre torr sec⁻¹ cm⁻² of total area of O-ring against time in hours. See Table 2 for key.

Vacuum Vol.16 No.3, 1966

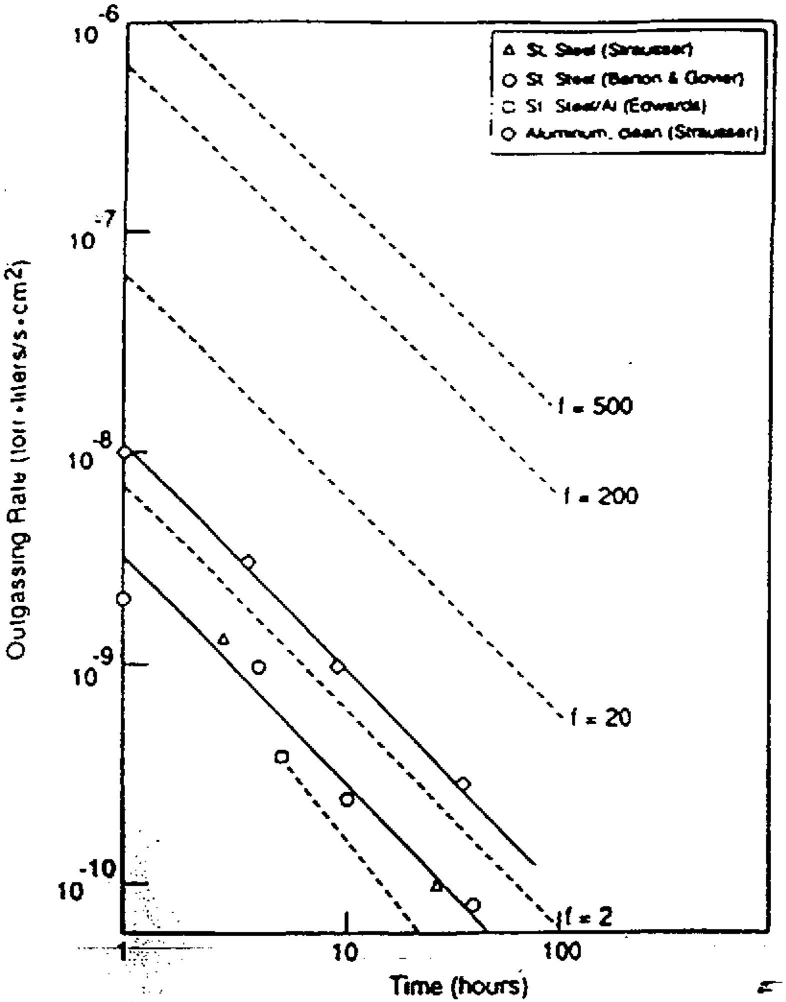


FIG. 1. A compilation of selected outgassing results from the literature for the outgassing of stainless steel and aluminum at ambient temperature. Measurements of Edwards (Ref. 1), Strausser (Ref. 5), and Barton and Govier (Ref. 6) are shown. The lower solid line indicates the literature average used for comparative stainless steel outgassing in this study. The dotted lines indicate the effect of increasing values of the surface roughness factor f.

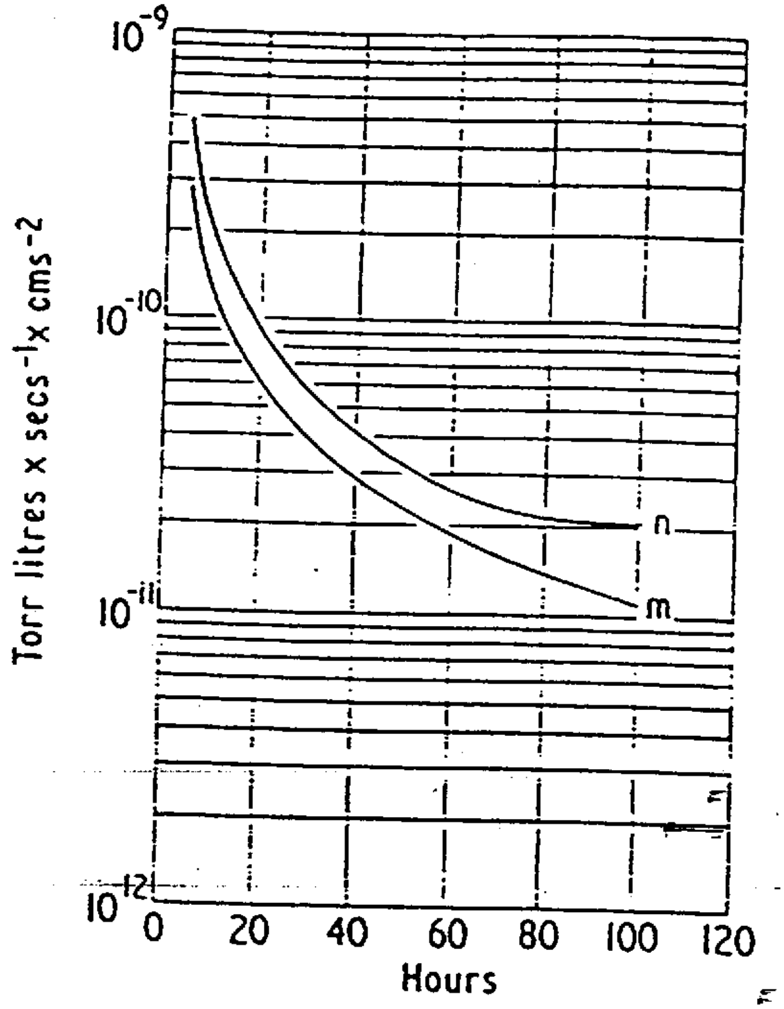
J. Vac. Sci Technology A, Vol. 11, No.5, 1993

Vacuum Vol.20, No.1, 1970

The effect of cleaning technique on the outgassing rate of 18/9/1 stainless steel

received 6 October 1969; accepted 3 November 1969 VACUUM VOL 20 NO I

R S Barton and R P Govier, *UKAEA Research Group, Culham Laboratory, Abingdon, Berkshire*



m. New sample machined & degreased. (Sample 10. Exp.31).
n. Same sample following vapour blasting & degreasing. (Sample 10. Exp.32).

Figure 8. Total outgassing per cm^2 of sample as a function of pumping time.

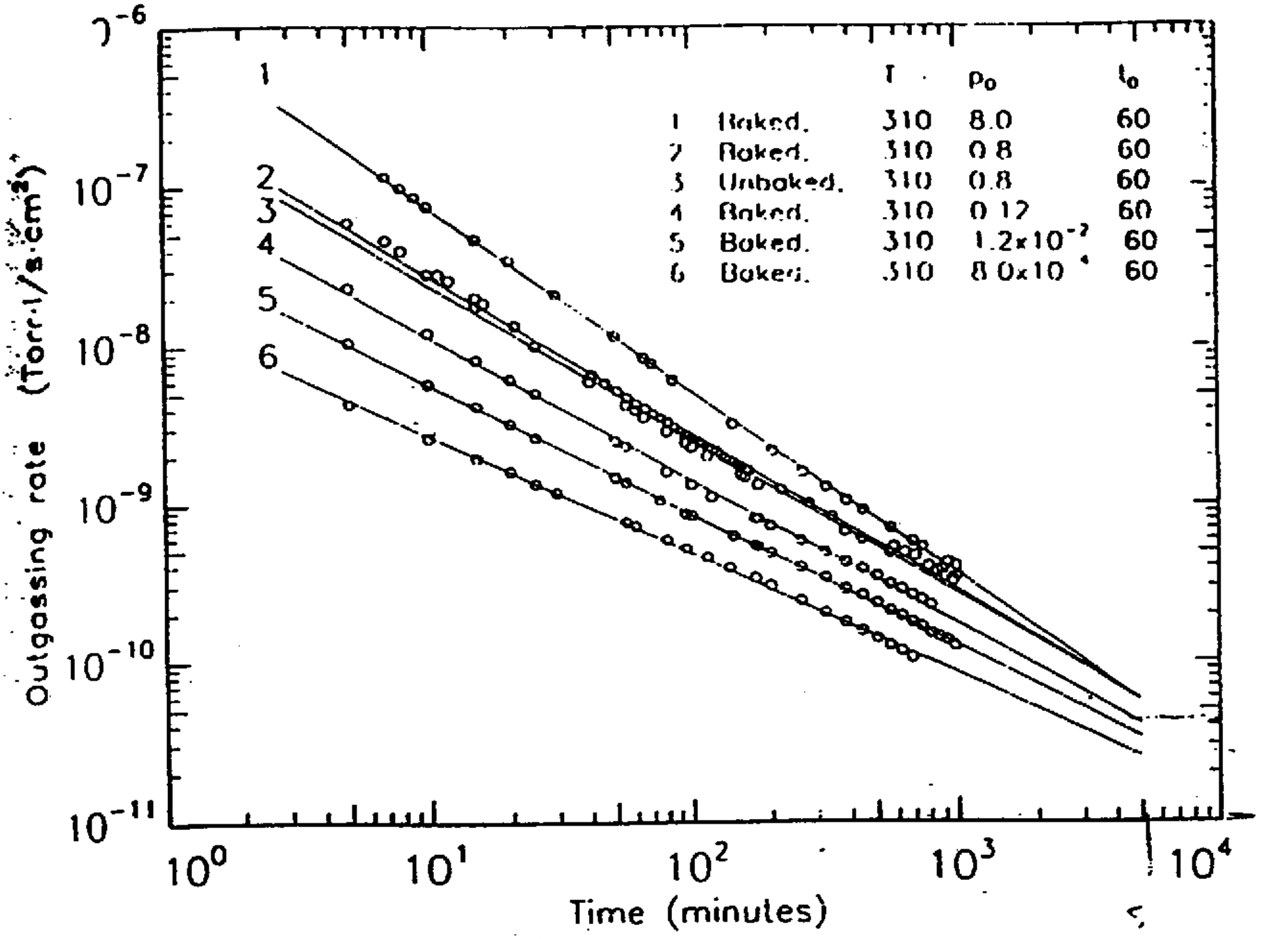


FIG. 1. Typical outgassing measurements for different H_2O exposure pressures in a log(Q) vs log(t) plot.

Vacuum/volume 20/number 1 Pergamon Press Ltd/Printed in Great Britain

R S Barton and R P Govier: The effect of cleaning technique on

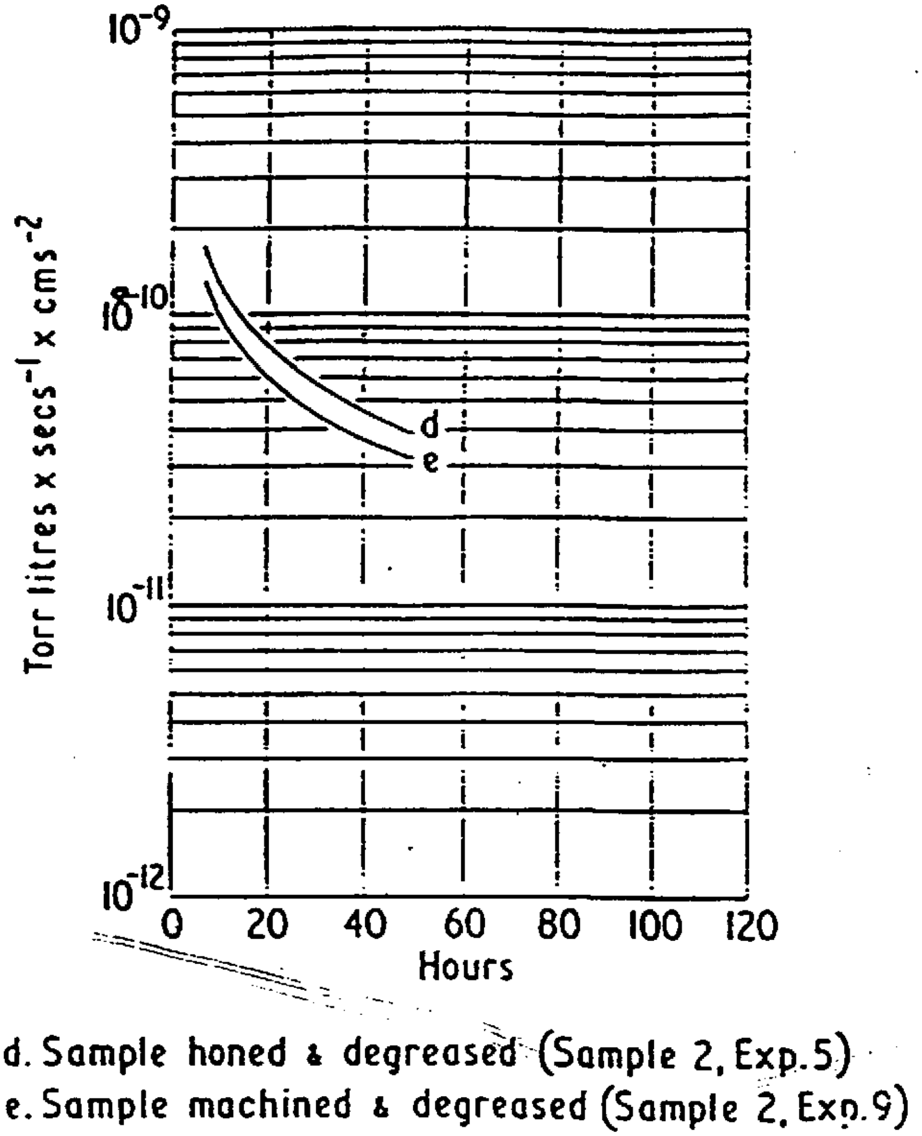
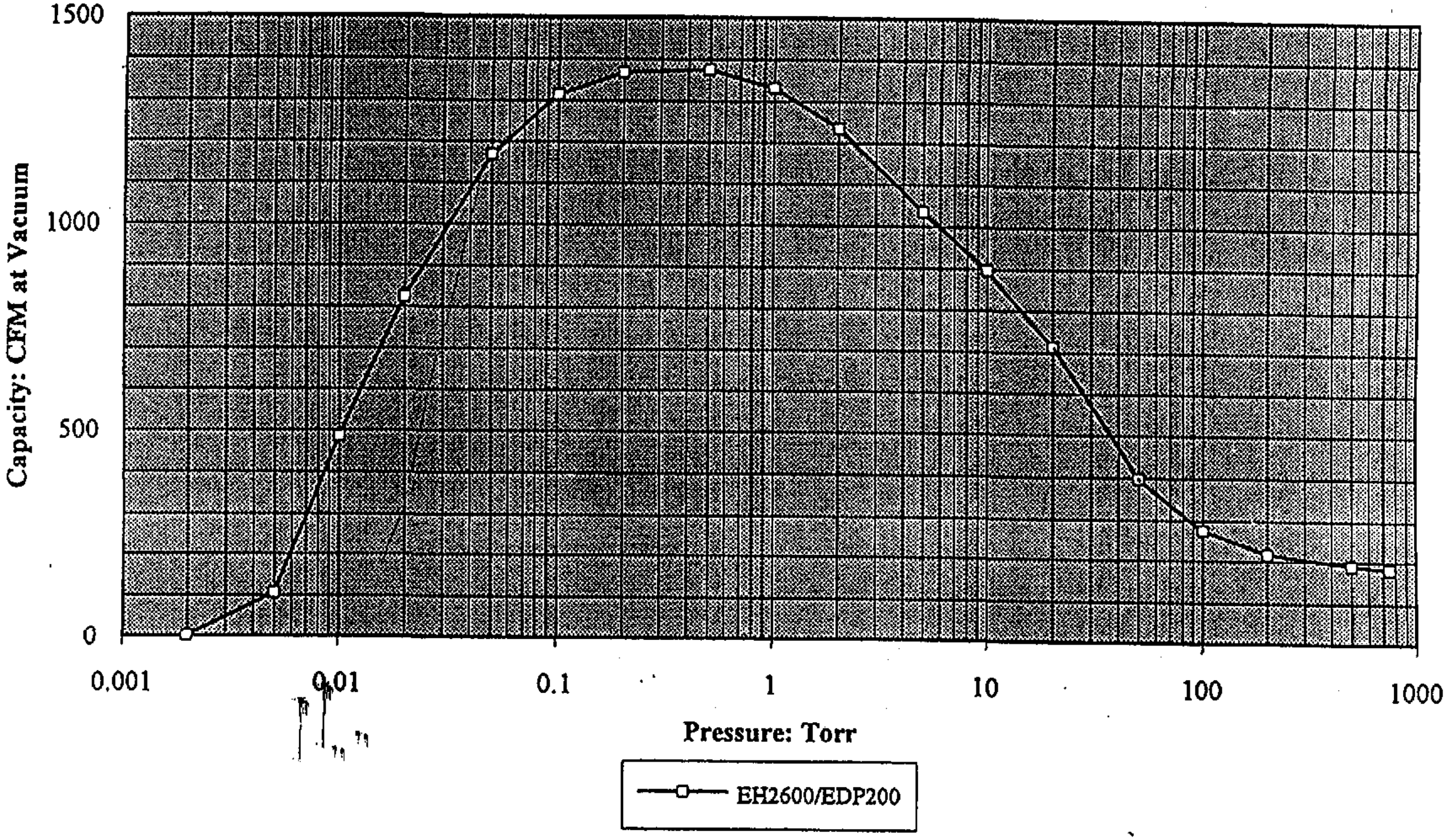
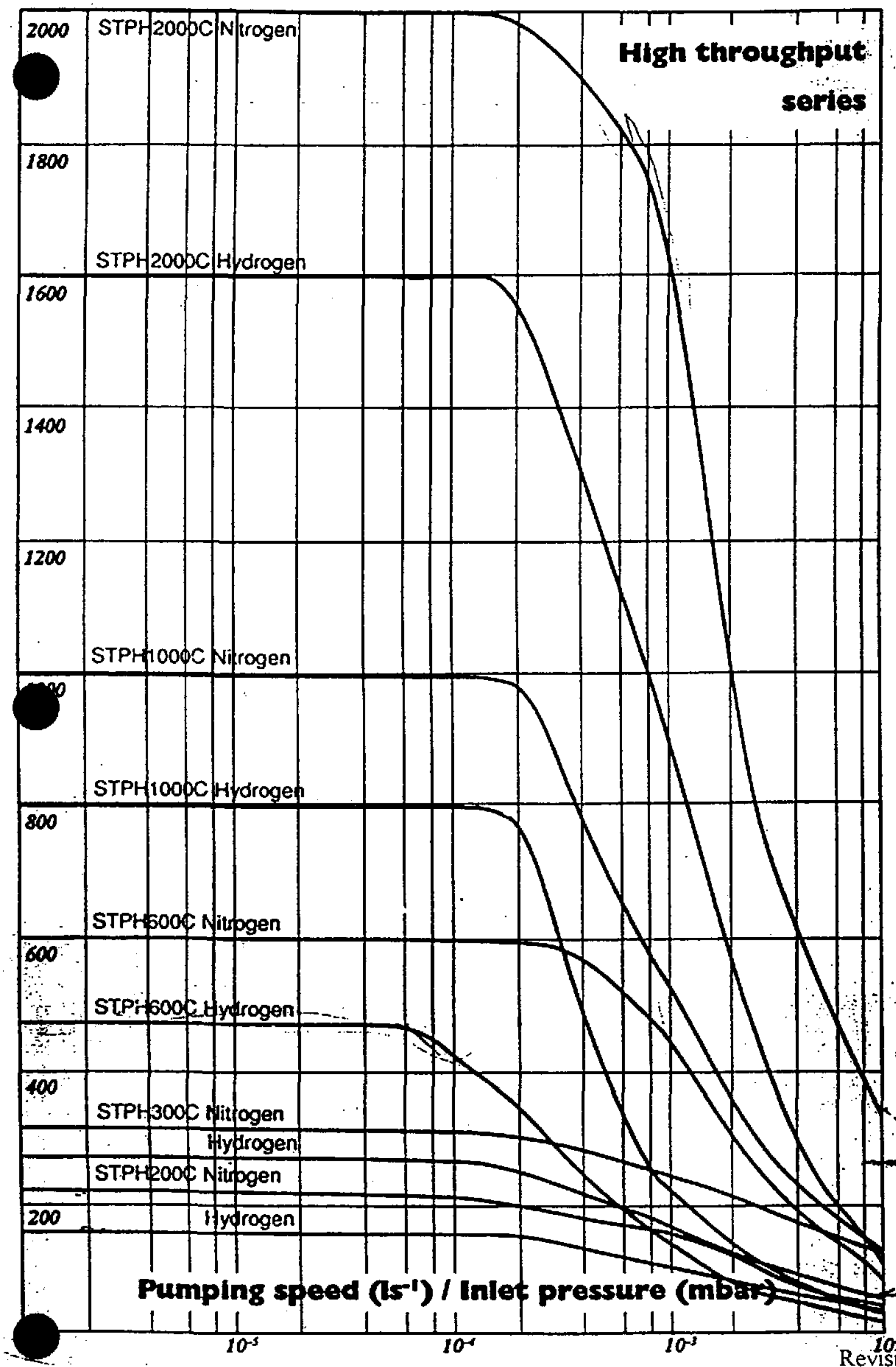
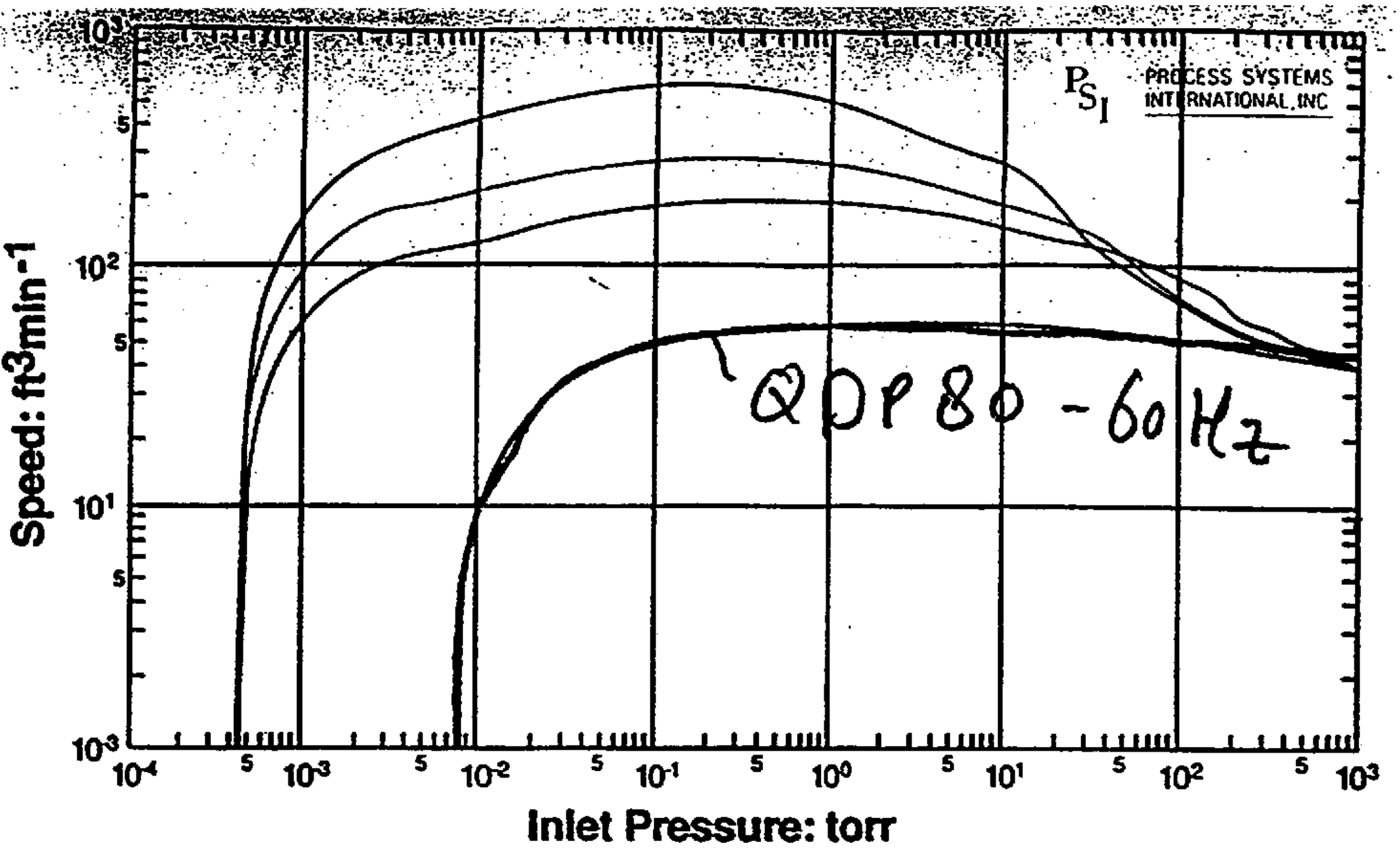


Figure 6. Total outgassing per cm^2 of sample as a function of pumping time.

EDP200/Booster Combinations

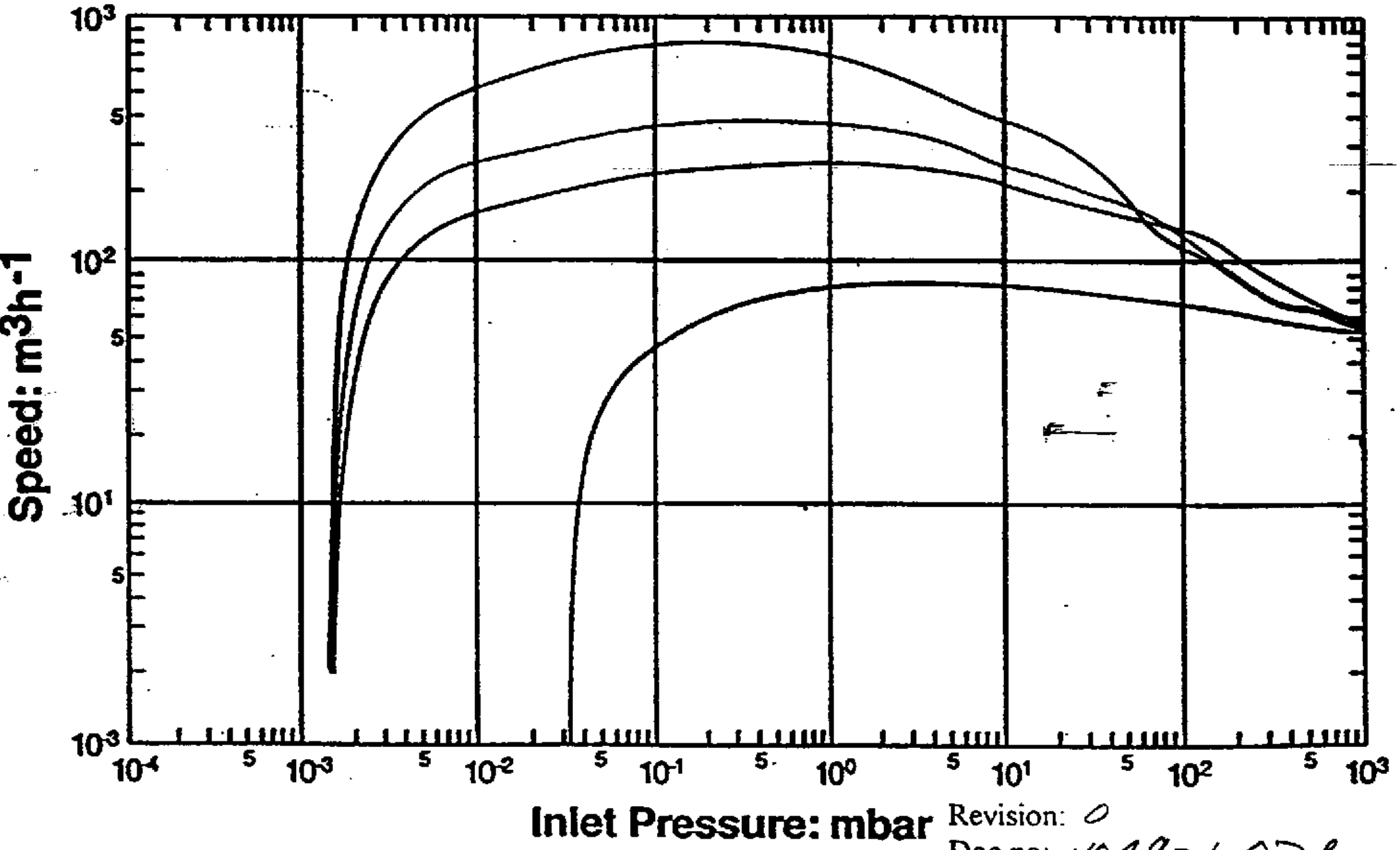



High throughput series
STPH2000C Nitrogen
STPH2000C Hydrogen
STPH1000C Nitrogen
STPH1000C Hydrogen
STPH600C Nitrogen
STPH600C Hydrogen
STPH300C Nitrogen
Hydrogen
STPH200C Nitrogen
Hydrogen
2000
1800
1600
1400
1200
1000
800
600
400
200
Pumping speed (ls^{-1}) / Inlet pressure (mbar)
10^{-5}
10^{-4}
10^{-3}
10^{-2}



QDP80 - 60 Hz

QMB1200 + QDP80 50Hz QMB500 + QDP80 50Hz
QMB250 + QDP80 50Hz QDP80 50Hz



Revision: 0
Doc no: V049-1-078
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PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

REV.	DEO #	DATE	BY:	CHECK
0	0038	1/3/96	D. Moore	D.M.W.
1	0052	1/29/96	D. Moore	D.M.W.
2	0296	8/20/96	D. Moore	

ENGINEERING CALCULATIONS

NO: V049-1-033

PAGE 1 OF 26

TITLE: Heat Load Calculations on Clean (No frost) 80K Pumps from Beam Tube & Vacuum Chamber

By: David Moore **DEPT.:** 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: To determine heat loads on long and short pumps in their clean condition due to thermal radiation exchange with the pump vacuum chamber and the beam tube.

METHOD: Radiation network equations.

ASSUMPTIONS: 1. One radiation shield in the vacuum annulus surrounding the pump LN_2 reservoir.
2. Low emissivity (.06) thermal sleeves in beam tube.
3. Pumps in clean condition.

INPUTS:

REFERENCES: 1. Heat Transfer, J.P. Holman, 3rd ed., McGraw-Hill.
2. Thermal Radiation Heat Transfer, Siegel & Howell, McGraw-Hill

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Radiation shield temp. = 269.5 K

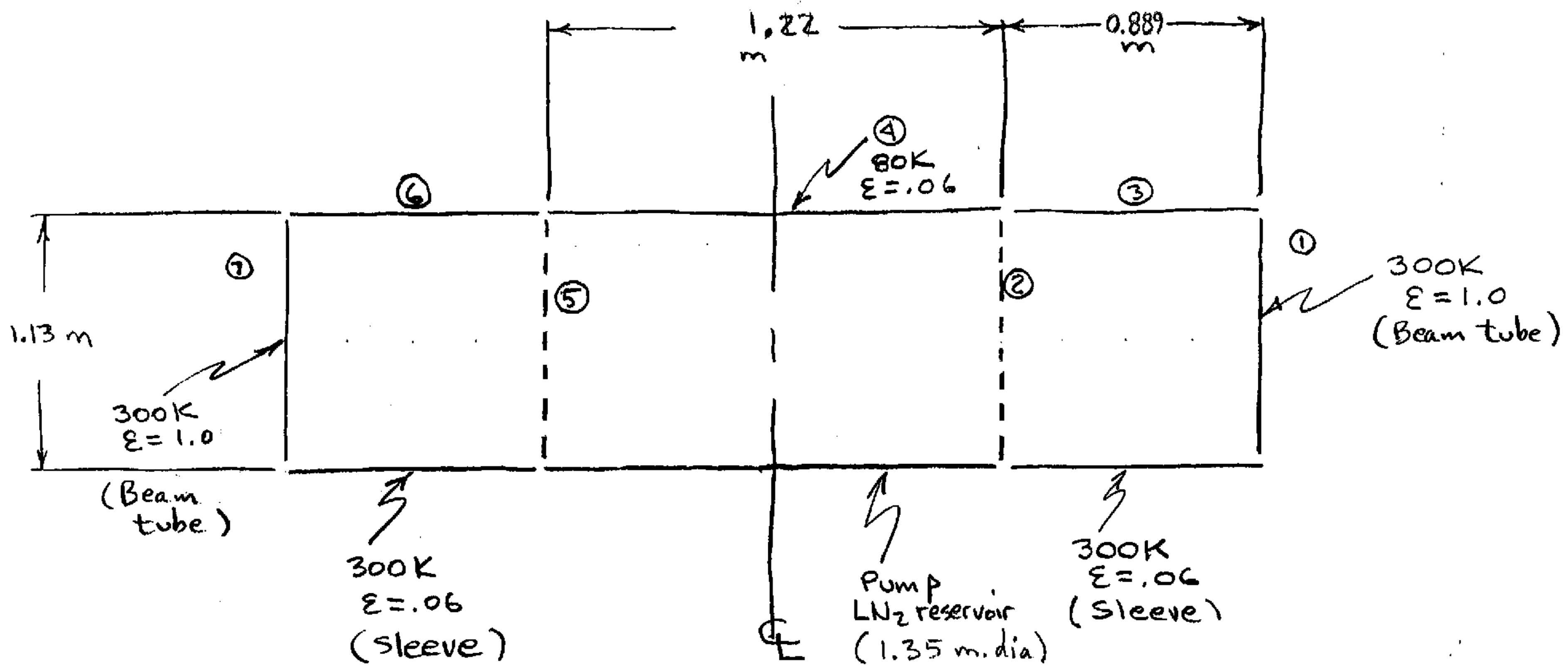
Long Pump (clean): 258 watts (from beam tube)
176 watts (from vac. cham.)
434 watts Total

Short Pump (clean): 117.0 watts
64.0 watts
181.0 total

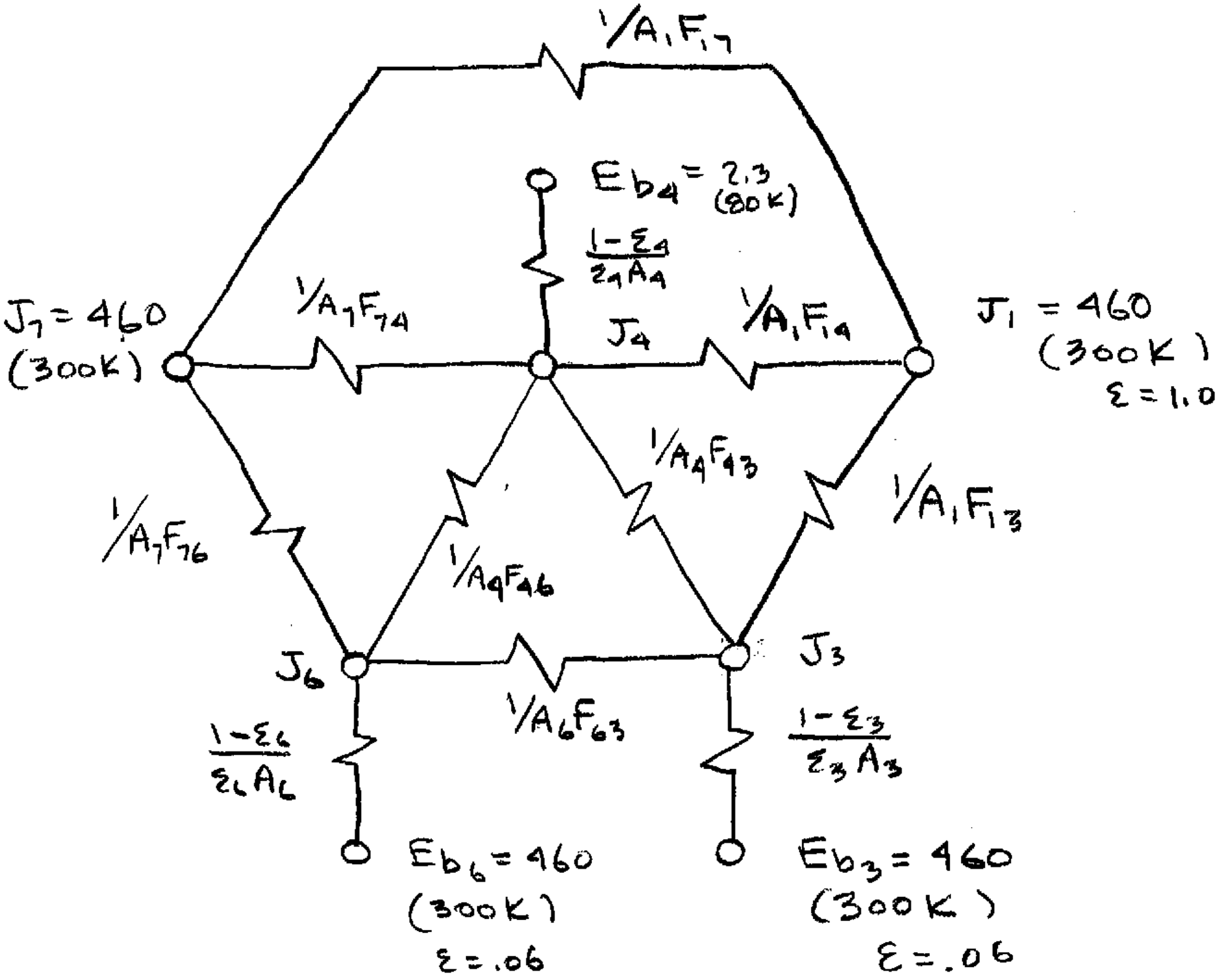
NOTES:

Pg 1 of 23

Short Pump
(No Frost)



Surfaces ② & ⑤ are fictitious surfaces used to simplify view factor calculations



Clean Pump

$\varepsilon_4 = .06$

View Factors

F_{12} : $\frac{d}{x} = \frac{1.13}{0.889} = 1.27$

$\therefore F_{12} = 0.25$ (Heat Transfer, Holman, 3rd ed., pp. 249)

Radiation Heat Transfer 249

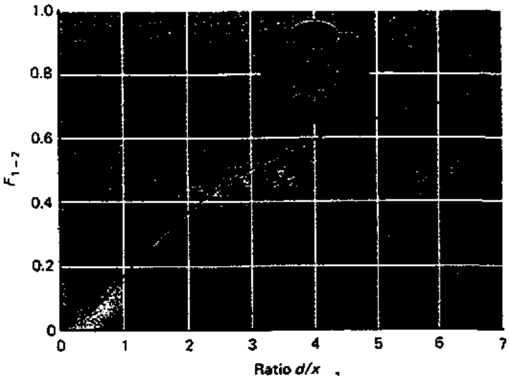


Fig. 8-13 Radiation shape factor for radiation between parallel disks.

$F_{13} = 1 - F_{12}$
$= 0.75$

F_{15} : $\frac{d}{x} = \frac{1.13}{(.889+1.22)} = 0.54$

$F_{15} = 0.07$

$\therefore F_{14} = F_{12} - F_{15}$
$= 0.25 - 0.07 = 0.18$

F_{17} : $\frac{d}{x} = \frac{1.13}{2(.889)+1.22} = 0.38$

$F_{17} = 0.04$

$F_{76} = F_{13} = 0.75$

$$F_{41} = \frac{A_1}{A_4} F_{14} = \frac{\pi/4\,(1.13)^2}{\pi(1.13)(1.22)}(.18)$$

$F_{41} = .042$

F_{25} : $\frac{d}{x} = \frac{1.12}{1.22} = 0.92$

$F_{25} = 0.15$

$F_{24} = 1 - F_{25}$
$= 0.85$

$$F_{42} = \frac{A_2}{A_4} F_{24}$$

$$= \frac{(\pi/4)(1.13)^2}{\pi(1.13)(1.22)} (.85)$$

$$= 0.197$$

$$F_{43} = F_{42} - F_{41}$$

$$= 0.197 - .042$$

$$= 0.15$$

Surface resistances

$$\frac{1-\varepsilon_4}{\varepsilon_4 A_4} = \frac{1-.06}{.06\pi(1.35)(1.22)}$$

$$= 3.03$$

$$\frac{1-\varepsilon_3}{\varepsilon_3 A_3} = \frac{1-0.06}{.06\pi(1.13)(.889)}$$

$$= 4.96$$

Geometry resistance :

$$\frac{1}{A_1 F_{14}} = 1/(\frac{\pi}{4}(1.13)^2(.18)) = 5.54$$

$$\frac{1}{A_4 F_{43}} = 1/(\pi(1.13\ (1.22)(.15)) = 1.54$$

$$\frac{1}{A_1\ F_{13}} = 1/(\frac{\pi}{4}(1.13)^2(.75, = 1.33$$

Sum currents

④ $$\frac{2.3 - J_4}{3.03} + 2\frac{(460 - J_4)}{5.54} + 2\frac{(J_3 - J_4)}{1.54} = 0$$

$(J_3 = J_6)$

③ $$\frac{460 - J_3}{1.33} + \frac{460 - J_3}{4.96} + \frac{J_4 - J_3}{1.54} = 0$$

From ④

$$.759 - .330 J_4 + 166.06 - .36 J_4 + 1.30 J_3 - 1.30 J_4 = 0$$

$$1.30 J_3 - 1.99 J_4 = -166.82$$

From ③

$$345.86 - .752 J_3 + 92.74 - .202 J_3 + .650(J_4 - J_3) = 0$$

$$-1.604 J_3 + .650 J_4 = -438.60$$

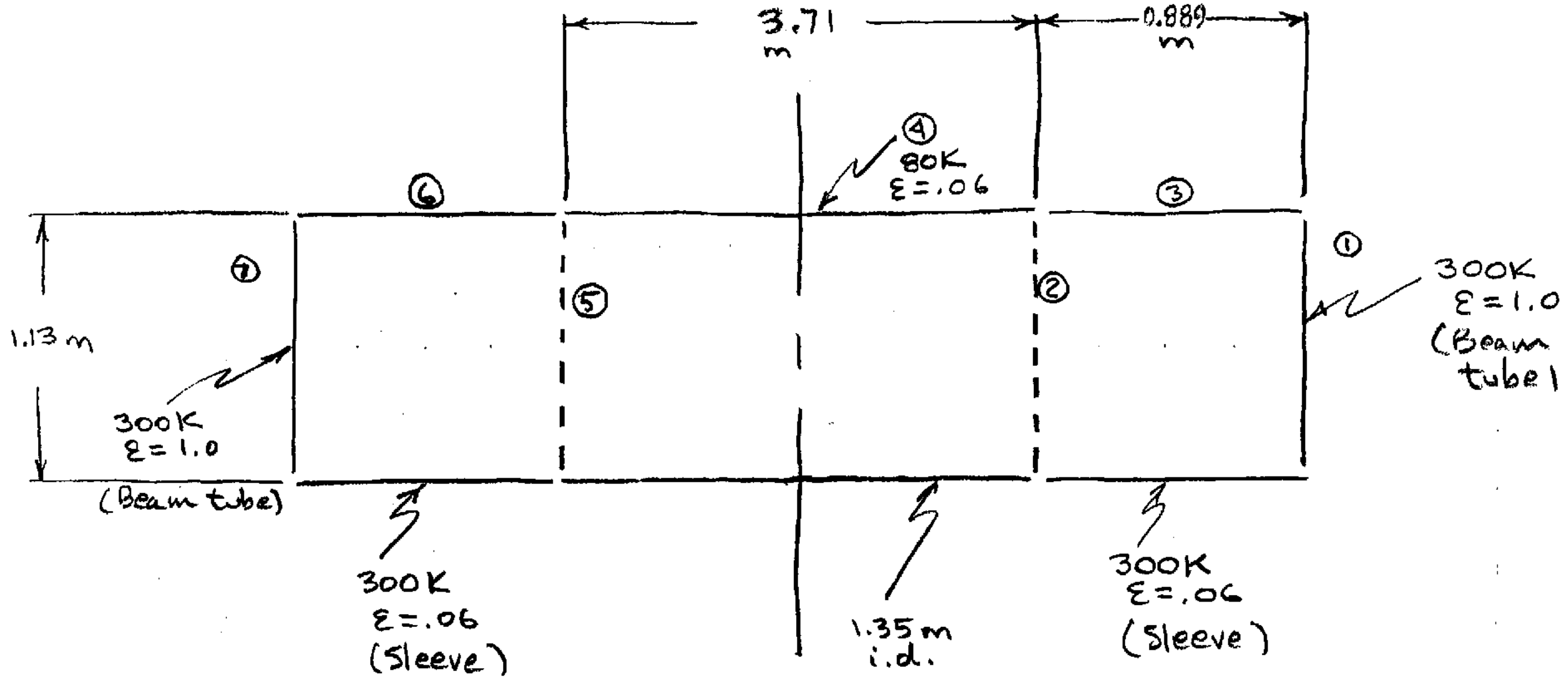
```
     1.3    -1.99           matrix              -166.82  constants
  -1.604     0.65                                -438.6


-0.27695 -0.84791
-0.68344 -0.55391           inverse


   J3=   418.0928 solution
   J4=   356.9551
```

$$Q_4 = (J_4 - E_{b4}) \Big/ \frac{1-\varepsilon_4}{\varepsilon_4 A_4}$$

$$= (356.96 - 2.3) / 3.03$$

$$= 117 \text{ watts}$$

Long Pump
(No Frost)



Surfaces ② & ⑤ are fictitious surfaces used to simplify view factor calculations.

View Factors :

F_{12} : $\frac{d}{x} = \frac{1.13}{.889} = 1.27$

$\therefore F_{12} = .25$ (Heat Transfer, Holman, 3rd ed., pp 249)

$F_{13} = 1 - F_{12}$

$= .75$

F_{15} : $\frac{d}{x} = \frac{1.13}{(.889+3.71)} = .245$

$F_{15} = 0.03$

$\therefore F_{14} = F_{12} - F_{15}$

$= .12 - .03 = .09$

F_{17} : $\frac{d}{x} = \frac{1.13}{2(.889)+3.71} = .205$ $F_{17} = .025$

$F_{76} = F_{13} = .75$

$F_{41} = \frac{A_1}{A_4} F_{14} = \frac{\pi/4\,(1.13)^2}{\pi\,(1.13)(3.71)}(.09)$

$F_{41} = .007$

F_{25} : $\frac{d}{x} = \frac{1.13}{3.71} = .30$

$F_{25} = .04$ $\therefore F_{24} = 1 - F_{25}$

$= .96$

$$F_{42} = \frac{A_2}{A_4} F_{24}$$

$$= \frac{(\pi/4)(1.13)^2}{\pi(1.13)(3.71)} (.96)$$

$$= .073$$

$$F_{43} = F_{42} - F_{41}$$

$$= .073 - .007$$

$$= .066$$

Surface resistances :

$$\frac{1-\varepsilon_4}{\varepsilon_4 A_4} = \frac{1-.06}{.06(\pi)(1.35)(3.71)}$$

$$= 1.00$$

$$\frac{1-\varepsilon_3}{\varepsilon_3 A_3} = \frac{1-.06}{.06(\pi)(1.13)(1.5)}$$

$$= 2.94$$

Geometry resistance :

$$\frac{1}{A_1 F_{14}} = \frac{1}{\frac{\pi}{4}(1.13)^2(.09)} = 11.08$$

$$\frac{1}{A_4 F_{43}} = \frac{1}{\pi(1.35)(3.71)(.066)} = 0.97$$

$$\frac{1}{A_1 F_{13}} = \frac{1}{\frac{\pi}{4}(1.13)^2(.75)} = 1.33$$

Sum currents :

④ $$\frac{2.3 - J_4}{1.00} + 2\frac{(460 - J_4)}{11.08} + 2\frac{(J_3 - J_4)}{0.97} = 0$$

$(J_3 = J_6)$

③ $$\frac{460 - J_3}{1.13} + \frac{460 - J_3}{2.94} + \frac{J_4 - J_3}{0.97} = 0$$

From ④

$$2.30 - 1.00 J_4 + 83.03 - .181 J_4 + 2.06 J_3 - 2.06 J_4 = 0$$

$$2.06 J_3 - 3.24 J_4 = -85.33$$

From ③ $$407.08 - .885 J_3 + 156.46 - .340 J_3 + 1.03(J_4 - J_3) = 0$$

$$-2.26 J_3 + 1.03 J_4 = -563.54$$

```
   J3=    367.9882 solution
   J4=    260.3042
    2.06     -3.24           matrix           -85.33  constants
   -2.26      1.03                           -563.54


-0.19805 -0.62301
-0.43457 -0.39611            inverse


   J3=    367.9882 solution
   J4=    260.3042
```

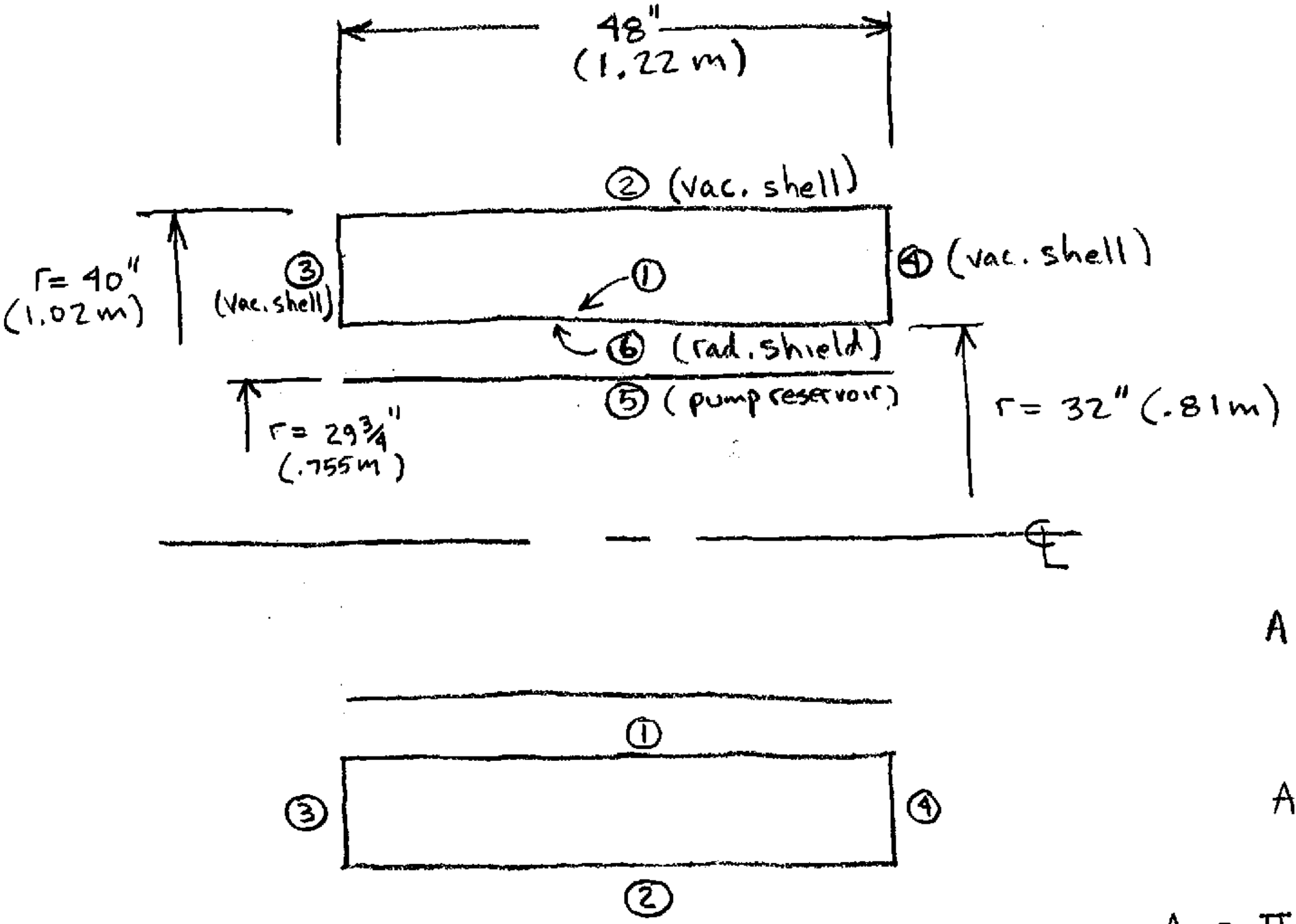
$$Q_4 = (J_4 - E_{b4}) \Big/ \frac{1-\varepsilon_4}{\varepsilon_4 A_4}$$

$$= (260.3 - 2.3)/1.00$$

$$= 258 \text{ watts}$$

Pump Radiation
Shield Thermal
Calculations

Short Pump Radiation Shield



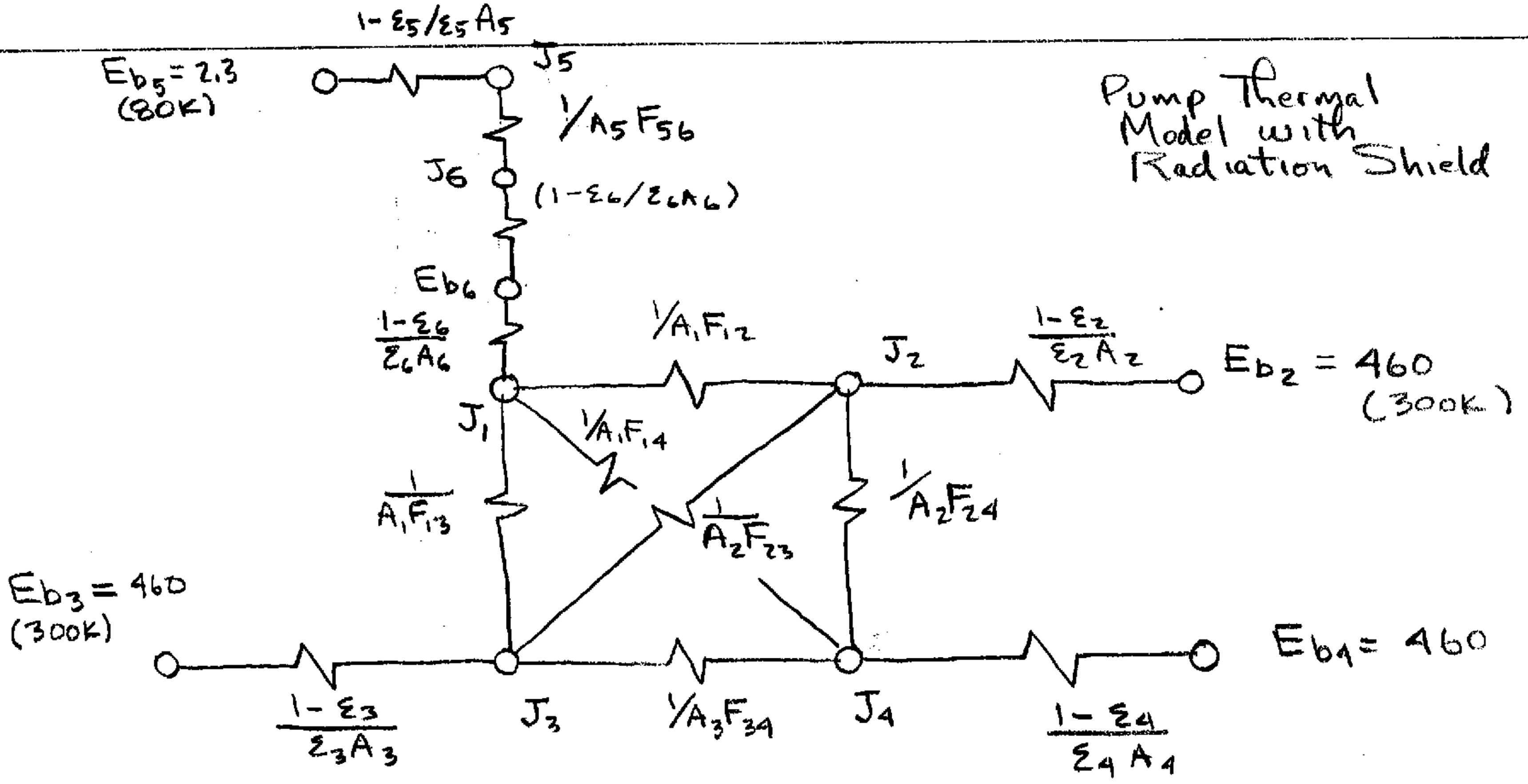
$$A_1 = \frac{2\pi(32)(48)}{(39.4)^2} = 6.22\ m^2$$

$$A_2 = \frac{2\pi(40)(48)}{(39.4)^2} = 7.77\ m^2$$

$$A_3 = \pi(40^2 - 32^2)/(39.4)^2 = 1.17\ m^2$$

$$A_5 = \frac{2\pi(29.75)(48)}{(39.4)^2} = 5.78\ m^2 \qquad A_4 = A_3 = 1.17\ m^2$$

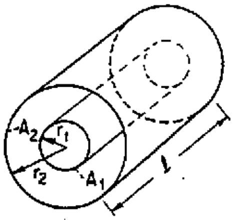
Pump Thermal Model with Radiation Shield



View Factor
Pump Shield to Chamber

(Siegel & Howell)

25



Two concentric cylinders of same finite length.

$R = \frac{r_2}{r_1} \qquad L = \frac{l}{r_1}$

$A = L^2 + R^2 - 1$

$B = L^2 - R^2 + 1$

$$F_{2\text{-}1} = \frac{1}{R} - \frac{1}{\pi R}\left\{\cos^{-1}\left(\frac{B}{A}\right) - \frac{1}{2L}\left[\sqrt{(A+2)^2 - (2R)^2}\cos^{-1}\left(\frac{B}{RA}\right) + B\sin^{-1}\left(\frac{1}{R}\right) - \frac{\pi A}{2}\right]\right\}$$

$$F_{2\text{-}2} = 1 - \frac{1}{R} + \frac{2}{\pi R}\tan^{-1}\left(\frac{2\sqrt{R^2-1}}{L}\right) - \frac{L}{2\pi R}\left\{\frac{\sqrt{4R^2+L^2}}{L}\sin^{-1}\left[\frac{4(R^2-1) + (L^2/R^2)(R^2-2)}{L^2 + 4(R^2-1)}\right] - \sin^{-1}\left(\frac{R^2-2}{R^2}\right) + \frac{\pi}{2}\left(\frac{\sqrt{4R^2+L^2}}{L} - 1\right)\right\}$$

where for any argument ξ:

$-\frac{\pi}{2} \leqslant \sin^{-1}\xi \leqslant \frac{\pi}{2}$

$0 \leqslant \cos^{-1}\xi \leqslant \pi$

Short Pump:

$R = \frac{40''}{32''} = 1.25$

$L = 48/32 = 1.5$

$A = 1.5^2 + 1.25^2 - 1 = 2.81$

$B = 1.5^2 - 1.25^2 + 1 = 1.69$

$\cos^{-1}\left(\frac{B}{A}\right) = .926$

$\cos^{-1}\left(\frac{B}{RA}\right) = 1.069$

$\sin^{-1}\left(\frac{1}{R}\right) = .927$

$$F_{2-1} = \frac{1}{1.25} - \frac{1}{\pi(1.25)}\left\{ .926 - \frac{1}{2(1.5)}\left[\sqrt{4.81^2 - 2.5^2} \times 1.069 + 1.69(.927) - \frac{\pi(2.81)}{2}\right]\right\}$$

$F_{2-1} = .695$ (Results same for long pump)

From view factor algebra

$$A_1 F_{1-2} = A_2 F_{2-1}$$

$$F_{1-2} = \frac{A_2}{A_1} F_{2-1} = \frac{D_2}{D_1} F_{2-1}$$

$$\therefore F_{1-2} = \left(\frac{80}{64}\right)(.695)$$

$$\underline{F_{1-2} = .869}$$

F_{2-2} :

$$\tan^{-1}\left(\frac{2\sqrt{1.25^2-1}}{1.5}\right) = .7854$$

$$\sin^{-1}\left(\frac{1.25^2-2}{1.25^2}\right) = -.284$$

$$\frac{\sqrt{4(1.25)^2+(1.5)^2}}{1.5} = 1.944$$

$$\sin^{-1}\left(\frac{4(1.25^2-1) + (1.5^2/1.25^2)(1.25^2-2)}{1.5^2+4(1.25^2-1)}\right) = .368$$

$$F_{2-2} = 1 - \frac{1}{1.25} + \frac{2}{\pi(1.25)}(.785)$$

$$- \frac{1.5}{2\pi(1.25)}\left\{ 1.944(.368) - (-.284) + \frac{\pi}{2}(1.302 - 1)\right\}$$

$$F_{2-2} = .318$$

From view factor algebra

$$F_{2-1} + F_{2-2} + F_{2-3} + F_{2-4} = 1.0$$

$$.695 + .318 + 2F_{2-3} = 1.0$$ (Not exactly = 1.0 due to round-off error)

$$\therefore F_{2-3} < .01 \quad (\text{use } .01)$$

$$\& \; F_{2-4} < .01$$

$$\& \quad F_{1-2} + F_{1-3} + F_{1-4} = 1.0$$

$$F_{1-2} + 2F_{1-3} = 1.0$$

$$.869 + 2F_{1-3} = 1.0$$

$$F_{1-3} = .0655$$

$$F_{1-4} = .0655$$

$$A_2 F_{2-3} = A_3 F_{3-2}$$

$$F_{3-2} = \left(\frac{7.77}{1.17}\right)(.01) = .066$$

$$A_1 F_{1-3} = A_3 F_{3-1}$$

$$F_{3-1} = \left(\frac{6.22}{1.17}\right)(.0655)$$

$$= .348$$

$$F_{3-1} + F_{3-2} + F_{3-4} = 1.0$$

$$\therefore F_{3-4} = .586 \quad \& \; F_{4-3} = .586 \quad \& \; F_{1-5} \approx 1.0$$

$E_{b5} = \sigma(80)^4 = 2.3 \ w/m^2$

$E_{b2} = E_{b3} = E_{b4} = \sigma(300)^4 = 460 \ w/m^2$

Unknowns: J_1, J_2, J_3; $J_3 = J_4$ by symmetry
J_6, E_{b6}, J_5

$\frac{1-\varepsilon_5}{\varepsilon_5 A_5} = \frac{1-.06}{.06(5.78)} = 2.710$ $\qquad$ $\frac{1-\varepsilon_3}{\varepsilon_3 A_3} = \frac{1-0.3}{0.3(1.17)} = 1.994$

$\frac{1-\varepsilon_2}{\varepsilon_2 A_2} = \frac{1-0.3}{0.3(7.77)} = 0.300$ $\qquad$ $\frac{1-\varepsilon_4}{\varepsilon_4 A_4} = 1.994$

$\frac{1-\varepsilon_6}{\varepsilon_6 A_6} = \frac{1-.06}{.06(6.22)} = 2.519$

$\frac{1}{A_1 F_{12}} = \frac{1}{6.22(.869)} = .185$ $\qquad$ $\frac{1}{A_1 F_{13}} = \frac{1}{6.22(.0655)} = 2.455$

$\frac{1}{A_2 F_{24}} = \frac{1}{7.77(.01)} = 12.87$ $\qquad$ $\frac{1}{A_1 F_{14}} = \frac{1}{6.22(.0655)} = 2.455$

$\frac{1}{A_2 F_{23}} = \frac{1}{7.77(.01)} = 12.87$ $\qquad$ $\frac{1}{A_3 F_{34}} = \frac{1}{1.17(.586)} = 1.459$

$\frac{1}{A_1 F_{15}} = \frac{1}{6.22(1.0)} = .1608$

$\frac{1}{A_5 F_{56}} = \frac{1}{5.78(1.0)} = .1730$

Sum the currents into the nodes

① J_1 : $\dfrac{E_{b_6} - J_1}{2.519} + \dfrac{J_2 - J_1}{.185} + \dfrac{J_3 - J_1}{2.455} + \dfrac{J_4 - J_1}{2.455} = 0$ ✓

② J_2 : $\dfrac{J_1 - J_2}{.185} + \dfrac{460 - J_2}{0.300} + \dfrac{J_3 - J_2}{12.87} + \dfrac{J_4 - J_2}{12.87} = 0$

③ J_3 : $\dfrac{460 - J_3}{1.994} + \dfrac{J_1 - J_3}{2.455} + \dfrac{J_2 - J_3}{12.87} + \cancelto{0}{\dfrac{J_4 - J_3}{1.459}} = 0$

④ J_4 : $\dfrac{460 - J_4}{1.994} + \dfrac{J_2 - J_4}{12.87} + \dfrac{J_1 - J_4}{2.455} + \cancelto{0}{\dfrac{J_3 - J_4}{1.459}} = 0$

(not an independent equation)

⑤ J_5 : $\dfrac{2.3 - J_5}{2.710} + \dfrac{J_6 - J_5}{.1730} = 0$

⑥ J_6 : $\dfrac{J_5 - J_6}{.1730} + \dfrac{E_{b_6} - J_6}{2.519} = 0$

⑦ E_{b_6} : $\dfrac{J_6 - E_{b_6}}{2.519} + \dfrac{J_1 - E_{b_6}}{2.519} = 0$

From ① $.397E_{b_6} - .397J_1 + 5.405J_2 - 5.405J_1 + .407J_3 - .407J_1$

$+ .407J_3 - .407J_1 = 0$

$.397E_{b_6} - 6.618J_1 + 5.405J_2 + .814J_3 = 0$

From ② $5.405J_1 - 5.405J_2 + 1533.33 - 3.333J_2 + .0777J_3$

$- .0777J_2 + .0777J_3 - .0777J_2 = 0$

$5.405J_1 - 8.893J_2 + .1554J_3 = -1533.33$

From ③ $230.692 - .502J_3 + .407J_1 - .407J_3$

$+ .0777J_2 - .0777J_3 = 0$

$.407J_1 + .0777J_2 - .987J_3 = -230.692$

From ⑤ $.849 - .369 J_5 + 5.78 J_6 - 5.78 J_5 = 0$

$$-6.149 J_5 + 5.78 J_6 = -.849$$

From ⑥ $5.78 J_5 - 5.78 J_6 + .397 E_{b6} - .397 J_6 = 0$

$$5.78 J_5 - 6.177 J_6 + .397 E_{b6} = 0$$

From ⑦ $.397 J_6 - .397 E_{b6} + .397 J_1 - .397 E_{b6} = 0$

$$.397 J_1 + .397 J_6 - .794 E_{b6} = 0$$

$$\begin{bmatrix} -6.618 & 5.405 & .814 & 0 & 0 & .397 \\ 5.405 & -8.893 & .1554 & 0 & 0 & 0 \\ .407 & .0777 & -.987 & 0 & 0 & 0 \\ 0 & 0 & 0 & -6.149 & 5.78 & 0 \\ 0 & 0 & 0 & 5.78 & -6.177 & .397 \\ .397 & 0 & 0 & 0 & .397 & -.794 \end{bmatrix} \begin{bmatrix} J_1 \\ J_2 \\ J_3 \\ J_5 \\ J_6 \\ E_{b6} \end{bmatrix} = \begin{bmatrix} 0 \\ -1533 \\ -230.692 \\ -.849 \\ 0 \\ 0 \end{bmatrix}$$

```
 -6.618    5.405    0.814        0          0    0.397          0
  5.405   -8.893   0.1554        0          0        0   -1533.33
  0.407   0.0777   -0.987        0          0        0   -230.692
      0        0        0   -6.149       5.78        0     -0.849
      0        0        0     5.78     -6.177    0.397          0
  0.397        0        0        0      0.397   -0.794          0

-0.37828 -0.23296 -0.34865 -0.12942 -0.137687 -0.25798
-0.23296 -0.25607 -0.23244  -0.0797 -0.084793 -0.15888
-0.17433 -0.11622 -1.17524 -0.05964 -0.063452 -0.11889
-0.12942  -0.0797 -0.11929  -1.8271 -1.770734 -0.95008
-0.13769 -0.08479  -0.1269 -1.77073 -1.883779 -1.01073
-0.25798 -0.15888 -0.23778 -0.95008 -1.010733  -1.8938

solution
  J1=   437.7435
  J2=   446.3248
  J3=   449.3749
  J5=    151.283
  J6=   160.7942
  Eb6=  299.2688
```

(Matrix inversion)

∴ Heat load on pump reservoir is:

$$\frac{J_5 - E_{b5}}{\left(\frac{1-\varepsilon_5}{\varepsilon_5 A_5}\right)} = \frac{151.28 - 2.3}{2.71}$$

$$= 55 \text{ watts}$$

For long pump the load may be scaled up by the length ratios to give a good approximation

$$\therefore \quad Q_{\substack{\text{Long}\\ \text{pump}}} = 55\left(\frac{146''}{48''}\right)$$

$$= 167 \text{ watts}$$

Shield temp $= \left(\frac{299.27}{5.67 \times 10^{-8}}\right)^{1/4} = 269.5 \text{ K}$

Calculation of Heat Load From Ends of 80K Pump*

For floating shield, the temperature of the shield was calculated from the computer model of the single pump shield as 269.5 K

Area of ends: $A = \frac{\pi}{4}(D_o^2 - D_i^2) \times 2$ ends

$= \frac{\pi}{4}(57.5^2 - 53^2) \times 2 \times 6.45$

$= 5038\ cm^2$

$Q = \sigma A \varepsilon F (T_1^4 - T_2^4)$

$= (5.67\times10^{-12})(5038)(.06)((269.5)^4 - (80)^4)$

$= \underline{9.0\ watts}$

* Ends of pump LN_2 reservoir are shielded from pump vacuum chamber.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-037 PAGE 1 OF 7
REV.	**DEO #**	**DATE**	**BY:**	**CHECK**	**TITLE:** Steady State LN_2 Requirements for 80K Pump and Two Phase Flow Regime Calculations for Supply Line	
0	0041	1/9/96	D. Moore	D.m		
1	0056	1/30/96	D. Moore	D.m		
					By: David Moore	**DEPT.:** 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: To determine LN_2 consumption for 80K pump & determine supply line size / two phase flow regime

METHOD: · Standard methods on a spreadsheet and use of published charts for two phase flow.

SUMPTIONS: Steady state conditions

INPUTS: Heat flux calculations

REFERENCES:
1. LIGO doc. # V049-1-033
2. Published charts for two phase flow in vertical & horizontal pipes
3. Nitrogen properties from GASPAK (see pg. 8)

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS:
1. Short pump consumption: range = .0224 – .0614 gpm
2. Long pump consumption: range = .0479 – .0781 gpm
3. Use 1/2" pipe for supply line. Slug flow unavoidable if supply line downstream of control valve is vertical.

TES:

LN2 Requirements for
80K pumps

1/30/96

Heat Load Summary
(watts)

	Short Pump Clean	Short Pump Frosted	Long Pump Clean	Long Pump Frosted
Beam Tube Load	116	499	249	546
Vac. chamber	64	64	176	176
Supports (est.)	9	9	14	14
Pump subtotal	189	572	439	736
VJ pipe (55')	6.06	6.06	6.06	6.06
Valves (3)	12.1	12.1	12.1	12.1
Bayonets	12.39	12.39	12.39	12.39
Supply line subtotal	30.55	30.55	30.55	30.55
Pump & supply line total (watts)	219.55	602.55	469.55	766.55
LN2 Consump. (gpm)				
-pump	0.01926359	0.05830038	0.04474453	0.0750159
-supply line	0.00311377	0.00311377	0.00311377	0.0031138
Total (gpm)	0.02237736	0.06141416	0.0478583	0.0781297

V049-1-037
Pg 2 of 7

LIGO 80K Pump 1/30/96

Flow Regime in
supply line

```
+-----------------+
¦Two Phase Flow   ¦
¦Horizontal pipe  ¦
+-----------------+
```

Pipe dia. 1/2 in. 0.0562 ft.

		Long pump Clean	Long Pump Frosted	Short Pump Clean	Short Pump Frosted
Transf. line heat leak	watts	30.55	30.55	30.55	30.55
Pump heat leak	watts	439	736	189	736
Total heat leak	watts	469.55	766.55	219.55	766.55
Mixture quality		0.11970043	0.09493444	0.19248617	0.10559136
Liquid Flow Rate	gpm	0.0478583	0.0781297	0.02237736	0.06141416
Liquid Flow Rate	lb/min.	0.3206762	0.52351077	0.14994028	0.41150771
Vapor Flow Rate	lb/min.	0.03838508	0.0496992	0.02886143	0.04345166
Liquid density	lb/ft**3	50.12	50.12	50.12	50.12
Vapor density	lb/ft**3	0.3293	0.3293	0.3293	0.3293
Surface tension	dyne/cm	12.26	12.26	12.26	12.26
Liquid viscosity	cp	0.1449	0.1449	0.1449	0.1449
Mixture velocity	ft/sec	0.82636998	1.08446858	0.60911571	0.94194922
Lamdba(flow param.)		1.87943254	1.87943254	1.87943254	1.87943254
Psi(flow param.)		1.100466	1.100466	1.100466	1.100466
Pipe area	ft**2	0.00248	0.00248	0.00248	0.00248
Gf(flow/unit area)	lb/hr -ft**2	7758.29523	12665.5832	3627.58738	9955.83179
Gg(flow/unit area)	lb/hr -ft**2	928.67129	1202.4	698.260403	1051.24984
Gg/lambda		494.123237	639.767576	371.52725	559.344279
Gf(lambda)(Psi)/Gg		17.2785643	21.7861051	10.7449362	19.5873182
Flow Regime		stratified	stratified	stratified	stratified

```
+-----------------+
|Two Phase Flow   |
|Vertical pipe    |
+-----------------+

Volumetric gas
fraction            Fv        0.94796708 0.93527163 0.96699312 0.94142174
Froude No.          NFr       0.37783024 0.65070118 0.20528029 0.49091084
Flow Regime                   slug       slug       slug       slug
```

The boundaries between flow regime[illegible]e not sharp and the pictures used to d[illegible]ribe them represent idealized descriptions of a very complex distribution of phases.

Figure 9 shows the flow regimes which have been identified by Baker [6] in a horizontal pipe, and Fig. 10 is the flow regime map. The slug and plug regimes are

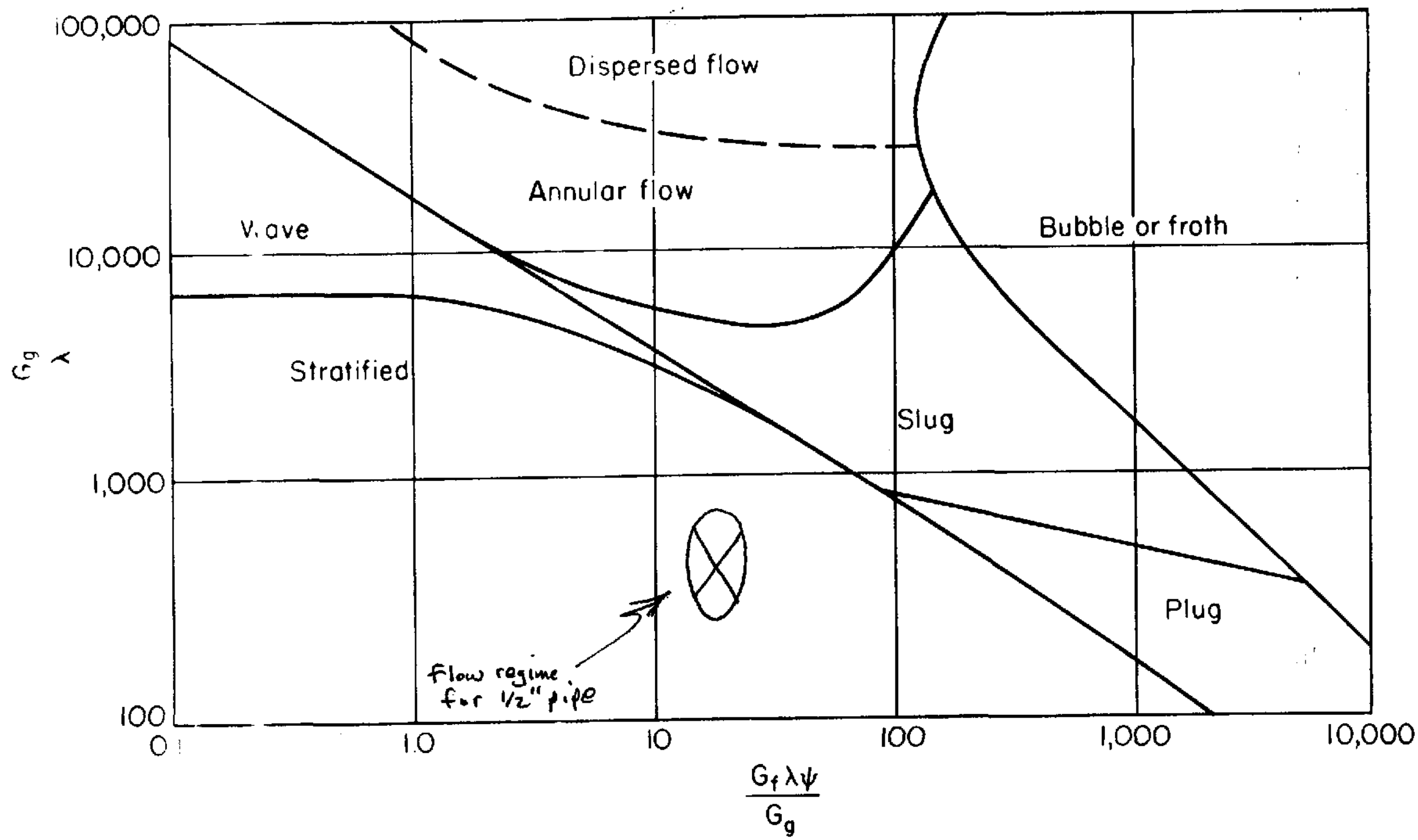


Fig. 10. Flow regime map for a horizontal pipe [6].

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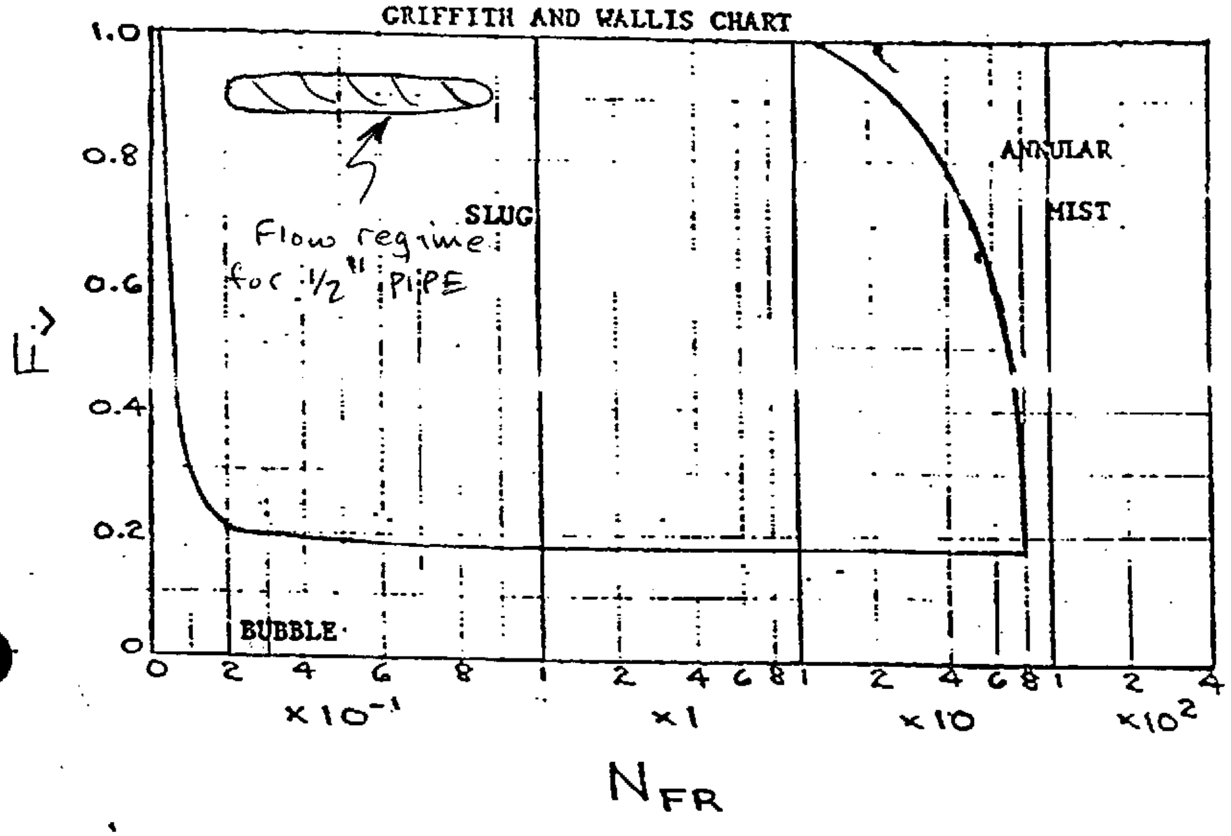
B) Vertical Lines

GRIFFITH AND WALLIS CHART



Nomenclature:

Fv = $Q_G/(Q_G+Q_L)$, flowing volumetric gas fraction

NFR = $\frac{(V_m)^2}{(g_c)(D_p)}$, Froude Number

Q_G = gas flow, ft^3/sec.

Q_L = liquid flow, ft^3/sec.

Vm = $\frac{(Q_G+Q_L)}{(A_p)}$, two phase mixture velocity, ft/sec.

Ap = cross sectional area of pipe, ft^2

Dp = diameter of pipe, ft

gc = gravitational constant, 32.2 ft/sec^2

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Nitrogen

```
   INPUT NEW VALUE  ONLY FOR TEMP                      INPUT 1
   QUIT                                                INPUT Q
   YOUR CHOICE ............................                  P

NAME THE FIRST INPUT VARIABLE
(B BACKS UP ONE STEP, Q STOPS, ? FOR HELP).........  PRESS

NAME THE SECOND INPUT VARIABLE
(B BACKS UP ONE STEP, Q STOPS, ? FOR HELP).......... SAT

INPUT VALUE OF PRESSURE   [PSI]      ........ 29.7

FLUID = NITROGEN
 PRESSURE    TEMP        DENSITY    CP          QUALITY     ENTHALPY    VISC
 [PSI]       [K]         [LB/FT3]   [J/G-K]     [-]         [J/G]       [LBM/FT-S]
  29.70       83.88       48.54      2.088      0.0000      -107.8      0.8097E-04
  29.70       83.88      0.5525      1.179       1.000       81.76      0.3888E-05


DECIDE WHAT TO DO NEXT:
   RETURN TO THE MAIN MENU                             INPUT M
   SELECT NEW INPUT PARAMETERS                         INPUT P
   INPUT NEW VALUE  ONLY FOR PRESSURE                  INPUT 1
   QUIT                                                INPUT Q
   YOUR CHOICE ............................

NAME THE SECOND INPUT VARIABLE
(B BACKS UP ONE STEP, Q STOPS, ? FOR HELP).......... ENTHALPY

INPUT VALUE OF PRESSURE   [PSI]      ........ 17

INPUT INITIAL VALUE OF ENTHALPY   [J/G]       -107.8

INPUT ITS INCREMENT (0 FOR ONE POINT)....... 0

FLUID = NITROGEN
 PRESSURE    TEMP        DENSITY    CP          QUALITY     ENTHALPY    VISC
 [PSI]       [K]         [LB/FT3]   [J/G-K]     [-]         [J/G]       [LBM/FT-S]
  17.00       78.62       50.12      2.066      0.0000      -118.8      0.9726E-04
  17.00       78.62       5.313     0.0000      0.5578E-01  -107.8      0.0000
  17.00       78.62      0.3293      1.132       1.000       78.17      0.3613E-05


DECIDE WHAT TO DO NEXT:
   RETURN TO THE MAIN MENU                             INPUT M
   SELECT NEW INPUT PARAMETERS                         INPUT P
   INPUT NEW VALUES FOR BOTH PARAMETERS                INPUT B
   INPUT NEW VALUE  ONLY FOR PRESSURE                  INPUT 1
   INPUT NEW VALUES ONLY FOR ENTHALPY                  INPUT 2
   QUIT                                                INPUT Q
   YOUR CHOICE ............................
```

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PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-072
PAGE 1 OF 15

REV.	DEO #	DATE	BY:	CHECK
0		3/19/96	DM	

TITLE: 80K Pump Roughdown ΔP analyses

BY: David Moore
DEPT.: 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: Determine if any significant pressure differential exists across the 5/16" gap separating the low e liner and the thermal radiation shield in the 80K pump during pumpdown which could structurally damage either of these components.

METHOD: Computer simulation of the roughdown of the 80K pump chamber volume. The computer program is a finite difference code which utilizes the Newton- Raphson method to solve the system equations.

ASSUMPTIONS: The gap which separates the low e liner and the radiation shield is modelled as a short pipe of equivalent diameter with entrance and exit losses equal to 1.5 velocity heads. The roughing process is assumed to be executed with the turbo backing pump, whose speed (90 cu. m./hr.) is approximately constant during the pressure range of interest.

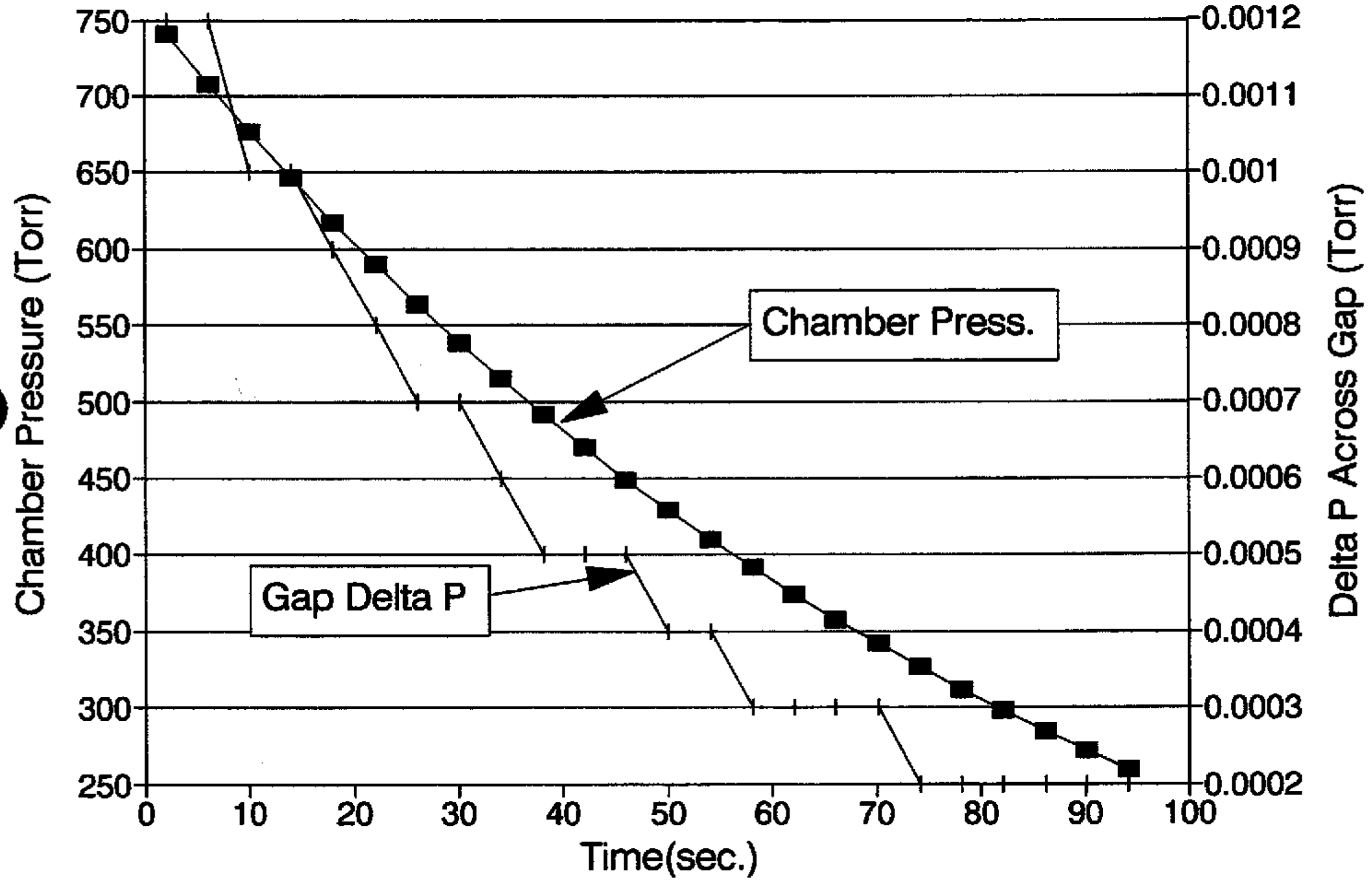
INPUTS: Input file attached.

REFERENCES:

CALCULATIONS: Related calculations attached.

CONCLUSIONS: Delta P across the gap is insignificant. No significant structural loads.

Roughdown of Short 80K Pump
Gate Valves Closed



```
 FLUID BCD 3GENERAL
       BCD 9  PRESS. VS TIME IN 80K PUMP CHAMBER
       BCD 9  ROUGHDOWN CHAMBER WITH TURBO BACKING PUMP
       END
       BCD 3PRESSURE DATA
       REM   NODE #, ELEVATION, INIT PRESS;  ETC.
           -1,        0.,       760.$
           5,         0.,       760.$
           10,         0.,       760.$
           9999,      0.,       1.0 $ DUMMY PRESSURE NODE
       END
       BCD 3TUBE DATA
C     ABS  TUBE #, INIT NODE, TERM NODE, A(REF #, ARRAY DATA)
       TUB 10,        1,        5,         A1,      0.0$
       TUB 30,        1,        5,         A1,      0.0$
       PMI -20,       5,        10,        A5,      0.0$
       END
       BCD 3CONSTANTS DATA
           GRAV=32.2 $
           GC1=89.6606 $CONVERSION TO TORR
           GC2=1.0 $
           USRFLO=0.1 $
C          SPARE6 = 0. (1.) CAUSES "DEBUG" TO BE .FALSE. (.TRUE.).
           SPARE6 = 1. $
C          SPARE7 = 0. (1.) CAUSES "NOFERR" TO BE .FALSE. (.TRUE.).
           SPARE7 = 1. $
C          THE FOLLOWING LINE CAUSES ORDER REDUCTION TO BE SUPRESSED.
           ISOLVE = 2
C          THE FOLLOWING PARAMETERS CONTROL CONVERGENCE FOR THE FLUID
C          NETWORK SOLUTION AND OVERRIDE THE DEFAULT VALUES ...
           KMAX=100 $
           PRSABS=0.001 $
           PRSREL=0.001 $
           FLOABS=0.0001 $
           FLOREL=0.0001 $
           NDIM=10000$
           NFLOOP= 10
           PRLXCA= 0.001
           EPS=0.01
           PMPTOL=0.005
           1=0.0        $ TOTAL MASS OUTFLOW, OUTER CHAM. VOLUME
           5=0.0        $ TOTAL MASS OUTFLOW, INNER CHAM. VOLUME
           10=760.      $ PRESSURE IN OUTER CHAM. VOLUME (TORR)
           50=760.      $ PRESSURE IN INNER CHAM. VOLUME (TORR)
           60=0.        $ DELTA P
           100= 0.0     $ ELAPSED TIME
           200= .0662     $ PUMP FLOW
           1000=2627.   $ INITIAL AIR MASS, OUTER CHAM. VOLUME, GM.
           2=16.0        $ TIME COUNTER
           3=.075        $ INITIAL AIR DENSITY
           6=.125        $ TIME STEP (SEC.)
       END
       BCD 3ARRAY DATA
       REM     L    ,    D , K ,    E/D , FIVE EMPTY FIELDS
           1,.125, .624,  1.50, .00018, 0.0, 0.0, 0.0, 0.0, 0.0, END$ANNULUS
C---  PUMP CHARACTERISTICS
C---  MASS FLOW RATE VS.(DOWNSTREAM - UPSTREAM PRESS.)
           5,.0,15.,1.0,15., END
C---  PUMP DOWN CURVE
           7,4.,.0004,13.,.0011,22.,.0019,27.,.0024,34.,.0030
```

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```
             43.,.0037,53.,.0047,67.,.0058,85.,.0073
             135.,.0117,170.,.0149,220.,.0190,355.,.0310
             460.,.0398,590.,.0512,760.,.0662,END
       END
       BCD 3EXECUTION
C---- OBTAIN PUMP MASS FLOW FROM CHAMBER PRESSURE
           D1DEG1(XK10,A7,XK200)
F     OPEN(UNIT=7,FILE='PRESS.OUT',ACCESS='SEQUENTIAL',
F    +    STATUS='OLD',FORM='FORMATTED')
F     WRITE(7,50)
F  50 FORMAT(5X,'TIME(SEC)',5X,
F    +       'DP(TORR)',1X,'P1(TORR)',/)
F 100 CONTINUE
C---- SET PUMP MASS FLOW
M     W20=XK200
F     CONTINUE
           FLDSOL
F     CALL PMPFLO
M     IF(P1.GE.250.0)THEN
F     CONTINUE
M      IF(XK2.LE.0.)THEN
F       CALL DATPRT
F 105     CONTINUE
F      END IF
M     XK2=XK2-1.0
F      GO TO 100
F     ELSE
F      CONTINUE
F     END IF
      CLOSE(UNIT=7)
       END
       BCD 3VARIABLES F

       REM  DYNAMIC VISCOSITY UNITS = LBM/FT-SEC
           TUBE(10,.0000123,K3,80.)
C           TUBE(20,.0000123,K3,80.)
           TUBE(30,.0000123,K3,80.)
       END
       BCD 3VARIABLES 1
       END
       BCD 3VARIABLES 2
       END
       BCD 3OUTPUT CALLS
M     IF(XK2.LE.0.)THEN
F       CALL PPRINT
F       CALL WPRINT
F     ELSE
F       CONTINUE
F     END IF
CM     IF(XK60.GE.2.0)THEN
CM      WRITE(7,800)XK100,XK60,P1
CM     ELSE
CM      CONTINUE
CM     END IF
  800   FORMAT(5X,',',F9.2,',',F8.2,',',F8.2)
       END
       BCD 3SINROUTINE PMPFLO
C---- COMPUTE MASS OUTFLOW DURING SELECTED TIME STEP
M       XK1=(W10+W30)*XK6*453.6
M       XK5=W20*XK6*453.6
```

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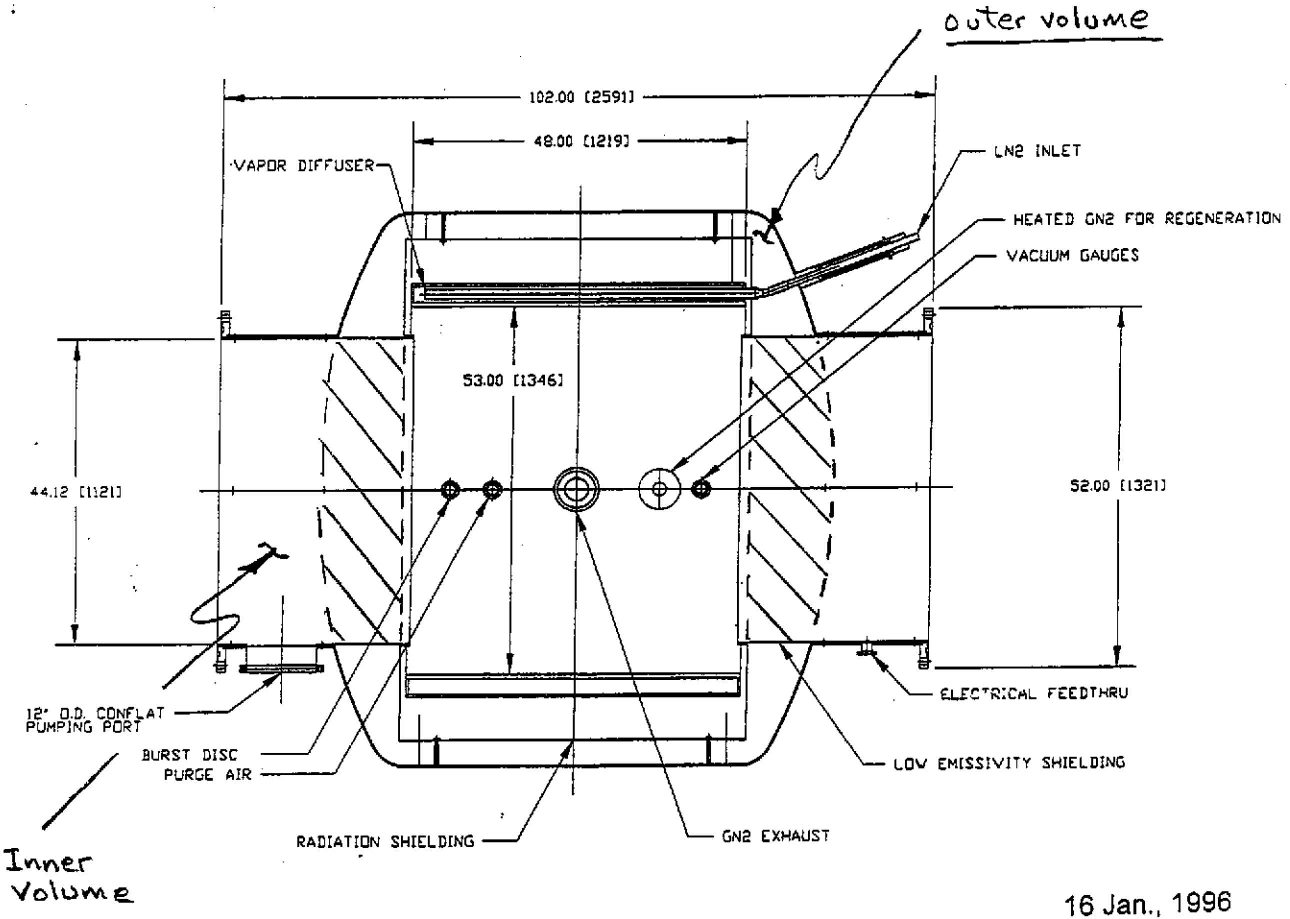
```
C---- COMPUTE DELTA P ACROSS GAP
M      XK60=ABS(P5-P1)
C---- COMPUTE NEW PRESSURE IN CHAMBER OUTER VOLUME
C
   -- OUTER VOLUME
M        XK10=.289*(XK1000-XK1)
M        P1=XK10
C
C---- COMPUTE ELAPSED TIME
M        XK100=XK100+XK6
C---- COMPUTE REMAINING AIR MASS
M        XK1000=XK1000-XK1
CM        XK5000=XK5000-XK5
C--- COMPUTE AIR DENSITY
M      XK3=XK1000/34926.
C----- UPDATE PUMP FLOW RATE
           D1DEG1(XK10,A7,XK200)
M      W20=XK200
C
        END
        BCD 3SINROUTINE DATPRT
M      IF(XK2.LE.0.)THEN
M       XK2=16.0
F      END IF
M        WRITE(6,200)XK1,XK5
M        WRITE(6,300)XK100
M        WRITE(6,400)XK1000
M        WRITE(6,700)XK10
M        WRITE(6,600)XK200
M        WRITE(6,980)XK3
M        WRITE(7,800)XK100,XK60,P1
M        CONTINUE
C
F 200    FORMAT(/,5X,'MASS OUTFLOW FROM OUTER VOL.= ',F10.4,' GRAMS',
F    +          /,5X,'MASS OUTFLOW FROM INNER VOL.= ',F10.4,' GRAMS',/)
F 300    FORMAT(5X,'ELAPSED TIME = ',F10.3,' SEC.')
F 400    FORMAT(5X,'REMAINING MASS,OUTER CHAM.= ', F10.2,' GRAMS')
F 500    FORMAT(5X,'REMAINING MASS,INNER CHAM.= ', F10.2,' GRAMS')
F 600    FORMAT(/,5X,'PUMPFLOW= ',F10.4,' LBM/SEC')
F 700    FORMAT(/,5X,'OUTER CHAMBER PRESS= ',F10.4)
F 800    FORMAT(5X,',',F9.2,',',F10.4,',',F8.2)
F 980    FORMAT(5X,'AIR DENSITY= ',F6.4,1X,'LBM/FT^^3')
        END
        BCD 3END OF DATA
```

Appendix
(Related Calculations)

Pumpdown of 80K
Pump Chamber
(Small Chamber)



16 Jan., 1996

PLAN VIEW

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Calculation of Volumes

Calculate the outer chamber volume (ref: sketch) by calculating the gross chamber volume bounded by the chamber shell & heads, & subracting out the volume inside the thermal radiation shield & the cross-hatched volume in the sketch:

Shell: $V = \frac{\pi d^2}{4} \times \text{length}$

$= \frac{\pi (79\frac{1}{2})^2}{4} (48)$

$= 238{,}147 \text{ in}^3 \; (3.89 \text{ m}^3)$

Heads:

Volume of elliptically dished head is approximated by:

$V = 7.6 \times 10^{-5} d_i^{\,3}$

d_i: in.
V: ft^3

$\therefore V = 7.6 \times 10^{-5} (79\frac{1}{2})^3$

$= 38.19 \text{ ft}^3$

For 2 heads, $76.37 \text{ ft}^3 \; (2.16 \text{ m}^3)$

$\therefore$ Gross chamber volume (excluding the protruding beam ports) is:

$$\begin{array}{r} 2.16 \\ +\ 3.89 \\ \hline 6.05 \text{ m}^3 \end{array}$$

Volume inside the radiation shield:

$$V = \frac{\pi}{4} d^2 \times \text{length}$$

$$= \frac{\pi}{4}(72)^2 \times (50)$$

$$= 203{,}472 \text{ in}^3 \ (3.33 \text{ m}^3)$$

Volume inside cross-hatched volume:

Approximate as cylinders $44\frac{1}{8}$" dia. x $10\frac{3}{4}$" high

$$\therefore \text{Vol} = 2 \times \frac{\pi}{4} d^2 \times \text{length}$$

$$= 2\left(\frac{\pi}{4}\right)\left(44\tfrac{1}{8}\right)^2\left(10\tfrac{3}{4}\right)$$

$$= 32877 \text{ in}^3 \ (.54 \text{ m}^3)$$

$\therefore$ Outer chamber volume is

$$6.05 - (3.33 + .54) = 2.18 \text{ m}^3$$

//

The inner volume to be evacuated is the volume between closed gate valves. This includes the volume inside the radiation shield, the beam tube ports, and the spool piece on one end of the pump.

Beam tube ports:

$$V = 2 \times \frac{\pi d_i^2}{4} \times \text{length}$$

$$= 2\left(\frac{\pi}{4}\right)\left(44\tfrac{1}{8}\right)^2\left(26\tfrac{1}{4}\right)$$

$$= 80282 \text{ in}^3 \quad (1.31 \text{ m}^3)$$

Spool piece:

$$V = \frac{\pi}{4}\left(44\tfrac{5}{8}\right)^2(36)$$

$$= 56277 \text{ in}^3 \quad (.92 \text{ m}^3)$$

∴ Total inner volume is:

$$3.33 + 1.31 + .92 = 5.56 \text{ m}^3$$

Mass of air in chamber:

Outer chamber volume initial air mass:

$$V = 2.18\ m^3$$

$$m = \rho V = 2.18\ m^3 \left(2.65\ \frac{lbm}{m^3}\right)$$

$$= 5.79\ lbm\ (2627\ gm.)$$

Inner volume:

$$V = 5.56\ m^3$$

$$m = 5.56(2.65)$$

$$= 14.73\ lbm\ (6689\ gm.)$$

//

Computations for computer simulation:

Density: $\rho = \frac{m}{V}$

For the outer chamber volume

$$\rho = XK1000/2180 \quad gm/liter$$

or $\rho = \left(\frac{XK1000}{2180}\ \frac{gm}{liter}\right)\left(\frac{liter}{.03532\ ft^3}\right)\left(\frac{lbm}{453.6\ gm}\right)$

$$\rho = \left(\frac{XK1000}{34926}\right)\frac{lbm}{ft^3}$$

Pressure computation

$$P = \frac{m\bar{R}T}{VM}$$

$M = 28.97 \ \frac{gm}{mole}$

$\bar{R} = 62.36 \ \frac{torr \cdot l}{mole \cdot K}$

$$P = \frac{m\,(62.36)(293)}{V\,(28.97)}$$

$$P = 630.703\,(m/V)$$

∴ Outer volume :

$$P = 630.703\,(m/2180)$$

$$P = .289\,m \text{ torr}$$

Inner volume :

$$P = 630.703\,(m/5560)$$

$$= .113\,m \text{ torr}$$

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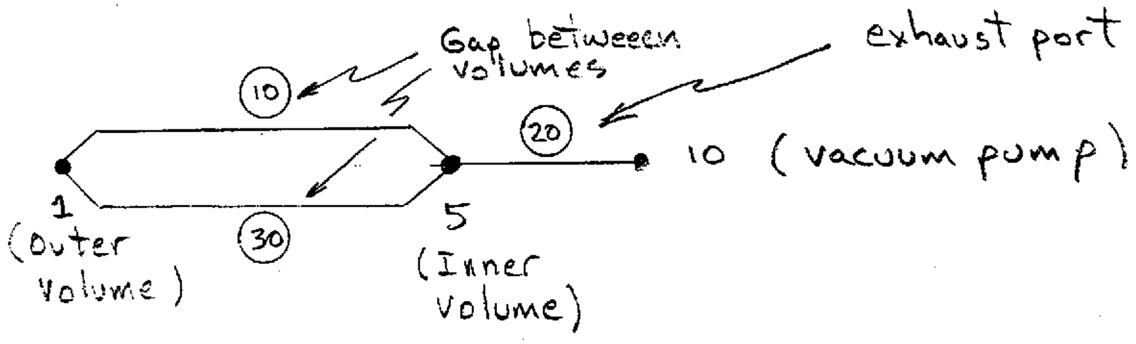
Turbo Backing Pump Curve

Pump has an approximately constant speed ($90\ m^3/hr$) for the pressures of interest.

Pressure (Torr)	S (acfm)	ρ (lbm/ft^3)	$\dot{m}$ (lbm/sec)
760	53.0	.0749	.0662
590		.0580	.0512
460		.0451	.0398
355		.0351	.0310
220		.0215	.0190
170		.0169	.0149
135		.0133	.0117
85		.0083	.0073
67		.0066	.0058
53		.0053	.0047
43		.0042	.0037
34		.0034	.0030
27		.0027	.0024
22		.0022	.0019
13		.0013	.0011
4		.0004	.0004

Pumpdown of
80K Pump Chamber

Fluid Flow Model:



80 K Cryopump
Annular Gap

For performance considerations, the annular gap area should be as large as the turbo inlet port (10" i.d.)

For one gap:

$$\frac{A}{2} = \frac{\pi}{4}\left(D_o^2 - D_i^2\right)$$ (Area of one gap = ½ total)

Di defined by low e shield (44.62")

$$\frac{1}{2} \times \cancel{\frac{\pi}{4}}\left(10^2\right) = \cancel{\frac{\pi}{4}}\left(D_o^2 - 44.62^2\right)$$

$$D_o = 45.18'' \text{ say } 45\tfrac{1}{4}''$$

$$\therefore \text{Gap} = \left(45\tfrac{1}{4} - 44\tfrac{5}{8}\right)/2$$

$$= .3125 \ (5/16'')$$

The equivalent pipe diameter of a 5/16" gap is

$$\frac{\pi}{4}\left(45\tfrac{1}{4}^2 - 44\tfrac{5}{8}^2\right) = \frac{\pi}{4} d_{equiv}^2$$

$$d_{equiv} = 7.49''$$

```
PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

CUSTOMER: LIGO                                                                            JOB NO:V59049                       PAGE: 1

PRESSURE DROP ROUTE OR LINE ID:

 PRESSURE:      100000.0 Pa              1.000 BAR
 TEMPERATURE:    293.000 K             293.000 K
 DENSITY :         1.150 KG/M^3          0.115E+01 KG/M^3
 QUALITY :         1.000

ITEMNAME                FLOWRATE    I.D.      K / DO     CV        LENGTH    PRESSURE  Z1        Z2        DP-F      DP-Z      DP-T      DP-SUM   DENSITY VELOCITY RE NO
                            KG/S    METER                          M          Pa       METER     METER     Pa        Pa        Pa        Pa       KG/M^3     M/S

 EQ PIPE LENGTH        0.800E-03    0.0900                           1.00  99999.99     0.00      0.00      0.01      0.00      0.01      0.01 0.115E+01      0.109 0.642E+03
 EXPANSION LOSS        0.800E-03    0.0900    1.5000                      99999.982     0.00      0.00      0.01      0.00      0.01      0.02 0.115E+01

                                                                                    TOTAL          0.0179    0.0000              0.0179
```

0.018 Pa = 0.0001 Torr ✓

$\frac{1}{2}\rho V^2 = \frac{1}{2}\, 1.1 \cdot 01^2 = 0.0055$ Pa.

No collapse problem due to pumpdown.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA	ENGINEERING CALCULATIONS	NO: V049-1-094 Rev. No. 1 Page 1a of 15
PROJECT: LIGO VACUUM EQUIPMENT	PROJECT NO:	V59049
CALCULATION TITLE: Relieving Requirements for 80K PumpVacuum Shell Relief Device		

REVISION HISTORY

Rev. 0 Original Issue - April 19, 1996

Rev. 1 Issue Date - Oct. 15, 1996

- Revised sizing of burst disc to take pressue drop of vent line into account. Relieving area increased to 3.36 sq. in.

Cases to consider for sizing relief device:

1. Leak in the LN_2 reservoir cools the entire pump vacuum shell to 80K. Control valve is sized for approx. 9 lb_m/hr., so it plays no significant role in this case.

2. Catastrophic rupture of LN_2 reservoir dumps entire liquid inventory at the bottom of the vacuum shell. Vent presumed blocked with ice.

3. LN_2 reservoir ruptures during cooldown. Manual cooldown valve is 100% open. GN_2 vent is open, since it will not have had sufficient time to ice up, and ∴ provides another relieving path. This case less severe than first two cases.

4. LN_2 reservoir ruptures during regen. cycle when pump is warming up. No liquid in reservoir. Max flow for regen is 10600 SCFH (~800 lb_m/hr). This case is less severe than the first 2 cases

Case 1: A leak in the LN_2 reservoir cools the entire vacuum chamber shell to 80K (highly unlikely). Heat is then transferred from the environment to the shell. The relieving device must then pass the following flow rate (see analysis, Attachment 1):

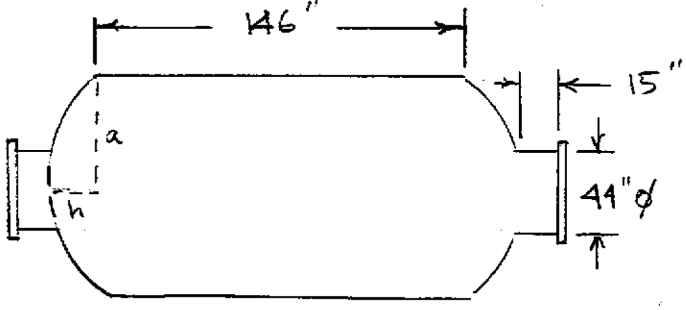
$$\dot{m} = \frac{Q\beta}{c_p}$$

Q = heat transferred from environment to cold vacuum shell.

c_p = specific heat of N_2

β = volume coefficient of expansion

Approximate Surface Area:
(Long Pump)



$a = 40''$

$h \approx 12\frac{1}{2}''$

Cylinder area $= \pi(80)(146) = 36{,}694 \text{ in}^2$

Ports: area $= 2(\pi)(44)(15) = 4147 \text{ in}^2$

Dished heads:

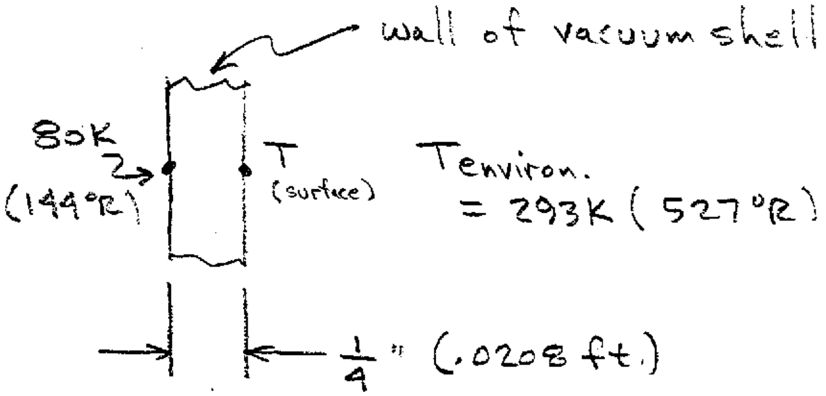
$$A = 2 \times \pi(a^2 + h^2)$$
$$= 2\pi\left(40^2 + (12\tfrac{1}{2})^2\right)$$
$$= 11035 \text{ in}^2$$

Total:

$$\begin{array}{r} 36694 \\ 4147 \\ \underline{11035} \\ 51876 \end{array} \text{ in}^2 \quad (3.346 \times 10^5 \text{ cm}^2)$$

—//—

Heat transferred to cold shell (per unit area):



Energy balance:

$$\frac{kA}{t}(T-144) = hA(527-T) + \sigma A \varepsilon (527^4 - T^4)$$

$A = 1.0 \text{ ft}^2$

$\varepsilon = 1.0$

& $h = 0.27\left(\frac{\Delta T}{d}\right)^{1/4}$

d = dia of cylinder (ft.)

= 6.667 ft

$k = 4.8 \frac{\text{Btu}}{\text{hr-ft°F}}$ (near 80K)

$$\frac{k}{t}(T-144) = 0.27\left(\frac{527-T}{d}\right)^{1/4}(527-T) + \sigma(527^4 - T^4)$$

$$\frac{4.8}{.0208}(T-144) = .17(527-T)^{1/4}(527-T) + .1714\times10^{-8}(527^4 - T^4)$$

$$230.77(T-144) = .17(527-T)^{5/4} + .1714\times10^{-8}(527^4 - T^4)$$

Solution: T = 146°R

$$Q = .17(527-146)^{5/4} + .1714\times10^{-8}(527^4 - 146^4)$$

$$= 418 \frac{\text{Btu}}{\text{hr-ft}^2}$$

$$\therefore Q_{total} = 418 \frac{Btu}{hr-ft^2} \times \left(\frac{51876}{144}\right) ft^2$$

$$= 150,585 \frac{Btu}{hr}$$

at 2 psig (16.7 psia) & 144 °R

$$\beta = \frac{1}{V}\left(\frac{dV}{dT}\right)_p$$

$$= .00789 \quad 1/°R$$

$$\& \quad C_p = .27 \quad Btu/lb_m\text{-}°R$$

$$\therefore \dot{m} = \frac{(150585)(.00789)}{.27}$$

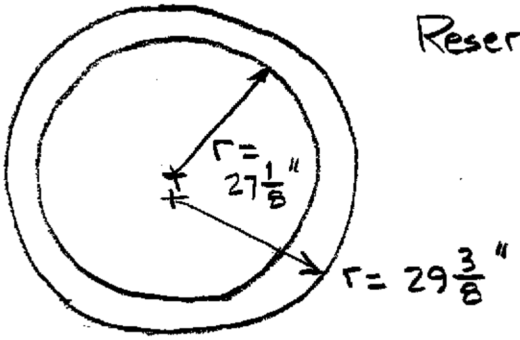
$$= 4402 \frac{lbm}{hr} \quad \left(1.22 \frac{lbm}{sec}\right)$$

—//—

Large gate valves at ends of pump are designed for 1¾ atm. differential pressure.

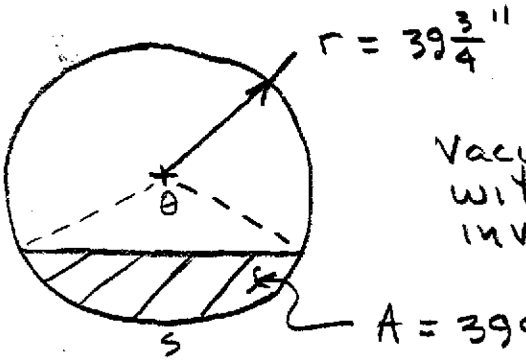
$1.75(14.7) = 25.73$ psia (11 psig)

Case 2: Catastrophic rupture of LN_2 reservoir; LN_2 inventory collects at bottom of vacuum chamber; energy stored in 70°F vacuum chamber vaporizes liquid.



Reservoir (assume full)

$$A = \pi\left(29.375^2 - 27.125^2\right)$$
$$= 399.4 \text{ in}^2$$



Vacuum chamber with reservoir liquid inventory at bottom.

$A = 399.4 \text{ in}^2$

$$A = \tfrac{1}{2} r^2 (\theta - \sin\theta)$$
$$399.4 = \tfrac{1}{2}(39.75)^2(\theta - \sin\theta)$$

Solution: $\theta = 1.503$ rad.

Arclength s: $s = r\theta$
$$= 39.75(1.503)$$
$$= 59.74''$$

∴ Total area at the liquid/vacuum shell interface is approximately

$$(14\ \text{ft})\left(\frac{12\ \text{in.}}{\text{ft}}\right)(59.74\ \text{in.}) = 10{,}036\ \text{in}^2$$
$$(69.69\ \text{ft}^2)$$

Due to the large temperature excess (70°F − (−320°F)), the liquid will form a vapor blanket between it & the vacuum chamber, resulting in film boiling.

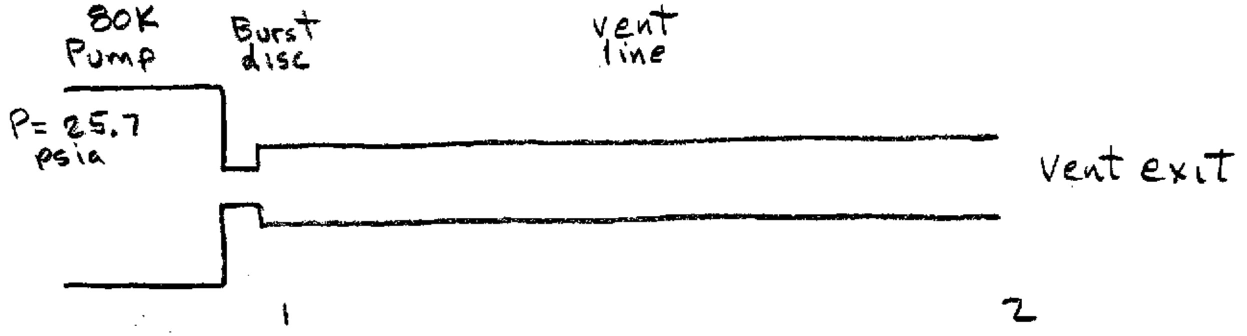
Referring to published boiling data for nitrogen, the heat flux at 390°F excess temperature is 8000 Btu/hr-ft²

or $Q_{total} = 8000\,(69.69)$
$= 557{,}520\ \text{Btu/hr}$

& vapor generation is:

$$\dot{m} = \frac{557{,}520\ \text{Btu/hr}}{85.46\ \text{Btu/lb}_m}$$
$$= 6524\ \text{lb}_m/\text{hr}.$$

Since mass flow rate is so large, pressure drop across vent line must be considered in sizing the required orifice area, and density changes must be considered.



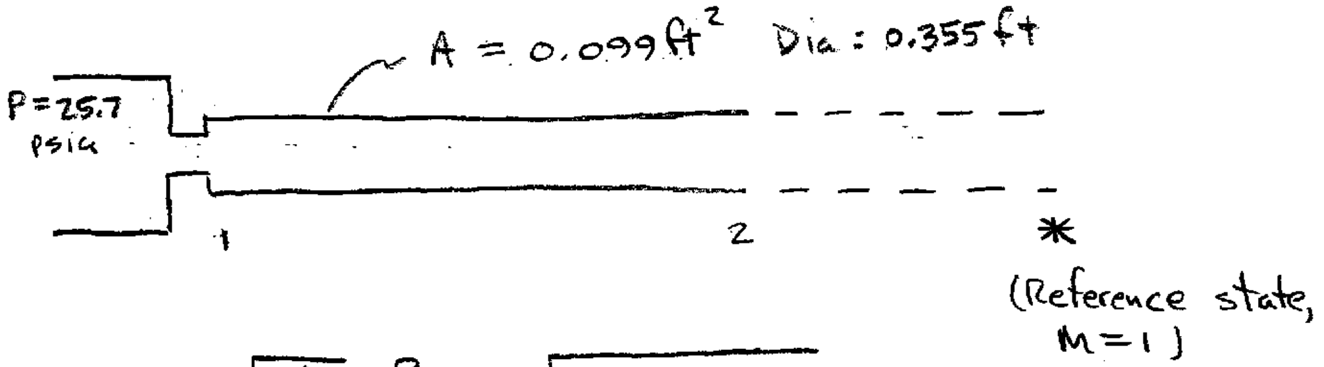
Vent line length = 63.2 ft plus 4 - 90° miters (Lequiv = 63 ft)

$$\text{Total Lequiv} = \begin{array}{r} 63.2 \\ 63 \\ \hline 126.2 \end{array}\ \text{ft.}$$

Since the pressure in the 80K pump is 25.7 psia, the flow in the vent will not choke & the pressure at the vent exit will be 14.7 psia.

Worst case assumption is that the vapor is that N_2 is at room temperature.

$$\therefore\ P_3 = 25.7\ \text{psia}$$
$$T_3 = 70\,°F\ (530\,°R)$$
$$= T_0 = \text{constant (treat as adiabatic flow)}$$



$$\frac{w}{a} = \sqrt{\frac{k}{R}}\,\frac{P}{\sqrt{T_o}}\,M\sqrt{1+\frac{k-1}{2}M^2}$$

$R = 55.13 \ \frac{ft-lb_f}{lb_m-°R}$ $\qquad P = 14.7(144) = 2117 \ \frac{lb_f}{ft^2}$

$$\frac{w}{A} = \frac{6524 \ lb_m/hr}{.099 \ ft^2} \times \frac{1}{3600} = 18.31 \ \frac{lb_m}{ft^2\text{-}sec}$$

Solve for M_2:

$$18.31 = \sqrt{\frac{1.4(32.16)}{55.13}}\ \frac{2117}{\sqrt{460+70}}\ M\sqrt{1+.2M^2}$$

$$0.22 = M\sqrt{1+.2M^2}$$

	M	$M\sqrt{1+.2M^2}$
	.215	.216
	.217	.218
root →	.22	.221

$\therefore M_2 = .22$ & $(P/P*)_{M_2} = 5.015$

From tables of compressible flow functions (pg 13, attached)

$$\left(4fL_{max}/D\right)_2 = 12.11$$

$$\text{Reynolds no} = \frac{\rho VD}{\mu} = \frac{wD}{\mu A}$$

$$= \frac{18.31(.355)}{1.17 \times 10^{-5}} \qquad \text{(Eval. at } 70\,°F)$$

$$= 555{,}600$$

$$4\bar{f} = .0172$$

$$\frac{4\bar{f}L}{D} = .0172\left(\frac{126.2}{.355}\right)$$

$$= 6.11$$

$$\frac{4\bar{f}L}{D} = \left(4\bar{f}\,\frac{L_{max}}{D}\right)_{M_1} - \left(4\bar{f}\,\frac{L_{max}}{D}\right)_{M_2}$$

$$\therefore \left(4\bar{f}\,\frac{L_{max}}{D}\right)_{M_1} = 6.11 + 12.11$$

$$= 18.22$$

From tables,

$$M_1 = .186$$

$$\& \quad (P/P^*)_{M_1} = 5.96$$

$$\frac{P_2}{P_1} = \frac{(P/P^*)_{M2}}{(P/P^*)_{M1}}$$

$$\therefore P_1 = 14.7\left(\frac{5.96}{5.015}\right)$$

$$P_2 = 17.47 \text{ psia}$$

∴ Size burst disc for 25.7 − 17.47
= 8.23 psid

TABLE B.4

FRICTIONAL, ADIABATIC, CONSTANT-AREA FLOW (FANNO LINE)

Perfect Gas, $k = 1.4$

M	T/T^*	p/p^*	p_0/p_0^*	V/V^* and ρ^*/ρ	F/F^*	$4fL_{\max}/D$
0.00	1.2000	∞	∞	0.00000	∞	∞
.05	1.1994	21.903	11.5914	.05476	9.1584	280.02
.10	1.1976	10.9435	5.8218	.10943	4.6236	66.922
.15	1.1946	7.2866	3.9103	.16395	3.1317	27.932
.20	1.1905	5.4555	2.9635	.21822	2.4004	14.533
.25	1.1852	4.3546	2.4027	.27217	1.9732	8.4834
.30	1.1788	3.6190	2.0351	.32572	1.6979	5.2992
.35	1.1713	3.0922	1.7780	.37880	1.5094	3.4525
.40	1.1628	2.6958	1.5901	.43133	1.3749	2.3085
.45	1.1533	2.3865	1.4486	.48326	1.2763	1.5664
.50	1.1429	2.1381	1.3399	.53453	1.2027	1.06908
.55	1.1315	1.9341	1.2549	.58506	1.1472	.72805
.60	1.1194	1.7634	1.1882	.63481	1.10504	.49081
.65	1.10650	1.6183	1.1356	.68374	1.07314	.32460
.70	1.09290	1.4934	1.09436	.73179	1.04915	.20814
.75	1.07856	1.3848	1.06242	.77893	1.03137	.12728
.80	1.06383	1.2892	1.03823	.82514	1.01853	.07229
.85	1.04849	1.2047	1.02067	.87037	1.00966	.03632
.90	1.03270	1.12913	1.00887	.91459	1.00399	.014513
.95	1.01652	1.06129	1.00215	.95782	1.00093	.003280
1.00	1.00000	1.00000	1.00000	1.00000	1.00000	0
1.05	.98320	.94435	1.00203	1.04115	1.00082	.002712
1.10	.96618	.89359	1.00793	1.08124	1.00305	.009933
1.15	.94899	.84710	1.01746	1.1203	1.00646	.02053
1.20	.93168	.80436	1.03044	1.1583	1.01082	.03364
1.25	.91429	.76495	1.04676	1.1952	1.01594	.04858
1.30	.89686	.72848	1.06630	1.2311	1.02169	.06483
1.35	.87944	.69466	1.08904	1.2660	1.02794	.08199
1.40	.86207	.66320	1.1149	1.2999	1.03458	.09974
1.45	.84477	.63387	1.1440	1.3327	1.04153	.11782
1.50	.82759	.60648	1.1762	1.3646	1.04870	.13605
1.55	.81054	.58084	1.2116	1.3955	1.05604	.15427
1.60	.79365	.55679	1.2502	1.4254	1.06348	.17236
1.65	.77695	.53421	1.2922	1.4544	1.07098	.19022
1.70	.76046	.51297	1.3376	1.4825	1.07851	.20780
1.75	.74419	.49295	1.3865	1.5097	1.08603	.22504
1.80	.72816	.47407	1.4390	1.5360	1.09352	.24189
1.85	.71238	.45623	1.4952	1.5614	1.1009	.25832
1.90	.69686	.43936	1.5552	1.5861	1.1083	.27433
1.95	.68162	.42339	1.6193	1.6099	1.1155	.28989
2.00	.66667	.40825	1.6875	1.6330	1.1227	.30499
2.05	.65200	.39389	1.7600	1.6553	1.1297	.31965
2.10	.63762	.38024	1.8369	1.6769	1.1366	.33385
2.15	.62354	.36728	1.9185	1.6977	1.1434	.34760
2.20	.60976	.35494	2.0050	1.7179	1.1500	.36091

TABLE B.4. F

M	T/T^*
2.25	.59627
2.30	.58309
2.35	.57021
2.40	.55762
2.45	.54533
2.50	.53333
2.55	.52163
2.60	.51020
2.65	.49906
2.70	.48820
2.75	.47761
2.80	.46729
2.85	.45723
2.90	.44743
2.95	.43788
3.00	.42857
3.50	.34783
4.00	.28571
4.50	.23762
5.00	.20000
6.00	.14634
7.00	.1111
8.00	.0869
9.00	.0697
10.00	.0571
∞	0

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Use sizing formula for subcritical flow from API 520:

4.3.3 SIZING FOR SUBCRITICAL FLOW: GAS OR VAPOR OTHER THAN STEAM

4.3.3.1 General

When the ratio of back pressure to inlet pressure exceeds the critical pressure ratio P_{cf}/P_1, the flow through the pressure relief valve is subcritical (see 4.3.1). Equations 5–7 may be used to calculate the required effective discharge area for a conventional relief valve that has its spring setting adjusted to compensate for superimposed back pressure and for sizing a pilot-operated relief valve.

Note: Balanced-bellows relief valves that operate in the subcritical region should be sized using Equations 2–4. The back pressure correction factor for this application should be obtained from the valve manufacturer.

$$A = \frac{W}{735F_2K_d}\sqrt{\frac{ZT}{MP_1(P_1 - P_2)}} \qquad (5)$$

$$A = \frac{V}{4645.2F_2K_d}\sqrt{\frac{ZTM}{P_1(P_1 - P_2)}} \qquad (6)$$

$$A = \frac{V}{863.63F_2K_d}\sqrt{\frac{ZTG}{P_1(P_1 - P_2)}} \qquad (7)$$

Where:

A = required effective discharge area of the valve, in square inches (see 1.2.2).

W = required flow through the valve, in pounds per hour.

F_2 = coefficient of subcritical flow (see Figure 29 for values)

$$= \sqrt{\left(\frac{k}{k-1}\right)(r)^{2/k}\left[\frac{1 - r^{(k-1)/k}}{1 - r}\right]}$$

k = ratio of the specific heats.

r = ratio of back pressure to upstream relieving pressure, P_2/P_1.

K_d = effective coefficient of discharge = 0.975 for use in Equations 5–7.

Z = compressibility factor for the deviation of the actual gas from a perfect gas, a factor evaluated at relieving inlet conditions.

T = relieving temperature of the inlet gas or vapor, in degrees Rankine (degrees Fahrenheit + 460).

M = molecular weight of the gas or vapor. Various handbooks carry tables of molecular weights of materials, but the composition of the flowing gas or vapor is seldom the same as that listed in the tables. This value should be obtained from the process data. Table 8 lists values for some common fluids.

P_1 = upstream relieving pressure, in pounds per square inch absolute. This is the set pressure plus the allowable overpressure (see 4.2) plus atmospheric pressure, in pounds per square inch absolute.

P_2 = back pressure, in pounds per square inch absolute.

V = required flow through the valve, in standard cubic feet per minute at 14.7 pounds per square inch absolute and 60°F.

G = specific gravity of gas referred to air = 1.00 for air at 14.7 pounds per square inch absolute and 60°F.

4.3.3.2 Example

In this example, the following relief requirements are given:

$$A = \frac{6524}{735(.811)(.975)} \times \sqrt{\frac{1.0\,(530)}{28.02(25.7)(25.7-17.47)}}$$

where:

$$r = \frac{17.47}{25.7} = 0.679$$

$$A = 3.357 \text{ in}^2$$

$$F_2 = \sqrt{\left(\frac{1.4}{.4}\right)(.679)^{1.429}} \times \sqrt{\frac{1-(.679)^{.286}}{1-.679}}$$

$$= .811$$

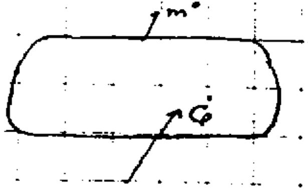
∴ Required diameter of relieving area is:

$$d = \sqrt{\frac{4A}{\pi}}$$

$$= \sqrt{\frac{4(3.357)}{\pi}}$$

$$d = 2.07 \text{ in.}$$

Attachment 1



mass Cons: $\dot{m} = -\frac{dm}{dt}$

1st law : $\frac{d(mu)}{dt} = \frac{dQ}{dT} - h\dot{m} = \frac{dQ}{dt} + h\frac{dm}{dT}$

$$u\frac{dm}{dt} + m\frac{du}{dt} = \frac{dQ}{dt} + h\frac{dm}{dt}$$

$$m\frac{du}{dt} = \frac{dQ}{dt} + (h-u)\frac{dm}{dt}$$

$$h \triangleq u + pv$$

$$m\frac{du}{dt} = \frac{dQ}{dt} + pv\frac{dm}{dT}$$

$$\frac{dQ}{dt} = m\frac{du}{dt} - pv\frac{dm}{dT}$$

Const. Volume (Control volume) : $m = \frac{V}{v}$

Const pressure process $h = u + pv$

$dh = du + pdv$

$$dm = -\frac{V\,dv}{v^2}$$

$$\frac{dQ}{dt} = m\frac{du}{dt} + \frac{Vp}{v}\frac{dv}{dT} = \frac{V}{v}\left(\frac{du}{dt} + p\frac{dv}{dt}\right) = \frac{V}{v}\frac{dh}{dT}$$

$$\dot{m} = \frac{dm}{dt} = -\frac{V}{v^2}\frac{dv}{dT}$$

$$\frac{\dot{Q}}{\dot{m}} = +\frac{v\,dh}{dv}$$

at const pressure $\left(\frac{T}{v}\frac{dv}{dT}\right) = \alpha$ & $\frac{dh}{dT} = c_p$

$$dh = c_p\,dT \quad \& \quad dv = \frac{\alpha}{T}v\,dT$$

$$\frac{dh}{dv} = \frac{c_p T}{\alpha v}$$

$$\frac{\dot{Q}}{\dot{m}} = \frac{c_p T}{\alpha} \Rightarrow \boxed{\dot{m} = \frac{\alpha\dot{Q}}{c_p T}}$$

Attachment 1 (cont.)

But by definition,

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p$$

$$\therefore \quad \frac{\dot{Q}}{\dot{m}} = \frac{c_p T}{\frac{T}{v}\left(\frac{\partial V}{\partial T}\right)}$$

$$= \frac{c_p}{\beta}$$

or $$\dot{m} = \frac{\dot{Q}\beta}{c_p}$$

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1-096 PAGE 1 OF 12
REV.	DEO #	DATE	BY:	CHECK	TITLE: Regen. System Process Calculations	
0	130	4/19/96	DMoore	D.h.W		
					BY: D. Moore	DEPT.: 744
PROJECT: LIGO					PROJECT NO: V59049	

PURPOSE: Determine process requirements for the 80K pump regen. heaters, and to estimate the warmup time (time to reach 150 deg. C) for the pump under wintertime conditions in Washington.

METHOD: Standard heat transfer manual calculations and on spreadsheet format.

ASSUMPTIONS: Used weather conditions for Kennewick, Washington: 15 deg. F dry bulb (Above this temperature 97.5% of the time.)

INPUTS: Max. regen flowrate = 100 gm/sec for long pump; 50 gm/sec for short pump. N2 temperature from the vaporizer = -5 deg. F (20 deg. F approach temp. specified by mfg.)

REFERENCES:

CALCULATIONS: See attached.

CONCLUSIONS: Long pump heater size: 25 kw adequate. Short pump heater size: 12 kw adequate. Estimated warmup times, including liquid vaporization: long pump = 16.75 hrs., short pump = 8.0 hrs.

80K Pump Regeneration Process Calculations

Sizing of Regen Heaters:

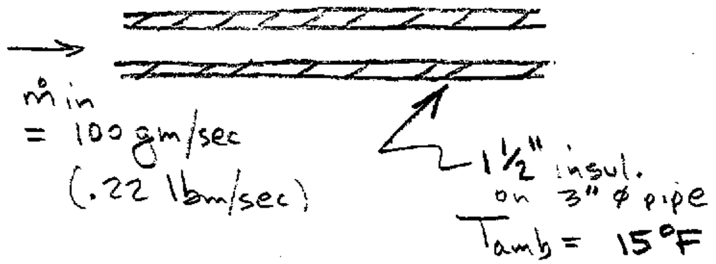
Heaters must be sized to deliver hot N_2 gas to the 80K pumps. The 80K pumps are to be heated to 302°F (150°C). Assuming a 20°F approach temperature, the gas temperature entering the cryopump should be about 325°F.

Wintertime Operation:

Using available design data, size the heater for 15°F dry bulb wintertime conditions (see Attachment 1). Assume a 10 m.p.h. wind blowing across the line supplying the regen. gas to the cryopump. ∴ Calculate the temperature exiting the heater in order to overcome heat losses from the supply line.

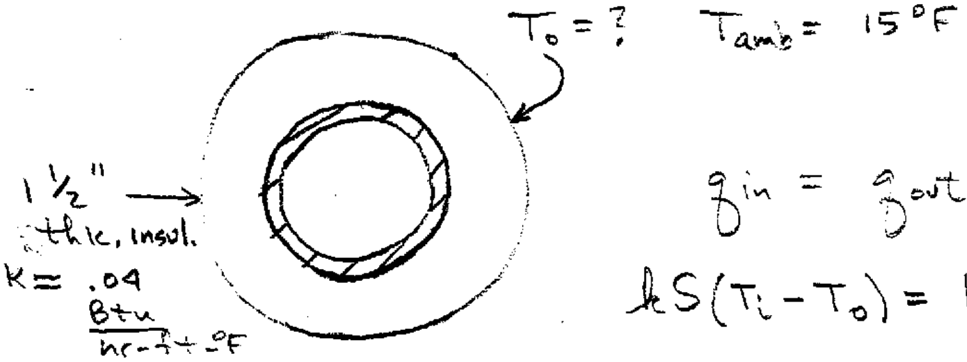
Heat Loss thru 60 ft. of regen pipe:

Long pump:



$T_{out} = 325$ °F

$T_{in} = ?$



$$q_{in} = q_{out}$$

$$kS(T_i - T_o) = hA(T_o - T_{amb})$$

Assume 10 mph wind

$$S = \frac{2\pi L}{\ln(r_o/r_i)}$$

$$= \frac{2\pi(1.0)}{\ln(6.5/3.5)} = 10.15 \text{ ft}$$

$$A = 2\pi r_o L$$

$$= 2\pi\left(\frac{3.25}{12}\right)(1.0)$$

$$= 1.70 \text{ ft}^2/\text{ft}$$

$$Re = \frac{D_o u_\infty}{\nu_f} = \frac{\rho_f D_o u_\infty}{\mu_f}$$

$$10 \frac{\text{mile}}{\text{hr}}\left(\frac{5280\,\text{ft}}{\text{mile}}\right) = 52800 \frac{\text{ft}}{\text{hr}}$$

$$Re_E = \frac{\left(\frac{6.5}{12}\right)(52800)(.084)}{.04} \qquad \mu_f = .04 \frac{\text{lb}_m}{\text{hr-ft}}$$

$$= 60000$$

$$\frac{hD_o}{k_f} = 170 \quad (\text{see pg } 7)$$

$$h = \frac{170(.0135)}{(6.5/12)}$$

$$= 4.24 \quad \text{Btu/hr-ft}^2\text{-}^\circ\text{F}$$

To account for radiation, say $h = 4.5 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}$

$$\therefore \quad .04(10.15)(325 - T_o) = 4.5(1.70)(T_o - 15)$$

$$131.95 - .406T_o = 7.65\,T_o - 114.75$$

$$8.06\,T_o = 246.7$$

$$T_o = 30.6\ ^\circ\text{F}$$

$$\therefore \quad q = kS(T_i - T_o)$$

$$= .04(10.15)(325 - 30.6)$$

$$= 119.5 \quad \frac{\text{Btu}}{\text{hr-ft}}$$

For 60 ft of pipe

$$q = 119.5(60) = 7172 \quad \text{Btu/hr}$$

$\therefore$ Calculate the temp drop of the N_2 inside the pipe

$$q = \dot{m} c_p \Delta T$$

$$7172 = .22(3600)(.25)\Delta T$$

$$\Delta T = 36^\circ F$$

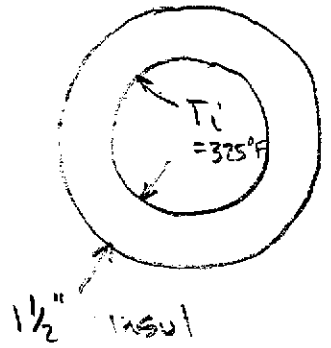
N_2 temp in needs to be

$$\begin{array}{r} 325 \\ +\ 36 \\ \hline 361\ ^\circ F \end{array} \quad \text{say } 360^\circ F$$

Short pump

$1\frac{1}{2}''$ ϕ pipe

($1.9''$ o.d.)



$$S = \frac{2\pi(1.0)}{\ln(4.9/1.9)} = 6.63 \text{ ft}$$

$$A = 2\pi\left(\frac{4.9}{2(12)}\right)(1.0)$$

$$= 1.28 \text{ ft}^2/\text{ft.}$$

10 m.p.h. wind

$$R_e = \frac{\left(\frac{4.9}{12}\right)(52800)(.084)}{.04}$$

$$= 45300$$

50 gm/sec

(.11 lbm/sec)

$$\frac{h D_o}{k_f} = 150 \quad \text{(see pg 7)}$$

$$h = \frac{150(.0135)}{(4.9/12)}$$

$= 4.96$ Btu/hr-ft²-°F

say 5.5 Btu/hr-ft²-°F

$$kS(T_i - T_o) = hA(T_o - T_{amb})$$

$$.04(6.63)(325 - T_o)$$

$$= 5.5(1.28)(T_o - 15)$$

$$86.19 - .265T_o = 7.04T_o - 105.6$$

$$191.8 = 7.305T_o$$

$$T_o = 26.3°F$$

$$q = kS(T_i - T_o)$$

$$= .04(6.63)(325 - 26.3)$$

$= 79.21$ Btu/hr-ft

for 60 ft of pipe

$q = 60(79.21) = 4753$ Btu/hr

∴ Temp drop of N_2:

$$q = \dot{m}c_p\Delta T$$

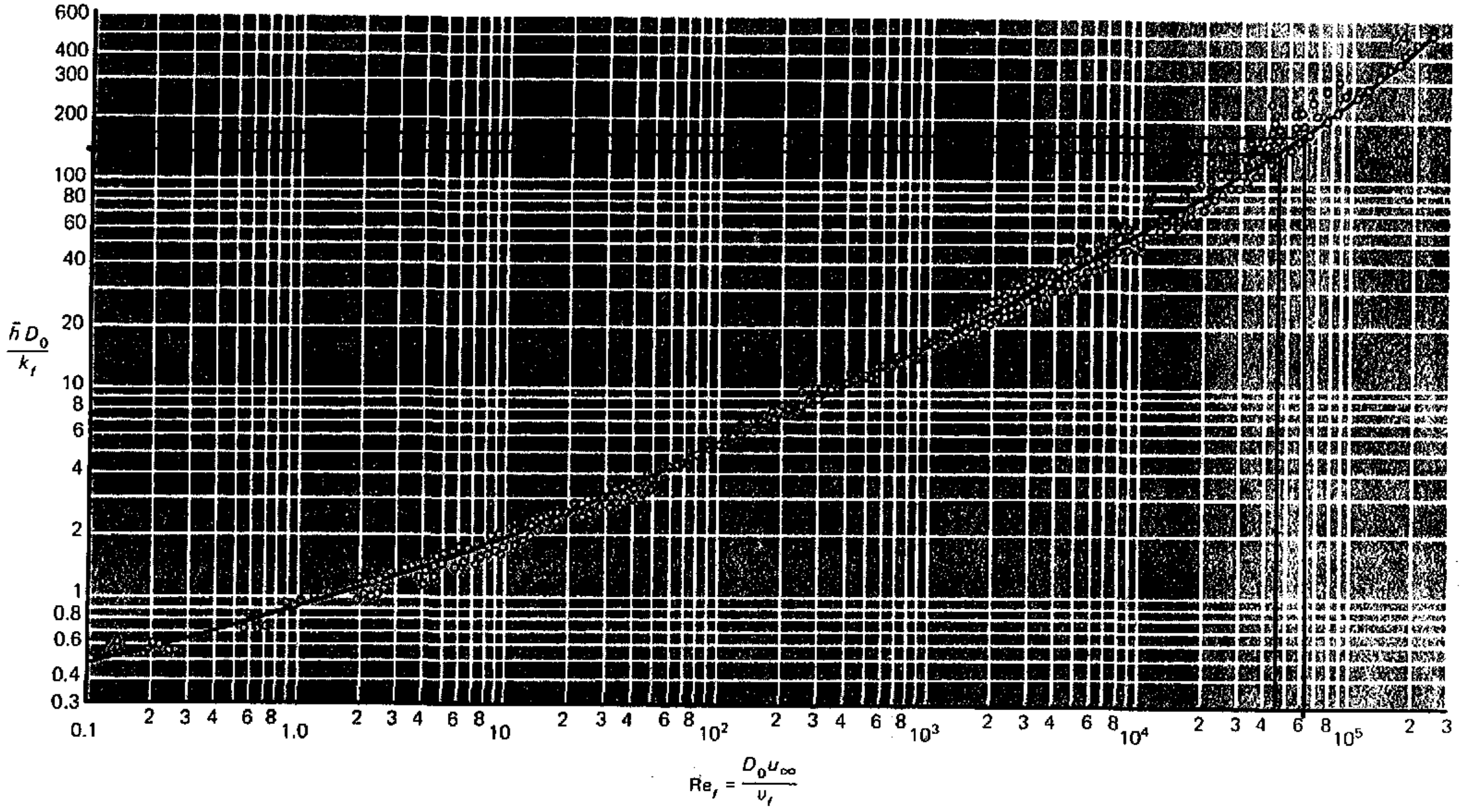
$$4753 = .11(3600)(.25)\Delta T$$

$$\Delta T = 48°F$$

∴ T_{in} must be

$$\begin{array}{r} 325 \\ +\ 48 \\ \hline 373 \end{array}$$ (say 375°F)

Fig. 6-9 Data for heating and cooling of air flowing normal to single cylinders, from McAdams [10].



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V049-1-096 REV O

Regen Heater sizes:

Vaporizer design is based on 20°F approach temp. ∴ the N_2 gas out of the vaporizer will be 15°F - 20°F = -5°F (253 K)

Long pump:

100 gm/sec. flowrate at 253K raised to 455K (360°F)

$$Q = \left(100 \frac{gm}{sec}\right)\left(472.8 - 262\right) \frac{j}{gm}$$

$$= 21080 \text{ watts}$$

(Heater size approx 25 kw)

100 gm/sec ⟶ 10572 SCFH (say 10600 SCFH)

Short pump:

50 gm/sec. flowrate at 253K raised to 464 K (375°F)

$$Q = 50 \frac{gm}{sec} \left(482.3 - 262\right) j/gm$$

$$= 11015 \text{ watts}$$ (Heater size approx 12 kw)

50 gm/sec → say 5300 SCFH

Time to vaporize LN_2:

Long pump: ~ 1700 lbm of LN_2 (772,700 gm)
Purge gas flow = 100 gm/sec.
@ 253K

$$(\dot{m}\Delta h)_{N_2\,gas} = \dot{m}\, h_{fg}$$

$$\dot{m}_{vaporized} = \frac{(\dot{m}\Delta h)_{N_2\,gas}}{h_{fg}}$$

$$= \frac{(100\ gm/sec)(262 - 79.6)\ j/gm}{(78.4 + 118.1)\ j/gm}$$

$$= 92.8\ gm/sec.\ (.204\ lbm/sec)$$

∴ Time to vaporize is:

$$t = \frac{1702\ lbm}{.204\ lbm/sec}$$

$$= 8324\ sec \quad (2.3\ hr.)$$

Short pump: ~ 550 lbm of N_2
Purge gas flow = 50 gm/sec.

$$\dot{m}_{vaporized} = \frac{(50)(262-79.6)}{(78.4+118.1)}$$

$$= 46.4\ gm/sec\ (.102\ lbm/sec)$$

∴ Time to vaporize is:

$$t = \frac{550}{.102} = 5392\ sec\ (1.5\ hr.)$$

Long Pump Regen.
Warmup Time
Winter Conditions

N2 flow (gm/sec)	Cp of N2 (j/gm-K)	N2 in (K)	N2 out (K)	Cp alum. (j/gm-K)	Initial alum. temp (K)	Final alum. temp. (K)	Alum. mass (gm.)	Elapsed time (sec)
50	1.05	253	80	0.357	80	100	1341000	1054.2
50	1.05	253	100	0.481	100	120	1341000	2660.22
50	1.05	253	120	0.58	120	140	1341000	4888.02
50	1.05	253	140	0.654	140	160	1341000	7844.66
50	1.05	253	160	0.713	160	180	1341000	11761.2
50	1.05	253	180	0.76	180	200	1341000	17079.7
50	1.05	253	200	0.797	200	220	1341000	24761.9
100	1.05	436	220	0.826	220	240	1341000	25738.7
100	1.05	436	240	0.849	240	260	1341000	26845.1
100	1.05	436	260	0.869	260	280	1341000	28106.3
100	1.05	436	280	0.886	280	300	1341000	29557
100	1.05	436	300	0.902	300	320	1341000	31251.1
100	1.05	436	320	0.918	320	340	1341000	33272.5
100	1.05	436	340	0.934	340	360	1341000	35757.6
100	1.05	436	360	0.934	360	380	1341000	38896.7
100	1.05	436	380	0.934	380	400	1341000	43156.8
100	1.05	436	400	0.934	400	420	1341000	49783.8
100	1.05	436	420	0.934	420	423	1341000	52020.4

Time to vaporize LN2 =	2.3	hours
Total warmup time =	16.75	hours

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V049-1-096 REV0

Short Pump Regen.
Warmup Time
Winter Conditions

N2 flow (gm/sec)	Cp of N2 (j/gm-K)	N2 in (K)	N2 out (K)	Cp alum. (j/gm-K)	Initial alum. temp (K)	Final alum. temp. (K)	Alum. mass (gm.)	Elapsed time (sec)
50	1.05	253	80	0.357	80	100	398000	312.879
50	1.05	253	100	0.481	100	120	398000	789.537
50	1.05	253	120	0.58	120	140	398000	1450.73
50	1.05	253	140	0.654	140	160	398000	2328.25
50	1.05	253	160	0.713	160	180	398000	3490.66
50	1.05	253	180	0.76	180	200	398000	5069.16
50	1.05	253	200	0.797	200	220	398000	7349.16
50	1.05	436	220	0.826	220	240	398000	7928.97
50	1.05	436	240	0.849	240	260	398000	8585.73
50	1.05	436	260	0.869	260	280	398000	9334.34
50	1.05	436	280	0.886	280	300	398000	10195.5
50	1.05	436	300	0.902	300	320	398000	11201.1
50	1.05	436	320	0.918	320	340	398000	12400.9
50	1.05	436	340	0.934	340	360	398000	13876.1
50	1.05	436	360	0.934	360	380	398000	15739.4
50	1.05	436	380	0.934	380	400	398000	18268.2
50	1.05	436	400	0.934	400	420	398000	22201.8
50	1.05	436	420	0.934	420	423	398000	23529.5

Time to vaporize LN2 =	1.5	hours
Total warmup time =	8.036	hours

Attachment 1.

Table C-1 (Cont.)

STATE AND STATION	WINTER		SUMMER		
	Latitude	DB 97½%	DB 2½%	WB 2½%	Outdoor Daily Range
Lubbock AP	33	15	97	72	26
Lufkin AP	31	28	96	80	20
McAllen	26	38	100	79	21
Midland AP	32	23	98	73	26
Mineral Wells AP	32	22	100	77	22
Palestine CO	31	25	97	79	20
Pampa	35	11	98	72	26
Pecos	31	19	100	71	27
Plainview	34	14	98	72	26
Port Arthur AP	30	33	92	80	19
San Angelo, Goodfellow AFB	31	25	99	75	24
San Antonio AP	29	30	97	77	19
Sherman-Perrin AFB	33	23	99	78	22
Snyder	32	19	100	74	26
Temple	31	27	99	78	22
Tyler AP	32	24	97	79	21
Vernon	34	18	101	76	24
Victoria AP	28	32	96	79	18
Waco AP	31	26	99	78	22
Wichita Falls AP	34	19	100	76	24
UTAH					
Cedar City AP	37	6	91	64	32
Logan	41	7	91	65	33
Moab	38	16	98	65	30
Ogden CO	41	11	92	65	33
Price	39	7	91	64	33
Provo	40	6	93	66	32
Richfield	38	3	92	65	34
St. George CO	37	26	102	70	33
Salt Lake City AP	40	9	94	66	32
Vernal AP	40	− 6	88	63	32
VERMONT					
Barre	44	−13	84	72	23
Burlington AP	44	− 7	85	73	23
Rutland	43	− 8	85	73	23
VIRGINIA					
Charlottsville	38	15	90	77	23
Danville AP	36	17	92	77	21
Fredericksburg	38	14	92	78	21
Harrisonburg	38	9	90	77	23
Lynchburg AP	37	19	92	76	21
Norfolk AP	36	23	91	78	18
Petersburg	37	18	94	79	20
Richmond AP	37	18	93	78	21
Roanoke AP	37	18	91	75	23
Staunton	38	12	90	77	23
Winchester	39	10	92	76	21
WASHINGTON					
Aberdeen	47	27	80	61	16
Bellingham AP	48	18	74	65	19
Bremerton	47	29	81	66	20
Ellensburg AP	47	6	89	65	34
Everett-Paine AFB	47	24	78	65	20
Kennewick	46	15	96	68	30
Longview	46	24	86	66	30
Moses Lake, Larson AFB	47	− 1	93	66	32
Olympia AP	47	25	83	65	32
Port Angeles	48	29	73	58	18
Seattle-Boeing Fld.	47	27	80	65	24
Seattle CO	47	32	79	65	19
Seattle-Tacoma AP	47	24	81	64	22
Spokane AP	47	4	90	64	28
Tacoma-McChord AFB	47	24	81	66	22
Walla Walla AP	46	16	96	68	27
Wenatchee	47	9	92	66	32
Yakima AP	46	10	92	67	36
WEST VIRGINIA					
Beckley	37	6	88	73	22
Bluefield AP	37	10	86	73	22
Charleston AP	38	14	90	75	20
Clarksburg	39	7	90	75	21
Elkins AP	38	5	84	73	22
Huntington CO	38	14	93	76	22
Martinsburg AP	39	10	94	77	21
Morgantown AP	39	7	88	74	22
Parkersburg CO	39	12	91	76	21
Wheeling	40	9	89	75	21
WISCONSIN					
Appleton	44	− 6	87	74	23
Ashland	46	−17	83	71	23
Beloit	42	− 3	90	76	24
Eau Claire AP	44	−11	88	74	23
Fond du Lac	43	− 7	87	74	23
Green Bay AP	44	− 7	85	73	23
La Crosse AP	43	− 8	88	76	22
Madison AP	43	− 5	88	75	22
Manitowoc	44	− 1	86	74	21
Marinette	45	− 4	86	72	20
Milwaukee AP	43	− 2	87	75	21
Racine	42	0	88	75	21
Sheboygan	43	0	87	74	20
Stevens Point	44	−12	87	73	23
Waukesha	43	− 2	89	75	22
Wausau AP	44	−14	86	72	23
WYOMING					
Casper AP	42	− 5	90	62	31
Cheyenne AP	41	− 2	86	62	30
Cody AP	44	− 9	87	60	32
Evanston	41	− 8	82	57	32
Lander AP	42	−12	90	62	32
Laramie AP	41	− 2	30	59	28
Newcastle	43	− 5	89	67	30
Rawlins	41	−11	84	61	40
Rock Springs AP	41	− 1	84	57	32
Sheridan AP	44	− 7	92	65	32
Torrington	42	− 7	92	67	30

EXPLANATION OF DESIGN CONDITIONS:

WINTER – 97½% indicates that the temperature will be at or above the design temperature shown 97½% of the time.

SUMMER – 2½% indicates that the temperature will exceed the design temperature shown only 2½% of the time.

OUTDOOR DAILY RANGE – The outdoor daily range of DB temperatures is the difference between the average maximum and average minimum temperatures during the warmest month at each location. Refer to page 39 when outdoor daily range is other than 20°.

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V049-1-096 REVO

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049- 1-092
PAGE 1 OF 4

REV.	DEO #	DATE	BY:	CHECK
0	0122	4/12/96	D Moore	R. Thom.

TITLE: Pressure Drop Calculations for 80K Pump Lines

BY: D. Moore
DEPT.:744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: To determine if regeneration and GN2 vent lines are adequately sized for the intended service.

METHOD: Use of in-house computer program for pressure drop analysis.

ASSUMPTIONS: 1) The length of each of the lines are equivalent to 60 ft. of straight pipe.
2) Regen. flow rate is 100 gm./sec.

INPUTS: Regen. heater delta p = .35 psid max. (vendor data)
Vaporizer delta p = 2 psid (budget imposed on vendor)
Estimated Cv for 1-1/2" globe valve in regen line = 31.66

REFERENCES:

CALCULATIONS: Calculations performed for :
Case 1) 80K pump normal operation (long pump, frosted)
Case 2) Long 80K pump cooldown from 150C (423K)
Case 3) Regen of Long 80K pump.

CONCLUSIONS: Case 1): Delta p = .0017 psid for 1-1/2 in. vent line.
Case 2): Delta p = .1392 psid for 1-1/2 in. vent line.
Case 3): Delta p = 9.413 psid from LN2 dewar to exit of vent line.
(by inspection, the 80K short pump system is adequate for 50 gm/sec.)
Conclusion: The lines are adequately sized for their intended service.

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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

CUSTOMER: LIGO                                                      JOB NO:V59049                          PAGE: 1

PRESSURE DROP ROUTE OR LINE ID:GN2 VENT, NORMAL OP.

 PRESSURE:      101270.8 Pa            14.684 PSIA
 TEMPERATURE:     77.778 K            140.000 R
 DENSITY :         4.581 KG/M^3          0.29 LBS/FT^3
 QUALITY :         1.000


ITEMNAME              FLOWRATE   I.D.     K / DO    CV        LENGTH   PRESSURE  Z1        Z2        DP-F      DP-Z      DP-T      DP-SUM
                          LB/S   INCHES                       FT       PSIA      FEET      FEET      PSI       PSI       PSI       PSI

1.5" PIPE               0.0096   1.6820                         6.00   14.684      0.00      0.00   0.00017    0.0000    0.0002    0.0002
1.5" PIPE               0.0096   1.6820                         6.00   14.684      0.00      0.00   0.00017    0.0000    0.0002    0.0003
1.5" PIPE               0.0096   1.6820                         6.00   14.684      0.00      0.00   0.00017    0.0000    0.0002    0.0005
1.5" PIPE               0.0096   1.6820                         6.00   14.684      0.00      0.00   0.00017    0.0000    0.0002    0.0007
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0008
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0010
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0012
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0014
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0015
1.5" PIPE               0.0096   1.6820                         6.00   14.683      0.00      0.00   0.00017    0.0000    0.0002    0.0017

                                                                                  TOTAL          0.0017    0.0000              0.0017


 BLOWER SUCTION DENSITY:     4.581 KG/M^3          0.286 LB/FT^3
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Pg 2 of 4

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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

CUSTOMER: LIGO                                                    JOB NO:V59049                    PAGE: 1

PRESSURE DROP ROUTE OR LINE ID:GN2 VENT, COOLDOWN FROM 423K

 PRESSURE:      101270.8 Pa           14.684 PSIA
 TEMPERATURE:     77.778 K           140.000 R
 DENSITY :         4.581 KG/M^3          0.29 LBS/FT^3
 QUALITY :         1.000

ITEMNAME               FLOWRATE   I.D.     K / DO    CV      LENGTH   PRESSURE  Z1      Z2      DP-F     DP-Z    DP-T    DP-SUM
                           LB/S   INCHES                     FT       PSIA      FEET    FEET    PSI      PSI     PSI     PSI

1.5" PIPE                0.0983   1.6820                       6.00   14.670     0.00    0.00  0.01386  0.0000  0.0139  0.0139
1.5" PIPE                0.0983   1.6820                       6.00   14.657     0.00    0.00  0.01387  0.0000  0.0139  0.0277
1.5" PIPE                0.0983   1.6820                       6.00   14.643     0.00    0.00  0.01389  0.0000  0.0139  0.0416
1.5" PIPE                0.0983   1.6820                       6.00   14.629     0.00    0.00  0.01390  0.0000  0.0139  0.0555
1.5" PIPE                0.0983   1.6820                       6.00   14.615     0.00    0.00  0.01391  0.0000  0.0139  0.0694
1.5" PIPE                0.0983   1.6820                       6.00   14.601     0.00    0.00  0.01393  0.0000  0.0139  0.0834
1.5" PIPE                0.0983   1.6820                       6.00   14.587     0.00    0.00  0.01394  0.0000  0.0139  0.0973
1.5" PIPE                0.0983   1.6820                       6.00   14.573     0.00    0.00  0.01396  0.0000  0.0140  0.1113
1.5" PIPE                0.0983   1.6820                       6.00   14.559     0.00    0.00  0.01397  0.0000  0.0140  0.1252
1.5" PIPE                0.0983   1.6820                       6.00   14.545     0.00    0.00  0.01398  0.0000  0.0140  0.1392

                                                                             TOTAL        0.1392   0.0000          0.1392


BLOWER SUCTION DENSITY:     4.536 KG/M^3         0.283 LB/FT^3
```

V049-1-092

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PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

CUSTOMER: LIGO

JOB NO:V59049   PAGE: 1

PRESSURE DROP ROUTE OR LINE ID:REGEN PUMP TO 423K(300F), VAPORIZER TO VENT 100 GM/SEC.

PRESSURE:	156520.5 Pa	22.695 PSIA
TEMPERATURE:	423.000 K	761.400 R
DENSITY :	1.246 KG/M^3	0.08 LBS/FT^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE LB/S	I.D. INCHES	K / DO	CV	LENGTH FT	PRESSURE PSIA	Z1 FEET	Z2 FEET	DP-F PSI	DP-Z PSI	DP-T PSI	DP-SUM PSI
VAPORIZER	0.2203	1.6820				20.695	0.00	0.00	2.00000	0.0000	2.0000	2.0000
1.5" GLOBE	0.2203	1.6820		31.660		18.5	0.00	0.00	2.22355	0.0000	2.2236	4.2236
1.5" PIPE	0.2203	1.6820			10.00	17.926	0.00	0.00	0.54589	0.0000	0.5459	4.7694
HEATER	0.2203	6.0000				17.576	0.00	0.00	0.35000	0.0000	0.3500	5.1194
3.0" PIPE	0.2203	3.2600			6.00	17.564	0.00	0.00	0.01247	0.0000	0.0125	5.1319
3.0" PIPE	0.2203	3.2600			6.00	17.551	0.00	0.00	0.01247	0.0000	0.0125	5.1444
3.0" PIPE	0.2203	3.2600			6.00	17.539	0.00	0.00	0.01248	0.0000	0.0125	5.1569
3.0" PIPE	0.2203	3.2600			6.00	17.526	0.00	0.00	0.01249	0.0000	0.0125	5.1694
3.0" PIPE	0.2203	3.2600			6.00	17.514	0.00	0.00	0.01250	0.0000	0.0125	5.1819
3.0" PIPE	0.2203	3.2600			6.00	17.501	0.00	0.00	0.01251	0.0000	0.0125	5.1944
3.0" PIPE	0.2203	3.2600			6.00	17.489	0.00	0.00	0.01252	0.0000	0.0125	5.2069
3.0" PIPE	0.2203	3.2600			6.00	17.476	0.00	0.00	0.01253	0.0000	0.0125	5.2194
3.0" PIPE	0.2203	3.2600			6.00	17.464	0.00	0.00	0.01254	0.0000	0.0125	5.2320
3.0" PIPE	0.2203	3.2600			6.00	17.451	0.00	0.00	0.01255	0.0000	0.0125	5.2445
80K PUMP	0.2203	0.0000				17.201	0.00	0.00	0.25000	0.0000	0.2500	5.4945
1.5" PIPE	0.2203	1.6820			6.00	16.849	0.00	0.00	0.35172	0.0000	0.3517	5.8462
1.5" PIPE	0.2203	1.6820			6.00	16.490	0.00	0.00	0.35906	0.0000	0.3591	6.2053
1.5" PIPE	0.2203	1.6820			6.00	16.123	0.00	0.00	0.36688	0.0000	0.3669	6.5722
1.5" PIPE	0.2203	1.6820			6.00	15.748	0.00	0.00	0.37522	0.0000	0.3752	6.9474
1.5" PIPE	0.2203	1.6820			6.00	15.364	0.00	0.00	0.38416	0.0000	0.3842	7.3315
1.5" PIPE	0.2203	1.6820			6.00	14.970	0.00	0.00	0.39376	0.0000	0.3938	7.7253
1.5" PIPE	0.2203	1.6820			6.00	14.566	0.00	0.00	0.40411	0.0000	0.4041	8.1294
1.5" PIPE	0.2203	1.6820			6.00	14.151	0.00	0.00	0.41532	0.0000	0.4153	8.5447
1.5" PIPE	0.2203	1.6820			6.00	13.723	0.00	0.00	0.42750	0.0000	0.4275	8.9722
1.5" PIPE	0.2203	1.6820			6.00	13.282	0.00	0.00	0.44082	0.0000	0.4408	9.4130
								TOTAL	9.4130	0.0000		9.4130

BLOWER SUCTION DENSITY: 0.730 KG/M^3   0.046 LB/FT^3

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PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO: V049-1-094
PAGE 1 OF 15

REV.	DEO #	DATE	BY:	CHECK
0	0124	4/19/96	D Moore	D.M.W
1	0307	10/15/96	D Moore	D.M.W

TITLE: Relieving requirements for 80K pump vacuum shell relief device.

BY: D.Moore

DEPT.: 744

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: To determine the relieving requirements for the vacuum shell of the 80K pump so that in the event of a failure of the 80K pump reservoir, the vacuum shell and the large gate valves in the beam tube are protected from overpressure.

METHOD: Standard thermodynamic and heat transfer analyses, and the use of standard API formula for sizing relief valve orifice.

ASSUMPTIONS: See calculations

INPUTS: Maximum delta p allowed, 1.75 atm., is based on highest pressure differential the large gate valves were designed for.

REFERENCES API 520

CALCULATIONS: See attached.

CONCLUSIONS: Relieving device should be sized to handle a flow rate of 6524 lbm/hr for the set pressure. This requires an orifice size of 3.36 sq. in.

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA					ENGINEERING CALCULATIONS	NO: V049-1- 116 PAGE 1 OF 21
REV.	DEO #	DATE	BY:	CHECK	TITLE: 80K Pump Liquid Supply Valve Sizing	
0	3311	10/17/96	DM	D.Wells		
					BY: D. Moore	DEPT.: 744

PROJECT: LIGO Vacuum Equipment

PROJECT NO: V59049

PURPOSE: Calculate required Cv for the liquid supply valve for the range of operating conditions that the pump will experience.

METHOD: Standard ISA formulas used in sizing control valves for two phase flow. Calculations have been programmed.

ASSUMPTIONS: a) Liquid nitrogen dewar full. b) Liquid nitrogen dewar 20% full c) 80K pump clean d) 80K pump frosted

INPUTS:

REFERENCES: ISA SP39.1 formulas for control valve sizing (excerpt of paper attached).

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS: Use valve plug with maximum Cv of 0.05. Minimum requirement is 0.0056.

NOTES:

PROCESS SYSTEMS INTERNATIONAL, INC. WESTBOROUGH, MA	ENGINEERING CALCULATIONS	NO: V049-1-116 Rev. No. 0 Page 2 of 21
PROJECT: LIGO VACUUM EQUIPMENT	PROJECT NO:	V59049
CALCULATION TITLE: 80K Pump Liquid Supply Valve Sizing		

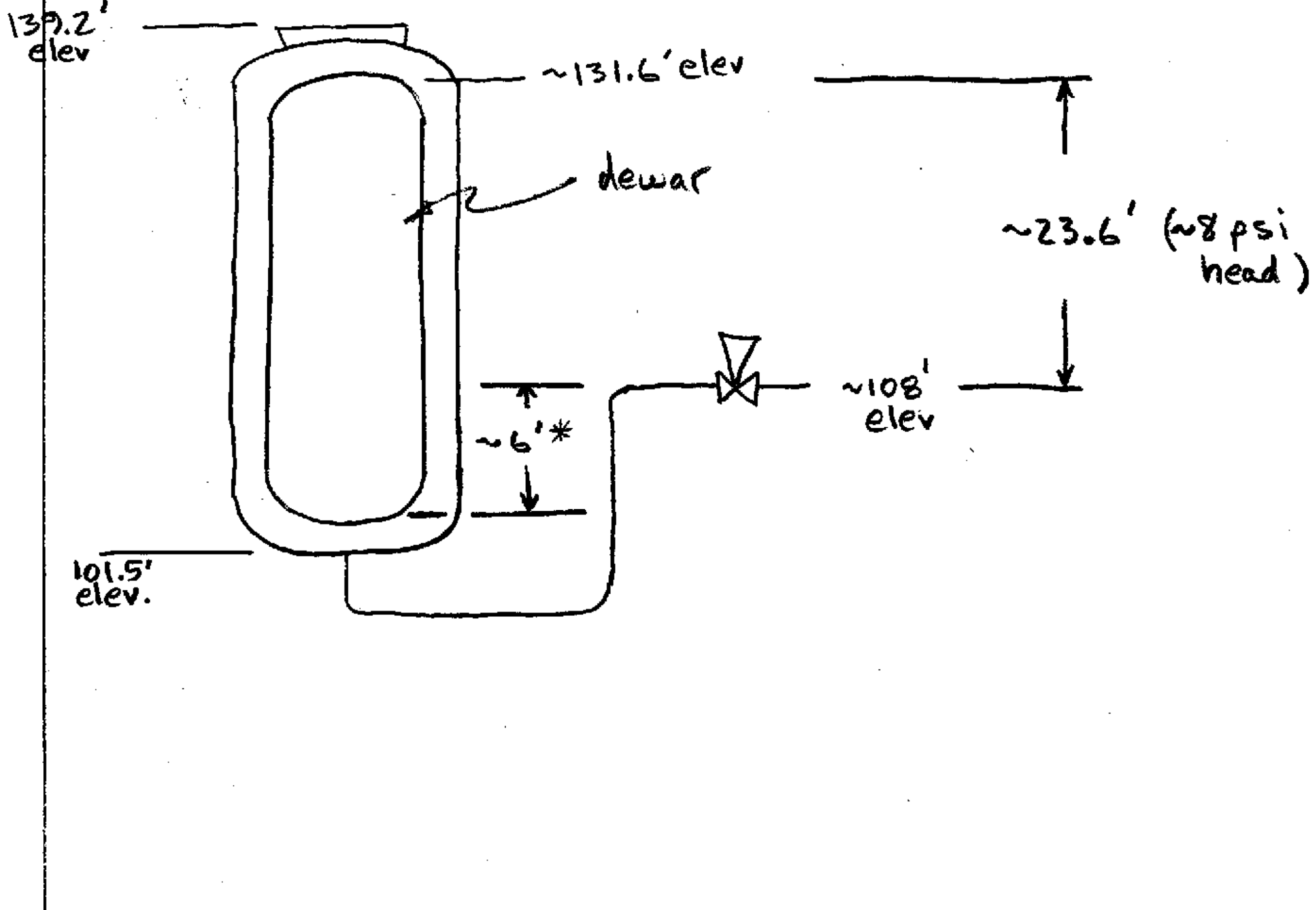
REVISION HISTORY

Rev. 0	Original Issue -Oct. 17, 1996

LN_2 Dewar
Short Pump

Set regulator at 5 psig (top of tank)
Pressure at control valve is 5 psig + liquid head

Tank full: 5 + 8 = 13 psig at valve
Tank "empty": 5 psig at valve
(~20% full)

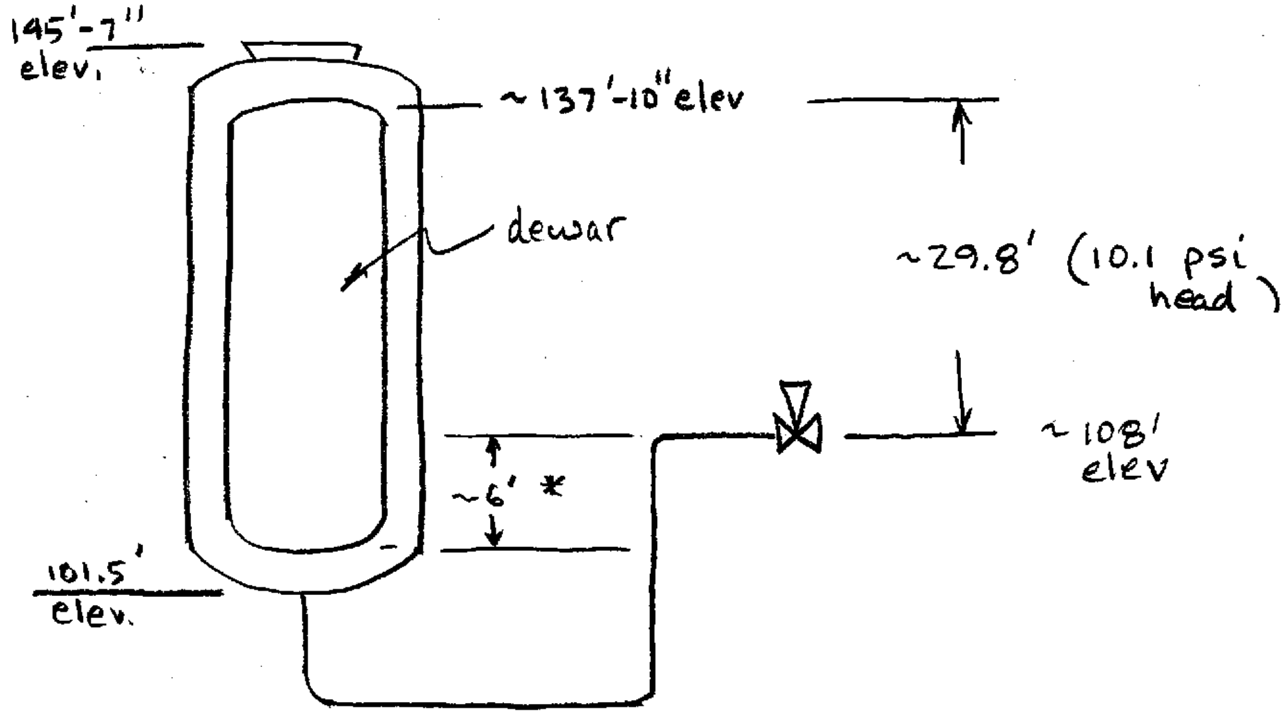


* approx. 20% of height of dewar

LN$_2$ Dewar
Long Pump

Set regulator at 5 psig (top of tank)
Pressure at control valve is 5 psig + liquid head

Tank full : 5 + 10 = 15 psig at valve
Tank "empty" : 5 psig at valve
(~16.5 % full)



* approx 16.5% of height of dewar

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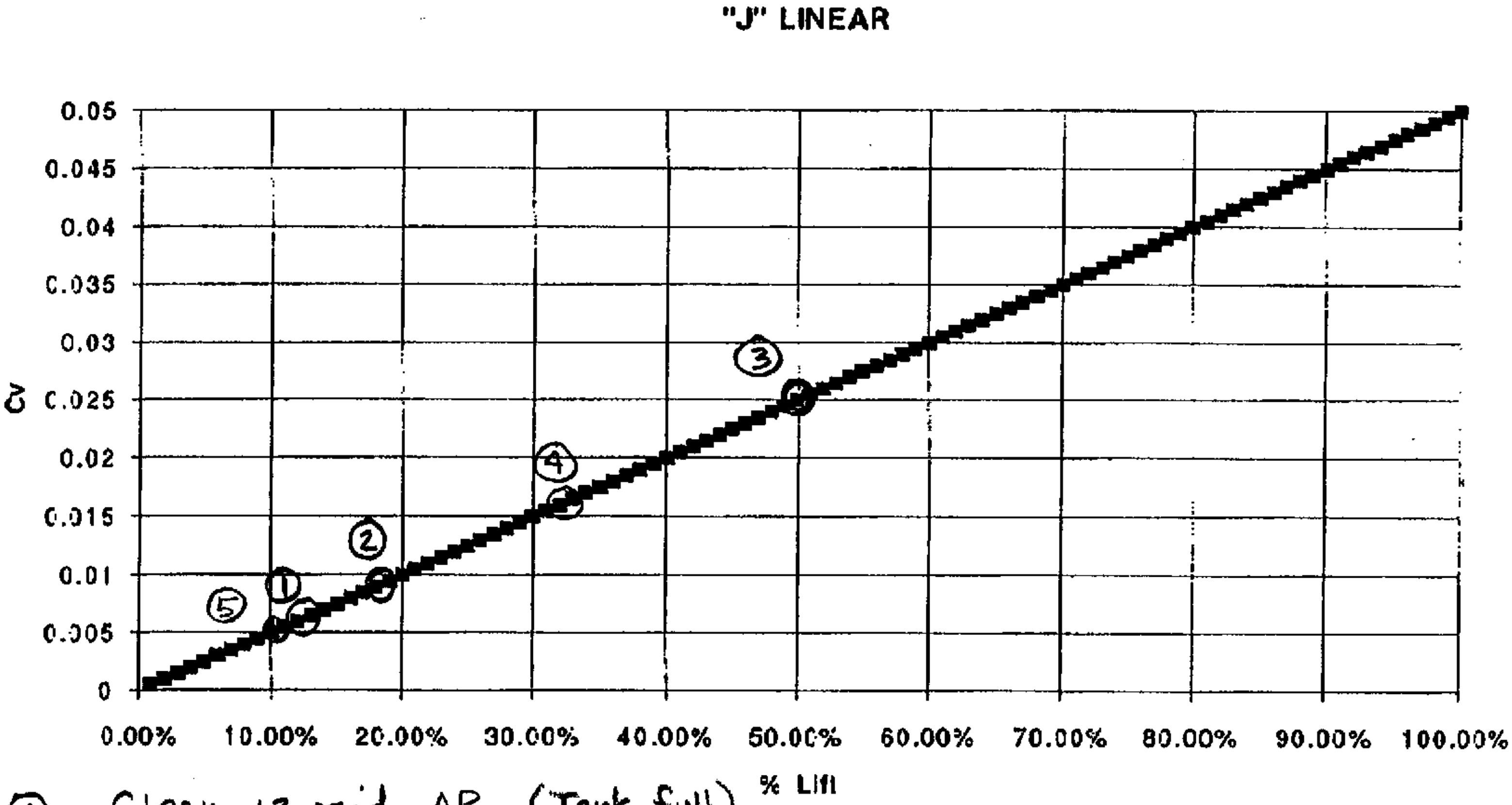
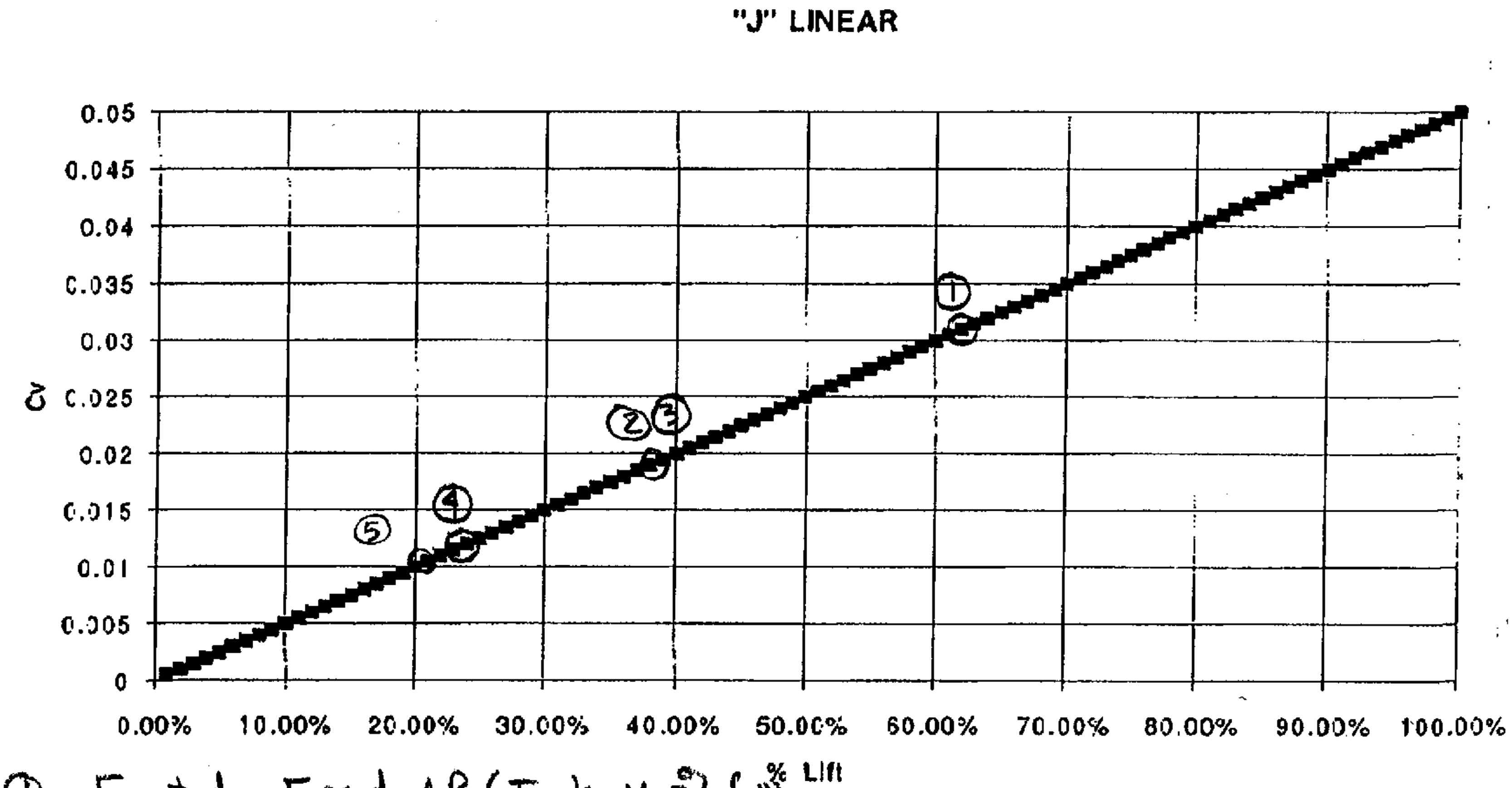
Short Pump



① Clean, 13 psid ΔP (Tank full)
② Clean, 5 psid ΔP (Tank 20% full)
③ Frosted, 5 psid ΔP
④ Frosted, 13 psid ΔP
⑤ Clean, 13 psid ΔP, subcooled case

Long Pump



① Frosted, 5psid ΔP (Tank 16.5% full)
② Clean, 5psid ΔP
③ Frosted, 15psid ΔP (Tank full)
④ Clean, 15 psid ΔP
⑤ Clean, 15psid ΔP, subcooled liquid

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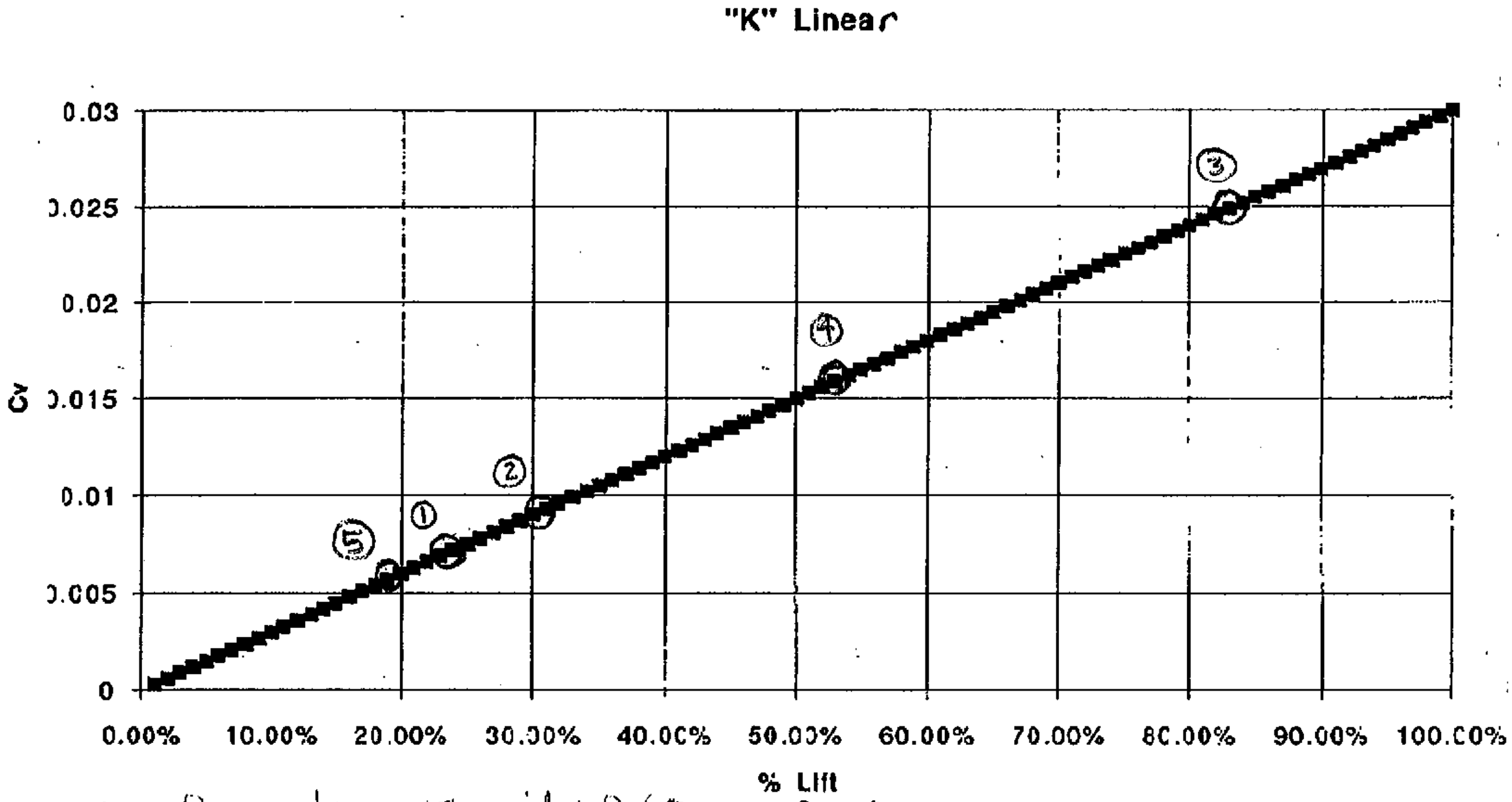
Short Pump

Smaller Cv



① Pump clean, 13 psid ΔP (Dewar full)
② Pump clean, 5 psid ΔP (Dewar 20% full)
③ Pump frosted, 5 psid ΔP
④ Pump frosted, 13 psid ΔP
⑤ Pump clean, 13 psid ΔP, liquid subcooled

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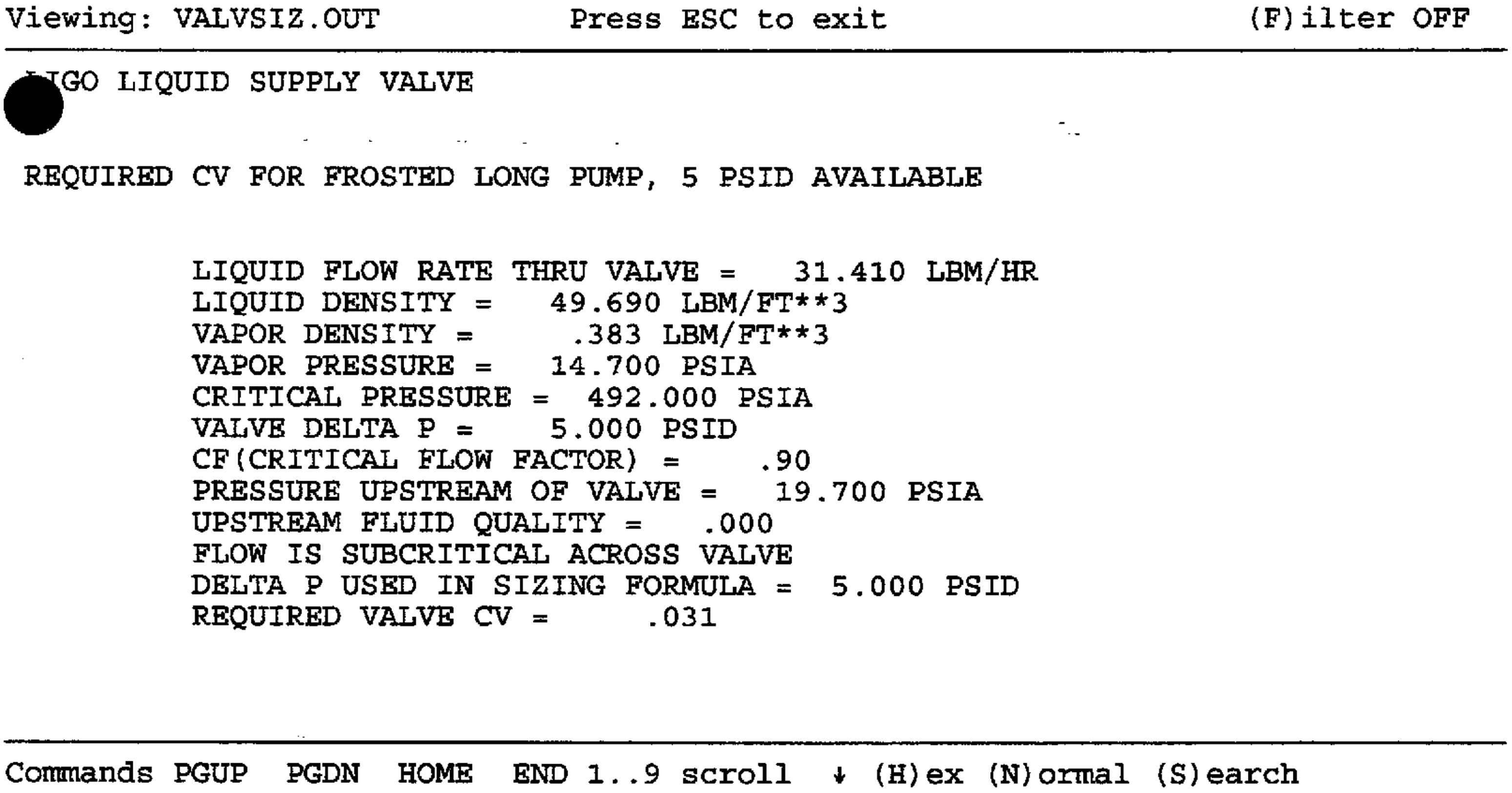

```
Viewing: VALVSIZ.OUT          Press ESC to exit                  (F)ilter OFF

LIGO LIQUID SUPPLY VALVE


 REQUIRED CV FOR FROSTED LONG PUMP, 5 PSID AVAILABLE


          LIQUID FLOW RATE THRU VALVE =   31.410 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =    5.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   19.700 PSIA
          UPSTREAM FLUID QUALITY =   .000
          FLOW IS SUBCRITICAL ACROSS VALVE
          DELTA P USED IN SIZING FORMULA =  5.000 PSID
          REQUIRED VALVE CV =     .031


Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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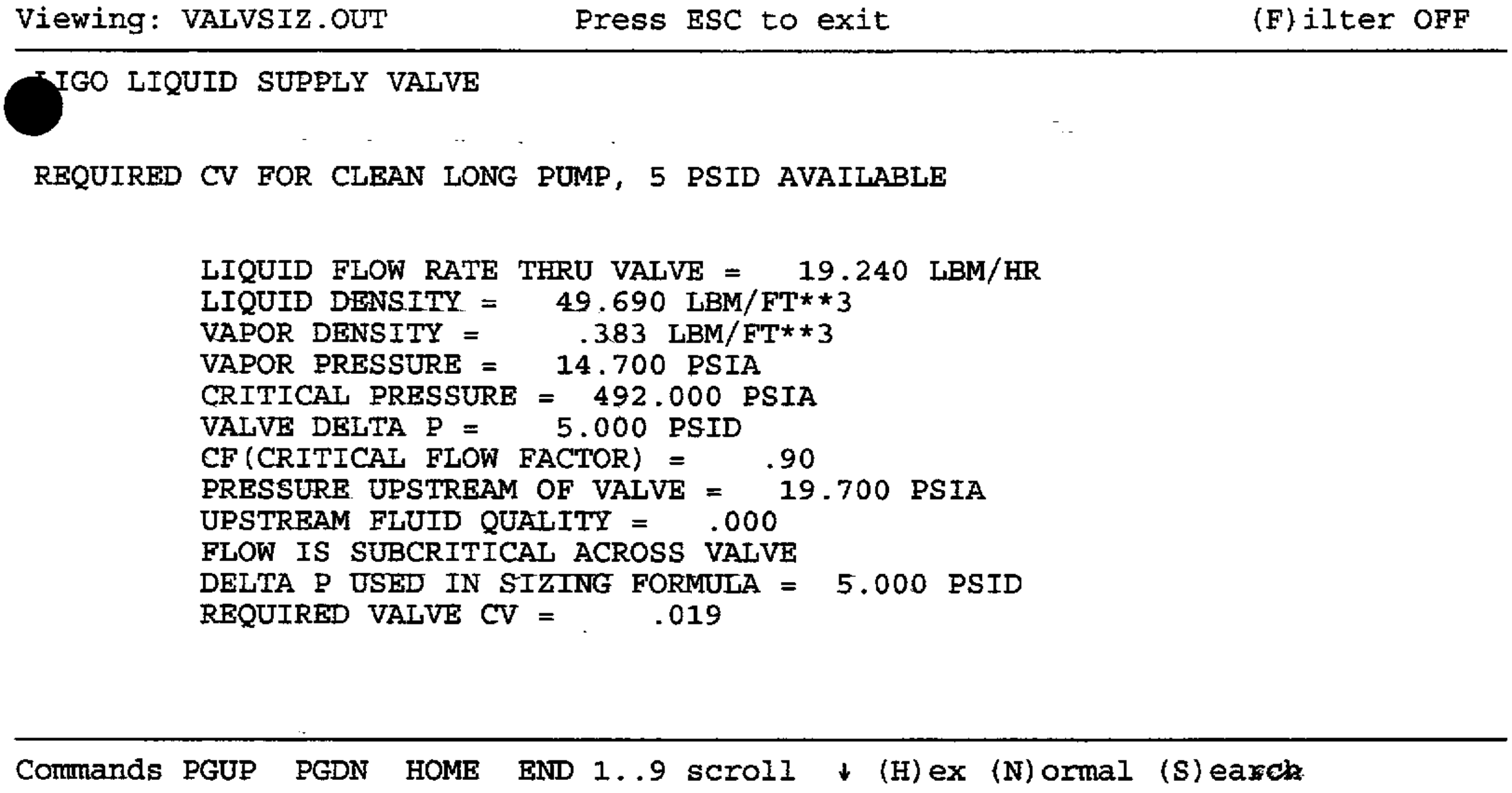

```
Viewing: VALVSIZ.OUT          Press ESC to exit                 (F)ilter OFF
LIGO LIQUID SUPPLY VALVE

 REQUIRED CV FOR CLEAN LONG PUMP, 5 PSID AVAILABLE

          LIQUID FLOW RATE THRU VALVE =   19.240 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =    5.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   19.700 PSIA
          UPSTREAM FLUID QUALITY =   .000
          FLOW IS SUBCRITICAL ACROSS VALVE
          DELTA P USED IN SIZING FORMULA =  5.000 PSID
          REQUIRED VALVE CV =      .019

Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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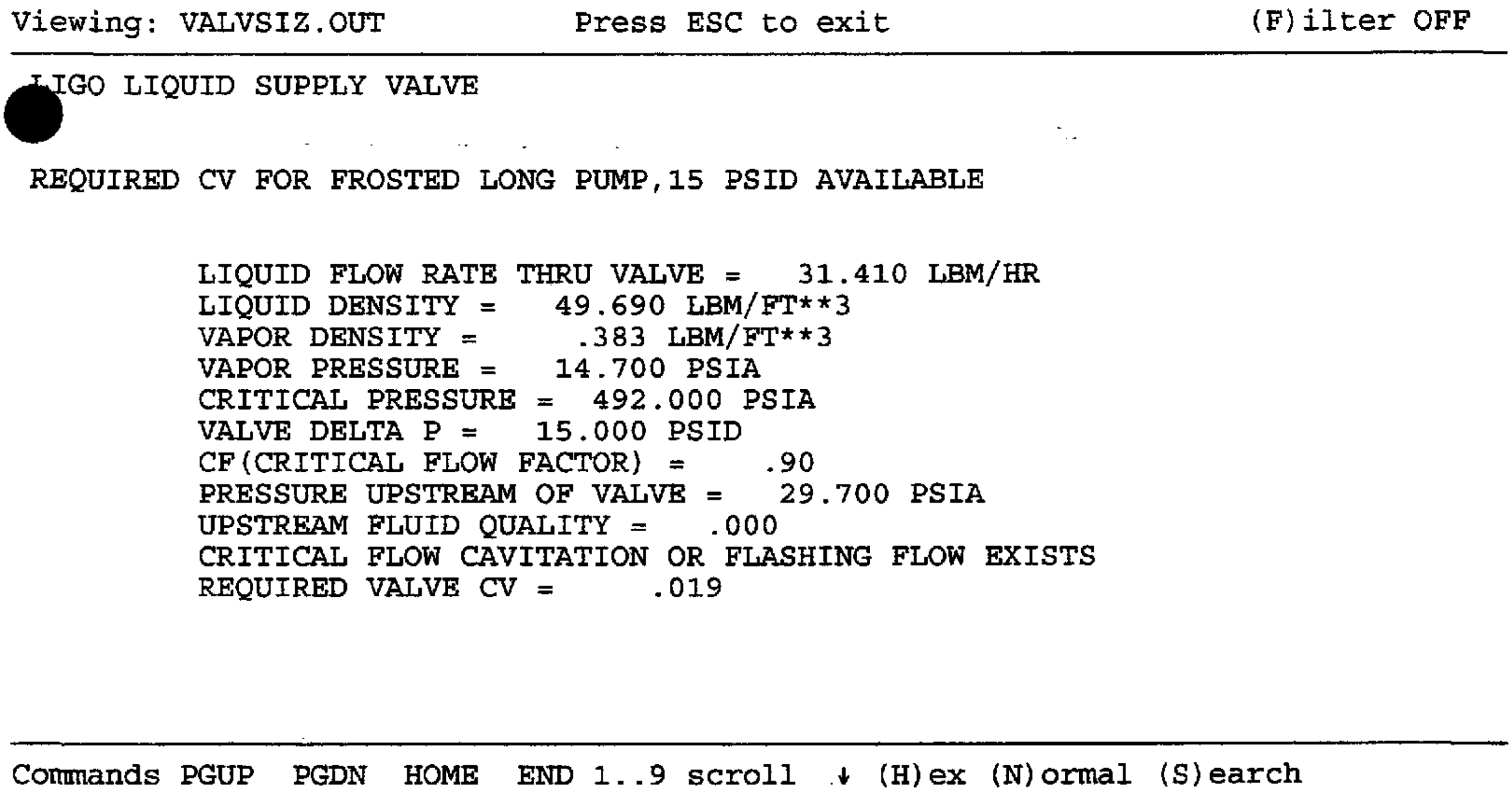

```
Viewing: VALVSIZ.OUT            Press ESC to exit                  (F)ilter OFF

LIGO LIQUID SUPPLY VALVE


 REQUIRED CV FOR FROSTED LONG PUMP,15 PSID AVAILABLE


          LIQUID FLOW RATE THRU VALVE =   31.410 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =   15.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   29.700 PSIA
          UPSTREAM FLUID QUALITY =    .000
          CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
          REQUIRED VALVE CV =     .019



Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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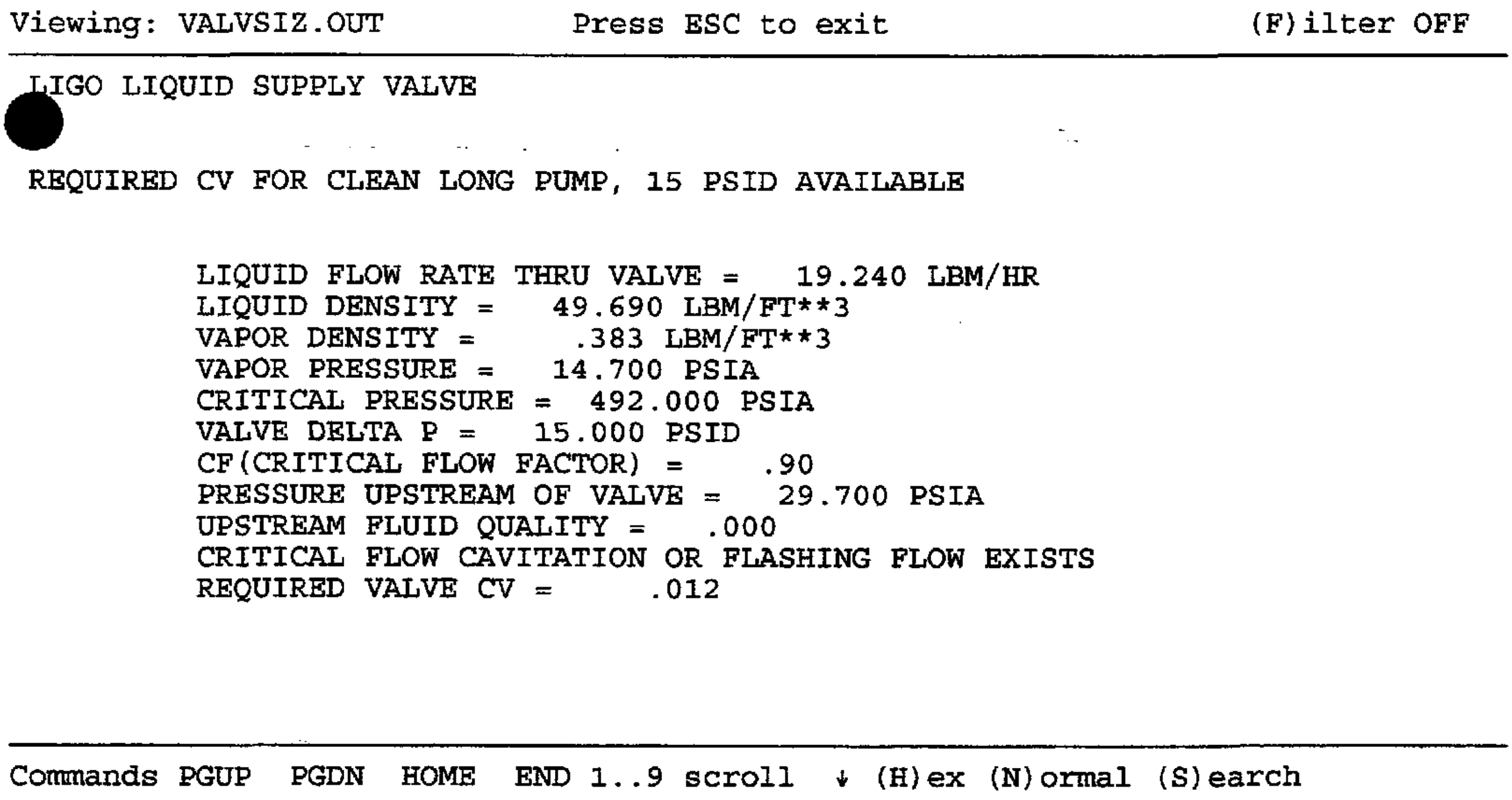
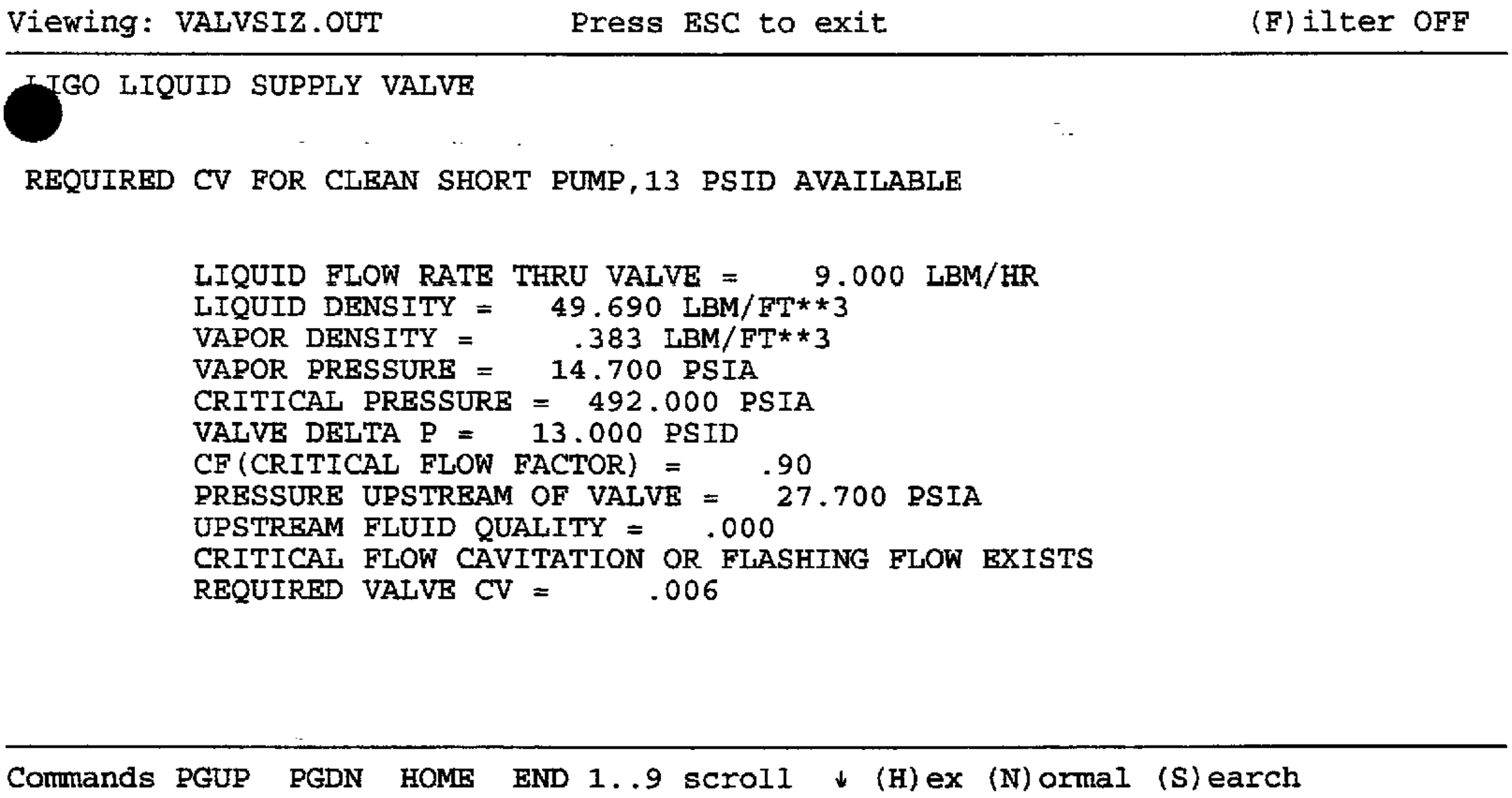


```
Viewing: VALVSIZ.OUT              Press ESC to exit                  (F)ilter OFF
LIGO LIQUID SUPPLY VALVE

REQUIRED CV FOR CLEAN LONG PUMP, 15 PSID AVAILABLE

         LIQUID FLOW RATE THRU VALVE =    19.240 LBM/HR
         LIQUID DENSITY =   49.690 LBM/FT**3
         VAPOR DENSITY =      .383 LBM/FT**3
         VAPOR PRESSURE =   14.700 PSIA
         CRITICAL PRESSURE =  492.000 PSIA
         VALVE DELTA P =   15.000 PSID
         CF(CRITICAL FLOW FACTOR) =     .90
         PRESSURE UPSTREAM OF VALVE =   29.700 PSIA
         UPSTREAM FLUID QUALITY =    .000
         CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
         REQUIRED VALVE CV =     .012

Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```



```
Viewing: VALVSIZ.OUT             Press ESC to exit                 (F)ilter OFF

LIGO LIQUID SUPPLY VALVE

 REQUIRED CV FOR CLEAN SHORT PUMP,13 PSID AVAILABLE

          LIQUID FLOW RATE THRU VALVE =    9.000 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =   13.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   27.700 PSIA
          UPSTREAM FLUID QUALITY =   .000
          CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
          REQUIRED VALVE CV =     .006

Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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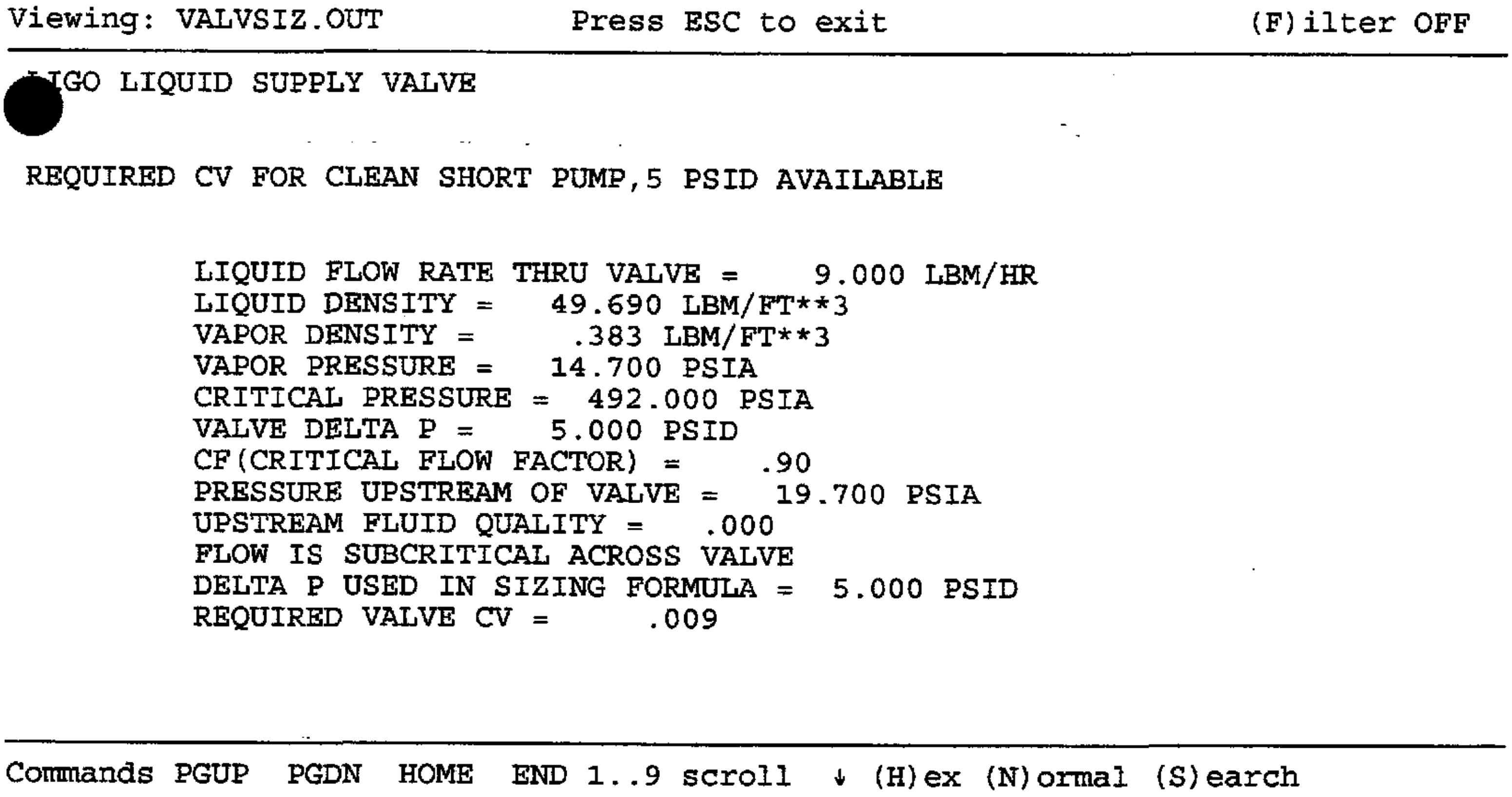

```
Viewing: VALVSIZ.OUT              Press ESC to exit                   (F)ilter OFF
--------------------------------------------------------------------------------
LIGO LIQUID SUPPLY VALVE


 REQUIRED CV FOR CLEAN SHORT PUMP,5 PSID AVAILABLE


          LIQUID FLOW RATE THRU VALVE =    9.000 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =    5.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   19.700 PSIA
          UPSTREAM FLUID QUALITY =   .000
          FLOW IS SUBCRITICAL ACROSS VALVE
          DELTA P USED IN SIZING FORMULA =  5.000 PSID
          REQUIRED VALVE CV =     .009


--------------------------------------------------------------------------------
Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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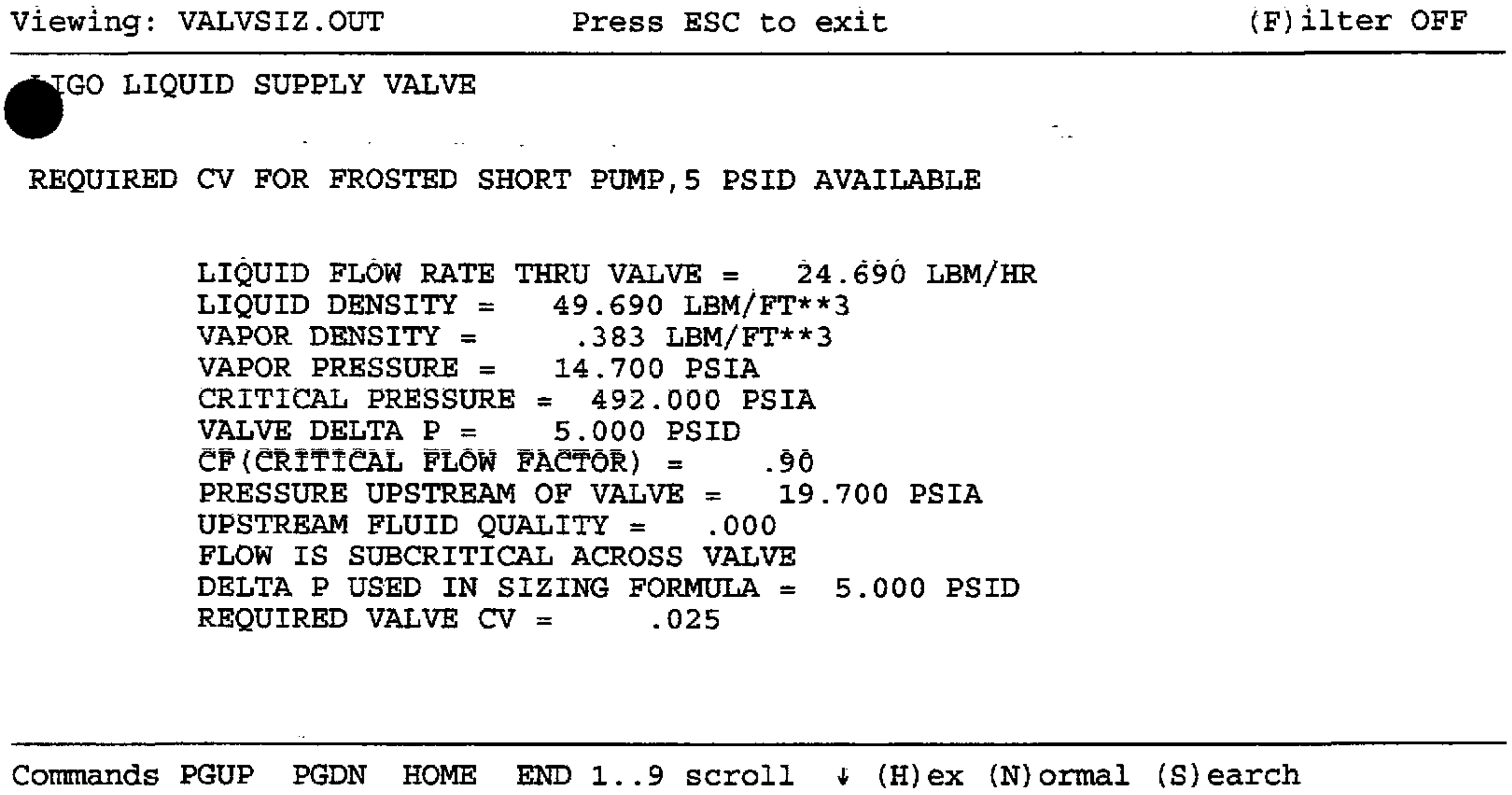

```
Viewing: VALVSIZ.OUT          Press ESC to exit                    (F)ilter OFF
________________________________________________________________________________
LIGO LIQUID SUPPLY VALVE


 REQUIRED CV FOR FROSTED SHORT PUMP,5 PSID AVAILABLE


          LIQUID FLOW RATE THRU VALVE =   24.690 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =    5.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   19.700 PSIA
          UPSTREAM FLUID QUALITY =    .000
          FLOW IS SUBCRITICAL ACROSS VALVE
          DELTA P USED IN SIZING FORMULA =  5.000 PSID
          REQUIRED VALVE CV =     .025


________________________________________________________________________________
Commands PGUP  PGDN  HOME  END 1..9 scroll  ↓ (H)ex (N)ormal (S)earch
```

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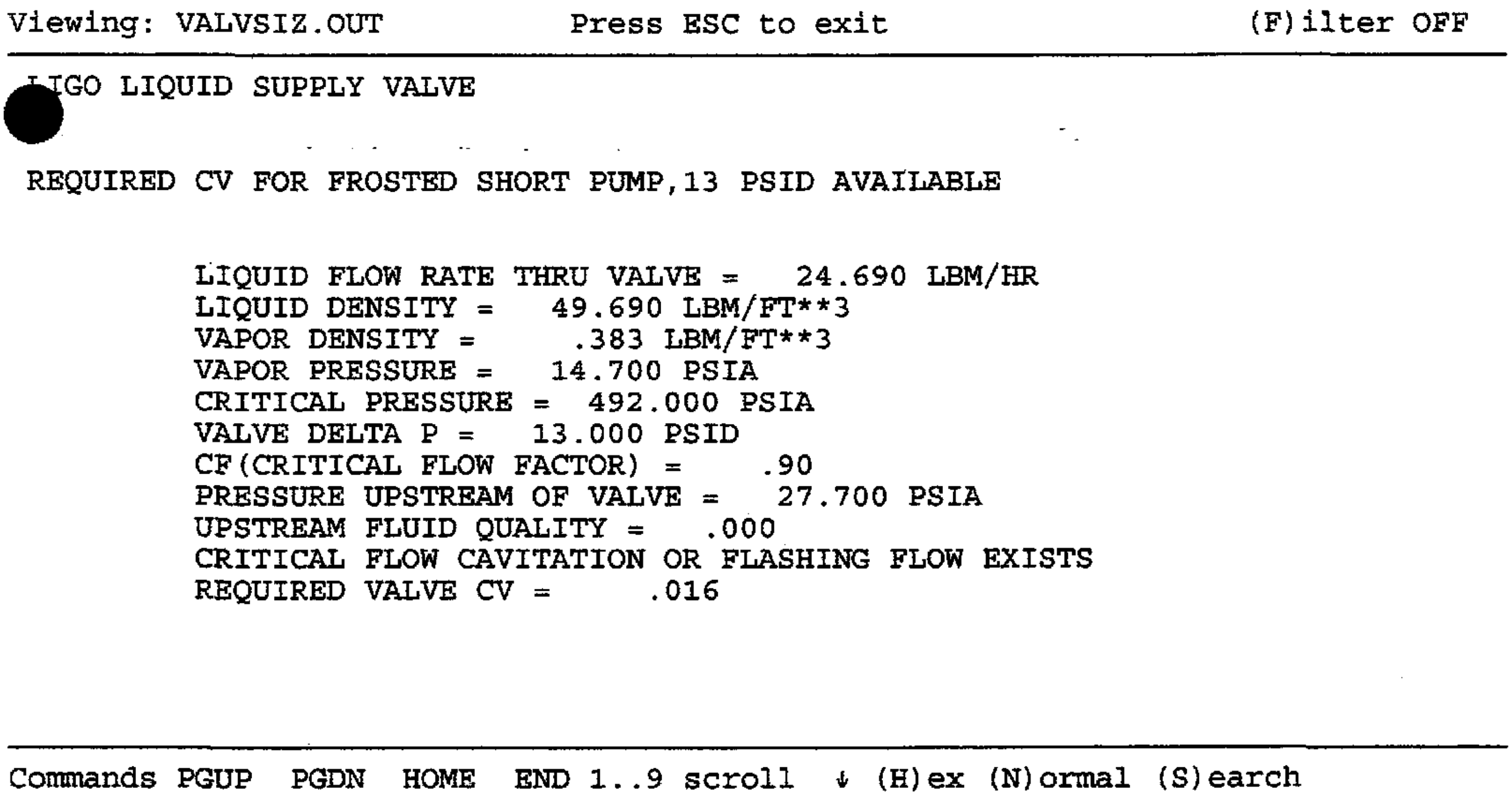

```
LIGO LIQUID SUPPLY VALVE

 REQUIRED CV FOR FROSTED SHORT PUMP,13 PSID AVAILABLE

          LIQUID FLOW RATE THRU VALVE =   24.690 LBM/HR
          LIQUID DENSITY =   49.690 LBM/FT**3
          VAPOR DENSITY =     .383 LBM/FT**3
          VAPOR PRESSURE =   14.700 PSIA
          CRITICAL PRESSURE =  492.000 PSIA
          VALVE DELTA P =   13.000 PSID
          CF(CRITICAL FLOW FACTOR) =    .90
          PRESSURE UPSTREAM OF VALVE =   27.700 PSIA
          UPSTREAM FLUID QUALITY =   .000
          CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
          REQUIRED VALVE CV =     .016
```

```
LIGO LIQUID SUPPLY VALVE

REQUIRED CV FOR CLEAN SHORT PUMP,13 PSID AVAILABLE,SUBCOOLED CASE

         LIQUID SERVICE
         LIQUID FLOW RATE THRU VALVE =    9.000 LBM/HR
         LIQUID DENSITY =   49.690 LBM/FT**3
         VAPOR DENSITY =      .383 LBM/FT**3
         VAPOR PRESSURE =   14.700 PSIA
         CRITICAL PRESSURE =  492.000 PSIA
         VALVE DELTA P =   13.000 PSID
         PRESSURE UPSTREAM OF VALVE =   27.700 PSIA
         UPSTREAM FLUID QUALITY =   .000
         REQUIRED VALVE CV =     .0056
```

```
LIGO LIQUID SUPPLY VALVE

REQUIRED CV FOR CLEAN LONG PUMP,15 PSID AVAILABLE,SUBCOOLED CASE

         LIQUID SERVICE
         LIQUID FLOW RATE THRU VALVE =   19.240 LBM/HR
         LIQUID DENSITY =   49.690 LBM/FT**3
         VAPOR DENSITY =      .383 LBM/FT**3
         VAPOR PRESSURE =   14.700 PSIA
         CRITICAL PRESSURE =  492.000 PSIA
         VALVE DELTA P =   15.000 PSID
         PRESSURE UPSTREAM OF VALVE =   29.700 PSIA
         UPSTREAM FLUID QUALITY =   .000
         REQUIRED VALVE CV =     .0111
```

```
C---------DATE: OCT. 1996
C-------- PROGRAMMER: DAVID MOORE
C
                   PROGRAM    VALVSIZ2
C                    VERSION 2.0
C
C--- THESE COMPUTATIONS ARE FOR 2 PHASE FLOW AND LIQUID FLOW THRU VALVES
C--- FORMULAS ARE COMPATIBLE WITH ISA SP39.1 AND ARE FROM MASONNEILAN
C--- PAPER ON CONTROL VALVE SIZING.
C
C--- NOTE: NO LOGIC IS PRESENTLY IN THIS CODE TO ACCOUNT FOR
C---       NON-CONDENSABLE GAS.
C
      REAL MDOTL
      CHARACTER TITLE1*80,TITLE2*80
      OPEN(UNIT=10,FILE='VALVSIZ.DAT',ACCESS='SEQUENTIAL',STATUS='OLD',
     +     FORM='FORMATTED')
      OPEN(UNIT=11,FILE='VALVSIZ.OUT',ACCESS='SEQUENTIAL',STATUS='OLD',
     +     FORM='FORMATTED')
$DEBUG
C
C-----READ DATA----------
      READ(10,*) TITLE1
      READ(10,*) TITLE2
      WRITE(11,*) TITLE1
      WRITE(11,*) TITLE2
C--- READ VALUE OF FLAGS. IF FLAG1 IS GREATER THAN 0.0, CALCULATE THE
C--- FLOWRATE WHEN GIVEN THE CV AND VALVE DP. OTHERWISE CALCULATE
   - THE REQ'D CV. FLAG2 GREATER THAN 0.0 IS FOR LIQUID SERVICE.
C
      READ(10,*) FLAG1,FLAG2
C
C--- READ CV, LIQ. DENS(LB/FT**3),LIQ. VAPOR PRESS AT FLOWING TEMP(PSIA),
C---THERMODYNAMIC CRITICAL PRESS.(PSIA), DELTA P ACROSS VALVE(PSIA)
      IF(FLAG1.GT.0.0.AND.FLAG2.EQ.0.0)THEN
C-----FLASHING FLOW
       READ(10,*) CV,RHOL,RHOV,VAPRES,CRPRES,DPVALV,CF,P1,X
       WRITE(11,100)CV
       WRITE(11,101)RHOL
       WRITE(11,111)RHOV
       WRITE(11,102)VAPRES
       WRITE(11,103)CRPRES
       WRITE(11,104)DPVALV
       WRITE(11,105)CF
       WRITE(11,106)P1
       WRITE(11,110)X
       DPMAX=CF**2*P1/2.0
       DPS=P1-(0.96-0.28*SQRT(VAPRES/CRPRES))*VAPRES
C
       CF2DP=CF**2*DPS
       DPWL=DPVALV*(RHOL/62.4/(RHOL/62.365))
        IF(CF2DP.LT.DPWL)THEN
         WRITE(11,107)
   - CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
         MDOTL=CV*500*CF*SQRT(DPS*(RHOL/62.365))
         WRITE(11,109)MDOTL
        ELSE
         WRITE(11,112)
C--- FLOW IS TWO-PHASE LIQUID & VAPOR, NO NON-CONDENSABLES & NO CHOKING
```

```
         W1=1.0/(X*(1/RHOV+1/RHOL)+1/RHOL)
          IF(DPVALV.GE.DPMAX)THEN
C--- MAX DELTA P FOR SIZING SUBSTITUTED FOR DPVALV
           DPVALV=DPMAX
           WRITE(11,108)DPVALV
          ELSE
           WRITE(11,108)DPVALV
          END IF
         MDOTL=CV*63.3*SQRT(DPVALV*W1)
         WRITE(11,109)MDOTL
       END IF
        ELSE IF(FLAG1.GT.0.0.AND.FLAG2.GT.0.0)THEN
         READ(10,*) CV,RHOL,RHOV,VAPRES,CRPRES,DPVALV,CF,P1,X
C--- LIQUID OR SUBCOOLED SERVICE
         WRITE(11,114)
         MDOTL=CV*500*SQRT(RHOL/62.4*DPVALV)
         WRITE(11,109)MDOTL
        ELSE IF(FLAG1.EQ.0.0.AND.FLAG2.EQ.0.0)THEN
         READ(10,*) CV,RHOL,RHOV,VAPRES,CRPRES,DPVALV,CF,P1,X
C---- FLASHING FLOW
C---  CODE HERE FOR CALCULATION OF CV WHEN GIVEN FLOW RATE
       READ(10,*) MDOTL,RHOL,RHOV,VAPRES,CRPRES,DPVALV,CF,P1,X
       WRITE(11,109)MDOTL
       WRITE(11,101)RHOL
       WRITE(11,111)RHOV
       WRITE(11,102)VAPRES
       WRITE(11,103)CRPRES
       WRITE(11,104)DPVALV
       WRITE(11,105)CF
       WRITE(11,106)P1
       WRITE(11,110)X
       DPMAX=CF**2*P1/2.0
       DPS=P1-(0.96-0.28*SQRT(VAPRES/CRPRES))*VAPRES
C
       CF2DP=CF**2*DPS
       DPWL=DPVALV*(RHOL/62.4/(RHOL/62.365))
        IF(CF2DP.LT.DPWL)THEN
         WRITE(11,107)
C--- CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS
         CV=MDOTL/(500*CF*SQRT(DPS*(RHOL/62.365)))
         WRITE(11,113)CV
        ELSE
         WRITE(11,112)
C--- FLOW IS TWO-PHASE LIQUID & VAPOR, NO NON-CONDENSABLES & NO CHOKING
         W1=1.0/(X*(1/RHOV+1/RHOL)+1/RHOL)
          IF(DPVALV.GE.DPMAX)THEN
C--- MAX DELTA P FOR SIZING SUBSTITUTED FOR DPVALV
           DPVALV=DPMAX
           WRITE(11,108)DPVALV
          ELSE
           WRITE(11,108)DPVALV
          END IF
         CV=MDOTL/(63.3*SQRT(DPVALV*W1))
         WRITE(11,113)CV
       END IF
        ELSE IF(FLAG1.EQ.0.0.AND.FLAG2.GT.0.0)THEN
       READ(10,*) MDOTL,RHOL,RHOV,VAPRES,CRPRES,DPVALV,CF,P1,X
       WRITE(11,114)
       WRITE(11,109)MDOTL
       WRITE(11,101)RHOL
```

```
       WRITE(11,111)RHOV
       WRITE(11,102)VAPRES
       WRITE(11,103)CRPRES
       WRITE(11,104)DPVALV
        WRITE(11,105)CF
       WRITE(11,106)P1
       WRITE(11,110)X
C--- LIQUID OR SUBCOOLED SERVICE
         CV=MDOTL/500/SQRT(RHOL/62.4*DPVALV)
         WRITE(11,113)CV
        ELSE
       END IF
C
C
C
C
C-----FORMATS FOR INPUT AND OUTPUT STATEMENTS---------
   90 FORMAT(3X,I2)
  100 FORMAT(10X,'VALVE CV = ',F6.2)
  101 FORMAT(10X,'LIQUID DENSITY = ',F8.3,' LBM/FT**3')
  102 FORMAT(10X,'VAPOR PRESSURE = ',F8.3,' PSIA')
  103 FORMAT(10X,'CRITICAL PRESSURE = ',F8.3,' PSIA')
  104 FORMAT(10X,'VALVE DELTA P = ',F8.3,' PSID')
  105 FORMAT(10X,'CF(CRITICAL FLOW FACTOR) = ',F6.2)
  106 FORMAT(10X,'PRESSURE UPSTREAM OF VALVE = ',F8.3,' PSIA')
  107 FORMAT(10X,'CRITICAL FLOW CAVITATION OR FLASHING FLOW EXISTS')
  108 FORMAT(10X,'DELTA P USED IN SIZING FORMULA = ',F6.3,' PSID')
  109 FORMAT(10X,'LIQUID FLOW RATE THRU VALVE = ',F8.3,' LBM/HR')
  110 FORMAT(10X,'UPSTREAM FLUID QUALITY = ',F6.3)
  111 FORMAT(10X,'VAPOR DENSITY = ',F8.3,' LBM/FT**3')
  112 FORMAT(10X,'FLOW IS SUBCRITICAL ACROSS VALVE')
  113 FORMAT(10X,'REQUIRED VALVE CV = ',F9.4)
  114 FORMAT(10X,'LIQUID SERVICE')
  216 CONTINUE
      CLOSE(UNIT=10)
      CLOSE(UNIT=11)
      STOP
      END
```

two-phase flow

The two-phase flow formulas, shown below, assume finely divided liquid particles in vapor moving at the same velocity. If insufficient vapor exists entering the valve, the flashing formula on page 3 will prevail.

Cf - .87

Therefore:

when $C_f^2 \Delta P_1 < \Delta P \left(\frac{w_1}{62.4 G_1}\right)$, use flashing formula on page 3.

ENGLISH FORMULAS:

A. Liquid And Non-Condensable Gas Entering Valve

If there is no vaporization of the liquid and if flow velocity assures a turbulent well-mixed stream.

$$C_v = \frac{W}{44.8\sqrt{\Delta P\,(w_1 + w_2)}}$$

B. Liquid And Its Vapor Entering Valve

Additional vaporization of liquid occurs. If flow velocity assures a turbulent well-mixed stream.

$$C_v = \frac{W}{63.3\sqrt{\Delta P\, w_1}}$$

Where:

$$\text{Max. } \Delta P \text{ For Sizing} = C_f^2 \left(\frac{P_1}{2}\right)$$

w_1 = Upstream specific, weight lb/cu. ft. calculated from weight fraction of gas or vapor in the stream X_g and specific volumes of gas or vapor and liquid at upstream pressure V_{g1} and V_f.

$$w_1 = \frac{1}{V_1} = \frac{1}{X_g\,(V_{g1} - V_f) + V_f}$$

w_2 = Downstream specific weight, lb/cu. ft. calculated using downstream gas specific volume V_{g2}.

$$w_2 = \frac{1}{V_2} = \frac{1}{X_g\,(V_{g2} - V_f) + V_f}$$

METRIC FORMULAS:

A. Liquid And Non-Condensable Gas Entering Valve

$$C_v = \frac{51.8\,W}{\sqrt{\Delta P\,(w_1 + w_2)}}$$

B. Liquid And Its Vapor Entering Valve

$$C_v = \frac{36.6\,W}{\sqrt{\Delta P\, w_1}}$$

Where:

w_1 = Upstream specific weight, (kg/m³)
w_2 = Downstream specific weight, (kg/m³)

compressibility

For many real gases subjected to commonly encountered temperatures and pressures the perfect gas laws are not satisfactory for flow measurement accuracy and correction factors must be used (Ref. 9).

Following conventional flow measurement practice, the compressibility factor Z in the equation $pv = ZRT$ will be used. Z can usually be ignored below 100 psi for common gases.

The value of Z does not differ materially for different gases when correlated as a function of the reduced temperature and reduced pressure, T_r and P_r, respectively and found from Figure 2 and 3.

Figure 2 is an enlargement of a portion of Figure 3. Values taken from these figures are probably accurate to approximately plus or minus two percent.

To obtain the value of Z for a pure substance the reduced pressure and reduced temperature are calculated as the ratio of the actual absolute gas pressure and absolute temperature and the corresponding critical absolute pressure and absolute critical temperature respectively (page 16).

The compressibility factor Z may be used directly in the volumetric gas formula as shown below:

ENGLISH UNITS $\quad C_v = \frac{Q\sqrt{GTZ}}{834\, C_f\, P_1\, (y - 0.148\, y^3)}$

METRIC UNITS $\quad C_v = \frac{Q\sqrt{GTZ}}{257\, C_f\, P_1\, (y - 0.148\, y^3)}$

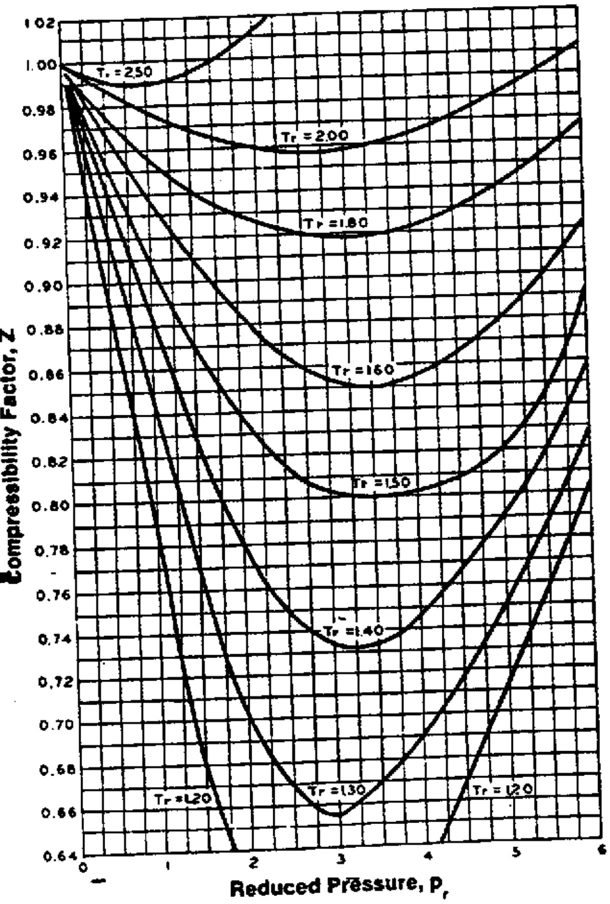

Figure 2
Compressibility Factors for Gases with Reduced Pressures from 0 to 6
(Data from the charts of L. C. Nelson and E. F. Obert, Northwestern Technological Institute)

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■ English Units
■ Metric Units

control valve sizing formulas

For Liquid Service

ENGLISH FORMULAS:

A. Subcritical Flow $\Delta P < C_f^2 (\Delta P_s)$	B. Critical Flow cavitation or flashing $\Delta P \geqq C_f^2 (\Delta P_s)$
Volumetric Flow $C_v = q\sqrt{\frac{G_f}{\Delta P}}$	$C_v = \frac{q}{C_f}\sqrt{\frac{G_f}{\Delta P_s}}$
Flow by Weight $C_v = \frac{W}{500\sqrt{G_f\,\Delta P}}$	$C_v = \frac{W}{500\,C_f\sqrt{G_f\,\Delta P_s}}$

$$^{*}\Delta P_s = P_1 - \left(0.96 - 0.28\sqrt{\frac{P_v}{P_c}}\right)P_v$$

or for simplicity, if $P_v < 0.5\,P_1$, $\Delta P_s = P_1 - P_v$

Where:

C_v = Valve flow coefficient
C_f = Critical flow factor (page 7) = †F_L
G_f = Specific gravity at flowing temperature (water = 1 @ 60° F)
P_1 = Upstream pressure, psia
P_2 = Downstream pressure, psia
P_c = Pressure at thermodynamic critical point, psia (see table, page 4)
P_v = Vapor pressure of liquid at flowing temperature, psia
ΔP = Actual pressure drop $P_1 - P_2$, psi
q = Liquid flow rate, U.S. gpm
W = Liquid flow rate, pounds per hour

$\frac{f_L}{f_{w_{60°F}}}$

(Ref. 1)

(Ref. 2)
(Ref. 7)

METRIC FORMULAS:

A. Subcritical Flow $\Delta P < C_f^2 (\Delta P_s)$	B. Critical Flow cavitation or flashing $\Delta P \geqq C_f^2 (\Delta P_s)$
Volumetric Flow $C_v = 1.16q\sqrt{\frac{G_f}{\Delta P}}$	$C_v = \frac{1.16q}{C_f}\sqrt{\frac{G_f}{\Delta P_s}}$
Flow by Weight $C_v = \frac{1.16\,W}{\sqrt{G_f\,\Delta P}}$	$C_v = \frac{1.16\,W}{C_f\sqrt{G_f\,\Delta P_s}}$

$$^{*}\Delta P_s = P_1 - \left(0.96 - 0.28\sqrt{\frac{P_v}{P_c}}\right)P_v$$

or for simplicity, if $P_v < 0.5\,P_1$, $\Delta P_s = P_1 - P_v$

Where:

C_v = Valve flow coefficient
C_f = Critical flow factor (page 7) = †F_L
G_f = Specific gravity at flowing temperature (water = 1 @ 15° C)
P_1 = Upstream pressure, bars absolute
P_2 = Downstream pressure, bars absolute
P_c = Pressure at thermodynamic critical point, bars absolute (see table, page 4)
P_v = Vapor pressure of liquid at flowing temperature, bars absolute
ΔP = Actual pressure drop $P_1 - P_2$, bars
q = Liquid flow rate, m^3/hr
W = Liquid flow rate, 1000 kg per hr

Note: 1 bar = 1.02 kg/cm²

Special considerations (see following pages)

a. cavitation in control valves (page 10)
b. high viscosity, laminar flow (page 14)
c. effect of pipe reducers (page 11)
d. two-phase flow (page 15)

*NOTE: $C_f^2 \Delta P_s$ is the maximum ΔP for sizing purposes. A valve is not limited in application to this pressure drop, but at higher pressure differential, choked flow will occur without increase in flow rate.
This formula for ΔP_s is sufficiently accurate for general use on liquids.

†**ISA Formulas:** The working equations on this page are entirely compatible with the general formulas shown in ISA SP39.1, "Control Valve Sizing Equations for Incompressible Fluids."

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■ English Units
■ Metric Units

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ENGINEERING
CALCULATIONS

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0		4/17/96	R.THAN	

TITLE:
BAKEOUT BLANKETS
HEAT TRANSFER ANALYSIS

BY: R.THAN
DEPT: 744

PROJECT: LIGO
PROJECT NO: V59049

PURPOSE: Determine power density, blanket thermal insulation requirements:
For : general vacuum vessel shell section; support legs; end effects; blanket failure; thermocouple patch, warmup time, cooldown time.

METHOD: Finite difference models. Radiation network models.

ASSUMPTIONS:

INPUTS:

REFERENCE:
-ASTM Annual Book of ASTM Standards, Section 4 Construction, Vol 0.406, Thermal Insulation; Environmental Acoustics.
-J.P. Holman, Heat Transfer, 1981 McGraw-Hill.
-M.N. Ozisik, Heat Conduction. 1980, John Wiley & Sons.
-Siegel and Howell, Thermal Radiation Heat Transfer, McGraw-Hill.

CALCULATIONS: See attached

CONCLUSIONS: See section 3.0 page 8

NOTES:

TABLE OF CONTENT

1. Bakeout requirements
    1.1 Bakeout system

2. Finite Difference models
    2.1 Blanket model
    2.2 Support leg model
    2.3 Gate valve end effect models

3. Results from the analyses
    3.1 Steady state profiles and parametric studies
    3.2 Warmup analysis
    3.3 CooldownaAnalysis
    3.4 Blanke failure analysis
    3.5 Thermal couple patch
    3.6 BSC Supporl Leg analysis
    3.7 End effects 48" Gate valve analysis
    3.8 Pressure gauge pair bakeout

2. FINITE DIFFERENCE MODEL

Several finite difference models were setup to model the heat transfer of the blanket/vessel system. This was used to generate warmup, cooldown, steady state, blanket failure gradients, and thermal couple patch gradients and support leg gradients.

2.1 Blanket Model on Shell Section

A finite difference model was used to calculate temperature gradients for the failure of one blanket surrounded by other blankets. The model was also used to determine warmup and cooldown transients and steady state requirements. The blanket was modeled in cylindrical coordinates with the thickness of the blanket in the z-direction and the size of the blanket in the r-direction (circular blanket). The axisymetry gives the effect in the third direction, thus a simulation of a failed blanket surrounded by operating blankets.

The boundary conditions on the surface of the blanket takes into account the convective and radiative losses. The boundary condition on the shell side is adiabatic (vacuum).

2.2 Support Leg Model

The support leg for the BSC was modeled with a blanket to determine the power density requirements for the blankets on the legs to maintain the appropriate bakeout temperature on the BSC. The support leg which is a square tube was modeled as a circular tube with the same material cross sectional area (length in z direction and thickness of blanket in the r direction. The legs on the BSC are 8 inch square tubes with 0.63 inch wall thickness. The internal boundary conditions was modeled as an adiabatic boundary condition. The radiation losses of the internal surface was ignored, but this is less than 20% of convective losses.

.2.3 Gate Valves End Effect Model

Because of the end effects additional blankets beyond the isolatable section may be required to maintain a minimum temperature of the vacuum envelope wall or the gate. There are 4 cases that may be considered.

1. 48 inch valve closed. Maintain gate temperature to ensure bakeout of gate
2. 48 inch valve open. Maintain vacuum envelope wall temperature.
3. 44 inch valve open with cryopump cold. Maintain vacuum envelope wall temperature on the beam manifold side of the gatevalve.
4. 44 inch valve closed. Maintain gate temperature to ensure bakeout of gate

A finite difference model was used to model the heat transfer around the gatevalve for case 1. The model consist of 2 D cylindrical section finite difference grid similar to the previous model with a radiation network model to solve the radiation among the boundary surfaces of the finite difference elements and the endbores of the cylindrical vacuum envelope.
The model consist of a layer of steel, heater, and insulation. The R coordinates is in the direction of the steel and blanket thickness and the Z coordinate in the direction of the length of the cylindrical section. The radiation heat transfer model among each finite difference section of the steel (vacuum side) and the endbore areas is solved by a radiation network model. During each iteration of the finite difference grid (steel, heater and insulation), the radiation network is solved to determine heat transfer among the finite difference sections boundary surfaces(vacuum side of the steel). The iteration continues until the solution converges.

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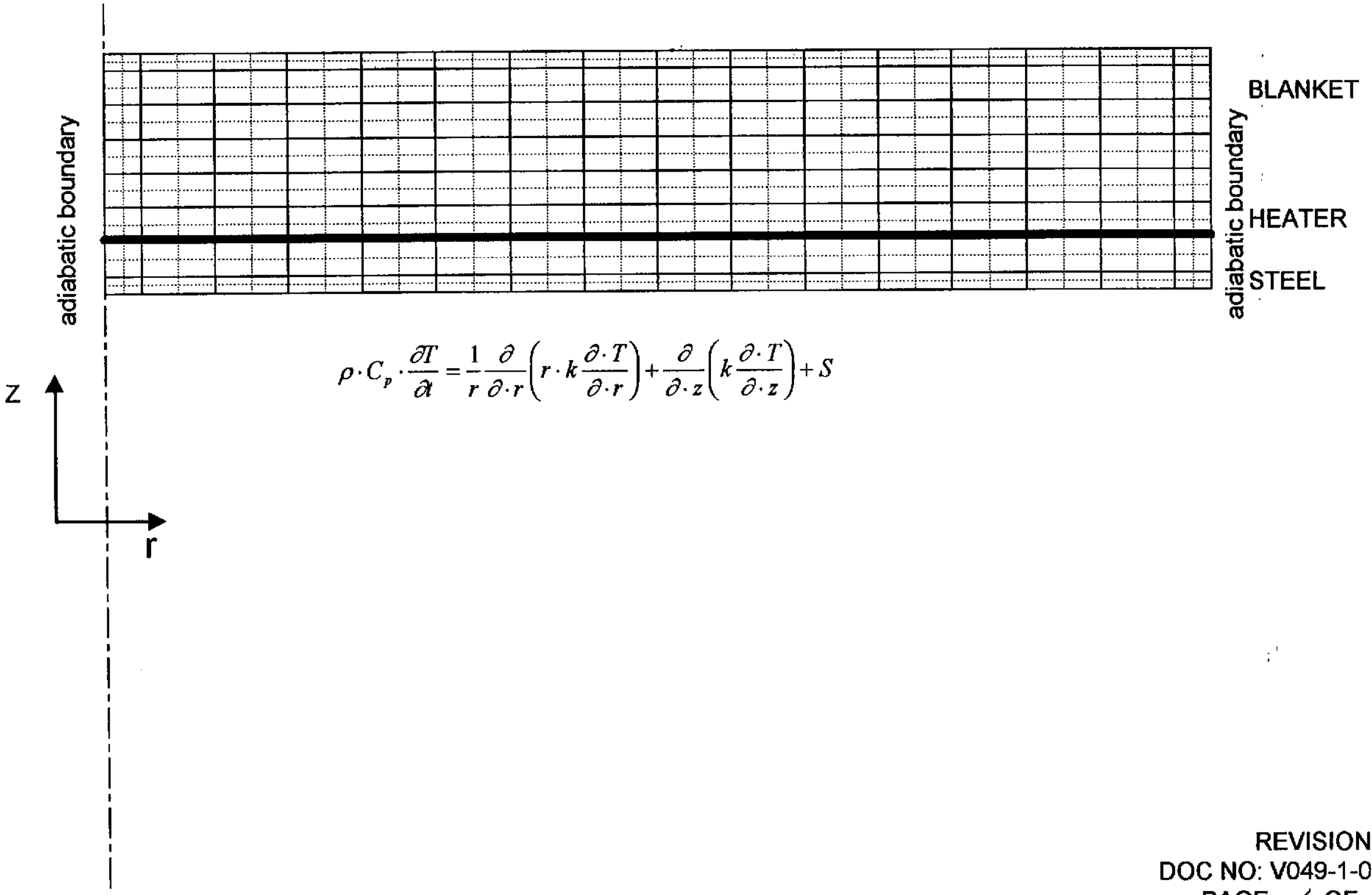
BLANKET MODEL

$$\frac{Q}{A} = h_{air} \cdot \left[T_{surface} - T_{ambient}\right] + \sigma \cdot \varepsilon \cdot \left[T_{surface}^4 - T_{ambient}^4\right]$$



$$\rho \cdot C_p \cdot \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial \cdot r}\left(r \cdot k \frac{\partial \cdot T}{\partial \cdot r}\right) + \frac{\partial}{\partial \cdot z}\left(k \frac{\partial \cdot T}{\partial \cdot z}\right) + S$$

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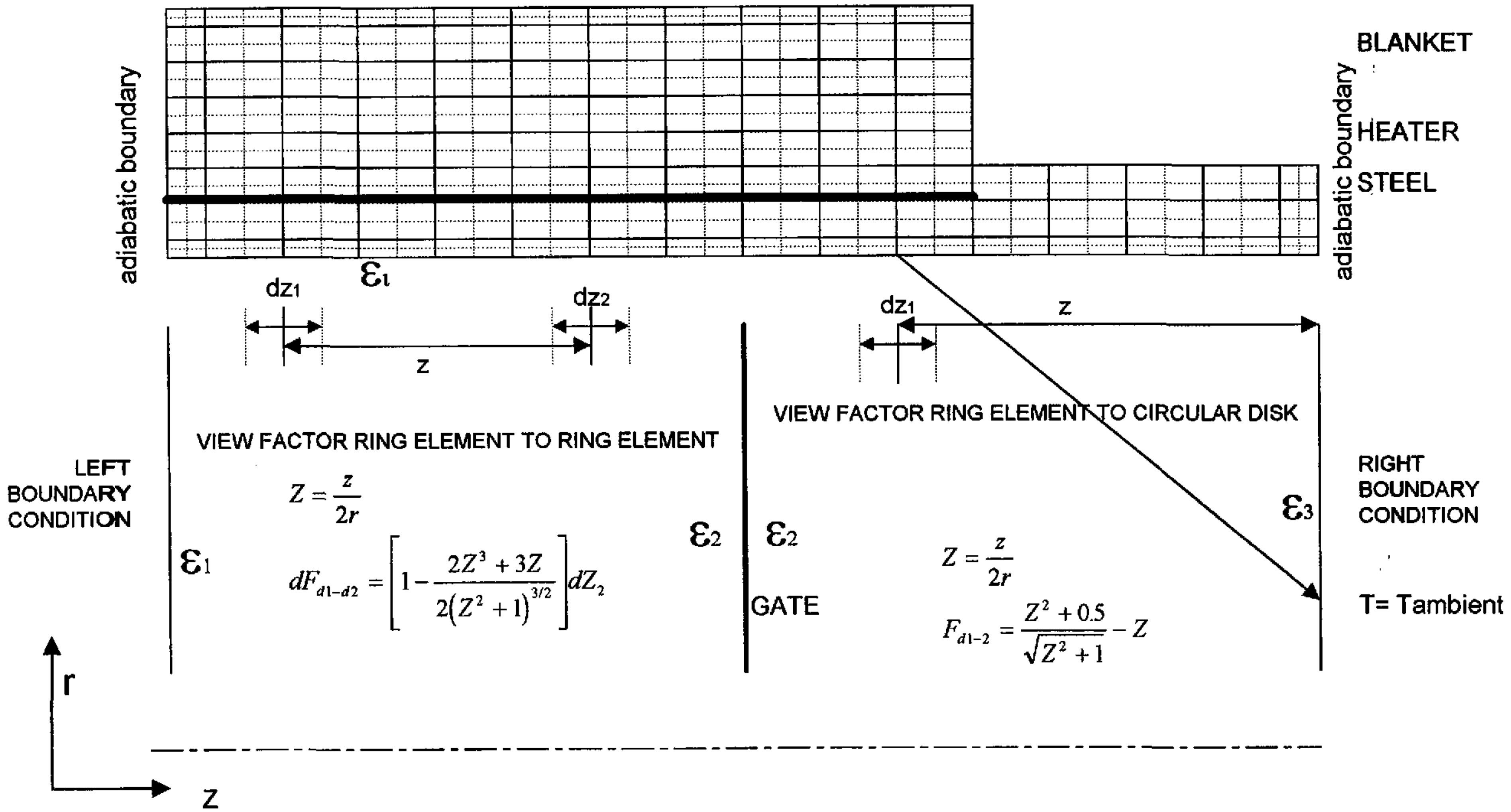
$$\rho \cdot C_p \cdot \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial \cdot r}\left(r \cdot k\frac{\partial \cdot T}{\partial \cdot r}\right) + \frac{\partial}{\partial \cdot z}\left(k\frac{\partial \cdot T}{\partial \cdot z}\right) + S$$

END EFFECTS GATE VALVE CLOSED

$$\frac{Q}{A} = h_{air} \cdot \left[T_{surface} - T_{ambient}\right] + \sigma \cdot \varepsilon \cdot \left[T_{surface}^4 - T_{ambient}^4\right]$$



VIEW FACTOR RING ELEMENT TO RING ELEMENT

$$Z = \frac{z}{2r}$$

$$dF_{d1-d2} = \left[1 - \frac{2Z^3 + 3Z}{2\left(Z^2+1\right)^{3/2}}\right] dZ_2$$

VIEW FACTOR RING ELEMENT TO CIRCULAR DISK

$$Z = \frac{z}{2r}$$

$$F_{d1-2} = \frac{Z^2 + 0.5}{\sqrt{Z^2+1}} - Z$$

3. RESULTS OF THE ANALYSES

a. With a design margin of 2 for the insulation performance (using fiberglass or calcium silicate) the required power density required to hold a temperature of 170C is 350W/m2.

b. Warmup of a 1.5 inch thick steel at a power density of 350W/m2 takes about 48 hours. Since this is the thickest piece the entire system will follow the warmup of the thickest piece.

c. Cooldown. With the insulation performing well, cooldown to 40C can take a full 72 hours.

d. Blanket failure. The resulting temperature gradient is dependent on the thermal contact of the blanket with the vessel, the insulation performance and the thickness of the vessel wall. For a 0.25 inch thick vessel wall the temperature gradient is about 70C for a well performing insulation. For a poor performing insulation the gradient could be as high as 100C.
With an additional insulation over the dead blanket the temperature gradient drops by 30C to 70C for poor insulation to 40C for a well performing insulation.

e. Thermo couple patch unheated spots will cause approximately 2°C (gradient) lower temperature reading at the patch.

f. Support legs. For the BSC support legs the required power density for the blankets on the support legs should be 600 W/m^2 or higher.

g. Gate valve end effects.
48" valve: For case where the adjacent spoolpiece is the shortest.
Gate closed: To be able to maintain the gate sufficiently warm, a blanket system on the 0.3m spool piece adjacent to the gate valve is required which has a heater power density of about 1700 W/m^2.
Gate open: If a heating blanket is used on the 0.3 m spool piece adjacent to the gate valve (unbaked section) an additional power density of 75 W/m^2 is required for the blankets on the spoolpiece on the bakeout side of the gatevalve to maintain the desired temperature. If no heating blanket is used on the spoolpiece on other side of the gatevalve, an additional power density of 160 W/m^2 is required for the blankets on the spoolpiece on the bakeout side of the gatevalve to maintain the desired temperature

44" valve: The power density of the blanket system adjacent to the gate valve on the beam manifold side requires an additional 200W/m^2 to maintain a vessel temperature of 423K. Because of the low e liner in the cryopump side adjacent to the gatevalve, heating of the vacuum vessel wall next to the gatevalve does not have a significant effect on the requirements for the blanket system on the other beam manifold side of the gate valve. However, a heating blanket is required on the cryopump side to minimize conductive effects on the gatevalve body. A blanket system with a normal power density is sufficient to maintain a 423K temperature of the shell on the cryopump side.

e. Pressure gauge pair bakeout jacket recommended power density to reach 250°C with 2 inch

e. Pressure gauge pair bakeout jacket recommended power density to reach 250°C with 2 inch fiberglass insulation or equivalent is about 600 W/m^2. To ensure that the temperature on the gauge is not excceeded each pressure gauge requires its only temperature control loop. If a thinner insulation thickness is used a higher power density is required.

f. Turbopump bakeout. The turbopump is allowed to be baked to 120°C. To ensure that this temperature is not exceeded the bakeout band on the turbopump should be independently controlled to at a setpoint no higher than 120°C. The blanket system for baking the turbopump isolation bellows could be controlled at 150C without affecting the temperature on the turbopump.

3.1 Steady State

Insulation Thermal conductivity and Thickness

Insulation thermal conductivity of fiberglass or a similar material has a value of about 0.05 W/m-K at ambient conditions.The apparent thermal conductivity increases with increasing temperature.
In order to have adequate margin for insulation performance and degradation a design margin of at least 2 is recommended.

Convective coefficient and radiant losses

In order to determine the sensitvity of the convective conditions a parametric study was carried out. The power density was determined to hold the vessel at 443K (170°C) for various insulation values while varying the convective conditions.

Figure 3.1-1 indicates that with forced convection over the blanket the required power density required for reaching 443K (170°C) is about 400 W/m² for a insulation thermal conductivity of 0.15 W/m-K and a blanket surface emissivity of 0.9. For an k value of 0.05 W/m-K the theorectical required power density for the blanket system is only about 150 W/m².

Figure 3.1-2 is a parametric study of the maximum operating temperature vs insulation thermal conductivity at three power densities.

Figure 3.1-3 is a graph of maximum operating temperature vs. power density with insulation k as a function of temperature and with a design margin of 2 for the k value. Two set of curves were generated, one with a low surface emissivity and low convective heat transfer, and one with a high emissivity and high convective values. In order to reach the operating temperature of 150 °C with a design margin of 2 the required power density is about 250W/m².

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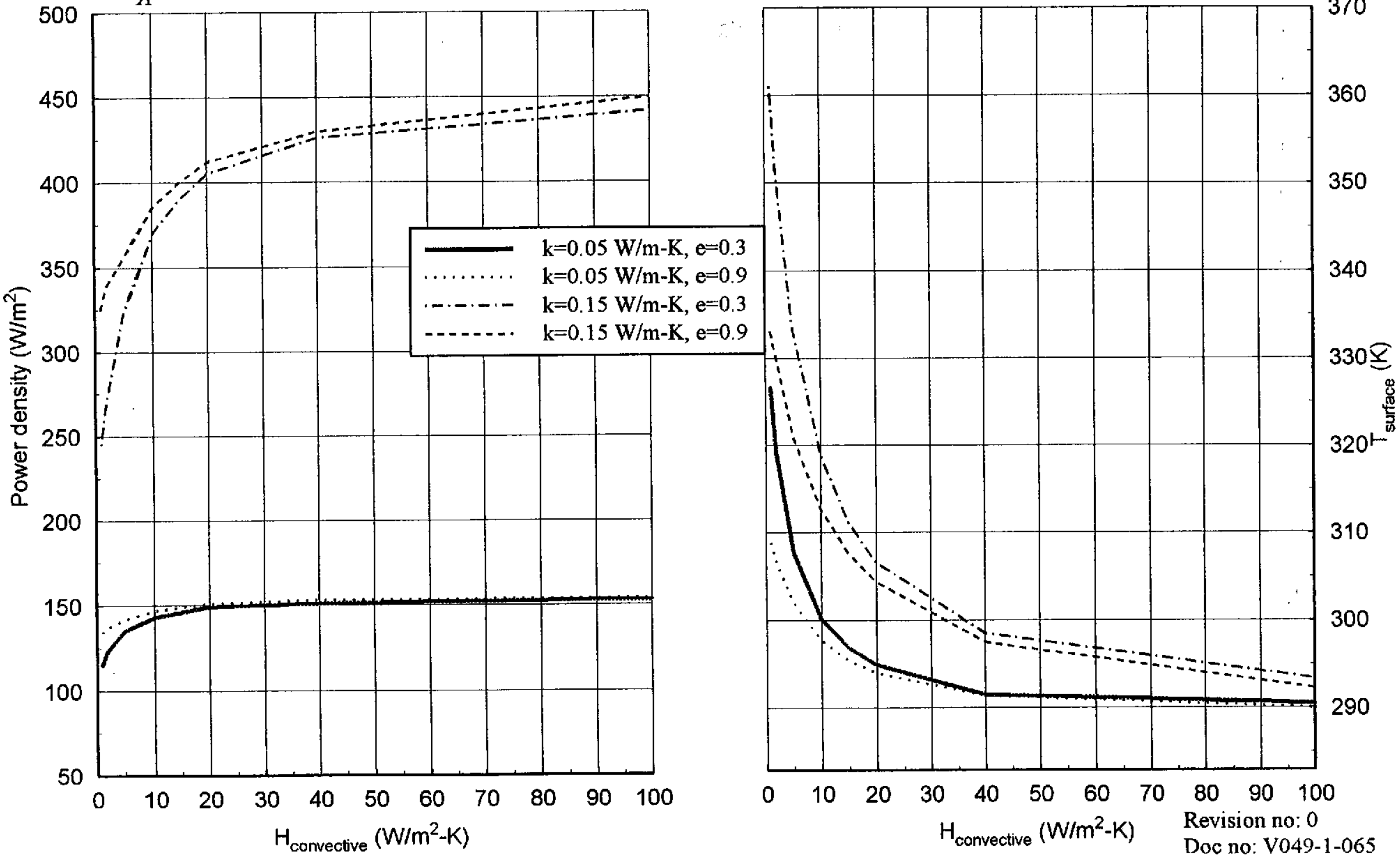
Figure: V049-1-065-3.1-1, Convective Heat Transfer effect on power density

$$\frac{Q}{A} = h_{air} \cdot \left[T_{surface} - T_{ambient}\right] + \sigma \cdot \varepsilon \cdot \left[T^4_{surface} - T^4_{ambient}\right]$$

Vessel temperature= 443 K (170°C)



PROJECT: LIGO   BY: R.THAN Figure: V049-1-065-3.1-2 Maximum Temperature vs Insulation value, 3 power densities
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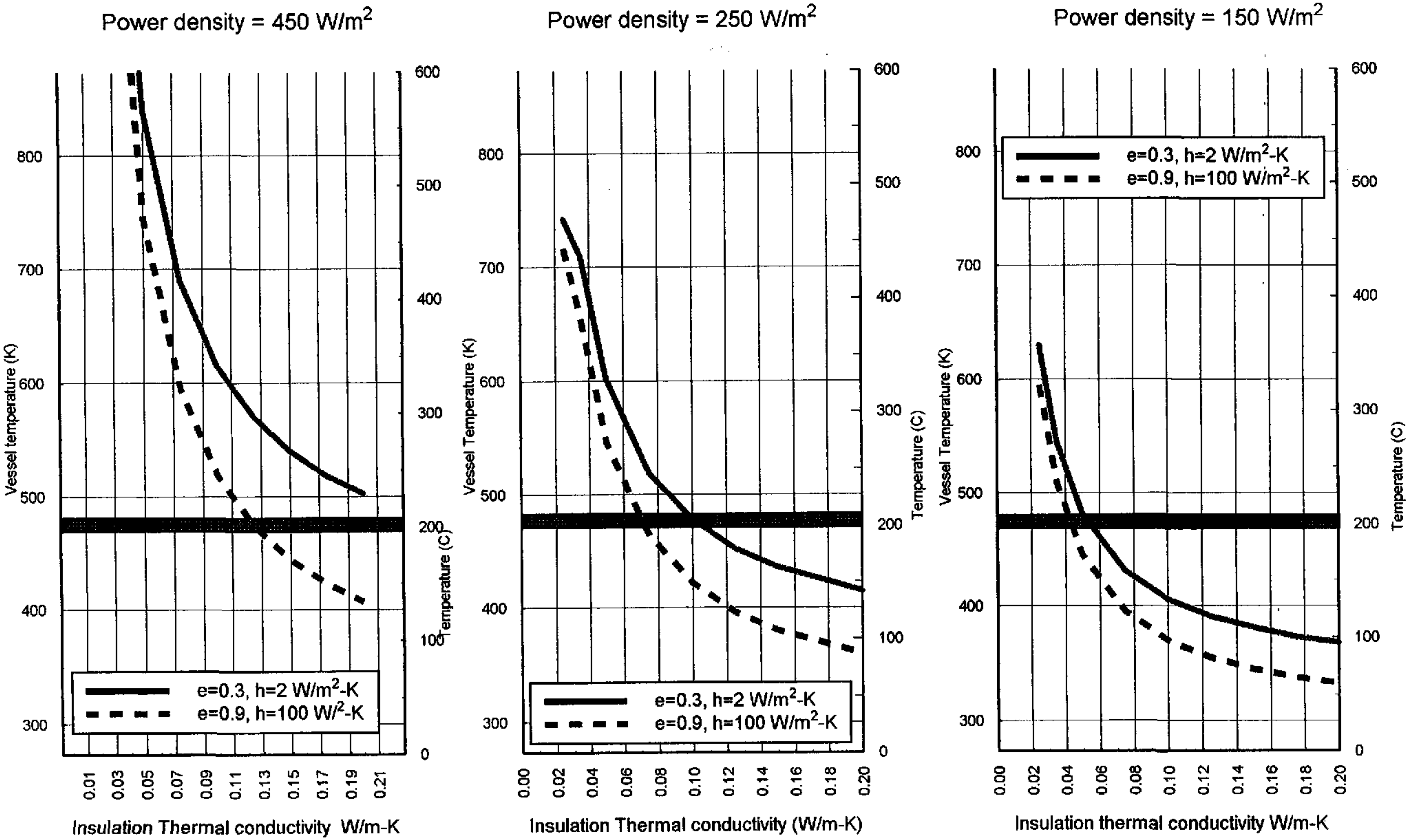

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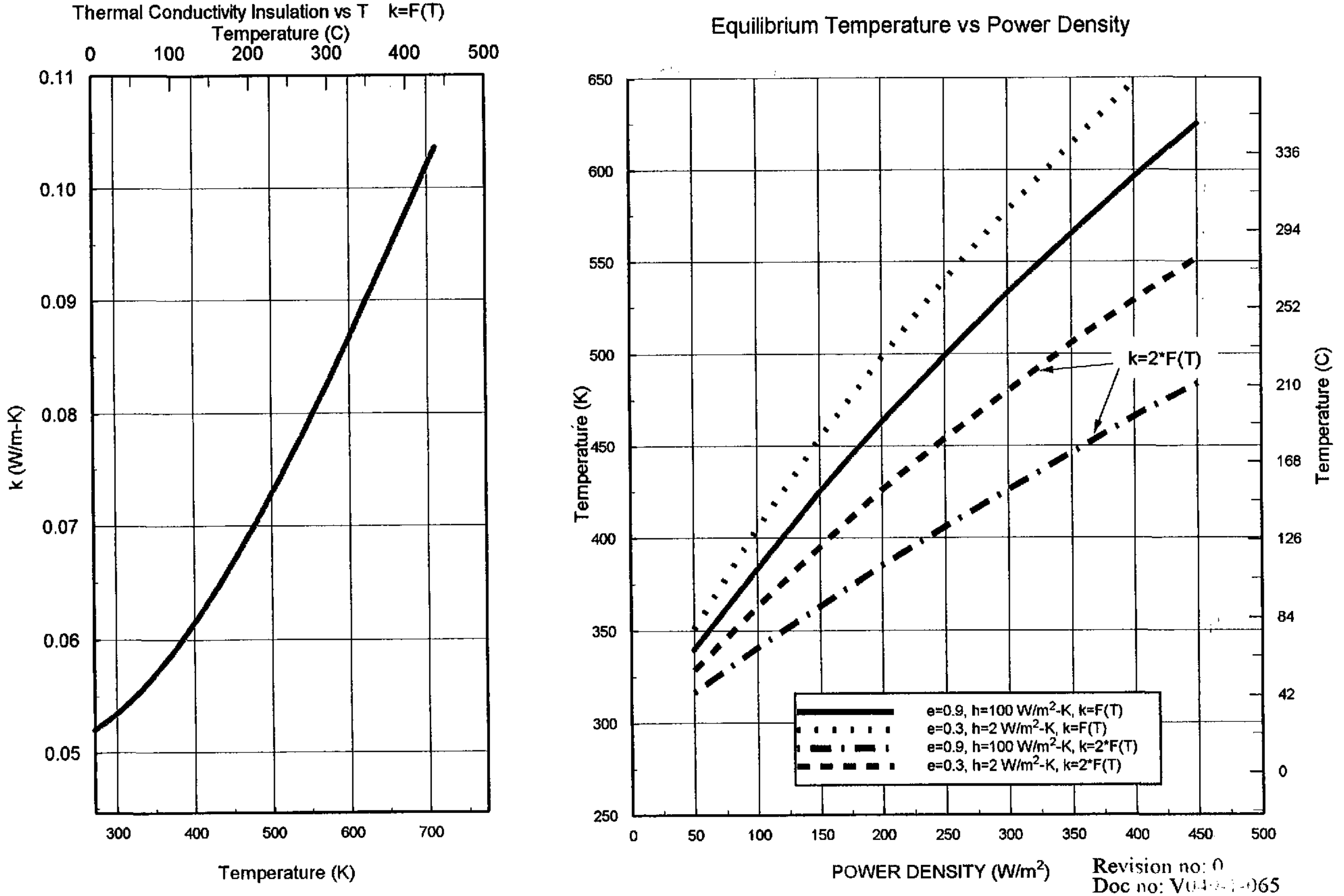
Figure: V049-1-065-3.1-3 Maximum Temperature vs Power Density, k=F(T), k=2*F(T)


Thermal Conductivity Insulation vs T k=F(T)

Equilibrium Temperature vs Power Density

3.2 Warmup Analysis

Because of the temperature uniformity requirements warmup of the vessel will be dictated by the component that has the largest mass per unit surface area. The control system will control warmup to maintain uniformity. This means the entire system will track the warmup of the slowest heating component. This will most likely be the large flanges. Warmup will be dictated by the flanges, power density and insulation performance. In order to speedup the warmup, the power density for the flange heater blankets needs to be increased.

Figure 3.2-1
Warmup curves are plotted for three different steel thicknesses at two insulation/convective values.
One set uses a design margin of 2 for the insulation's thermal conductivity along with a high convective coefficient. The other set uses a no margin for insulation's thermal conductivity along with a low convective coefficient.

Figure 3.2-2 and Figure 3.2-3
Warmup curves for 1.5 inch thick steel section, with heater and blanket surface temperature plotted for two insulation performance values.

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Figure: V049-1-065-3.2-1 WARM-UP TIME

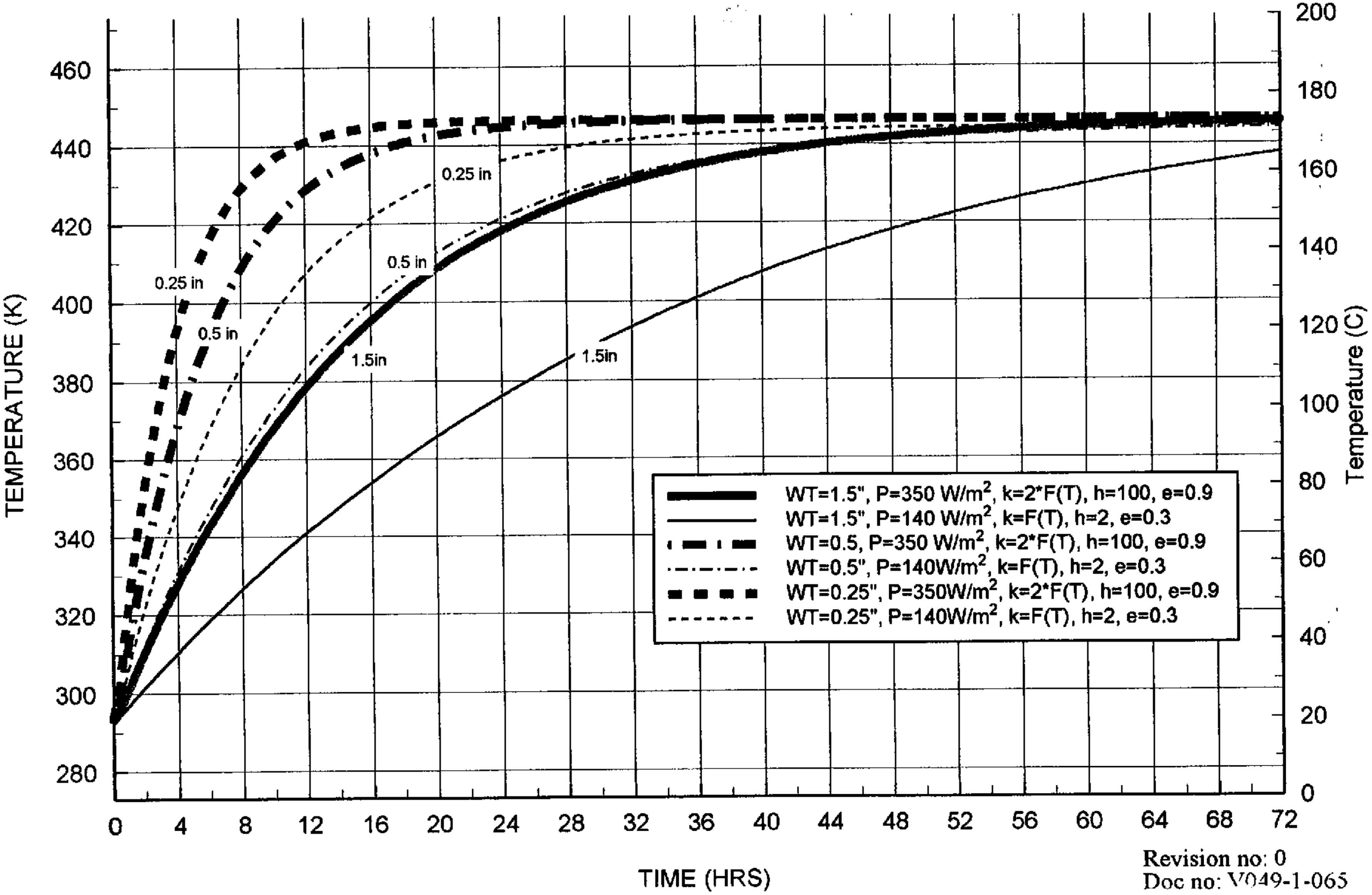

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Figure: V049-1-065-3.2-2 WARM-UP TIME, FLANGE, LOW POWER

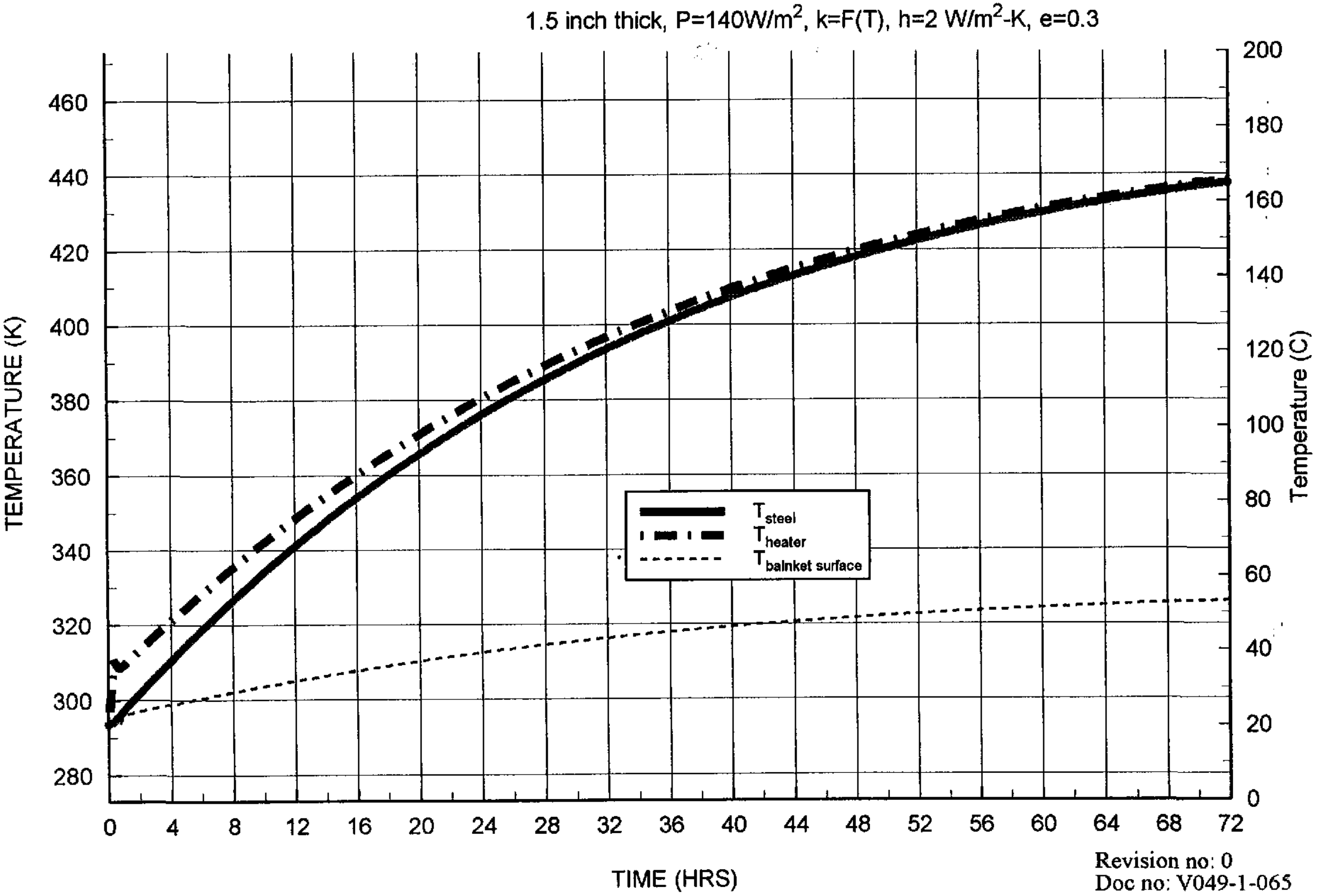

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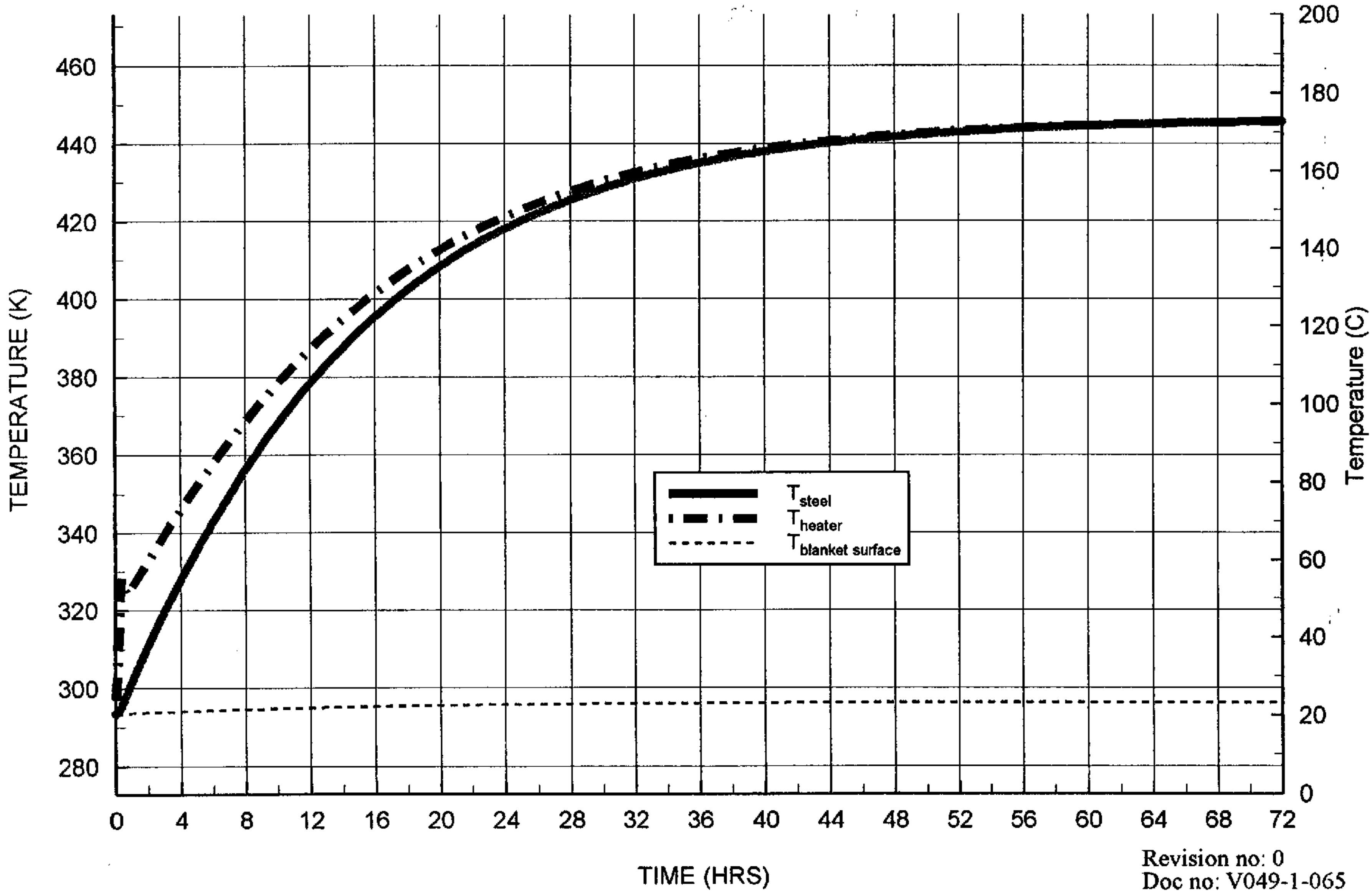
Figure: V049-1-065-3.2-3 WARM-UP TIME, FLANGE, HIGH POWER

1.5 inch thick, P=350W/m^2, k=2*F(T), h=100 W/m^2-K, e=0.9



3.3 Cooldown

During cooldown, the control system is also operating to maintain temperature uniformity. Again this will result in the flanges dictating the cooldown of the entire system. With the insulation performing well cooldown will take 72 hours or more.

Figure 3.3-1
Cooldown of 0.25 inch thick steel section with good insulation values.

Figure 3.3-2
Cooldown of 0.50 inch thick steel section with good insulation values.

Figure 3.3-3
Cooldown of 1.50 inch thick steel section with good insulation values.

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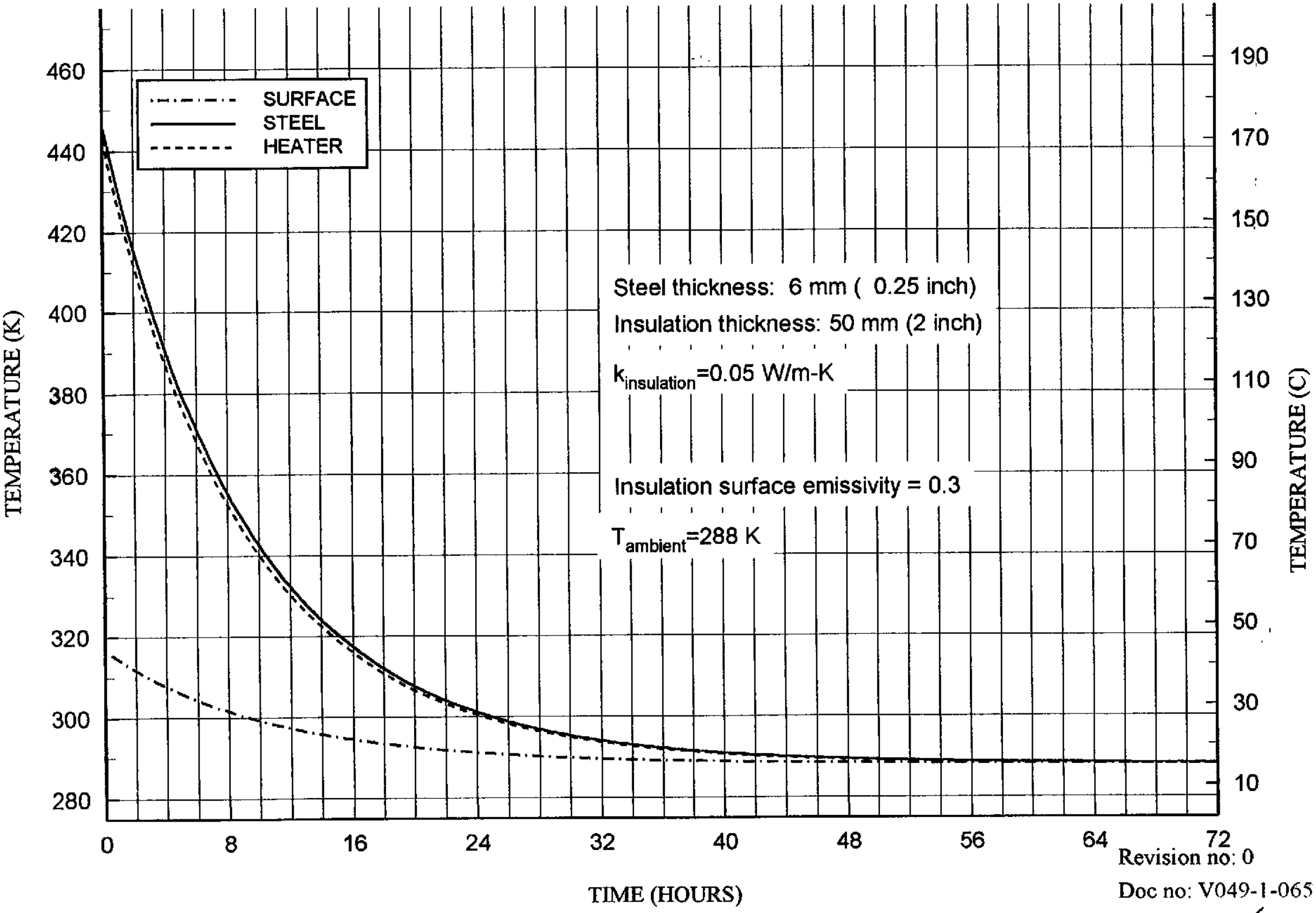
Figure: V049-1-065-3.3-1 COOL-DOWN TIME



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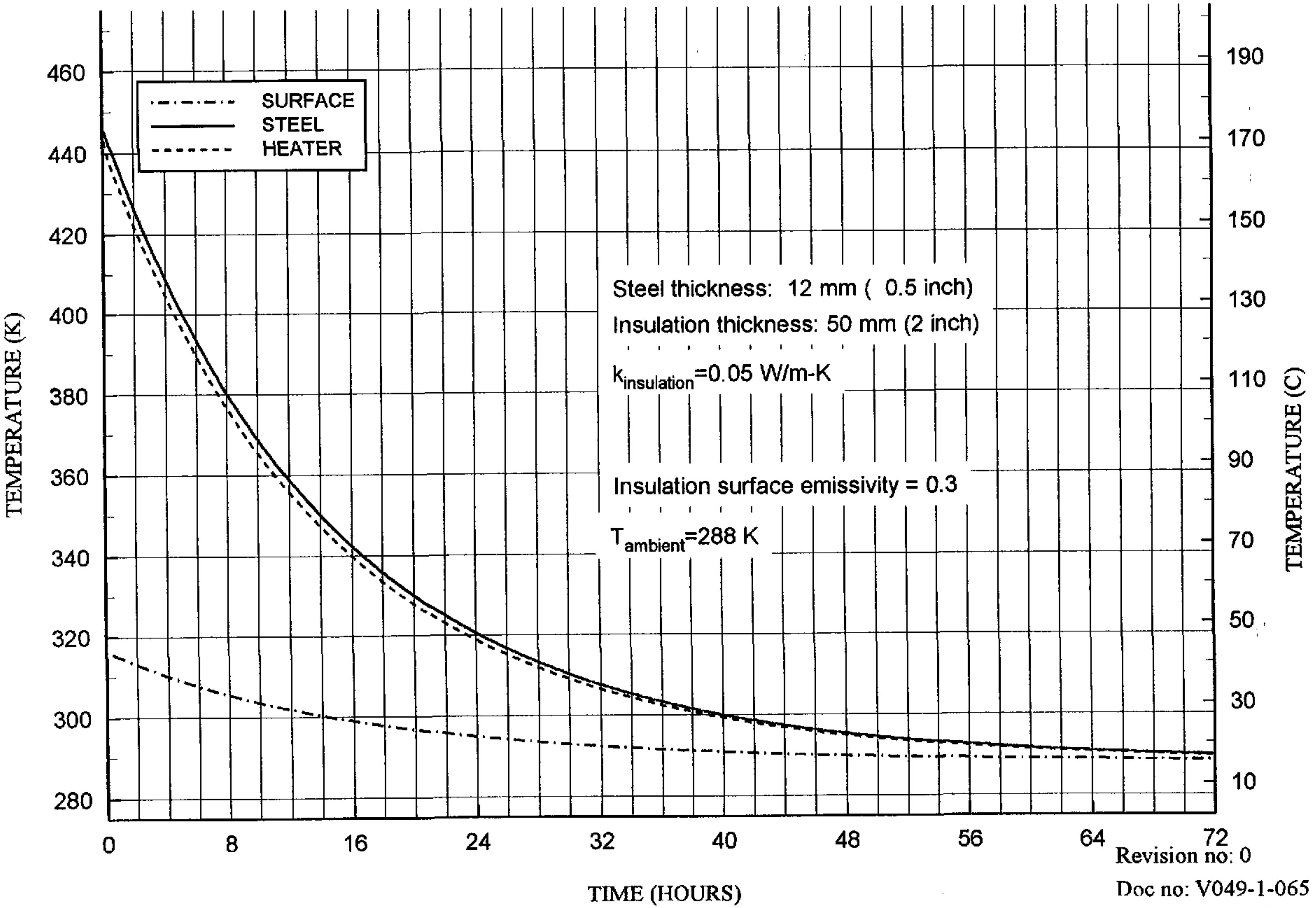

Figure: V049-1-065-3.3-2 COOL-DOWN TIME

Steel thickness: 12 mm (0.5 inch)

Insulation thickness: 50 mm (2 inch)

$k_{insulation}$=0.05 W/m-K

Insulation surface emissivity = 0.3

$T_{ambient}$=288 K

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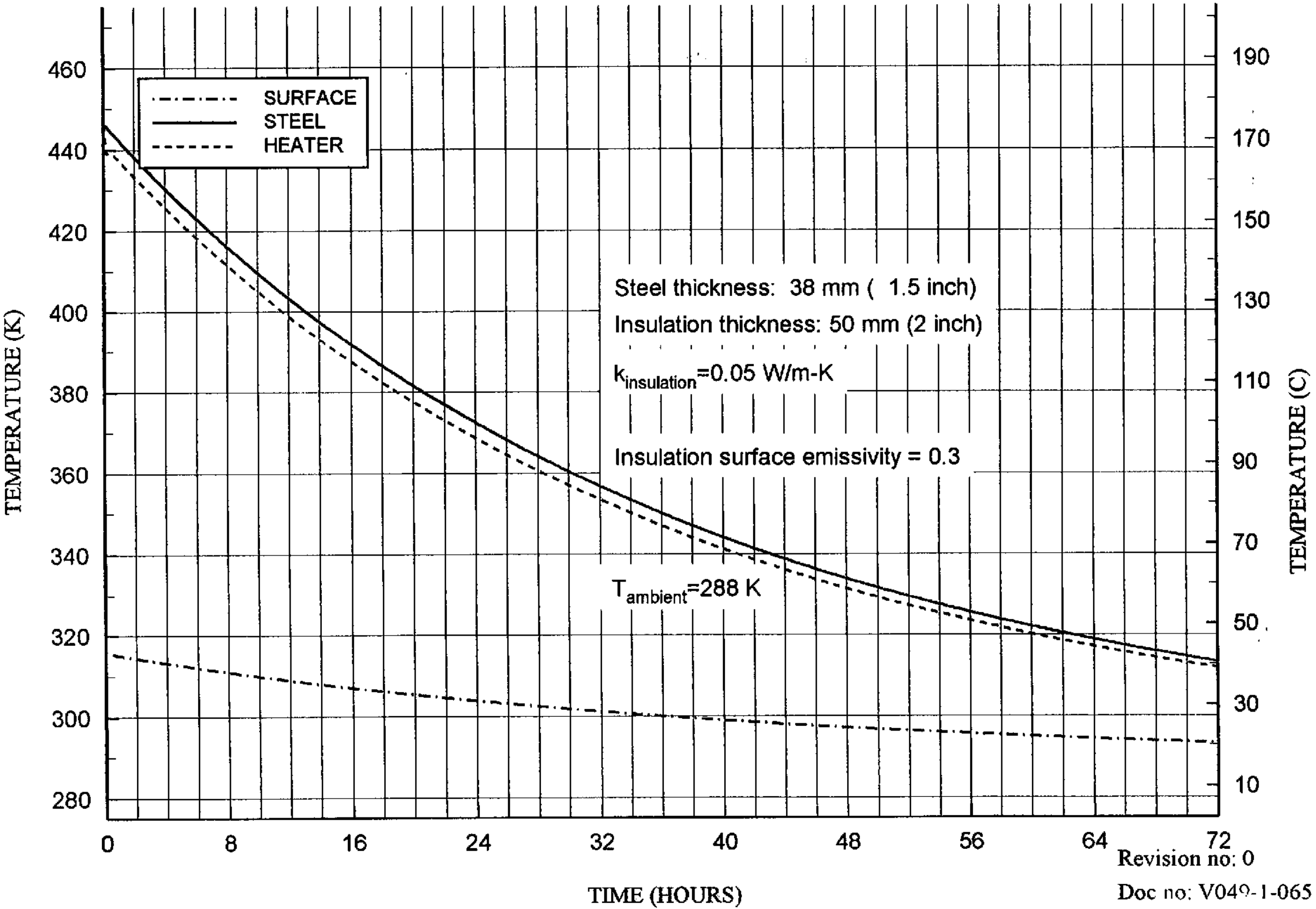
Figure: V049-1-065-3.3-3 COOL-DOWN TIME



3.4 Blanket Heater Failure

The blanket/heater/steel system was modeled, as described in section 2, to determine the temperature gradients developed under heater failure conditions. Calculations were done for two effective insulating values on 0.25 inch steel shell.

Figure 3.4-1 Blanket heater failure with poor performing insulation for 0.25 inch thick wall. The resulting gradient is about 100°C.

Figure 3.4-2 Blanket heater failure with well performing insulation for 0.25 inch thick wall. The resulting gradient is about 70°C.

Figure 3.4-3 Additional insulation above failed blanket with poor performing insulation for 0.25 inch thick wall. The resulting gradient is about 70°C.

Figure 3.4-4 Additional insulation above failed blanket with well performing insulation for 0.25 inch thick wall. The resulting gradient is about 40°C.

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Figure: V049-1-065-3.4-1 STEADY STATE PROFILE WITH HEATER FAILURE

$k_{steel}=F(T)$
$k_{insulation}=2*F(T)$ W/m-K
$\varepsilon=0.9$ h_{air} = 100 W/m^2-K
Power density=350 W/m^2
Shell Wall Thickness=6.4 mm (0.25 in)

$$\frac{Q}{A}=\frac{Q_{convective}}{A}+\frac{Q_{radiation}}{A}=h_{air}\cdot\left[T_{surface}-T_{ambient}\right]+\sigma\cdot\varepsilon\cdot\left[T_{surface}^{4}-T_{ambient}^{4}\right]$$

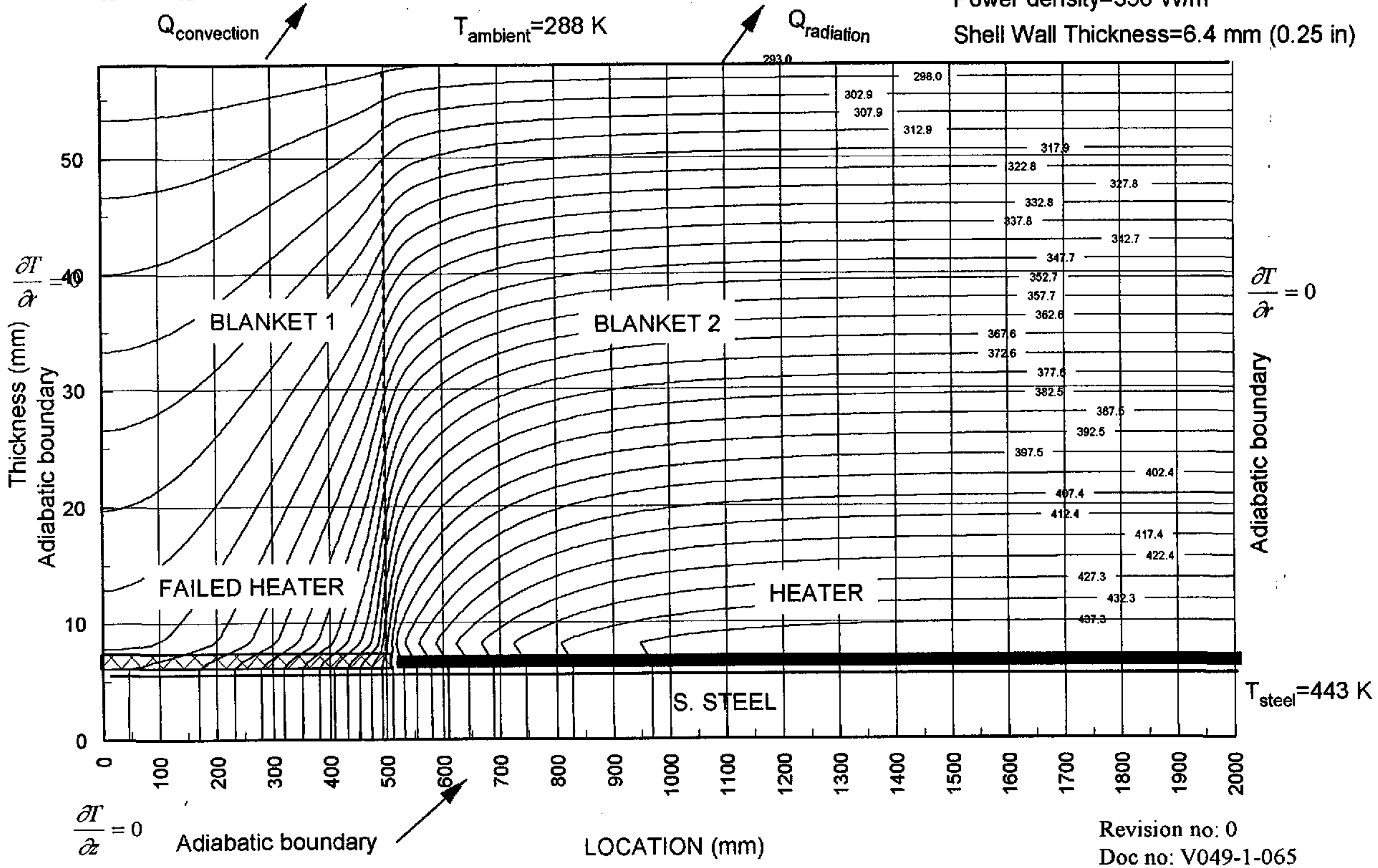

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Figure: V049-1-065-3.4-2 STEADY STATE PROFILE WITH HEATER FAILURE

k_{steel}=F(T)
$k_{insulation}$=F(T) W/m-K
ε=0.3 h_{air} = 2 W/m^2-K
Power density=140 W/m^2
Shell Wall Thickness=6.4 mm (0.25 in)

$$\frac{Q}{A}=\frac{Q_{convective}}{A}+\frac{Q_{radiation}}{A}=h_{air}\cdot\left[T_{surface}-T_{ambient}\right]+\sigma\cdot\varepsilon\cdot\left[T^4_{surface}-T^4_{ambient}\right]$$

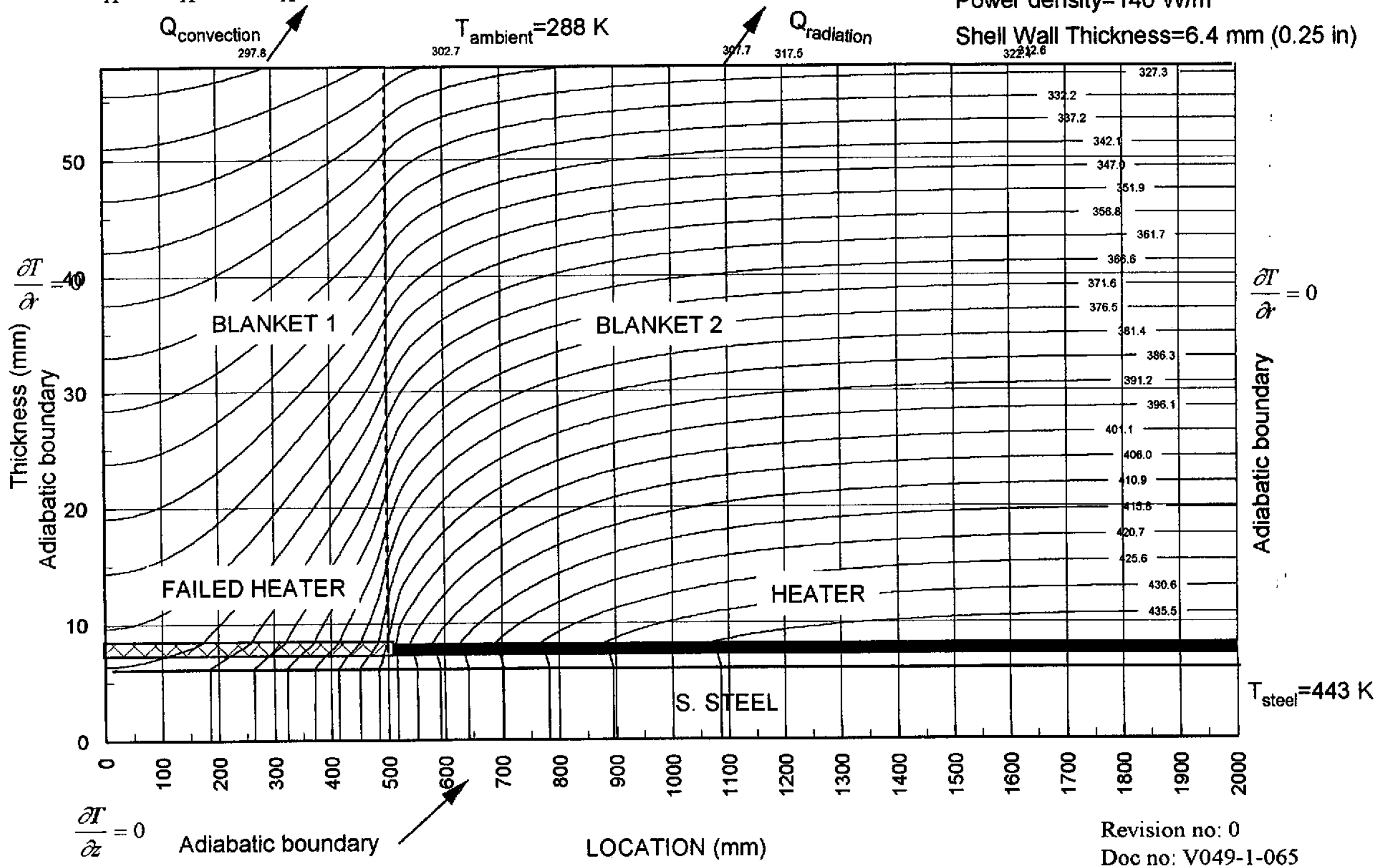

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Figure: V049-1-065-3.4-3 PROFILE WITH HEATER FAILURE with additional blanket

k_{steel}=F(T)
$k_{insulation}$=2*F(T) W/m-K
$\varepsilon=0.9$ h_{air} = 100 W/m^2-K
Power density=350 W/m^2
Shell Wall Thickness=6.4 mm (0.25 in)

$$\frac{Q}{A}=\frac{Q_{convective}}{A}+\frac{Q_{radiation}}{A}=h_{air}\cdot\left[T_{surface}-T_{ambient}\right]+\sigma\cdot\varepsilon\cdot\left[T^4_{surface}-T^4_{ambient}\right]$$

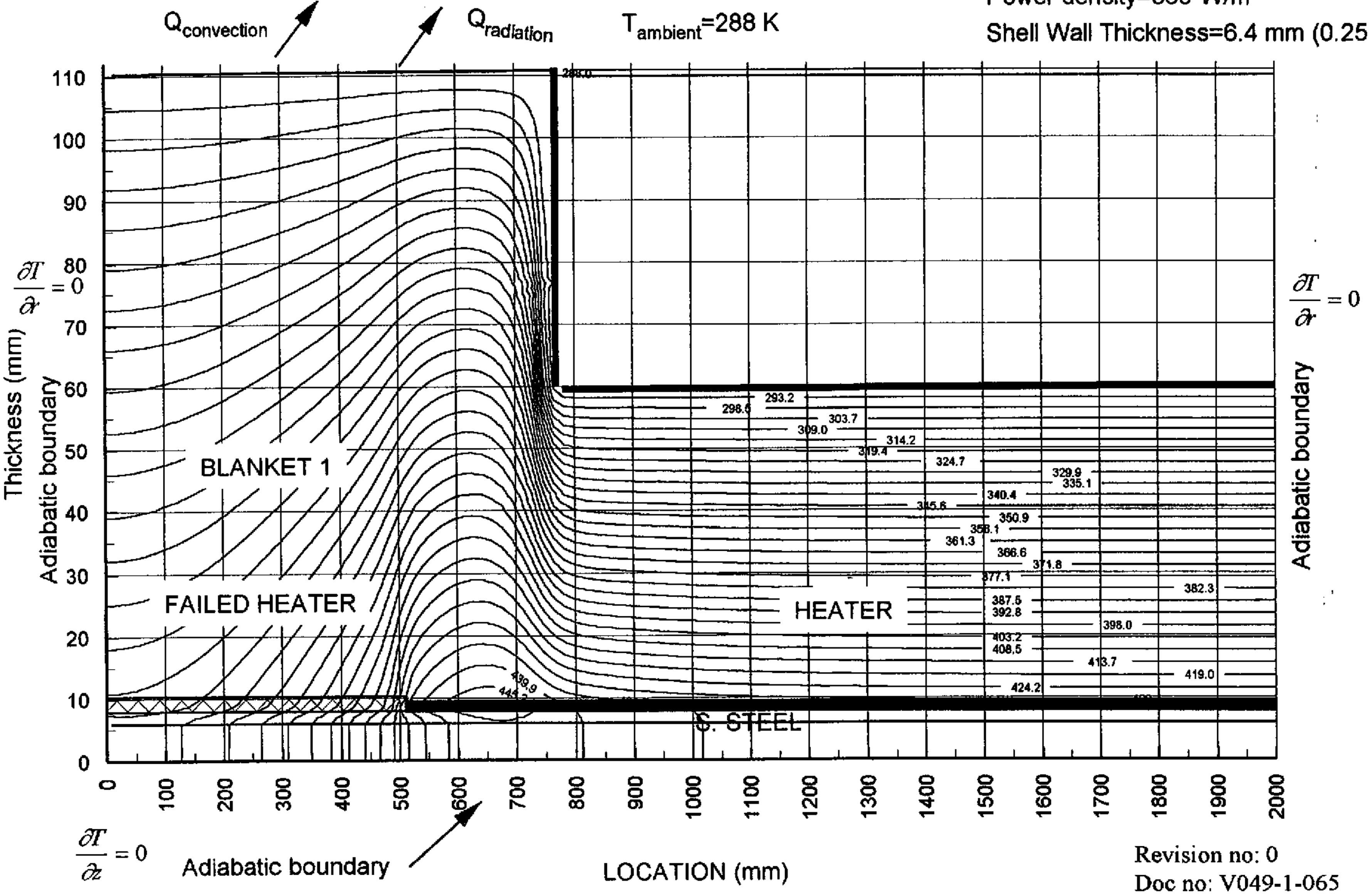

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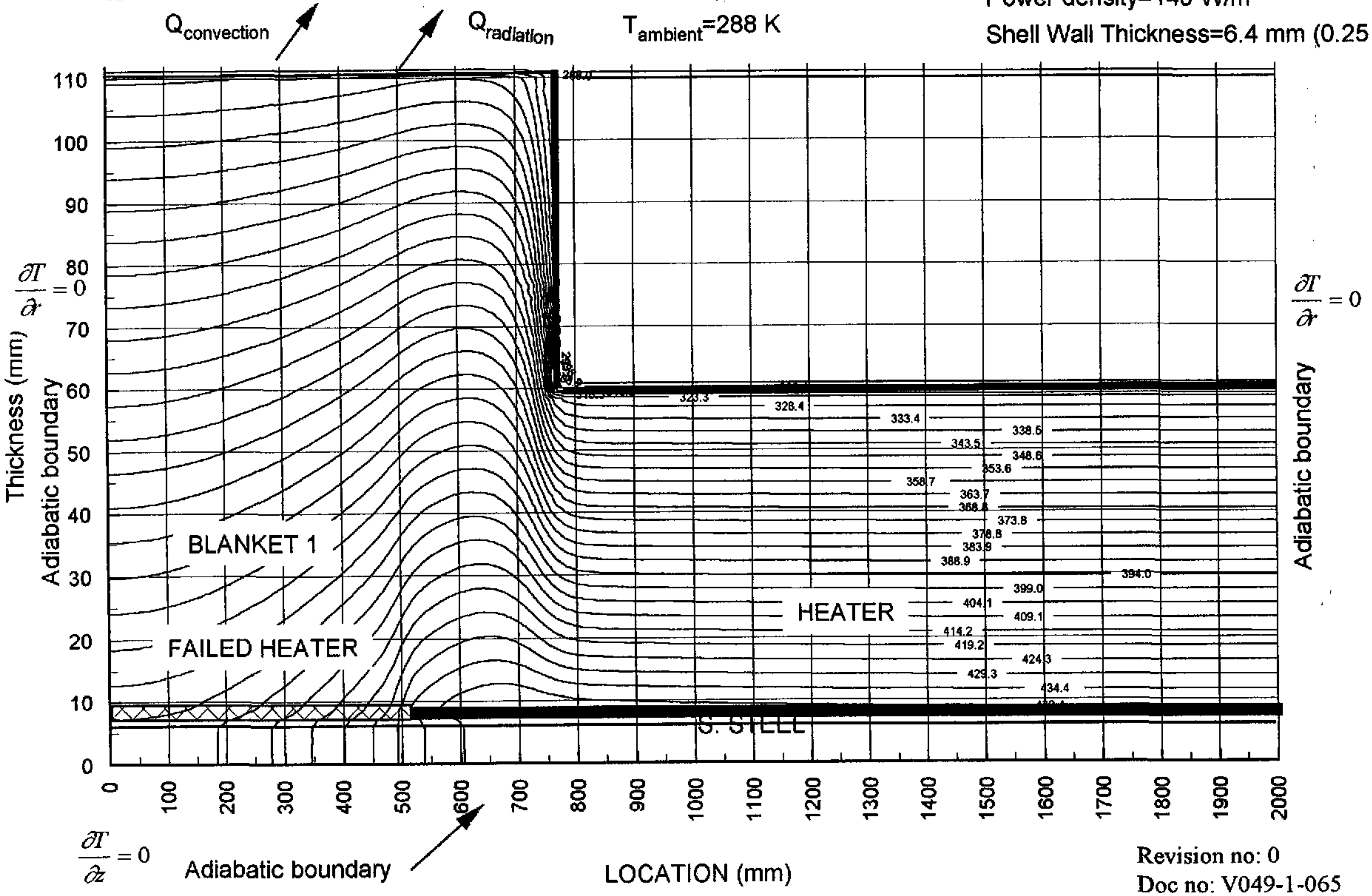
Figure: V049-1-065-3.4-4 PROFILE WITH HEATER FAILURE with additional blanket

$k_{steel}=F(T)$
$k_{insulation}=F(T)$ W/m-K
$\varepsilon=0.3$ $h_{air} = 2$ W/m^2-K
Power density=140 W/m^2
Shell Wall Thickness=6.4 mm (0.25 in)

$$\frac{Q}{A}=\frac{Q_{convective}}{A}+\frac{Q_{radiation}}{A}=h_{air}\cdot\left[T_{surface}-T_{ambient}\right]+\sigma\cdot\varepsilon\cdot\left[T_{surface}^4-T_{ambient}^4\right]$$



3.5 Thermal Couple Patch (3 inch X 3inch)

The unheated patch where the thermocouple is mounted will cause the thermocouple to read a lower local temperature. The case of a poor insulation performance was calculated to determine the gradient.

Figure 3.5-1 Temperature profile in steel/ blanket with unheated thermocouple patch. Poor performing insulation on 0.25 inch thick wall. The temperature in the patch is 1.3K lower than the other end of the blanket.

Figure 3.5-2 Temperature profile in steel/ blanket with unheated thermocouple patch. Poor performing insulation on 0.50 inch thick wall. The temperature in the patch is 1K lower than the other end of the blanket.

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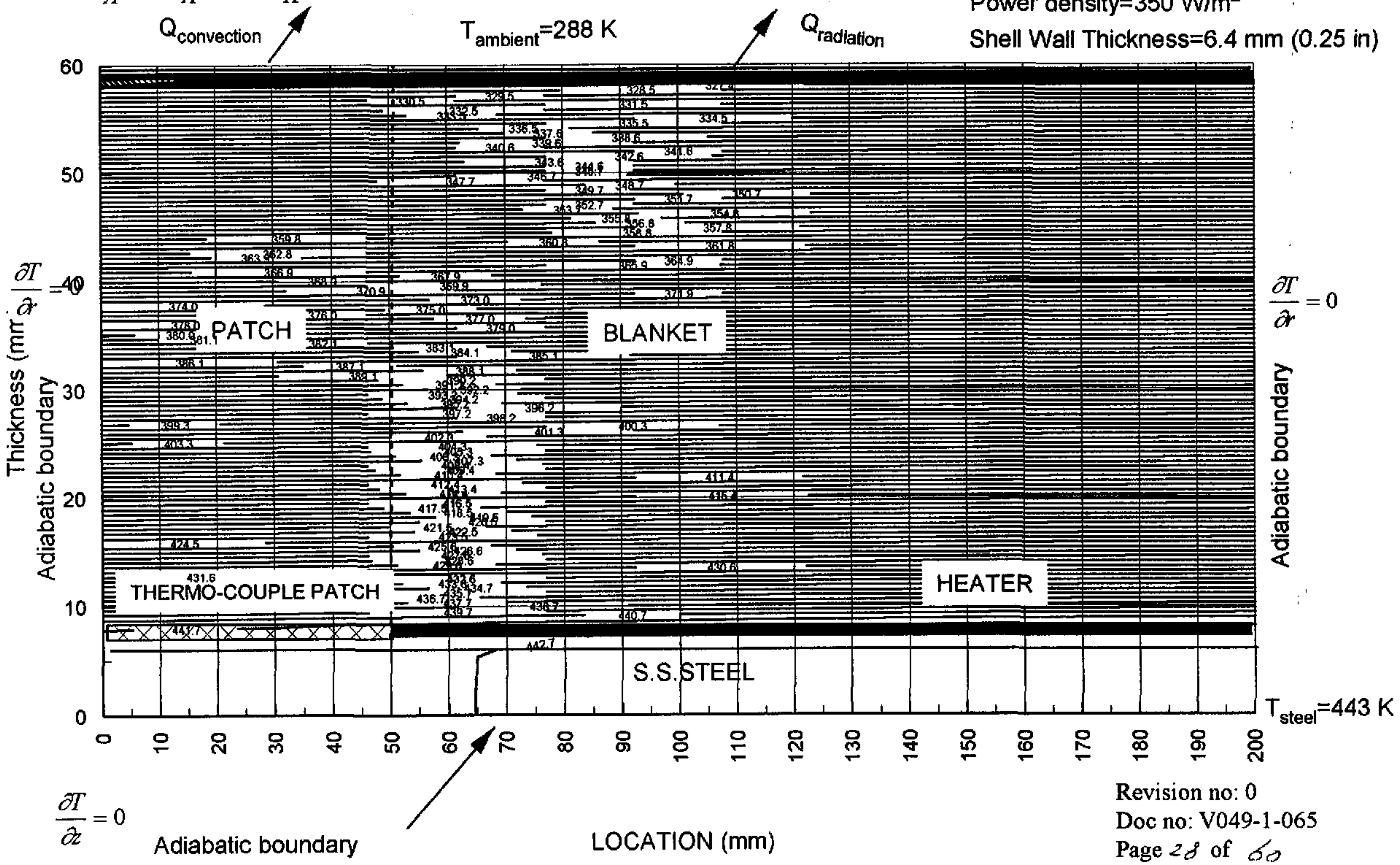
Figure: V049-1-065-3.5-1 STEADY STATE PROFILE THERMO-COUPLE PATC

k_{steel}=F(T)
$k_{insulation}$=0.15 W/m-K
ε=0.9
Power density=350 W/m^2
Shell Wall Thickness=6.4 mm (0.25 in)

$$\frac{Q}{A}=\frac{Q_{convective}}{A}+\frac{Q_{radiation}}{A}=h_{air}\cdot\left[T_{surface}-T_{ambient}\right]+\sigma\cdot\varepsilon\cdot\left[T^4_{surface}-T^4_{ambient}\right]$$



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PROJECT: LIGO BY: R.THAN

PROJECT NO: V59049 DATE: Apr. 8, 1996

Figure: V049-1-065-3.5-2 STEADY STATE PROFILE THERMO-COUPLE PATC

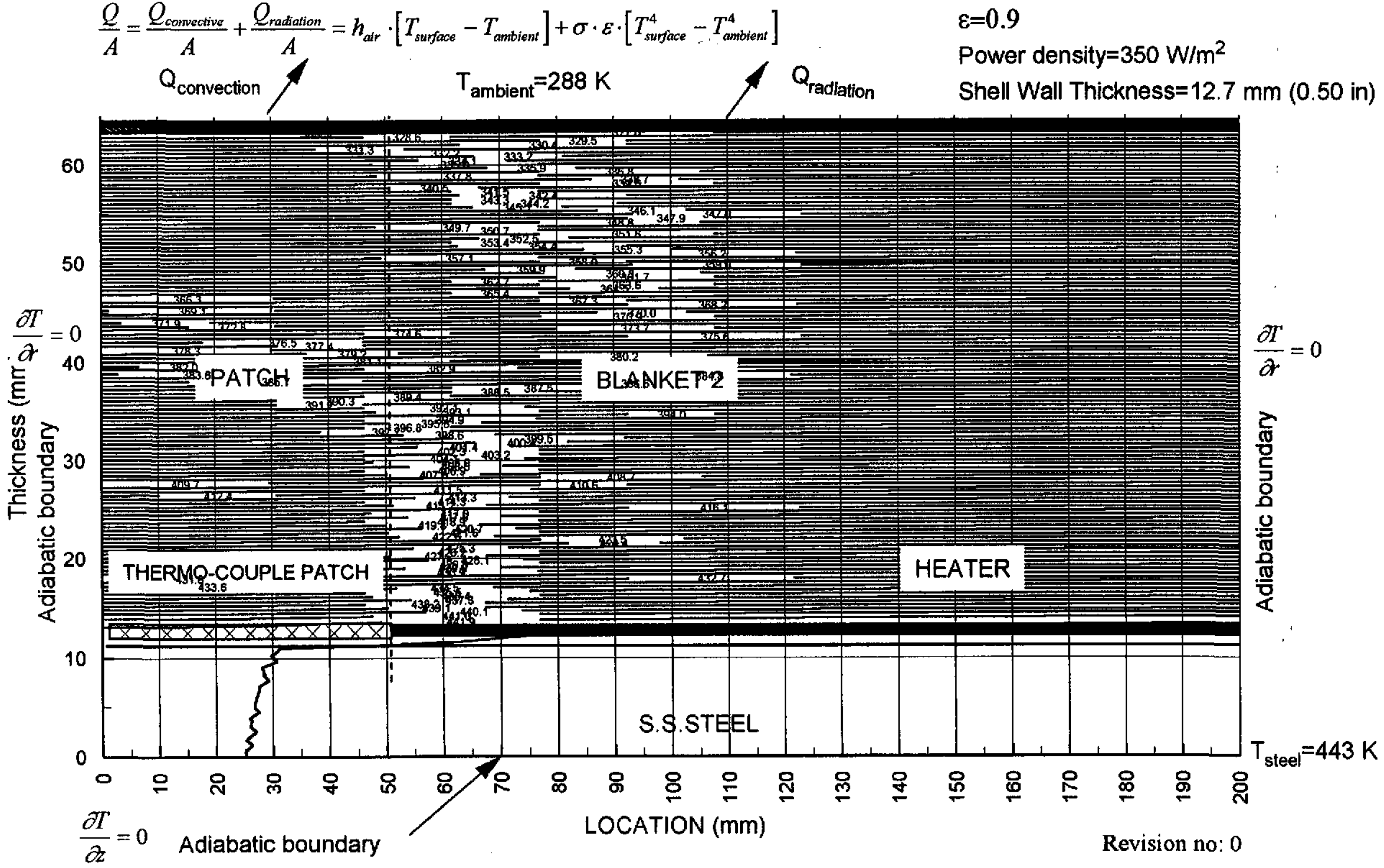
k_{steel}=F(T)

$k_{insulation}$=0.15 W/m-K

ε=0.9

Power density=350 W/m^2

Shell Wall Thickness=12.7 mm (0.50 in)



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3.6 Support Legs Analysis

BSC support leg

The legs are made of carbon steel, which have a much higher thermal conductivity than stainless steel. The support leg heating blanket system was modeled with a specified boundary temperature of 288K at the floor/leg interface and a power density sufficient to maintain a temperature of 423K at an insulation thermal conductivity of 0.15 W/m-K. A solution was sought that gave a zero heat flux at the vessel wall / leg interface. A minimum heater power density of 600W/m² is required to satisfy the above conditions.

Figure 3.6-1 Temperature profile at 600W/m².

Ham support leg

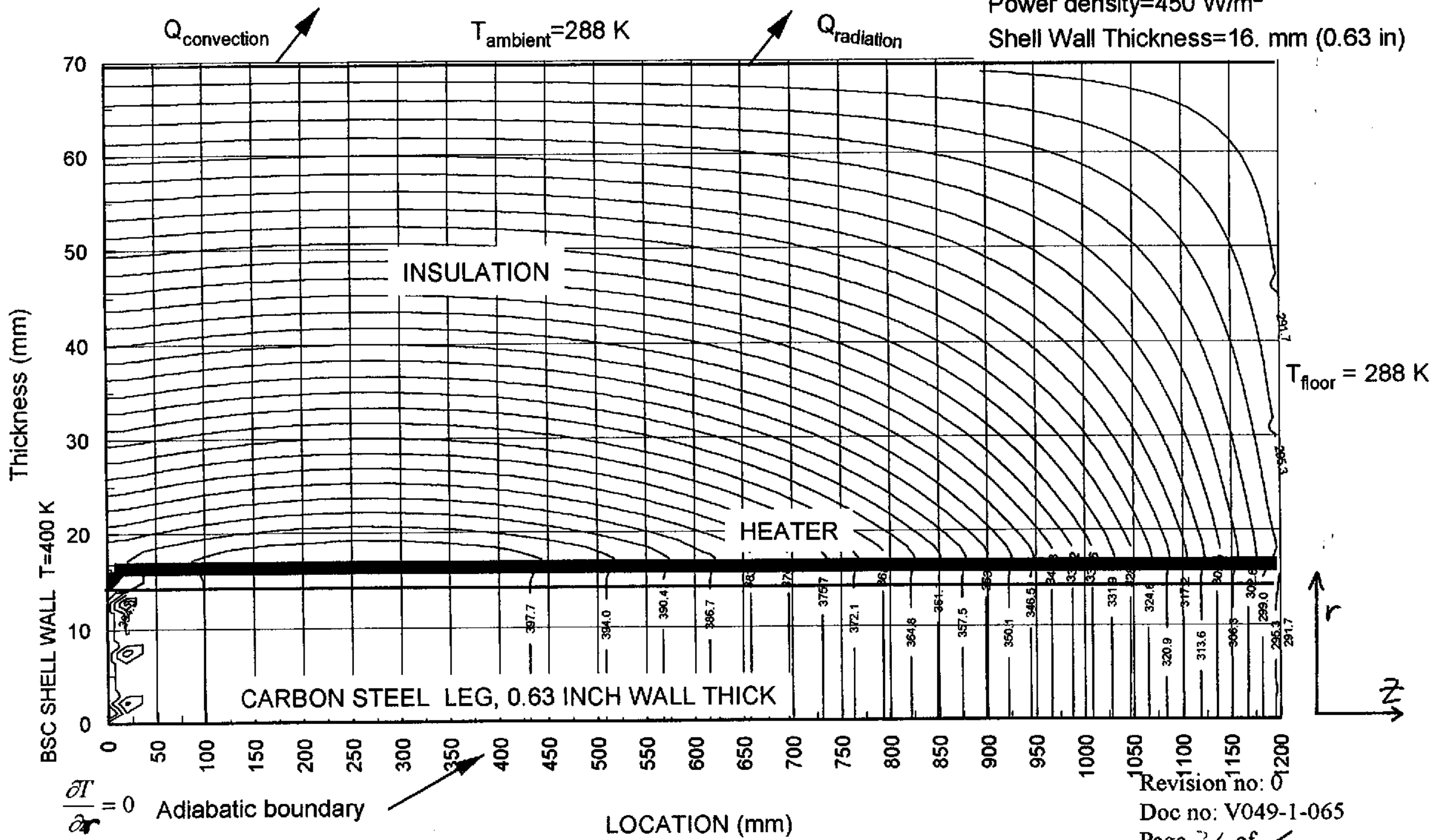
The supports for the HAM is much shorter than for the BSC. The shortest section is about 330mm. A minimum heater power density of approximately 3000 to 3500 W/m² is required for a zero heat flux solution and a vessel wall temperature of 423K (150C).

PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE: Apr.3, 1996

Figure: V049-1-065-3.6-[illegible] STEADY STATE PROFILE BSC SUPPORT LEG

$$\frac{Q}{A} = \frac{Q_{convective}}{A} + \frac{Q_{radiation}}{A} = h_{air} \cdot \left[T_{surface} - T_{ambient}\right] + \sigma \cdot \varepsilon \cdot \left[T^4_{surface} - T^4_{ambient}\right]$$

k_{steel}=F(T)
$k_{insulation}$=0.05 W/m-K
ε=0.9
Power density=450 W/m^2
Shell Wall Thickness=16. mm (0.63 in)



3.7 End effects Gate Valve Analyses

48 inch gate valve.
For the 48 inch gate valve, which is located between two BSC's or 48" tube interconnect between the vertex and diagonal section, the spool piece on the other of the gate valve needs to be blanketed to keep the gate sufficiently hot when the gate is in the closed position.
The shortest spool piece (A-15) is about 0.3 m long

1.Gate valve closed
With the gate closed the blanket on the other side (0.3 m spoolpiece) of the gate requires a power density of 1700 W/m² to maintain the gate at 400K. A large portion of the energy is lossed through conduction to the uninsulated section of the vessel. From the simple network model analysis (case I) only about 210 W/m² is lost to radiation.
2. Gate valve open.
From the simple network model analysis (case II): If a heating blanket is used on the 0.3 m spool piece adjacent to the gate valve (unbaked section) an additional power density of 75 W/m² is required for the blankets on the spoolpiece on the bakeout side of the gatevalve to maintain the desired temperature. If no heating blanket is used on the spoolpiece on other side of the gatevalve, an additional power density of 160 W/m² is required for the blankets on the spoolpiece on the bakeout side of the gatevalve to maintain the desired temperature.

44 inch gate valve
For the 44 inch gate valve at the cryopump, there are a few cases to be considered:

1. When the beam manifold isolatable section is being baked out the cryopumped may be used to cryopump the gasses. The gate is open and the shell near the gatevalve and the gate valve loses heat by radiation cooling to the 80K surface. To maintain the spoolpiece on the beammanifold side at 423K the additional power density required for the blankets on this spoolpiece is 200W/m².
2.When the beam manifold isolatable section is being baked out and the cryopump is not used to pump water vapo, the gate is closed. The gate loses heat by radiation cooling to the cryopump side. In this case however the cryopump could be left at ambient. It would make sense to bakeout the cryopump also.

Figure 3.7-1 Gate valve end effects. Gate at 393K with 1700W/m² power density on the other side of gate and high convective coefficient. The convective coefficient is very conservative.

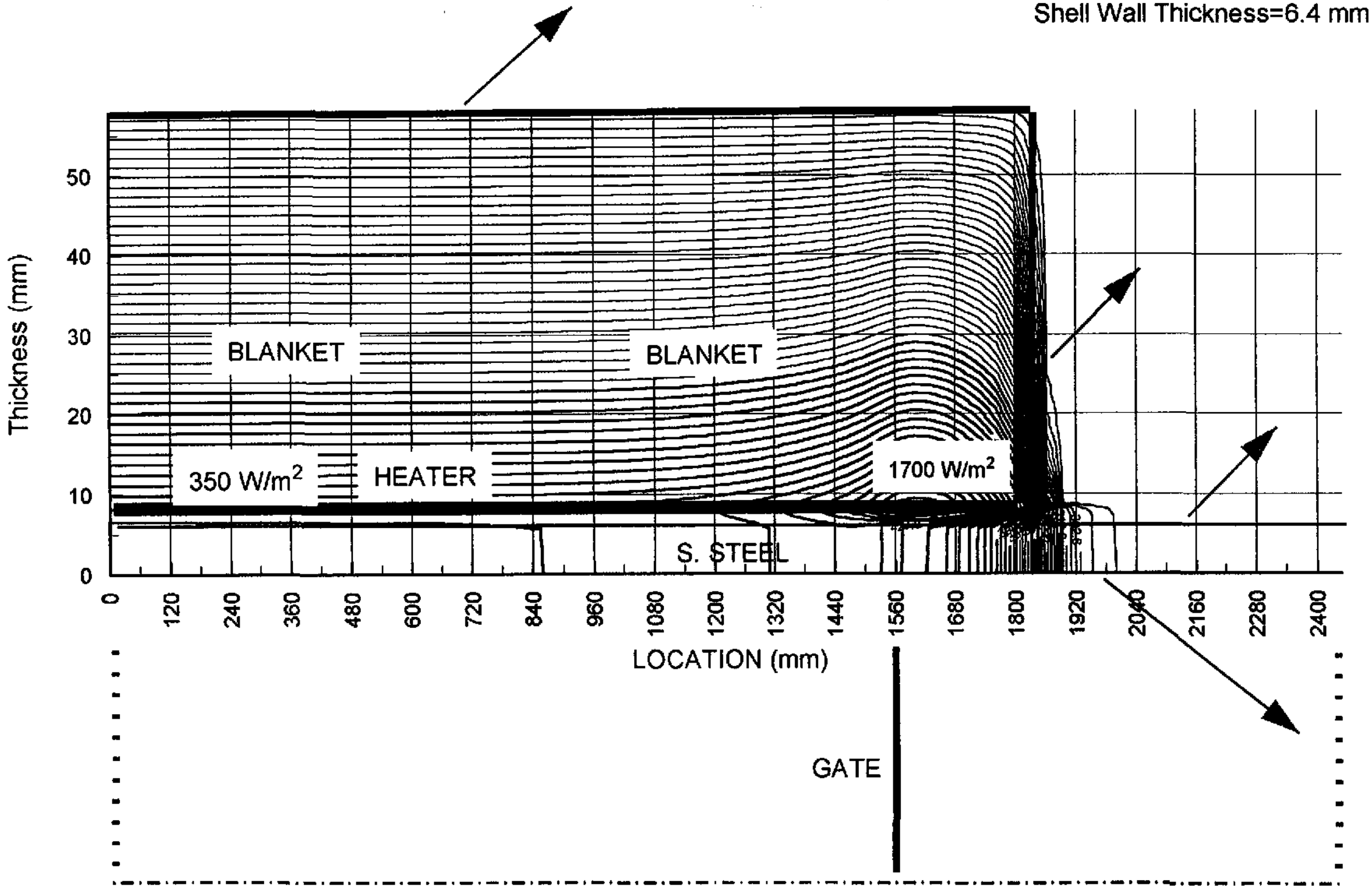
Figure 3.7-2 Gate valve end effects. Gate at 413K with 1500W/m² power density on the other side of gate and low convective coefficient.

I. Simple radiation network model case I 48" gate valve closed.
II. Simple radiation network model case I 48" gate valve open.
III. Simple radiation network model case I 44" gate valve open with low emissivity liner.

Figure: V049-1-065-3.7-1 GATE VALVE END EFFECT

k_{steel}=F(T)
$k_{insulation}$=2*F(T) W/m-K
ε=0.9 h_{air} = 100 W/m^2-K

Shell Wall Thickness=6.4 mm (0.25 in)



```
INSULATION THICKNESS 1          :    50.000 mm
LENGTH 1                        :  1500.000 mm
LENGTH 2                        :    30.000 mm
LENGTH 3                        :   900.000 mm
BLANKET SURFACE EMMISIVITY      :     0.900
LEFT HEATER POWER DENSITY       :   325.000 W/M^2
RIGHT HEATER POWER DENSITY      :  1700.000 W/M^2
TEMPERATURE AMBIENT             :   293.000 K
DIAMETER VESSEL                 :     1.270 M
QLEFT BORE      :    -4.435 W
QGATE           :  -188.482 W
QRIGHT BORE     :  -399.769 W
TEMPERATURE LEFT BORE         :  423.000 K     E : 0.90
TEMPERATURE GATE LEFT SURFACE :  393.102 K     E : 0.30
TEMPERATURE GATE RIGHT SURFACE:  393.102 K     E : 0.30
TEMPERATURE RIGHT BORE        :  293.000 K     E : 0.90
EMISSIVITY SHELL              :     0.70

Kinsulation=2*F(T)
Hair = 100 W/m^2
Wall thickness 0.25 inch

             LOCATION             TEMPERATURE                      LOCATION            TEMPERATURE
                                       K                                                    K
  1   1       0.00         0.00  424.4506        43    1     1245.00        0.00  426.7801
  2   1      15.00         0.00  424.4506        44    1     1275.00        0.00  427.2161
  3   1      45.00         0.00  424.4525        45    1     1305.00        0.00  427.7137
  4   1      75.00         0.00  424.4556        46    1     1335.00        0.00  428.2713
  5   1     105.00         0.00  424.4591        47    1     1365.00        0.00  428.8776
  6   1     135.00         0.00  424.4626        48    1     1395.00        0.00  429.5040
  7   1     165.00         0.00  424.4661        49    1     1425.00        0.00  430.0883
  8   1     195.00         0.00  424.4693        50    1     1455.00        0.00  430.5089
  9   1     225.00         0.00  424.4721        51    1     1485.00        0.00  430.5350
[illegible]   1     255.00         0.00  424.4745        52    1     1515.00        0.00  429.7526
 11   1     285.00         0.00  424.4765        53    1     1545.00        0.00  426.3849
 12   1     315.00         0.00  424.4780        54    1     1575.00        0.00  424.4080
 13   1     345.00         0.00  424.4790        55    1     1605.00        0.00  422.7239
 14   1     375.00         0.00  424.4797        56    1     1635.00        0.00  420.7158
 15   1     405.00         0.00  424.4801        57    1     1665.00        0.00  417.9706
 16   1     435.00         0.00  424.4802        58    1     1695.00        0.00  414.1466
 17   1     465.00         0.00  424.4803        59    1     1725.00        0.00  408.8718
 18   1     495.00         0.00  424.4804        60    1     1755.00        0.00  401.6407
 19   1     525.00         0.00  424.4808        61    1     1785.00        0.00  391.6745
 20   1     555.00         0.00  424.4818        62    1     1815.00        0.00  377.6942
 21   1     585.00         0.00  424.4835        63    1     1845.00        0.00  357.5135
 22   1     615.00         0.00  424.4863        64    1     1875.00        0.00  327.4201
 23   1     645.00         0.00  424.4907        65    1     1905.00        0.00  309.3670
 24   1     675.00         0.00  424.4971        66    1     1935.00        0.00  301.3976
 25   1     705.00         0.00  424.5060        67    1     1965.00        0.00  297.9092
 26   1     735.00         0.00  424.5182        68    1     1995.00        0.00  296.3607
 27   1     765.00         0.00  424.5343        69    1     2025.00        0.00  295.6476
 28   1     795.00         0.00  424.5553        70    1     2055.00        0.00  295.2939
 29   1     825.00         0.00  424.5822        71    1     2085.00        0.00  295.0957
 30   1     855.00         0.00  424.6162        72    1     2115.00        0.00  294.9656
 31   1     885.00         0.00  424.6587        73    1     2145.00        0.00  294.8662
 32   1     915.00         0.00  424.7113        74    1     2175.00        0.00  294.7812
 33   1     945.00         0.00  424.7761        75    1     2205.00        0.00  294.7035
 34   1     975.00         0.00  424.8551        76    1     2235.00        0.00  294.6294
 35   1    1005.00         0.00  424.9509        77    1     2265.00        0.00  294.5559
 36   1    1035.00         0.00  425.0666        78    1     2295.00        0.00  294.4780
 37   1    1065.00         0.00  425.2054        79    1     2325.00        0.00  294.3859
 38   1    1095.00         0.00  425.3714        80    1     2355.00        0.00  294.2564
 39   1    1125.00         0.00  425.5689        81    1     2385.00        0.00  294.0357
 40   1    1155.00         0.00  425.8029        82    1     2415.00        0.00  293.5955
 41   1    1185.00         0.00  426.0789        83    1     2430.00        0.00  293.0000
 42   1    1215.00         0.00  426.4027
```

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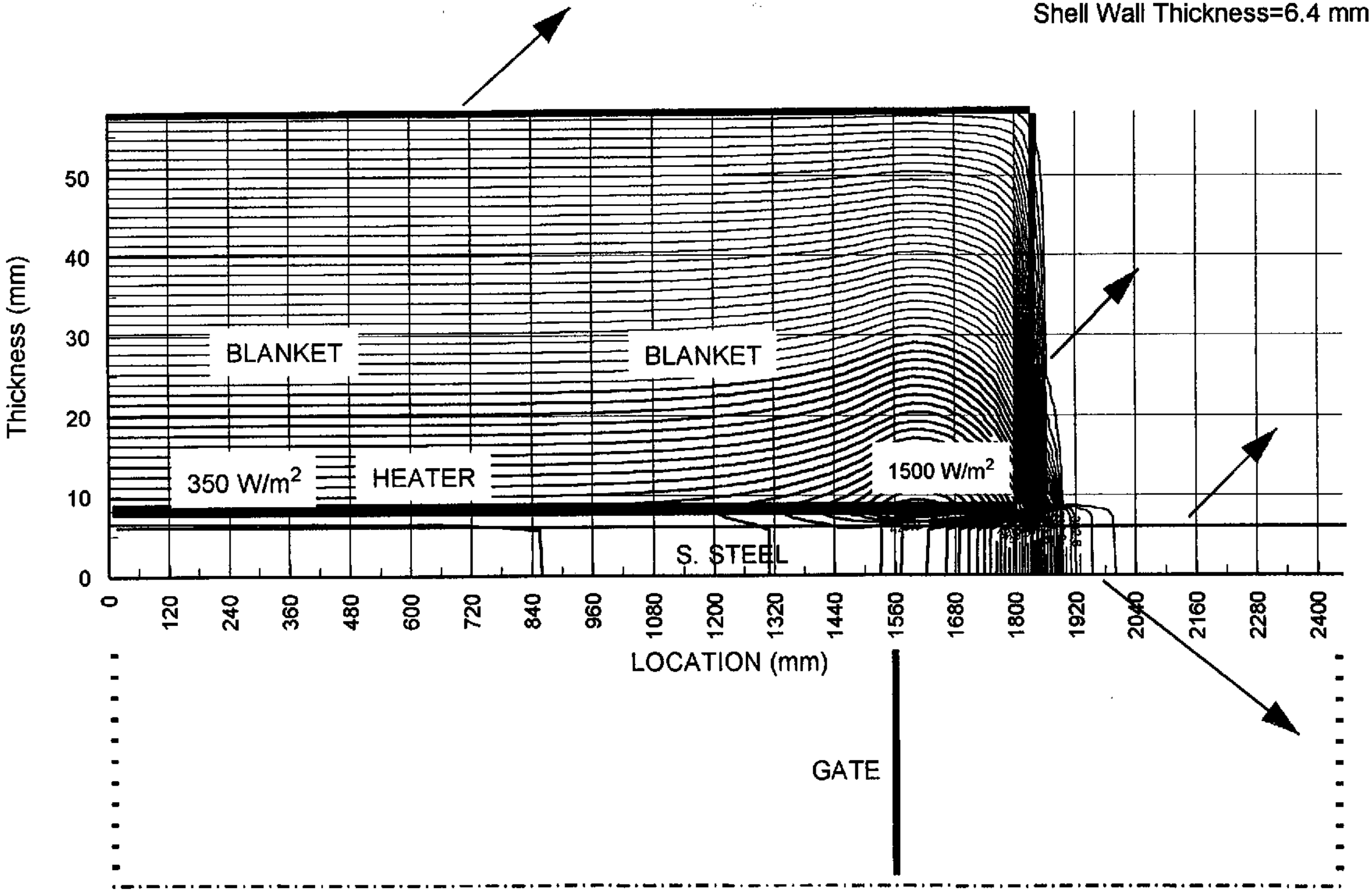
Figure: V049-1-065-3.7-2 GATE VALVE END EFFECT

k_{steel}=F(T)
$k_{insulation}$=F(T) W/m-K
ε=0.3 h_{air} = 2 W/m^2-K

Shell Wall Thickness=6.4 mm (0.25 in)



```
INSULATION THICKNESS 1          :    50.000 mm
LENGTH 1                        :  1500.000 mm
LENGTH 2                        :    30.000 mm
LENGTH 3                        :   900.000 mm
BLANKET SURFACE EMMISIVITY      :     0.300
LEFT HEATER POWER DENSITY       :   140.000 W/M^2
RIGHT HEATER POWER DENSITY      :  1500.000 W/M^2
TEMPERATURE AMBIENT             :   293.000 K
DIAMETER VESSEL                 :     1.270 M
QLEFT BORE      :  -156.212 W
QGATE           :  -148.772 W
QRIGHT BORE     :  -827.104 W
TEMPERATURE LEFT BORE          :   423.000 K     E : 0.90
TEMPERATURE GATE LEFT SURFACE :   412.470 K     E : 0.30
TEMPERATURE GATE RIGHT SURFACE:   412.470 K     E : 0.30
TEMPERATURE RIGHT BORE         :   293.000 K     E : 0.90
EMISSIVITY SHELL               :      0.70

Kinsulation=1*F(T)
Hair = 2 W/m^2
Wall thickness 0.25 inch

           LOCATION             TEMPERATURE                   LOCATION          TEMPERATURE
                                     K                                                K
 1    1      0.00       0.00  429.0842      43    1     1245.00       0.00  440.0959
 2    1     15.00       0.00  429.0842      44    1     1275.00       0.00  441.1628
 3    1     45.00       0.00  429.1180      45    1     1305.00       0.00  442.3658
 4    1     75.00       0.00  429.1751      46    1     1335.00       0.00  443.7187
 5    1    105.00       0.00  429.2490      47    1     1365.00       0.00  445.2324
 6    1    135.00       0.00  429.3358      48    1     1395.00       0.00  446.9097
 7    1    165.00       0.00  429.4327      49    1     1425.00       0.00  448.7369
 8    1    195.00       0.00  429.5380      50    1     1455.00       0.00  450.6677
 9    1    225.00       0.00  429.6502      51    1     1485.00       0.00  452.5944
 0    1    255.00       0.00  429.7685      52    1     1515.00       0.00  454.3256
11    1    285.00       0.00  429.8920      53    1     1545.00       0.00  452.8546
12    1    315.00       0.00  430.0203      54    1     1575.00       0.00  452.7483
13    1    345.00       0.00  430.1530      55    1     1605.00       0.00  453.0192
14    1    375.00       0.00  430.2897      56    1     1635.00       0.00  453.1597
15    1    405.00       0.00  430.4303      57    1     1665.00       0.00  452.8727
16    1    435.00       0.00  430.5748      58    1     1695.00       0.00  451.9569
17    1    465.00       0.00  430.7231      59    1     1725.00       0.00  450.2308
18    1    495.00       0.00  430.8754      60    1     1755.00       0.00  447.4691
19    1    525.00       0.00  431.0320      61    1     1785.00       0.00  443.3279
20    1    555.00       0.00  431.1931      62    1     1815.00       0.00  437.2351
21    1    585.00       0.00  431.3593      63    1     1845.00       0.00  428.2025
22    1    615.00       0.00  431.5310      64    1     1875.00       0.00  414.5161
23    1    645.00       0.00  431.7091      65    1     1905.00       0.00  397.0903
24    1    675.00       0.00  431.8943      66    1     1935.00       0.00  383.6293
25    1    705.00       0.00  432.0878      67    1     1965.00       0.00  373.1451
26    1    735.00       0.00  432.2906      68    1     1995.00       0.00  364.8459
27    1    765.00       0.00  432.5043      69    1     2025.00       0.00  358.1534
28    1    795.00       0.00  432.7305      70    1     2055.00       0.00  352.6382
29    1    825.00       0.00  432.9712      71    1     2085.00       0.00  347.9749
30    1    855.00       0.00  433.2286      72    1     2115.00       0.00  343.9110
31    1    885.00       0.00  433.5054      73    1     2145.00       0.00  340.2444
32    1    915.00       0.00  433.8046      74    1     2175.00       0.00  336.8058
33    1    945.00       0.00  434.1298      75    1     2205.00       0.00  333.4453
34    1    975.00       0.00  434.4850      76    1     2235.00       0.00  330.0204
35    1   1005.00       0.00  434.8749      77    1     2265.00       0.00  326.3860
36    1   1035.00       0.00  435.3050      78    1     2295.00       0.00  322.3844
37    1   1065.00       0.00  435.7815      79    1     2325.00       0.00  317.8344
 8    1   1095.00       0.00  436.3116      80    1     2355.00       0.00  312.5198
39    1   1125.00       0.00  436.9036      81    1     2385.00       0.00  306.1762
40    1   1155.00       0.00  437.5666      82    1     2415.00       0.00  298.4579
41    1   1185.00       0.00  438.3116      83    1     2430.00       0.00  293.0000
42    1   1215.00       0.00  439.1502
```

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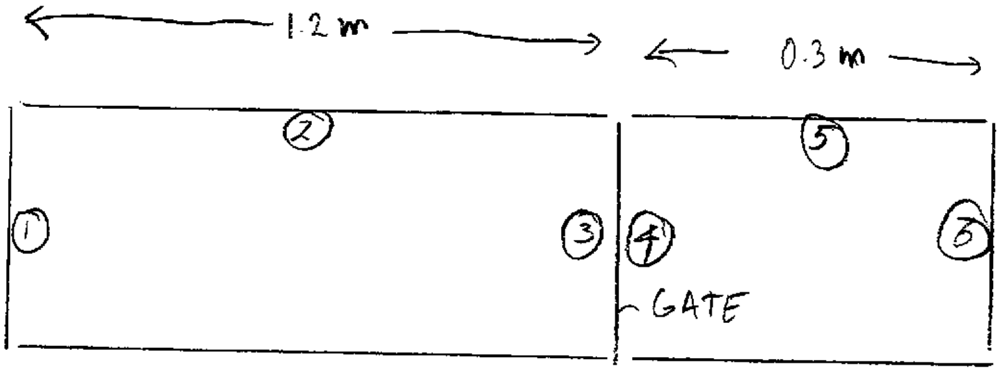
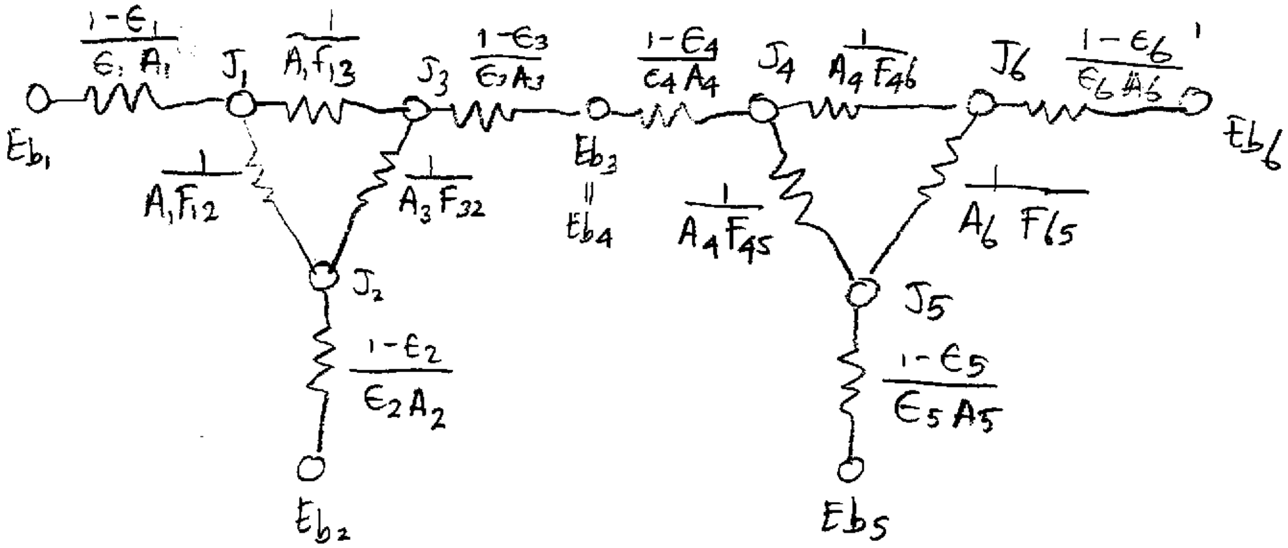
I. Simple Radiation Network Model 48" Gate Valve Closed





Areas

$\text{rad}_1 := 0.64\cdot\text{m}$ $\text{rad}_2 := 0.64\cdot\text{m}$ $\text{rad}_3 := 0.64\cdot\text{m}$ $\text{rad}_4 := 0.64\cdot\text{m}$ $\text{rad}_5 := 0.64\cdot\text{m}$ $\text{rad}_6 := 0.64\cdot\text{m}$

$h_2 := 1.2\cdot\text{m}$ $h_5 := 0.3\cdot\text{m}$ $\sigma := 56.7\cdot 10^{-9}\cdot\frac{\text{watt}}{\text{m}^2\cdot\text{K}^4}$

$A_1 := \pi\cdot\text{rad}_1^{\,2}$ $A_1 = 1.287\cdot\text{m}^2$

$A_2 := \pi\cdot 2\cdot\text{rad}_2\cdot h_2$ $A_2 = 4.825\cdot\text{m}^2$

$A_3 := \pi\cdot\text{rad}_3^{\,2}$ $A_3 = 1.287\cdot\text{m}^2$

$A_4 := A_3$ $A_4 = 1.287\cdot\text{m}^2$

$A_5 := \pi\cdot 2\cdot\text{rad}_5\cdot h_5$ $A_5 = 1.206\cdot\text{m}^2$

$A_6 := A_4$ $A_6 = 1.287\cdot\text{m}^2$

Emissivity

$\varepsilon_1 := 0.9$ $\varepsilon_2 := 0.7$ $\varepsilon_3 := 0.3$ $\varepsilon_4 := 0.3$ $\varepsilon_5 := 0.7$ $\varepsilon_6 := 0.9$

Viewfactor parallel circular disks

$RR_1 := \frac{\text{rad}_1}{h_2}$ $RR_1 = 0.533$ $RR_2 := RR_1$

$$X_1 := 1. + \frac{1. + RR_1^{\,2}}{RR_1^{\,2}}$$

$F_{1,3} := 0.5\cdot\left[X_1 - \sqrt{\left(X_1^{\,2} - 4\right)}\right]$ $F_{1,3} = 0.188$

$F_{1,2} := 1. - F_{1,3}$ $F_{1,2} = 0.812$

$RR_4 := \frac{\text{rad}_4}{h_5}$ $RR_4 = 2.133$ $RR_6 := RR_4$

$$X_4 := 1. + \frac{1. + RR_4^{\,2}}{RR_4^{\,2}}$$

$F_{4,6} := 0.5\cdot\left[X_4 - \sqrt{\left(X_4^{\,2} - 4\right)}\right]$ $F_{4,6} = 0.628$

View factor algebra

$F_{1,3} = 0.188$

$F_{1,2} = 0.812$

$F_{1,1} := 0$

$F_{3,1} := F_{1,3}$

$F_{2,1} := \frac{A_1}{A_2} \cdot F_{1,2}$ $\quad F_{2,1} = 0.217$

$F_{2,3} := F_{2,1}$ $\quad F_{2,3} = 0.217$

$F_{2,2} := 1 - F_{2,1} - F_{2,3}$ $\quad F_{2,2} = 0.567$

$F_{3,3} := 0.0$

$F_{3,2} := F_{1,2}$

$F_{4,5} := 1. - F_{4,6}$ $\quad F_{4,5} = 0.372$

$F_{6,4} := F_{4,6}$ $\quad F_{6,4} = 0.628$

$F_{5,4} := \frac{A_4}{A_5} \cdot F_{4,5}$ $\quad F_{5,4} = 0.396$

$F_{6,5} := F_{4,5}$ $\quad F_{6,5} = 0.372$

$F_{5,6} := F_{5,4}$ $\quad F_{5,6} = 0.396$

$F_{5,5} := 1 - F_{5,4} - F_{5,6}$

$i := 1 .. 6 \qquad j := 1 .. 6$

$T_1 := 423 \cdot K \qquad T_2 := 423.0 \cdot K \qquad T_5 := 400 \cdot K \qquad T_6 := 323.0 \cdot K$

$$F = \begin{bmatrix} 0 & 0.812 & 0.188 & 0 & 0 & 0 \\ 0.217 & 0.567 & 0.217 & 0 & 0 & 0 \\ 0.188 & 0.812 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.372 & 0.628 \\ 0 & 0 & 0 & 0.396 & 0.207 & 0.396 \\ 0 & 0 & 0 & 0.628 & 0.372 & 0 \end{bmatrix} \qquad A = \begin{bmatrix} 1.287 \\ 4.825 \\ 1.287 \\ 1.287 \\ 1.206 \\ 1.287 \end{bmatrix} \cdot m^2$$

$i := 1..6 \qquad j := 1..6$

$Eb_i := \sigma \cdot (T_i)^4$

$E_i := \varepsilon_i \cdot Eb_i$

Node 1

$B_{1,j} := -(1-\varepsilon_1)\cdot F_{1,j}$

$B_{1,1} := 1 - F_{1,1}\cdot(1-\varepsilon_1)$

Node 2

$B_{2,j} := -(1-\varepsilon_2)\cdot F_{2,j}$

$B_{2,2} := 1 - F_{2,2}\cdot(1-\varepsilon_2)$

Node 3 and Node 4 radiant balance

$B_{3,j} := -(1-\varepsilon_3)\cdot F_{3,j}$

$B_{3,3} := 1 - F_{3,3}\cdot(1-\varepsilon_3) - 0.5\cdot\varepsilon_3$

$B_{3,4} := -(1-\varepsilon_3)\cdot F_{3,4} - 0.5\cdot\varepsilon_3$

$B_{4,j} := -(1-\varepsilon_4)\cdot F_{4,j}$

$B_{4,4} := 1 - F_{4,4}\cdot(1-\varepsilon_4) - 0.5\cdot\varepsilon_4$

$B_{4,3} := -(1-\varepsilon_4)\cdot F_{4,3} - 0.5\cdot\varepsilon_4$

Node 5

$B_{5,j} := -(1-\varepsilon_5)\cdot F_{5,j}$

$B_{5,5} := 1 - F_{5,5}\cdot(1-\varepsilon_5)$

$B_{6,j} := -(1-\varepsilon_6)\cdot F_{6,j}$

$B_{6,6} := 1 - F_{6,6}\cdot(1-\varepsilon_6)$

$$B = \begin{bmatrix} 1 & -0.081 & -0.019 & 0 & 0 & 0 \\ -0.065 & 0.83 & -0.065 & 0 & 0 & 0 \\ -0.131 & -0.569 & 0.85 & -0.15 & 0 & 0 \\ 0 & 0 & -0.15 & 0.85 & -0.26 & -0.44 \\ 0 & 0 & 0 & -0.119 & 0.938 & -0.119 \\ 0 & 0 & 0 & -0.063 & -0.037 & 1 \end{bmatrix} \qquad E = \begin{bmatrix} 1.634\cdot 10^{3} \\ 1.271\cdot 10^{3} \\ 0 \\ 0 \\ 1.016\cdot 10^{3} \\ 555.438 \end{bmatrix}\cdot \mathrm{kg}\cdot \mathrm{sec}^{-3}$$

$$J := B^{-1}\cdot E$$

$$J = \begin{bmatrix} 1.812\cdot 10^{3} \\ 1.804\cdot 10^{3} \\ 1.67\cdot 10^{3} \\ 1.039\cdot 10^{3} \\ 1.3\cdot 10^{3} \\ 669.017 \end{bmatrix}\cdot \frac{\mathrm{watt}}{\mathrm{m}^2}$$

$$Eb_3 := 0.5\cdot\left(J_3 + J_4\right)$$

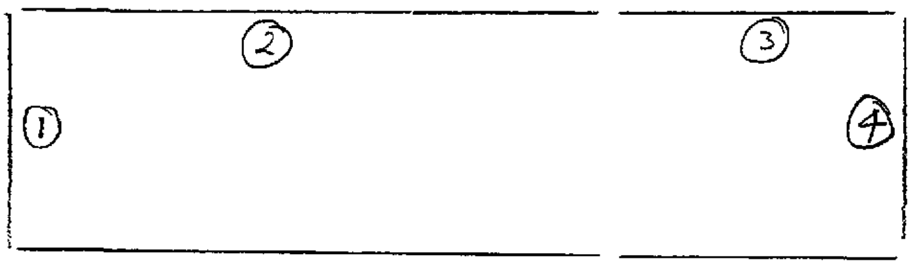
$$Eb_4 := Eb_3$$

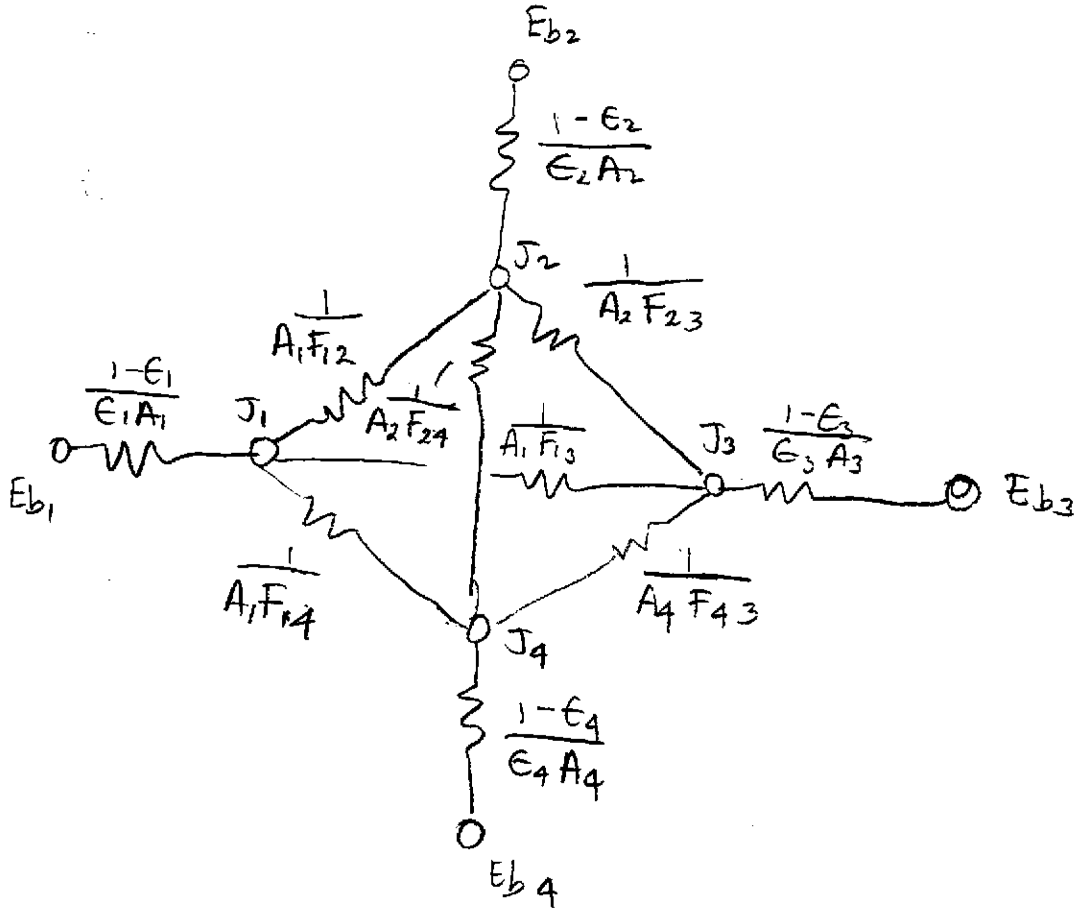
$$T_i := \left(\frac{Eb_i}{\sigma}\right)^{0.25}$$

$$T = \begin{bmatrix} 423 \\ 423 \\ 393.126 \\ 393.126 \\ 400 \\ 323 \end{bmatrix}\cdot \mathrm{K} \qquad Q_i := \left[\frac{\varepsilon_i}{\left(1-\varepsilon_i\right)}\right]\cdot A_i\cdot\left(Eb_i - J_i\right)$$

$$Q = \begin{bmatrix} 42.592 \\ 131.443 \\ -174.034 \\ 174.034 \\ 426.611 \\ -600.645 \end{bmatrix}\cdot \mathrm{watt}$$

II. Simple Radiation Network Model 48" Gate Valve Open





PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:4/06/96
TITLE: BAKEOUT BLANKETS HEAT TRANSFER ANALYSIS

Areas

$\text{rad}_1 := 0.64\cdot\text{m}$ $\text{rad}_2 := 0.64\cdot\text{m}$ $\text{rad}_3 := 0.64\cdot\text{m}$ $\text{rad}_4 := 0.64\cdot\text{m}$

$h_2 := 1.2\cdot\text{m}$ $h_3 := 0.3\cdot\text{m}$ $h_4 := h_2 + h_3$

$\sigma := 56.7\cdot 10^{-9}\cdot\dfrac{\text{watt}}{\text{m}^2\cdot\text{K}^4}$

$A_1 := \pi\cdot\text{rad}_1^{\;2}$

$A_2 := \pi\cdot 2\cdot\text{rad}_2\cdot h_2$

$A_3 := \pi\cdot 2\cdot\text{rad}_3\cdot h_3$

$A_4 := \pi\cdot\text{rad}_4^{\;2}$

Emissivity

$\varepsilon_1 := 0.9$ $\varepsilon_2 := 0.7$ $\varepsilon_3 := 0.7$ $\varepsilon_4 := 0.1$

Viewfactor parallel circular disks

$RR_1 := \dfrac{\text{rad}_1}{h_2}$ $RR_1 = 0.533$ $RR_2 := RR_1$

$X_1 := 1. + \dfrac{1. + RR_1^{\;2}}{RR_1^{\;2}}$

Calculate view factor to imaginary gate surface

$F_{1\text{gate}} := 0.5\cdot\left[X_1 - \sqrt{\left(X_1^{\;2} - 4\right)}\right]$ $F_{1\text{gate}} = 0.188$

$F_{1,2} := 1. - F_{1\text{gate}}$ $F_{1,2} = 0.812$

$RR_4 := \dfrac{\text{rad}_4}{h_4}$ $RR_4 = 0.427$

$RR_3 := \dfrac{\text{rad}_4}{h_3}$ $RR_3 = 2.133$

$X_4 := 1. + \dfrac{1. + RR_4^{\;2}}{RR_4^{\;2}}$

$X_3 := 1. + \dfrac{1. + RR_3^{\;2}}{RR_3^{\;2}}$

$F_{1,4} := 0.5\cdot\left[X_4 - \sqrt{\left(X_4^{\;2} - 4\right)}\right]$ $F_{1,4} = 0.136$

$F_{4\text{gate}} := 0.5\cdot\left[X_3 - \sqrt{\left(X_3^{\;2} - 4\right)}\right]$ $F_{4\text{gate}} = 0.628$

View factor algebra

$F_{1,3} := 1 - F_{1,2} - F_{1,4}$ $\qquad$ $F_{4,1} := \dfrac{A_1}{A_4} \cdot F_{1,4}$

$F_{1,1} := 0$

$F_{2,1} := \dfrac{A_1}{A_2} \cdot F_{1,2}$

$F_{2,2} := 1 - 2 \cdot F_{2,1}$

$F_{4,2} := F_{4gate} - F_{4,1}$

$F_{4,3} := 1 - F_{4gate}$ $\qquad$ $F_{4,4} := 0.0$ $\qquad$ $F_{4,3} = 0.372$

$F_{2,4} := \dfrac{A_4}{A_2} \cdot F_{4,2}$

$F_{2,3} := 1 - F_{2,1} - F_{2,4} - F_{2,2}$

$F_{3,1} := \dfrac{A_1}{A_3} \cdot F_{1,3}$ $\qquad$ $F_{3,2} := \dfrac{A_2}{A_3} \cdot F_{2,3}$

$F_{3,4} := \dfrac{A_4}{A_3} \cdot F_{4,3}$

$F_{3,3} := 1 - F_{3,1} - F_{3,2} - F_{3,4}$ $\qquad$ $F_{3,4} = 0.396$

$T_1 := 423 \cdot K$ $\qquad$ $T_2 := 423.0 \cdot K$ $\qquad$ $T_3 := 300.K$ $\qquad$ $T_4 := 293.0 \cdot K$

$$F = \begin{bmatrix} 0 & 0.812 & 0.052 & 0.136 \\ 0.217 & 0.567 & 0.085 & 0.131 \\ 0.055 & 0.341 & 0.207 & 0.396 \\ 0.136 & 0.492 & 0.372 & 0 \end{bmatrix} \qquad A = \begin{bmatrix} 1.287 \\ 4.825 \\ 1.206 \\ 1.287 \end{bmatrix} \cdot m^2$$

$i := 1..4 \qquad j := 1..4$

$Eb_i := \sigma \cdot (T_i)^4$

$E_i := \varepsilon_i \cdot Eb_i$

Node 1

$B_{1,j} := -(1 - \varepsilon_1) \cdot F_{1,j}$

$B_{1,1} := 1 - F_{1,1} \cdot (1 - \varepsilon_1)$

Node 2

$B_{2,j} := -(1 - \varepsilon_2) \cdot F_{2,j}$

$B_{2,2} := 1 - F_{2,2} \cdot (1 - \varepsilon_2)$

Node 3 and Node 4

$B_{3,j} := -(1 - \varepsilon_3) \cdot F_{3,j}$

$B_{3,3} := 1 - F_{3,3} \cdot (1 - \varepsilon_3)$

$B_{4,j} := -(1 - \varepsilon_4) \cdot F_{4,j}$

$B_{4,4} := 1 - F_{4,4} \cdot (1 - \varepsilon_4)$

$$B = \begin{bmatrix} 1 & -0.081 & -0.005 & -0.014 \\ -0.065 & 0.83 & -0.026 & -0.039 \\ -0.017 & -0.102 & 0.938 & -0.119 \\ -0.122 & -0.443 & -0.334 & 1 \end{bmatrix}$$

$$E = \begin{bmatrix} 1.634\cdot10^{3} \\ 1.271\cdot10^{3} \\ 321.489 \\ 41.788 \end{bmatrix} \cdot\mathrm{kg}\cdot\mathrm{sec}^{-3}$$

$$J := B^{-1}\cdot E$$

$$J = \begin{bmatrix} 1.798\cdot10^{3} \\ 1.755\cdot10^{3} \\ 728.818 \\ 1.283\cdot10^{3} \end{bmatrix} \cdot\frac{\mathrm{watt}}{\mathrm{m}^2}$$

$$T_i := \left(\frac{Eb_i}{\sigma}\right)^{0.25}$$

$$T = \begin{bmatrix} 423 \\ 423 \\ 300 \\ 293 \end{bmatrix} \cdot K$$

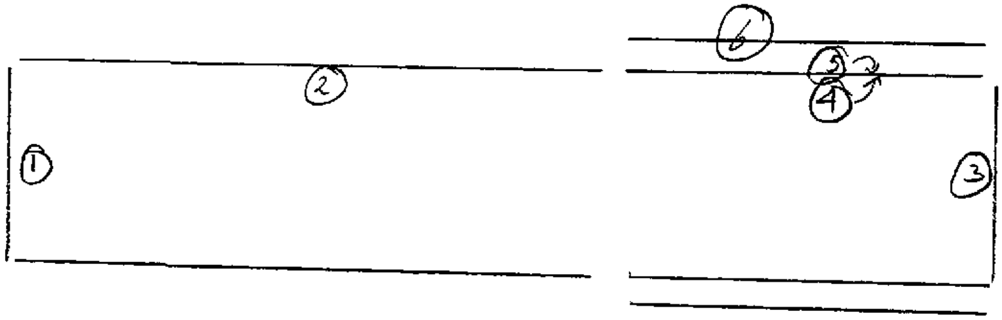
$$Q_i := \left[\frac{\varepsilon_i}{(1-\varepsilon_i)}\right]\cdot A_i\cdot\left(Eb_i - J_i\right)$$

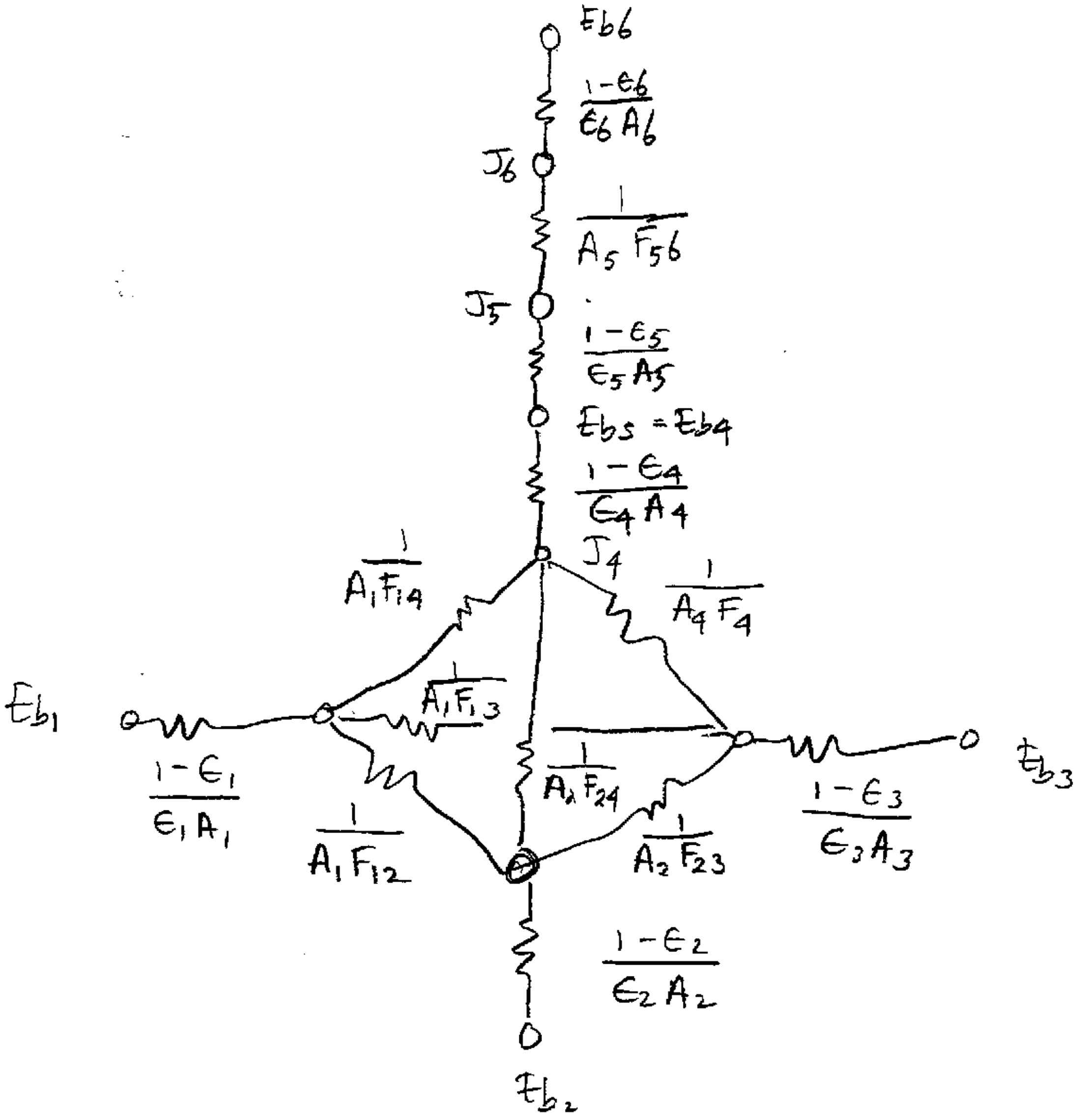
$$Q = \begin{bmatrix} 205.437 \\ 677.051 \\ -758.742 \\ -123.746 \end{bmatrix} \cdot\mathrm{watt}$$

$$Qa_i := \frac{Q_i}{A_i}$$

$$Qa = \begin{bmatrix} 159.65 \\ 140.307 \\ -628.945 \\ -96.166 \end{bmatrix} \cdot\frac{\mathrm{watt}}{\mathrm{m}^2}$$

III. Simple Radiaton Network Model 44" Gate Valve Open with low ε liner





PROJECT: LIGO BY: R.THAN
PROJECT NO: V59049 DATE:4/06/96
TITLE: BAKEOUT BLANKETS HEAT TRANSFER ANALYSIS

Areas

$\mathrm{rad}_1 := 0.60 \cdot \mathrm{m}$ $\mathrm{rad}_2 := 0.60 \cdot \mathrm{m}$ $\mathrm{rad}_3 := 0.60 \cdot \mathrm{m}$ $\mathrm{rad}_4 := 0.60 \cdot \mathrm{m}$ $\mathrm{rad}_5 := 0.60 \cdot \mathrm{m}$ $\mathrm{rad}_6 := 0.60 \cdot \mathrm{m}$

$h_2 := 1.2 \cdot \mathrm{m}$ $h_5 := 1.2 \cdot \mathrm{m}$ $h_4 := 1.2 \cdot \mathrm{m}$ $h_6 := 1.2 \cdot \mathrm{m}$ $\sigma := 56.7 \cdot 10^{-9} \cdot \frac{\mathrm{watt}}{\mathrm{m}^2 \cdot \mathrm{K}^4}$

$A_1 := \pi \cdot \mathrm{rad}_1{}^2$ $A_1 = 1.131 \cdot \mathrm{m}^2$

$A_2 := \pi \cdot 2 \cdot \mathrm{rad}_2 \cdot h_2$ $A_2 = 4.524 \cdot \mathrm{m}^2$

$A_3 := \pi \cdot \mathrm{rad}_3{}^2$ $A_3 = 1.131 \cdot \mathrm{m}^2$

$A_4 := \pi \cdot 2 \cdot \mathrm{rad}_4 \cdot h_4$ $A_4 = 4.524 \cdot \mathrm{m}^2$

$A_5 := \pi \cdot 2 \cdot \mathrm{rad}_5 \cdot h_5$ $A_5 = 4.524 \cdot \mathrm{m}^2$

$A_6 := \pi \cdot 2 \cdot \mathrm{rad}_6 \cdot h_6$ $A_6 = 4.524 \cdot \mathrm{m}^2$

Emissivity

$\varepsilon_1 := 0.9$ $\varepsilon_2 := 0.7$ $\varepsilon_3 := 0.9$ $\varepsilon_4 := 0.1$ $\varepsilon_5 := 0.1$ $\varepsilon_6 := 0.7$

Viewfactor parallel circular disks

$L_2 := h_2 + h_4$

$RR_1 := \frac{\mathrm{rad}_1}{L_2}$ $RR_1 = 0.25$ $RR_2 := RR_1$

$X_1 := 1. + \frac{1. + RR_1{}^2}{RR_1{}^2}$

$F_{1,3} := 0.5 \cdot \left[X_1 - \sqrt{\left(X_1{}^2 - 4 \right)} \right]$ $F_{1,3} = 0.056$

$RR_I := \frac{\mathrm{rad}_2}{h_2}$ $RR_I = 0.5$

$X_I := 1. + \frac{1. + RR_I{}^2}{RR_I{}^2}$

$F_I := 0.5 \cdot \left[X_I - \sqrt{\left(X_I{}^2 - 4 \right)} \right]$ $F_I = 0.172$

$RR_K := \frac{\mathrm{rad}_4}{h_4}$ $RR_K = 0.5$

$X_K := 1. + \frac{1. + RR_K{}^2}{RR_K{}^2}$

$F_K := 0.5 \cdot \left[X_K - \sqrt{\left(X_K{}^2 - 4 \right)} \right]$ $F_K = 0.172$

View factor algebra

$F_{1,3} = 0.056$ $F_{1,2} := 1. - F_I$

$F_{1,2} = 0.828$

$F_{1,4} := 1 - F_{1,2} - F_{1,3}$ $F_{1,4} = 0.116$

$F_{1,1} := 0.0$

$F_{3,1} := F_{1,3}$

$F_{2,1} := \frac{A_1}{A_2} \cdot F_{1,2}$ $F_{4,1} := \frac{A_1}{A_4} \cdot F_{1,4}$

$F_{3,2} := F_K - F_{3,1}$

$F_{2,3} := \frac{A_3}{A_2} \cdot F_{3,2}$

$F_{3,4} := 1 - F_{3,2} - F_{3,1}$ $F_{3,3} := 0.0$

$F_{1,5} := 0.0$ $F_{1,6} := 0.0$ $F_{4,5} := 0.0$ $F_{4,6} := 0.0$ $F_{5,1} := 0.0$ $F_{6,2} := 0.0$

$F_{2,5} := 0.0$ $F_{2,6} := 0.0$ $F_{5,5} := 0.0$ $F_{5,6} := 1.0$ $F_{6,1} := 0.0$ $F_{5,3} := 0.0$

$F_{3,5} := 0.0$ $F_{3,6} := 0.0$ $F_{6,5} := 1.0$ $F_{6,6} := 0.0$ $F_{5,2} := 0.0$ $F_{5,4} := 0.0$

$F_{6,3} := 0.0$ $F_{5,4} := 0.0$ $F_{6,4} := 0.0$

$F_{2,4} := F_I - F_{2,3}$

$F_{2,2} := 1 - F_{2,1} - F_{2,4} - F_{2,3}$ $F_{4,2} := \frac{A_2}{A_4} \cdot F_{2,4}$

$F_{4,3} := \frac{A_3}{A_4} \cdot F_{3,4}$ $F_{4,4} := 1 - F_{4,3} - F_{4,1} - F_{4,2}$

$T_1 := 423 \cdot K$ $T_2 := 423.0 \cdot K$ $T_3 := 80. \cdot K$ $T_6 := 293.0 \cdot K$ $T_4 := 0.0 \cdot K$ $T_5 := 0.0 \cdot K$

$$F = \begin{bmatrix} 0 & 0.828 & 0.056 & 0.116 & 0 & 0 \\ 0.207 & 0.621 & 0.029 & 0.143 & 0 & 0 \\ 0.056 & 0.116 & 0 & 0.828 & 0 & 0 \\ 0.029 & 0.143 & 0.207 & 0.621 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \qquad A = \begin{bmatrix} 1.131 \\ 4.524 \\ 1.131 \\ 4.524 \\ 4.524 \\ 4.524 \end{bmatrix} \cdot m^2$$

$i := 1..6 \qquad j := 1..6$

$Eb_i := \sigma \cdot (T_i)^4$

$E_i := \varepsilon_i \cdot Eb_i$

Node 1

$B_{1,j} := -(1-\varepsilon_1)\cdot F_{1,j}$

$B_{1,1} := 1 - F_{1,1}\cdot(1-\varepsilon_1)$

Node 2

$B_{2,j} := -(1-\varepsilon_2)\cdot F_{2,j}$

$B_{2,2} := 1 - F_{2,2}\cdot(1-\varepsilon_2)$

Node 3

$B_{3,j} := -(1-\varepsilon_3)\cdot F_{3,j}$

$B_{3,3} := 1 - F_{3,3}\cdot(1-\varepsilon_3)$

Node 4 and Node 5 radiant balance

$B_{4,j} := -(1-\varepsilon_4)\cdot F_{4,j}$

$B_{4,4} := 1 - F_{4,4}\cdot(1-\varepsilon_4) - 0.5\cdot\varepsilon_4$

$B_{4,5} := -(1-\varepsilon_4)\cdot F_{4,5} - 0.5\cdot\varepsilon_4$

$B_{5,j} := -(1-\varepsilon_5)\cdot F_{5,j}$

$B_{5,5} := 1 - F_{5,5}\cdot(1-\varepsilon_5) - 0.5\cdot\varepsilon_5$

$B_{5,4} := -(1-\varepsilon_5)\cdot F_{5,4} - 0.5\cdot\varepsilon_5$

Node 6

$B_{6,j} := -(1-\varepsilon_6)\cdot F_{6,j}$

$B_{6,6} := 1 - F_{6,6}\cdot(1-\varepsilon_6)$

$$B = \begin{bmatrix} 1 & -0.083 & -0.006 & -0.012 & 0 & 0 \\ -0.062 & 0.814 & -0.009 & -0.043 & 0 & 0 \\ -0.006 & -0.012 & 1 & -0.083 & 0 & 0 \\ -0.026 & -0.128 & -0.186 & 0.391 & -0.05 & 0 \\ 0 & 0 & 0 & -0.05 & 0.95 & -0.9 \\ 0 & 0 & 0 & 0 & -0.3 & 1 \end{bmatrix}$$

$$E = \begin{bmatrix} 1.634\cdot10^3 \\ 1.271\cdot10^3 \\ 2.09 \\ 0 \\ 0 \\ 292.517 \end{bmatrix} \cdot \frac{watt}{m^2}$$

$J := B^{-1} \cdot E$

$$J = \begin{bmatrix} 1.788 \cdot 10^{3} \\ 1.741 \cdot 10^{3} \\ 98.072 \\ 794.859 \\ 445.601 \\ 426.198 \end{bmatrix} \cdot \frac{\text{watt}}{\text{m}^2}$$

$Eb_4 := 0.5 \cdot (J_4 + J_5)$

$Eb_5 := Eb_4$

$$T_i := \left(\frac{Eb_i}{\sigma} \right)^{0.25}$$

$$T = \begin{bmatrix} 423 \\ 423 \\ 80 \\ 323.402 \\ 323.402 \\ 293 \end{bmatrix} \cdot K$$

$$Q_i := \left[\frac{\varepsilon_i}{(1 - \varepsilon_i)} \right] \cdot A_i \cdot (Eb_i - J_i)$$

$$Q = \begin{bmatrix} 280.215 \\ 782.175 \\ -974.612 \\ -87.778 \\ 87.778 \\ -87.778 \end{bmatrix} \cdot \text{watt}$$

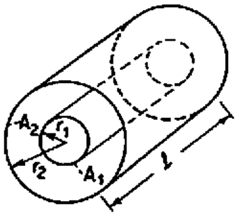
$$Qa_i := \frac{Q_i}{A_i}$$

$$Qa = \begin{bmatrix} 247.764 \\ 172.899 \\ -861.746 \\ -19.403 \\ 19.403 \\ -19.403 \end{bmatrix} \cdot \frac{\text{watt}}{\text{m}^2}$$

3.8 Pressure Gauge Pair Bakeout

The pressure gauge pair will be baked out at 250°C. Since the gauge pair is mounted on a 1.5 inch conflat tee that is in turn mounted on a 14 inch nozzle conflat blank, the thermal path to the 150°C mass is reasonably long. To ensure that temperature is reached at the gauge the entire tee along with the gauge pair is heated to 250°C. With the temperature sensor mounted at the gauges, the gauges are insured to reach temperature. A temperature gradient will develop along the tee from 250°C to 150°C. The required power density required to reach 250°C with 2 inch thick fiberglass insulation is about 600 W/m^2.

25



Two concentric cylinders of same finite length.

$R = \frac{r_2}{r_1} \qquad L = \frac{l}{r_1}$

$A = L^2 + R^2 - 1$

$B = L^2 - R^2 + 1$

$$F_{2-1} = \frac{1}{R} - \frac{1}{\pi R}\left\{\cos^{-1}\left(\frac{B}{A}\right) - \frac{1}{2L}\left[\sqrt{(A+2)^2 - (2R)^2}\cos^{-1}\left(\frac{B}{RA}\right) + B\sin^{-1}\left(\frac{1}{R}\right) - \frac{\pi A}{2}\right]\right\}$$

$$F_{2-2} = 1 - \frac{1}{R} + \frac{2}{\pi R}\tan^{-1}\left(\frac{2\sqrt{R^2-1}}{L}\right) - \frac{L}{2\pi R}\left\{\frac{\sqrt{4R^2+L^2}}{L}\sin^{-1}\left[\frac{4(R^2-1) + (L^2/R^2)(R^2-2)}{L^2 + 4(R^2-1)}\right] - \sin^{-1}\left(\frac{R^2-2}{R^2}\right) + \frac{\pi}{2}\left(\frac{\sqrt{4R^2+L^2}}{L} - 1\right)\right\}$$

where for any argument ξ:

$$-\frac{\pi}{2} \leqslant \sin^{-1}\xi \leqslant \frac{\pi}{2}$$

$$0 \leqslant \cos^{-1}\xi \leqslant \pi$$

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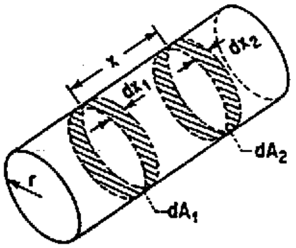
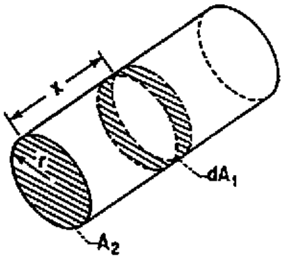


Two ring elements on the interior of a right circular cylinder.

$X = \frac{x}{2r}$

$$dF_{d1-d2} = \left[1 - \frac{2X^3 + 3X}{2(X^2+1)^{3/2}}\right] dX_2$$

27

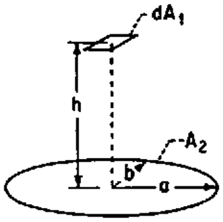


Ring element dA_1 on interior of right circular cylinder to circular disk A_2 at end of cylinder.

$X = \frac{x}{2r}$

$$F_{d1-2} = \frac{X^2 + \frac{1}{2}}{\sqrt{X^2+1}} - X$$

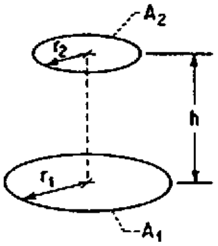
17



Plane element dA_1 to elliptical plate in plane parallel to element; normal to element passes through center of plate.

$$F_{d1-2} = \frac{ab}{\sqrt{(h^2 + a^2)(h^2 + b^2)}}$$

18



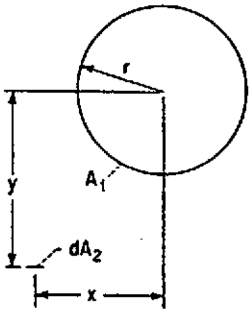
Parallel circular disks with centers along the same normal.

$$R_1 = \frac{r_1}{h} \qquad R_2 = \frac{r_2}{h}$$

$$X = 1 + \frac{1 + R_2^2}{R_1^2}$$

$$F_{1-2} = \frac{1}{2}\left[X - \sqrt{X^2 - 4\left(\frac{R_2}{R_1}\right)^2}\right]$$

19

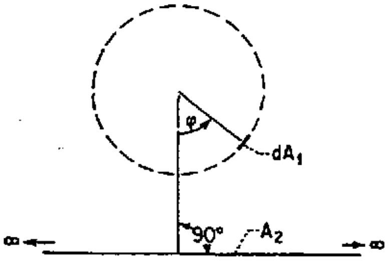


Strip element dA_2 of any length to infinitely long cylinder.

$$X = \frac{x}{r} \qquad Y = \frac{y}{r}$$

$$F_{d2-1} = \frac{Y}{X^2 + Y^2}$$

20



Element of any length on cylinder to plane of infinite length and width.

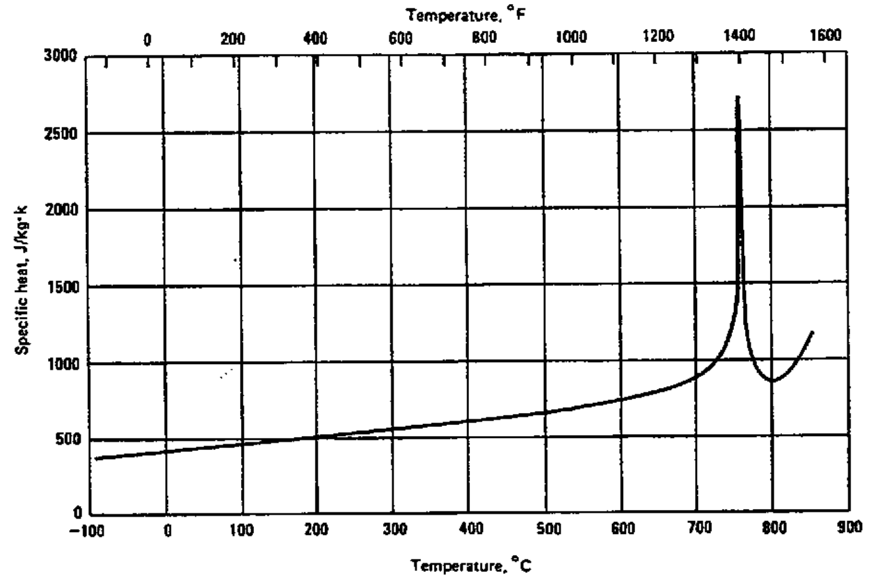
$$F_{d1-2} = \tfrac{1}{2}(1 + \cos\varphi)$$

Specific heat of steels

Nearest AISI-SAE grade	Chemical composition, % C	Mn	Cr	Ni	Mo	Other	Treatment or condition	Mean apparent specific heat, J/Kg·K, Temperature ranges, °C 50 to 100	150 to 200	200 to 250	250 to 300	300 to 350	350 to 400	450 to 500	550 to 600	650 to 700	700 to 750	750 to 800	850 to 900
1008	0.06	0.38	···	···	···	···	Annealed	481	519	536	553	574	595	662	754	867	1105	875	846
1008	0.08	0.31	···	···	···	···	Annealed	481	523	544	557	569	595	662	741	858	1139	960	···
1010(a)	0.10	0.42	···	···	···	0.008 P; 0.028 S	Not known	450	500	520	535	565	590	650	730	825	(a)	(a)	(a)
1025	0.23	0.64	···	···	···	···	Annealed	486	519	532	557	574	599	662	749	846	1432	950	···
1042	0.42	0.64	···	···	···	···	Annealed	486	515	528	548	569	586	649	708	770	1583	624	548
1078	0.80	0.32	···	···	···	···	Annealed	490	532	548	565	586	607	670	712	770	2081	615	···
(b)	1.22	0.35	···	···	···	···	Annealed	486	540	544	557	578	599	636	699	816	2089	649	···
1524	0.23	1.51	···	···	···	0.11 Cu	Annealed	477	511	528	544	565	590	649	741	837	1449	821	536
4130(c)	0.3	0.5	0.95	···	0.2	···	Hardened and tempered	477	515	···	544	···	595	657	737	825	···	833	···
4140	0.41	0.67	1.01	···	0.23	···	Hardened and tempered	···	473(d)	···	···	···	519(d)	···	561(d)	···	···	···	···
5132	0.32	0.69	1.09	0.073	···	···	Annealed	494	523	536	553	574	595	657	741	837	1499	934	574
5140	0.39	0.79	1.03	···	···	···	Hardened and tempered	452(d)	473(d)	···	···	···	519(d)	···	561(d)	···	···	···	···
(b)	0.35	0.59	0.88	0.26	0.20	···	Annealed	477	515	528	544	569	595	657	737	825	1616	883	···
(b)	0.33	0.55	0.17	3.47	···	···	Not known	481	523	536	548	569	590	662	749	1637	955	603	640
(b)	0.34	0.55	0.78	3.53	0.39	···	Hardened and tempered	486	523	540	557	582	607	670	770	1051	1662	636	636
(b)	0.49	0.90	···	···	···	1.98 Si; 0.64 Cu	Not known	498	523	540	557	578	603	666	749	829	904	1365	···

(a) See graph of specific heat versus temperature. (b) No equivalent grade. (c) Nominal composition. (d) Value presented is mean value for range of temperatures between room temperature and the higher of the cited temperatures.

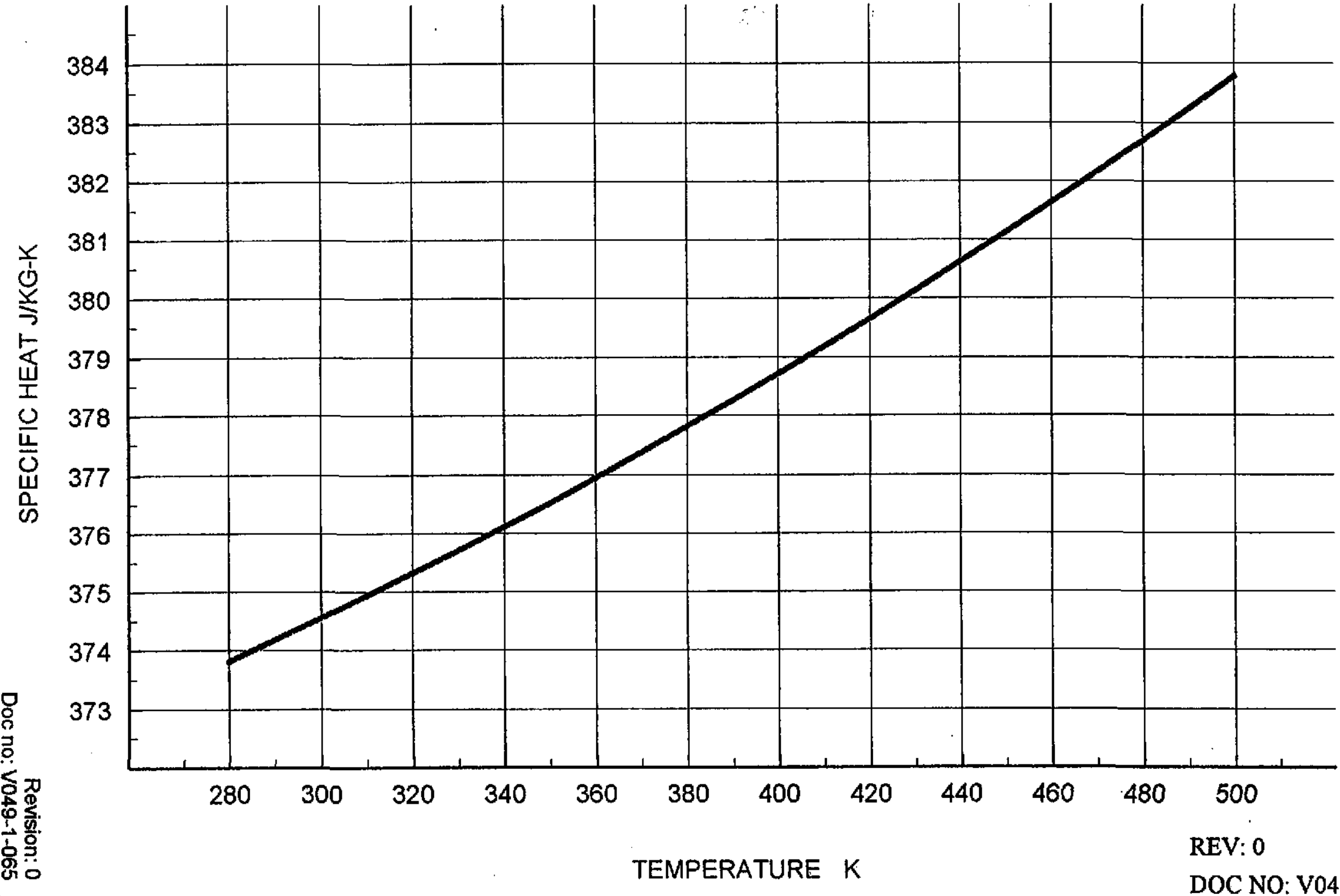
Specific heat of 1010 steel



PROJECT: LIGO
PROJECT NO: V59049
TITLE BAKEOUT BLANKETS HEAT TRANSFER ANALYSIS

BY: R.THAN
DATE:

SPECIFIC HEAT ANSI 304



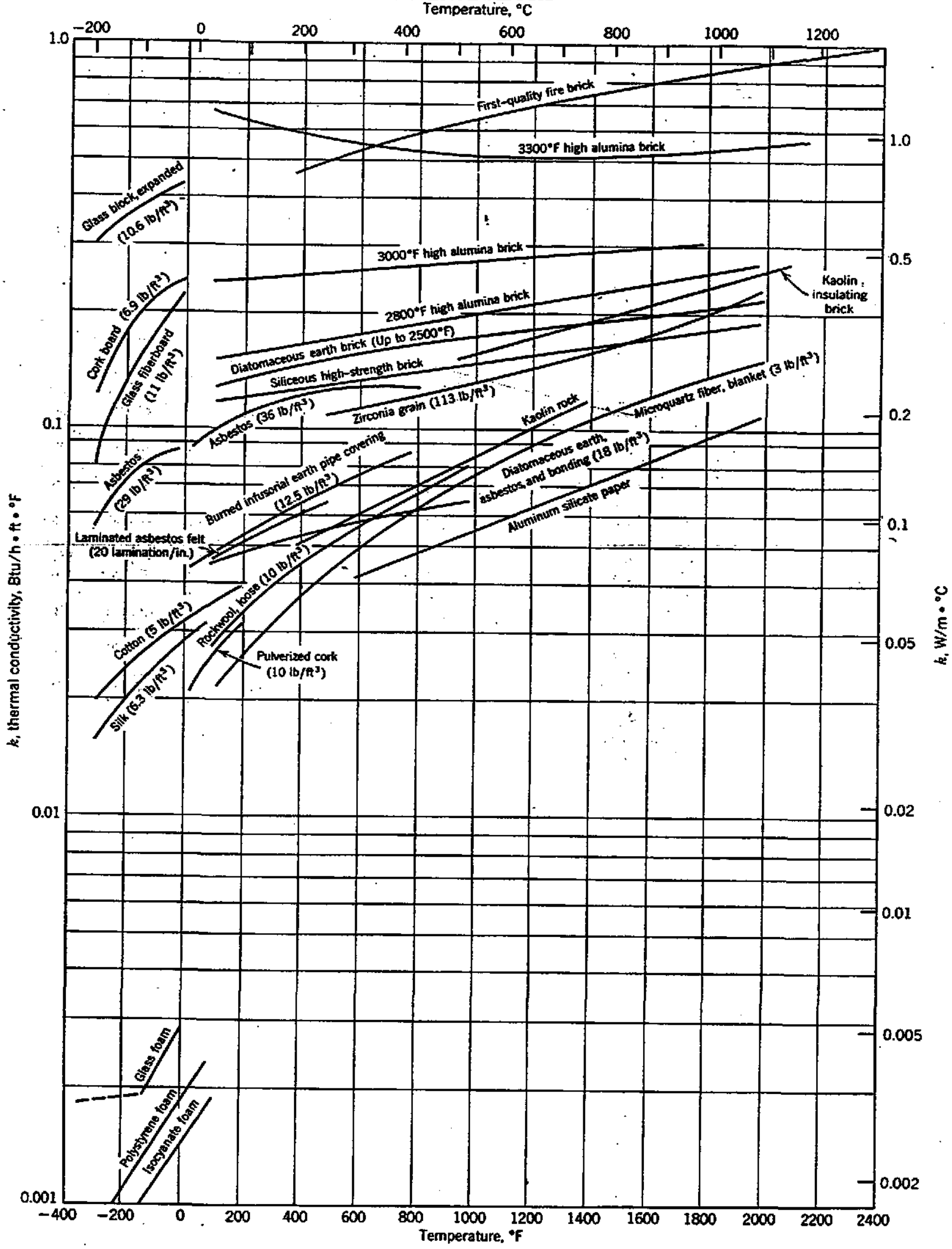


Figure H2.1 Effects of temperature on the thermal conductivities of thermal insulating materials. (Data from a number of sources—including Ref. 8, in Chapter 20 and Refs. 4, 14, and 19 of this handbook—were selected, plotted, and averaged to yield these curves.)

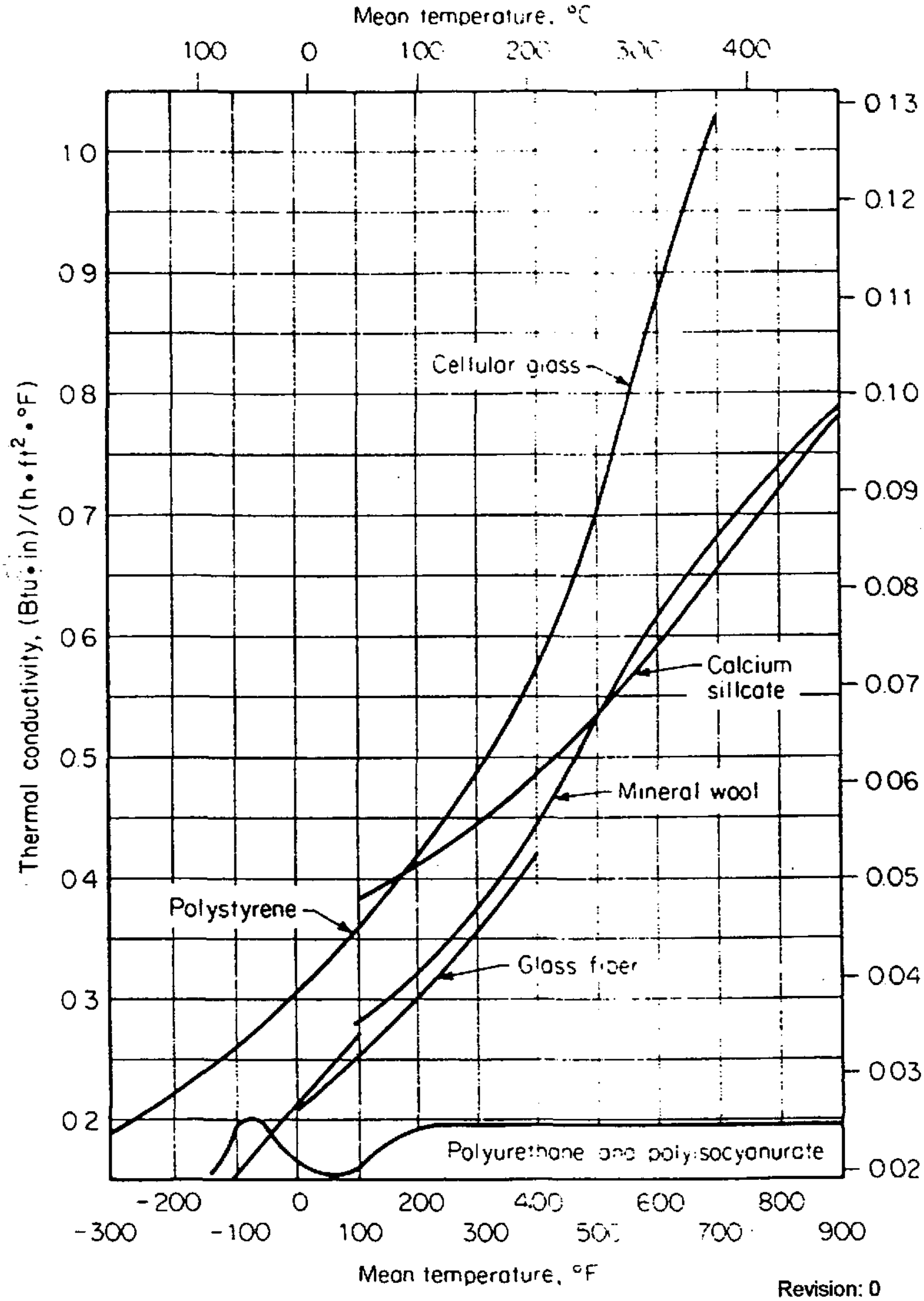


FIG. 11-42 Thermal conductivity of insulating materials.

Table 4 Typical Thermal Properties of Common Building and Insulating Materials—Design Values[a]

Description		Density, lb/ft³	Conductivity[b] (k), Btu·in./h·ft²·°F	Conductance (C), Btu/h·ft²·°F	Resistance[c] (R) Per inch thickness (1/k), °F·ft²·h/Btu·in.	Resistance[c] (R) For thickness listed (1/C), °F·ft²·h/Btu	Specific Heat, Btu/lb·°F
BUILDING BOARD							
Asbestos-cement board		120	4.0	—	0.25	—	0.24
Asbestos-cement board	0.125 in.	120	—	33.00	—	0.03	
Asbestos-cement board	0.25 in.	120	—	16.50	—	0.06	
Gypsum or plaster board	0.375 in.	50	—	3.10	—	0.32	0.26
Gypsum or plaster board	0.5 in.	50	—	2.22	—	0.45	
Gypsum or plaster board	0.625 in.	50	—	1.78	—	0.56	
Plywood (Douglas Fir)[d]		34	0.80	—	1.25	—	0.29
Plywood (Douglas Fir)	0.25 in.	34	—	3.20	—	0.31	
Plywood (Douglas Fir)	0.375 in.	34	—	2.13	—	0.47	
Plywood (Douglas Fir)	0.5 in.	34	—	1.60	—	0.62	
Plywood (Douglas Fir)	0.625 in.	34	—	1.29	—	0.77	
Plywood or wood panels	0.75 in.	34	—	1.07	—	0.93	0.29
Vegetable Fiber Board							
Sheathing, regular density[e]	0.5 in.	18	—	0.76	—	1.32	0.31
	0.78125 in.	18	—	0.49	—	2.06	
Sheathing intermediate density[e]	0.5 in.	22	—	0.92	—	1.09	0.31
Nail-base sheathing[e]	0.5 in.	25	—	0.94	—	1.06	0.31
Shingle backer	0.375 in.	18	—	1.06	—	0.94	0.31
Shingle backer	0.3125 in.	18	—	1.28	—	0.78	
Sound deadening board	0.5 in.	15	—	0.74	—	1.35	0.30
Tile and lay-in panels, plain or acoustic		18	0.40	—	2.50	—	0.14
	0.5 in.	18	—	0.80	—	1.25	
	0.75 in.	18	—	0.53	—	1.89	
Laminated paperboard		30	0.50	—	2.00	—	0.33
Homogeneous board from repulped paper		30	0.50	—	2.00	—	0.28
Hardboard[e]							
Medium density		50	0.73	—	1.37	—	0.31
High density, service temp. service underlay		55	0.82	—	1.22	—	0.32
High density, std. tempered		63	1.00	—	1.00	—	0.32
Particleboard[e]							
Low density		37	0.71	—	1.41	—	0.31
Medium density		50	0.94	—	1.06	—	0.31
High density		62.5	1.18	—	0.85	—	0.31
Underlayment	0.625 in.	40	—	1.22	—	0.82	0.29
Waferboard		37	0.63	—	1.59	—	[illegible]
Wood subfloor	0.75 in.	—	—	1.06	—	0.94	0.33
BUILDING MEMBRANE							
Vapor—permeable felt		—	—	16.70	—	0.06	
Vapor—seal, 2 layers of mopped 15-lb felt		—	—	8.35	—	0.12	
Vapor—seal, plastic film		—	—	—	—	Negl.	
FINISH FLOORING MATERIALS							
Carpet and fibrous pad		—	—	0.48	—	2.08	[illegible]
Carpet and rubber pad		—	—	0.81	—	1.23	[illegible]
Cork tile	0.125 in.	—	—	3.60	—	0.28	[illegible]
Terrazzo	1 in.	—	—	12.50	—	0.08	[illegible]
Tile—asphalt, linoleum, vinyl, rubber		—	—	20.00	—	0.05	[illegible]
vinyl asbestos							[illegible]
ceramic							[illegible]
Wood, hardwood finish	0.75 in.	—	—	1.47	—	0.68	[illegible]
INSULATING MATERIALS							
Blanket and Batt[f,g]							
Mineral Fiber, fibrous form processed from rock, slag, or glass							
approx. 3–4 in.		0.3–2.0	—	0.091	—	11	
approx. 3.5 in.		0.3–2.0	—	0.077	—	13	
approx. 5.5–6.5 in.		0.3–2.0	—	0.053	—	19	
approx. 6–7.5 in.		0.3–2.0	—	0.045	—	22	
approx. 9–10 in.		0.3–2.0	—	0.033	—	30	
approx. 12–13 in.		0.3–2.0	—	0.026	—	38	
Board and Slabs							
Cellular glass		8.5	0.35	—	2.86	—	[illegible]
Glass fiber, organic bonded		4.0–9.0	0.25	—	4.00	—	[illegible]
Expanded perlite, organic bonded		1.0	0.36	—	2.78	—	[illegible]
Expanded rubber (rigid)		4.5	0.22	—	4.55	—	[illegible]

Heat Transfer
Division

Section 515.2
Page 13
June 14, 1955

PROPERTIES OF SOLIDS
THERMAL CONDUCTIVITY

G-E designation (1)	Material	Condition (2) Density or pressure lb/ft^3 except as noted	Average temp Deg F	Average temp Deg C	k_B Conductivity (3) $\frac{(\text{Btu})(\text{ft})}{\text{hr}(\text{ft}^2)\text{ F}}$	k_W Conductivity (3) $\frac{\text{watt(in.)}}{\text{in.}^2\text{ (C)}}$	$1/k_W$ Resistivity (3) $\frac{\text{in.}^2\text{ (C)}}{\text{watt(in.)}}$	Range of $1/k_W$ values	Rating (4)	Ref No. (5)
NON-METALLIC MINERALS (Continued)										
	Fiberglas, white (glass wool blankets or bolts) All samples 1 inch thick and faced with aluminum foil	7.75 psia	86.0	30	.0287	.00126	794		A	130
		4.66 psia	87.8	31	.0278	.00122	820		A	130
		3.65 psia	84.2	29	.0276	.00121	826		A	130
		1.73 psia	86.0	30	.0276	.00121	826		A	130
		.266 psia	86.0	30	.0269	.00118	847		A	130
		1.75								
		14.7 psia	95.0	35.0	.0257	.00113	885		A	130
		11.0 psia	96.1	35.6	.0253	.00111	901		A	130
		7.26 psia	88.9	31.6	.0234	.00103	971		A	130
		4.42 psia	89.2	31.8	.0232	.00102	980		A	130
		.398 psia	96.3	35.7	.0209	.00092	1087		A	130
		2.45								
		14.6 psia	92.1	33.4	.0276	.00121	826		A	130
		11.5 psia	93.2	34.0	.0273	.00120	833		A	130
		8.31 psia	86.0	30	.0250	.00110	909		A	130
		4.61 psia	86.0	30	.0246	.00108	926		A	130
		.320 psia	92.5	33.6	.0237	.00104	962		A	130
		2.8								
		14.6 psia	90.0	32.2	.0230	.00101	990		A	130
		12.7 psia	91.4	33.0	.0234	.00103	971		A	130
		10.3 psia	91.8	33.2	.0228	.00100	1000		A	130
		82.5 psia	90.7	32.6	.0223	.000985	1020		A	130
		6.00 psia	91.6	33.4	.0223	.000985	1020		A	130
		2.94 psia	92.5	33.6	.0218	.000964	1042		A	130
		3.5								
		14.6 psia	86.9	30.5	.0234	.00103	971		A	130
		12.5 psia	86.5	30.3	.0230	.00101	990		A	130
		10.0 psia	86.0	30.0	.0227	.000996	1005		A	130
		7.37 psia	85.5	29.7	.0223	.000982	1020		A	130
		5.48 psia	87.4	30.8	.0223	.000382	1020		A	130
		3.43 psia	88.0	31.1	.0221	.000967	1031		A	130
		2.79 psia	90.0	32.2	.0221	.000967	1031		A	130
		1.53 psia	90.0	32.2	.0218	.000956	1042		A	130
		.202 psia	91.6	33.1	.0203	.000890	1124		A	130
	Fiberglas batts (basic form) (TW-F)	3	68	20	.0207	.000912	1099		A	136
			300	149	.0342	.00150	667		A	136
			399	204	.0453	.00212	472		A	136
		6	68.0	20	.0191	.000843	1190		A	136
			300	149	.0271	.00119	840		A	136
			399	204	.0351	.00154	649		A	136
		9	68.0	20	.0184	.000806	1234		A	136
			300	149	.0234	.00103	971		A	136
			399	204	.0287	.00126	794		A	136
A7A8	Fiberglas (for use up to 500 C) Preformed (PF) (same as TW-F with a small percentage of thermosetting plastic added to give rigidity of form)									
[illegible]	PF-511 .00095 fiber	2	75.2	24	.0216	.000953	1052		A	136
[illegible]	PF-515 .00043 fiber	3.75	75.2	24	.0191	.000843	1190		A	136
A7A8B1	PF-611	2.0	50	10	.0207	.000908	1099		A	117
			100	38	.0246	.00108	926		A	117
			151	66	.0291	.00128	781		A	117

(1) - (5) See bottom of page 8.

GENERAL ELECTRIC ★ Supersedes Issue of

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

REV.	DEO #	DATE	BY:	CHECK
0	0029	4-11-96	AGR	RDC

ENGINEERING CALCULATIONS

NO: V049-1-086
PAGE 1 **OF** 9

TITLE: 44" GATE VALVE SUPPORT

By: ART ROUSSOPOULOS **DEPT.:** 749

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: DESIGN A GROUND SUPPORT FOR THE 44" GATE VALVE

METHOD: · CLASSICAL STRESS ANALYSIS

ASSUMPTIONS: SEE CALCS

INPUTS: GATE VALVE VENDOR DWG'S D103279 + D103225-01 FOR ASSEMBLED DW = 7000# + SUPPORT LOCATIONS/GEOMETRY

REFERENCES: AISC - MSC - 9TH ED
BLODGETT - "DESIGN OF WELDED STRUCTURES"
DOC. NO. V049-1-066, LIGO VACUUM EQUIP STRUCTURAL DESIGN CRITERIA

CALCULATIONS: (SEE ATTACHED)

CONCLUSIONS:

NOTES:

TABLE OF CONTENTS

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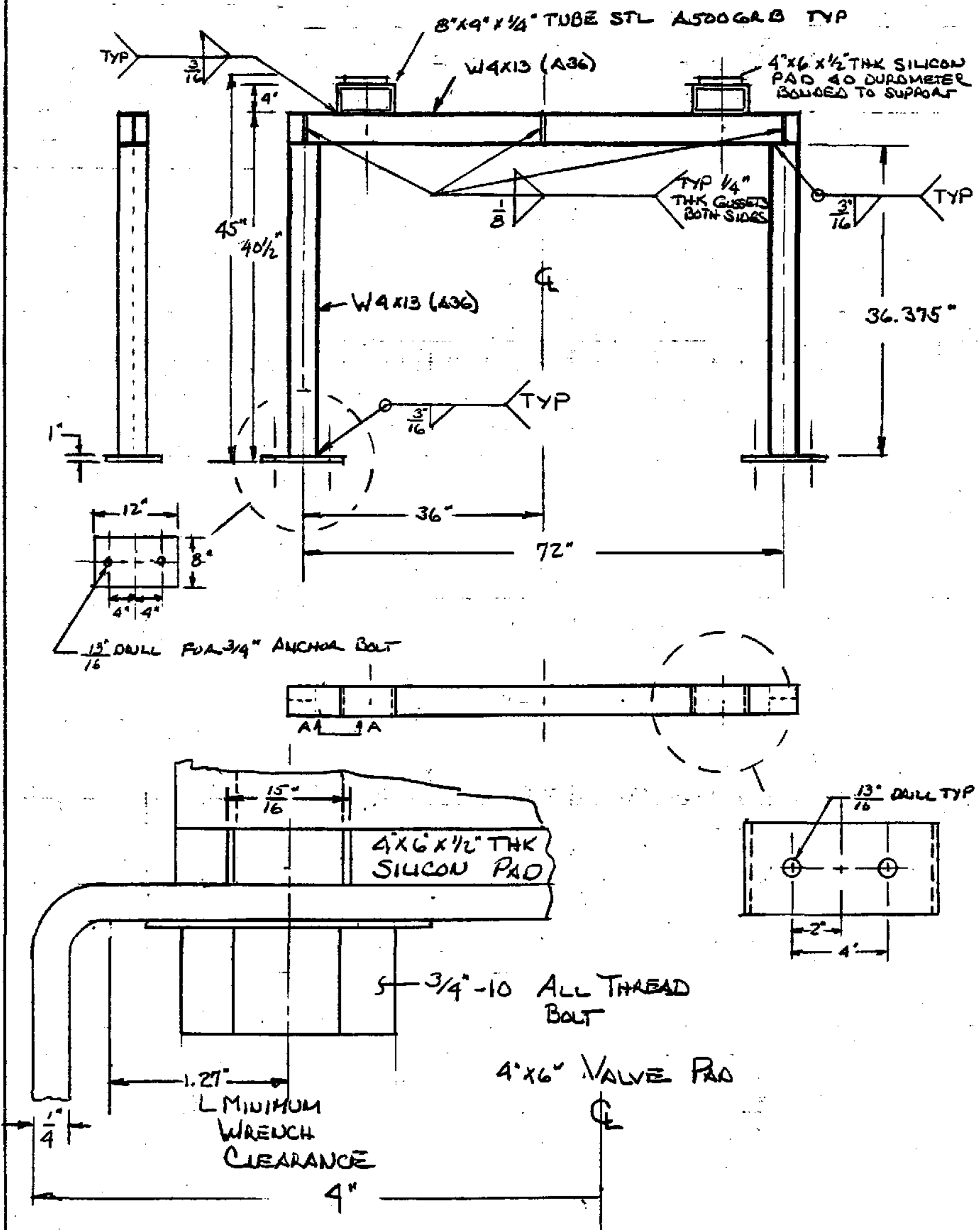
1. - DESIGN SKETCH 3
2. - DEADWEIGHT CALCS 4
3. - HORIZONTAL W4x13 BEAM SUPPORT 5
4. - VERTICAL W4x13 COLUMN SUPPORT 7
5. - ANCHOR BOLTS 9

1.0 -

DESIGN SKETCH
SK-V049-1-086, REV 0



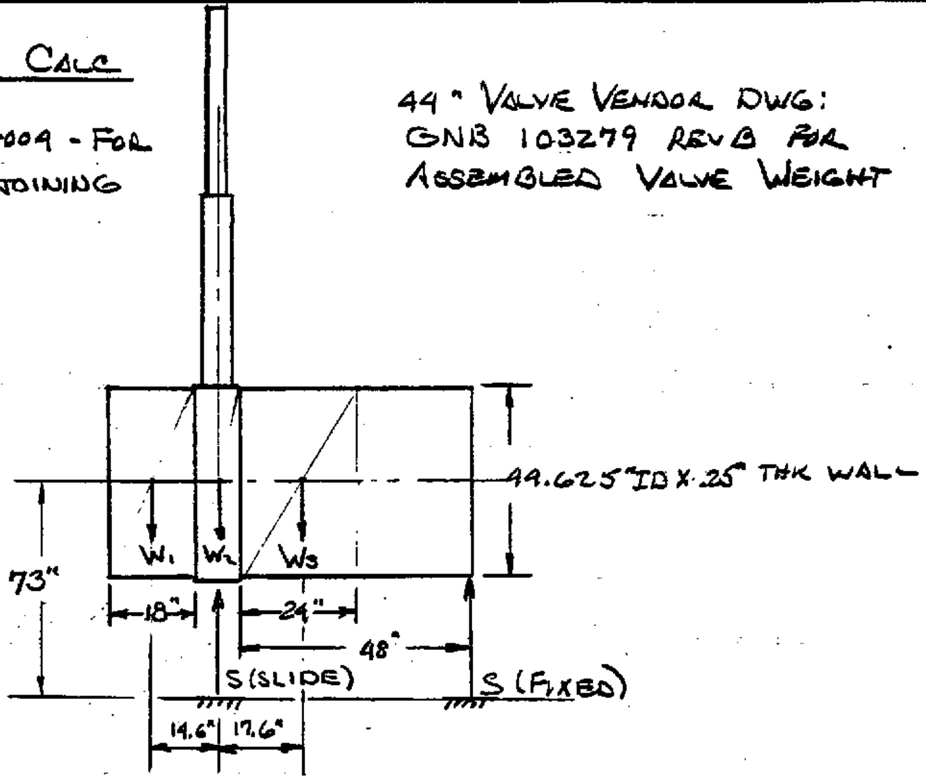
SECTION A-A

REV 0
Doc. No. V049-1-086
P. 3 OF 9

2.- DEADWEIGHT CALC

REF: DWG. V049-5-009 - FOR
WORSE CASE ADJOINING
TUBE LOADS

44" VALVE VENDOR DWG:
GNB 103279 REV B FOR
ASSEMBLED VALVE WEIGHT



$$W_1 = \pi/4\,(45.125^2 - 44.625^2)(18)(.283) = 180\#$$

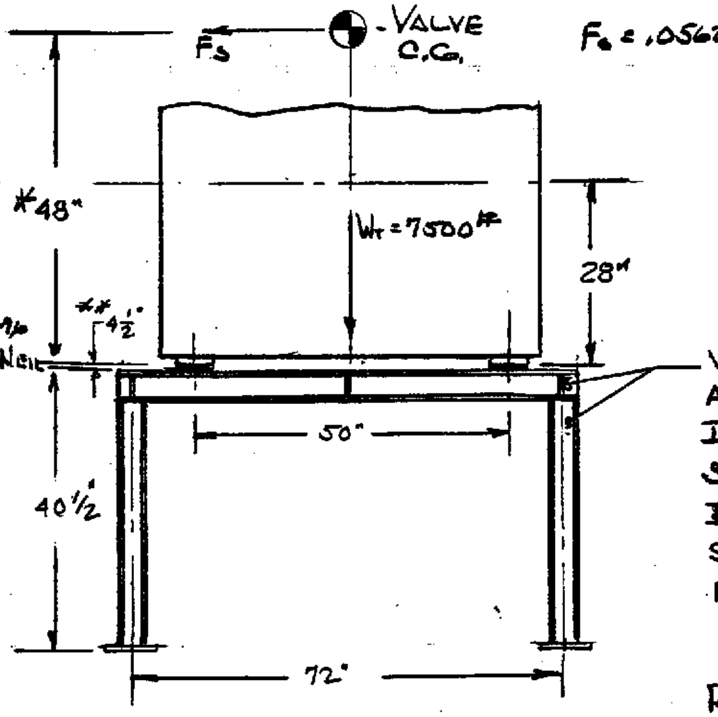
$$W_2 = 7000\#\ \text{(ASSEMBLED VALVE WEIGHT)}$$

$$W_3 = \pi/4\,(45.125^2 - 44.625^2)(24)(.283) = 239\#$$

$$\Sigma W = 180 + 7000 + 239 = 7{,}419\#$$

- USE 7500# FOR SUPPORT DESIGN

$F_s = .05625(7500) = 422\#$



* NOTE:
48" C.G. LOCATION
FOR 44" VALVE IS
PER TELECON ON 4-11-96
WITH GNP SHAWN McNEIL

** SEE DESIGN
SKETCH FOR ACTUAL
SUPPORT DETAIL

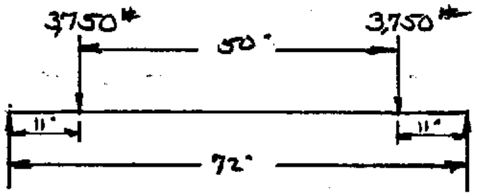
W4X13
$A = 3.83\ IN^2$
$I_x = 11.3\ IN^4$
$S_x = 5.46\ IN^3$
$I_y = 3.86\ IN^4$
$S_y = 1.9\ IN^3$
$r_y = 1.0\ IN$

REV O
DOC. NO. V049-1-086
P. 4 OF 9

3. – HORIZONTAL W4X13 BEAM SUPPORT

MODEL:

- DEADWEIGHT



REF: BLODGETT, CASE 3AC, P. 8.1-6

$M_{MAX} = 11(3750) = 41,250$ IN-#

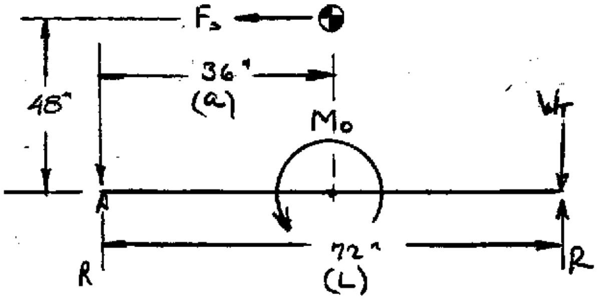
$\sigma_{MAX} = .6S_y = .6(36,000) = 21,600$ PSI

∴ $S_{REQ} = \dfrac{M_{MAX}}{\sigma_{MAX}} = \dfrac{41,250}{21,600} = 1.91$ IN³

$S_{ACTUAL} = 5.46$ IN³ > 1.91 IN³ ∴ OK

$\sigma_{ACTUAL} = \dfrac{41,250}{5.46} = 7,555$ PSI $= \sigma_{DW}$

- LATERAL SEISMIC



$M_o = 48(422) = 20,256$ IN-#

WHERE: $F_s = 422$#

$R = M_o/L = 20,256/72 = 281$#

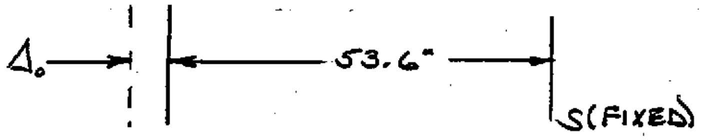
$W_T = 7419/2 - 281 = 3428$# (COMPRESSION)

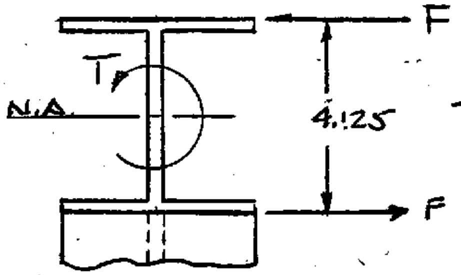
REF: BLODGETT, CASE 3Eb, P. 8.1-10.

$M_{MAX} = \dfrac{M_o a}{L} = \dfrac{(20,256)(36)}{(72)} = 10,128$ IN-#

$\sigma_{SEIS} = \dfrac{10128}{5.46} = 1,855$ PSI

- <u>TORSION DUE TO THERMAL EXPANSION LOADS</u>



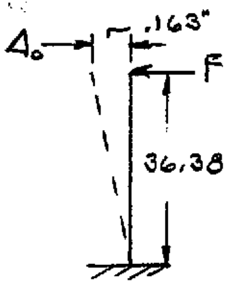


$T = 4.125 F_{TH} = 4.125(2274) = 9380 \text{ IN-\#}$

$$\Delta_o = \alpha L \Delta T = 9.19 \times 10^{-6} (53.6)(330) = .163''$$

WHERE: $\alpha = 9.19 \times 10^{-6}$ IN/IN/°F AT 400°F*

<u>MODEL:</u> - DEFLECTION DUE TO THERMAL MOVEMENT: .163"

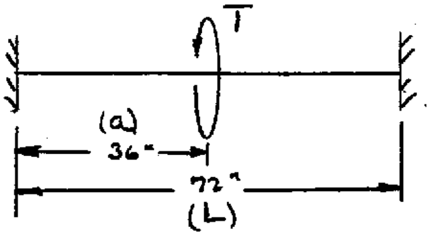


REF: BLODGETT, CASE 1Aa, P. 8.1-3

$$\Delta_o = \frac{FL^3}{3EI}$$

$$F_{TH} = \frac{3EI\Delta_o}{L^3} = \frac{3(29 \times 10^6)(2 \times 3.86)(.163)}{(36.38)^3} = 2274\ \#$$

<u>MODEL</u> - TORSIONAL STRESS



REF: BLODGETT, CASE 3, P. 8.2-1

$$\tau_T = \frac{Ta}{L} = \frac{9380(36)}{72} = 4690 \text{ PSI.}$$

- COMBINING STRESSES - FOR HORIZONTAL BEAM SUPPORT

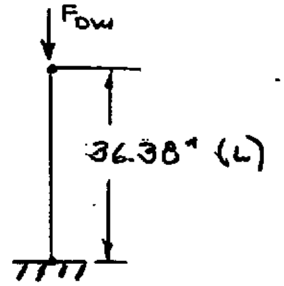
- BY SUPERPOSITION:

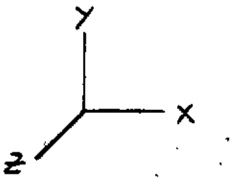
$\sigma = \sigma_{DW} + \sigma_{SEISMIC} = 7555 + 1855 = 9410 < .6S_y \therefore OK$

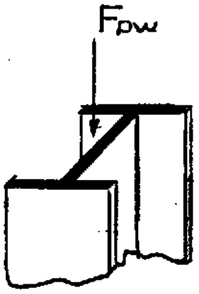
$\tau = 4{,}690\ PSI < .4S_y = 19{,}400\ PSI \therefore OK$

4.- VERTICAL W4x13 COLUMN SUPPORT

MODEL:







$$\frac{KL}{r} = \frac{(1.0)(36.38)}{1.0} = 36.38$$

A. - CON'T

- **AXIAL COMPRESSIVE STRESS**

$$\sigma_A = \frac{F_{DW}}{A} = \frac{7500}{2(3.83)} = 979 \text{ PSI} = f_a$$

- **ALLOWABLE COMPRESSIVE STRESS** REF: AISC, E2, P.5-42

$$\frac{KL}{r} = 36.38$$

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2(\pi^2)(29 \times 10^6)}{(36,000)}} = 126$$

$$KL/r < C_c$$

$$\therefore F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right]F_y}{\frac{5}{3} + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}}$$

$$F_a = \frac{\left[1 - \frac{(36.38)^2}{2(126)^2}\right](36,000)}{\frac{5}{3} + \frac{3(36.38)}{8(126)} - \frac{(36.38)^3}{8(126)^3}} = 19,470 \text{ PSI} > \sigma_A = 979 \text{ PSI}$$

$\therefore$ OK

5.- ANCHOR BOLTS.

- VERTICAL LOAD COMPRESSION ONLY ∴ SHEAR LOAD USED FOR 3/4" DIA ANCHOR BOLT DESIGN

- SHEAR LOAD:

- SEISMIC SHEAR = F_s = 422# (SEE P.5)

- THERMAL SHEAR = 1201#

TOTAL SHEAR = 422+1201 = 1623#

- SHEAR LOAD PER TWO(2) ANCHOR BOLTS:

$$\frac{1623}{2} = 812^{\#} < 4800^{\#}$$ FOR 3/4 HILTI HVA ∴ OK

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING
CALCULATIONS

NO:V049-1-010
PAGE 1 OF 2

REV.	DEO #	DATE	BY:	CHECK
1	0135	4/23/96	SM	D.mw

TITLE: Cooling Water System Heat Loads

BY: S.Motew

DEPT.:

PROJECT: LIGO

PROJECT NO: V59049

PURPOSE: Summary of cooling water requirements for LIGO project.

METHOD: Table

ASSUMPTIONS: Cooling water available pressure= 65.psig (5.5bar).temperature = 68.F(20C)

INPUTS: Vacuum pump and clean air compressor requirements.

REFERENCES: Edwards High Vacuum Inc.

CALCULATIONS: NA

CONCLUSIONS: See table

NOTES:Table will be updated with final clean air system cooling water requirements.

LIGOV4.WB1

PROJECT:LIGO

DATE:11/10/95 REV 1, 4/23/96

COOLING WATER SYSTEM HEAT LOADS

	INSTALLED		Q REJECTED		COOLING WATER		NO.	TOTAL C.WATER	
	KW	BTU/HR	KW	BTU/HR.	GPM	LPM		GPM	LPM
WA-CORNER:									
ROUGHING PUMP CART	22.5	76793	11.3	38396	3.8	14.5	2	7.7	29.1
MAIN TURBO CART	6.0	20478	3.6	12287	2.0	7.6	2	4.0	15.1
AUX.TURBO	0.8	2730	0.0	0	0.0	0.0	2	0.0	0.0
PURGE COMPRESSOR	44.8	152766	40.3	137489	13.7	52.0	1	13.7	52.0
	74.1	252767	55.1	188172	19.6	74.1		25.4	96.2
WA-MID									
MAIN TURBO CART	6.0	20478	3.6	12287	2.0	7.6	2	4.0	15.1
AUX.TURBO	0.8	2730	0.0	0	0.0	0.0	1	0.0	0.0
PURGE COMPRESSOR									
				12287	2.0	7.6		4.0	15.1
WA-END									
MAIN TURBO CART	6.0	20478	3.6	12287	2.0	7.6	2	4.0	15.1
AUX.TURBO	0.8	2730	0.0	0	0.0	0.0	1	0.0	0.0
PURGE COMPRESSOR									
				12287	2.0	7.6		4.0	15.1
LA-CORNER									
ROUGHING PUMP CART	22.5	76793	11.3	38396	3.8	14.5	2	7.7	29.1
MAIN TURBO CART	6.0	20478	3.6	12287	2.0	7.6	2	4.0	15.1
AUX.TURBO	0.8	2730	0.0	0	0.0	0.0	2	0.0	0.0
PURGE COMPRESSOR	44.8	152766	40.3	137489	13.7	52.0	1	13.7	52.0
	74.1	252767	55.1	188172	19.6	74.1		25.4	96.2
LA-END									
MAIN TURBO CART	6.0	20478	3.6	12287	2.0	7.6	2	4.0	15.1
AUX.TURBO	0.8	2730	0.0	0	0.0	0.0	1	0.0	0.0
PURGE COMPRESSOR									
				12287	2.0	7.6		4.0	15.1

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-034
PAGE 1 OF 15

REV	DEO#	DATE	BY:	CHECK
0	0042	01/05/96	R. Than	DMW
1	0126	04/12/96	R.Than	D.MW

TITLE:
COOLING WATER LINES SIZING
CORNER STATION
END / MID STATION

BY: R. THAN
DEPT: 744

PROJECT: LIGO
PROJECT NO: V59049

PURPOSE:
Determine cooling water lines / header sizes requirements

METHOD:
Turbulent flow: Cole brook formula, "Moody chart"
Laminar flow: Hagen-Poiseuille Flow

ASSUMPTIONS:

INPUTS: Budget 35 psi drop for equipment

Main flow from the cooling water system is provided in the mechanical room
Flow is distributed from the mechanical room to the interferometer room

REFERENCE:

CALCULATIONS:

see Attachments

CONCLUSIONS:
Corner stations: 3" Tube size Main supply into mechanical room, 1" or 1½" Tube header in Interferometer room. A 65 psid head is required from the cooling water system at the mechanical room battery limits
End / Mid stations: 1½" Tube size Main supply into mechanical room, 0.5" Tube header in Interferometer room.. A 65 psid head is required from the cooling water system at the mechanical room battery limits

NOTES:

PROJECT: LIGO BY: R.THAN DEPT: 744

PROJECT NO: V59049 DATE:

TITLE: COOLING WATER LINE SIZES PAGE : OF

CORNER STATION

TUBE SIZE	Flowrate GPM	Flowrate kg/s	ΔP Budget psid	ΔP Budget kPa	Header Velocity ft/s	Header Velocity m/s
3" Tube Mechanical Room Main Supply	50	3.12				
1" Tube Interferometer Room	8	0.50	17	117	3.2	0.98
Equipment Budget			35	69		
Margin			13	90		
Required from LIGO			**65**	**276**		

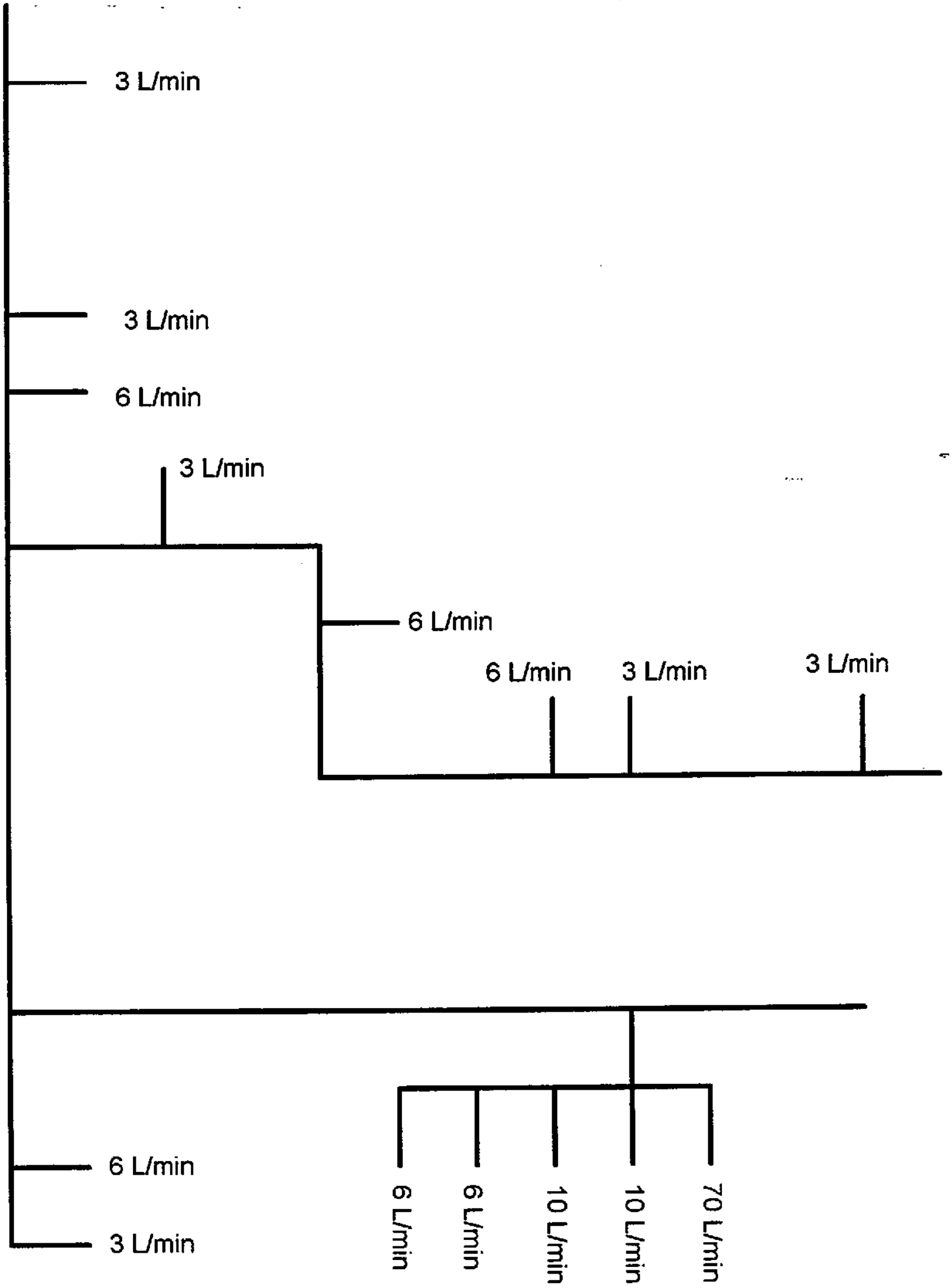
END/ MID STATIONS

TUBE SIZE	Flowrate GPM	Flowrate kg/s	ΔP Budget psi	ΔP Budget kPa	Header Velocity ft/s	Header Velocity m/s
1½" Tube Mechanical Room Main Supply	15	0.94				
½" Tube Interferometer Room	1.3	0.08	7	76	1.75	0.53
Equipment Budget			35	69		
Margin			23	158		
Required from LIGO			**65**	**276**		

PROJECT: LIGO BY: R.Than
PROJECT NO: V59049 4/12/96
TITLE: COOLING WATER LINES SIZING

COOLING WATER LINES					
CORNER STATION					
	Qty'	Each	Total		
Mechanical Room		L/min	L/min	GPM	kg/s
EDP200 Roughing cart	2	10	20	5.33	0.33
QDP80 Main Turbo backing Pump	2	6	12	3.20	0.20
Purge Compressor	1	70	70	18.67	1.17
			102	**27.20**	**1.70**
Design			***128***	***34.00***	***2.13***
Interferometer Room					
EH2600 Roughing Blower	2	6	12	3.20	0.20
STPH2000 Main Turbo	2	3	6	1.60	0.10
Aux Turbo cart	2	1	2	0.53	0.03
			20	**5.33**	**0.33**
Design			***25***	***6.67***	***0.42***
STATION TOTAL			**153**	**40.67**	**2.54**
END/MID STATION					
	Qty'	Each	Total		
Mechanical Room		L/min	L/min	GPM	kg/s
QDP80 Main Turbo backing Pump	1	6	6	1.60	0.10
Purge Compressor	1	35	35	9.33	0.58
			41	**10.93**	**0.68**
Design			***51***	***13.67***	***0.85***
Interferometer Room					
STPH2000 Main Turbo	1	3	3	0.80	0.05
Aux Turbo cart	1	1	1	0.27	0.02
			4	**1.07**	**0.07**
Design			***5***	***1.33***	***0.08***
STATION TOTAL			**56**	**15.00**	**0.94**

PROJECT: LIGO R.THAN
PROJECT NO: V59049 4/12/96
TITLE: COOLING WATER LINES SIZING



PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: COOLING WATER LINES SIZING COPPER TYPE L

BY: R. THAN
DATE: 4/12/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES CORNER STATION VACUUM EQUIPMENT ROOM

PRESSURE:	72.5 PSIA	57.810 PSIG
TEMPERATURE:	518.400 R	58.400 F
DENSITY :	62.390 LBS/FT^3	0.624E+02 LBS/FT^3
QUALITY :	1.000	

ITEMNAME	FLOWRATE Lbs/S	I.D. in	K / DO	CV	LENGTH FT	PRESSURE PSI	Z1 FT	Z2 FT	DP-F PSI	DP-Z PSI	DP-T PSI	DP-SUM PSI	DENSITY Lbs/ft^3	VELOCITY ft/S	RE NO
1.5" TUBE LENGTH	0.110E+01	1.5000			262.40	71.64	0.00	0.00	0.86	0.00	0.86	0.86	0.624E+02	1.439	0.168E+05
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			71.622	0.00	0.00	0.01	0.00	0.01	0.88	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			71.608	0.00	0.00	0.01	0.00	0.01	0.89	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			71.594	0.00	0.00	0.01	0.00	0.01	0.91	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			71.580	0.00	0.00	0.01	0.00	0.01	0.92	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			71.566	0.00	0.00	0.01	0.00	0.01	0.93	0.624E+02		
1/2" TUBE	0.275E+00	0.5450			32.80	70.30	0.00	0.00	1.27	0.00	1.27	2.20	0.624E+02	2.726	0.115E+05
1/2" ELBOW LR-90	0.275E+00	0.5450	3.0000			70.148	0.00	0.00	0.15	0.00	0.15	2.35	0.624E+02		
EQUIPMENT DP	0.275E+00	0.5450				35.145	0.00	0.00	35.00	0.00	35.00	37.35	0.624E+02		
1/2" ELBOW LR-90	0.275E+00	0.5450	3.0000			34.995	0.00	0.00	0.15	0.00	0.15	37.50	0.624E+02		
1/2" TUBE .035WT	0.275E+00	0.5450			32.80	33.73	0.00	0.00	1.27	0.00	1.27	38.77	0.624E+02	2.726	0.115E+05
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			33.714	0.00	0.00	0.01	0.00	0.01	38.79	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			33.700	0.00	0.00	0.01	0.00	0.01	38.80	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			33.686	0.00	0.00	0.01	0.00	0.01	38.81	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			33.672	0.00	0.00	0.01	0.00	0.01	38.83	0.624E+02		
1.5" ELBOW LR-90	0.110E+01	1.5000	1.0000			33.658	0.00	0.00	0.01	0.00	0.01	38.84	0.624E+02		
1.5" TUBE LENGTH	0.110E+01	1.5000			262.40	32.79	0.00	0.00	0.86	0.00	0.86	39.71	0.624E+02	1.439	0.168E+05
								TOTAL	39.7061	0.0000		39.7061			

REVISION: 0
DOC NO: V049-1-034
PAGE: 5 OF 15

PROCESS SYSTEMS INTERNATIONAL, INC 20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: COOLING WATER LINES SIZING COPPER TYPE L

BY: R. THAN
DATE: 4/12/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES CORNER STATION VACUUM EQUIPMENT ROOM

PRESSURE: 72.5 PSIA 57.810 PSIG
TEMPERATURE: 518.400 R 58.400 F
DENSITY : 62.390 LBS/FT^3 0.624E+02 LBS/FT^3
QUALITY : 1.000

ITEMNAME	FLOWRATE Lbs/S	I.D. in	K / DO	CV	LENGTH FT	PRESSURE PSI	Z1 FT	Z2 FT	DP-F PSI	DP-Z PSI	DP-T PSI	DP-SUM PSI	DENSITY Lbs/ft^3	VELOCITY ft/S	RE NO
1" TUBE LENGTH	0.110E+01	1.0000			262.40	66.11	0.00	0.00	6.39	0.00	6.39	6.39	0.624E+02	3.239	0.252E+05
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			66.041	0.00	0.00	0.07	0.00	0.07	6.46	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			65.970	0.00	0.00	0.07	0.00	0.07	6.53	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			65.899	0.00	0.00	0.07	0.00	0.07	6.60	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			65.829	0.00	0.00	0.07	0.00	0.07	6.67	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			65.758	0.00	0.00	0.07	0.00	0.07	6.74	0.624E+02		
1/2" TUBE .035WT	0.275E+00	0.5450			32.80	64.49	0.00	0.00	1.27	0.00	1.27	8.01	0.624E+02	2.726	0.115E+05
1/2" ELBOW LR-90	0.275E+00	0.5450	3.0000			64.340	0.00	0.00	0.15	0.00	0.15	8.16	0.624E+02		
EQUIPMENT DP	0.275E+00	0.5450				29.337	0.00	0.00	35.00	0.00	35.00	43.16	0.624E+02		
1/2" ELBOW LR-90	0.275E+00	0.5450	3.0000			29.187	0.00	0.00	0.15	0.00	0.15	43.31	0.624E+02		
1/2" TUBE .035WT	0.275E+00	0.5450			32.80	27.92	0.00	0.00	1.27	0.00	1.27	44.58	0.624E+02	2.726	0.115E+05
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			27.849	0.00	0.00	0.07	0.00	0.07	44.65	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			27.778	0.00	0.00	0.07	0.00	0.07	44.72	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			27.708	0.00	0.00	0.07	0.00	0.07	44.79	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			27.637	0.00	0.00	0.07	0.00	0.07	44.86	0.624E+02		
1" ELBOW LR-90	0.110E+01	1.0000	1.0000			27.566	0.00	0.00	0.07	0.00	0.07	44.93	0.624E+02		
1" TUBE LENGTH	0.110E+01	1.0000			262.40	21.18	0.00	0.00	6.39	0.00	6.39	51.32	0.624E+02	3.239	0.252E+05
								TOTAL	51.3223	0.0000		51.3223			

PROCESS SYSTEMS INTERNATIONAL, INC   20 Walkup Drive, Westborough, MA 01581

PROJECT: LIGO
PROJECT NO:V59049
TITLE: COOLING WATER LINES SIZING

BY: R. THAN
DATE: 4/12/**
PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES CORNER STATION CLEAN AIR COMPRESSOR

PRESSURE: 72.5 PSIA 57.810 PSIG
TEMPERATURE: 518.400 R 58.400 F
DENSITY : 62.390 LBS/FT^3 0.624E+02 LBS/FT^3
QUALITY : 1.000

ITEMNAME	FLOWRATE Lbs/S	I.D. in	K / DO	CV	LENGTH FT	PRESSURE PSI	Z1 FT	Z2 FT	DP-F PSI	DP-Z PSI	DP-T PSI	DP-SUM PSI	DENSITY Lbs/ft^3	VELOCITY ft/S	RE NO
1.5" TUBE LENGTH	0.264E+01	1.5000			65.60	71.42	0.00	0.00	1.08	0.00	1.08	1.08	0.624E+02	3.454	0.402E+05
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			71.342	0.00	0.00	0.08	0.00	0.08	1.16	0.624E+02		
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			71.261	0.00	0.00	0.08	0.00	0.08	1.24	0.624E+02		
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			71.181	0.00	0.00	0.08	0.00	0.08	1.32	0.624E+02		
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			71.101	0.00	0.00	0.08	0.00	0.08	1.40	0.624E+02		
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			71.020	0.00	0.00	0.08	0.00	0.08	1.48	0.624E+02		
1.5" ELBOW LR-90	0.264E+01	1.5000	1.0000			70.940	0.00	0.00	0.08	0.00	0.08	1.56	0.624E+02		
								TOTAL	1.5601	0.0000		1.5601			

REVISION: 0
DOC NO: V049-1-034
PAGE: 7 OF 15

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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                                  BY: R. THAN
 PROJECT NO:V59049                                                DATE: 4/12/**
 TITLE:     COOLING WATER LINES SIZING                            PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES CORNER STATION CLEAN AIR COMPRESSOR

 PRESSURE:         72.5 PSIA          57.810 PSIG
 TEMPERATURE:   518.400 R           58.400 F
 DENSITY :        62.390 LBS/FT^3      0.624E+02 LBS/FT^3
 QUALITY :         1.000

ITEMNAME              FLOWRATE   I.D.       K / DO    CV      LENGTH   PRESSURE  Z1       Z2       DP-F     DP-Z     DP-T     DP-SUM  DENSITY VELOCITY RE NO
                           Lbs/S  in                           FT       PSI      FT       FT       PSI      PSI      PSI      PSI     Lbs/ft^3   ft/S

1" TUBE LENGTH       0.264E+01   1.0000                        65.60    64.18     0.00     0.00     8.32     0.00     8.32     8.32 0.624E+02     7.773 0.604E+05
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      63.772     0.00     0.00     0.41     0.00     0.41     8.73 0.624E+02
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      63.365     0.00     0.00     0.41     0.00     0.41     9.13 0.624E+02
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      62.958     0.00     0.00     0.41     0.00     0.41     9.54 0.624E+02
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      62.551     0.00     0.00     0.41     0.00     0.41     9.95 0.624E+02
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      62.145     0.00     0.00     0.41     0.00     0.41    10.36 0.624E+02
1" ELBOW LR-90       0.264E+01   1.0000    1.0000                      61.738     0.00     0.00     0.41     0.00     0.41    10.76 0.624E+02

                                                                        TOTAL           10.7623   0.0000             10.7623
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REVISION: 0
DOC NO: V049-1-034
PAGE: 8 OF 15

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PROCESS SYSTEMS INTERNATIONAL, INC    20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                          BY: R. THAN
 PROJECT NO:V59049                                        DATE: 4/12/**
 TITLE:     COOLING WATER LINES SIZING                    PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES CORNER STATION MECHANICAL ROOM MAIN

 PRESSURE:         72.5 PSIA           57.810 PSIG
 TEMPERATURE:   518.400 R            58.400 F
 DENSITY :       62.390 LBS/FT^3       0.624E+02 LBS/FT^3
 QUALITY :        1.000

ITEMNAME               FLOWRATE   I.D.       K / DO     CV        LENGTH    PRESSURE  Z1        Z2        DP-F      DP-Z      DP-T      DP-SUM   DENSITY VELOCITY RE NO
                          Lbs/S   in                              FT        PSI       FT        FT        PSI       PSI       PSI       PSI      Lbs/ft^3   ft/S

3" TUBE LENGTH        0.559E+01   3.0000                          656.00    71.10      0.00      0.00      1.40      0.00      1.40      1.40 0.624E+02    1.828 0.426E+05

                                                                                      TOTAL               1.3968    0.0000              1.3968
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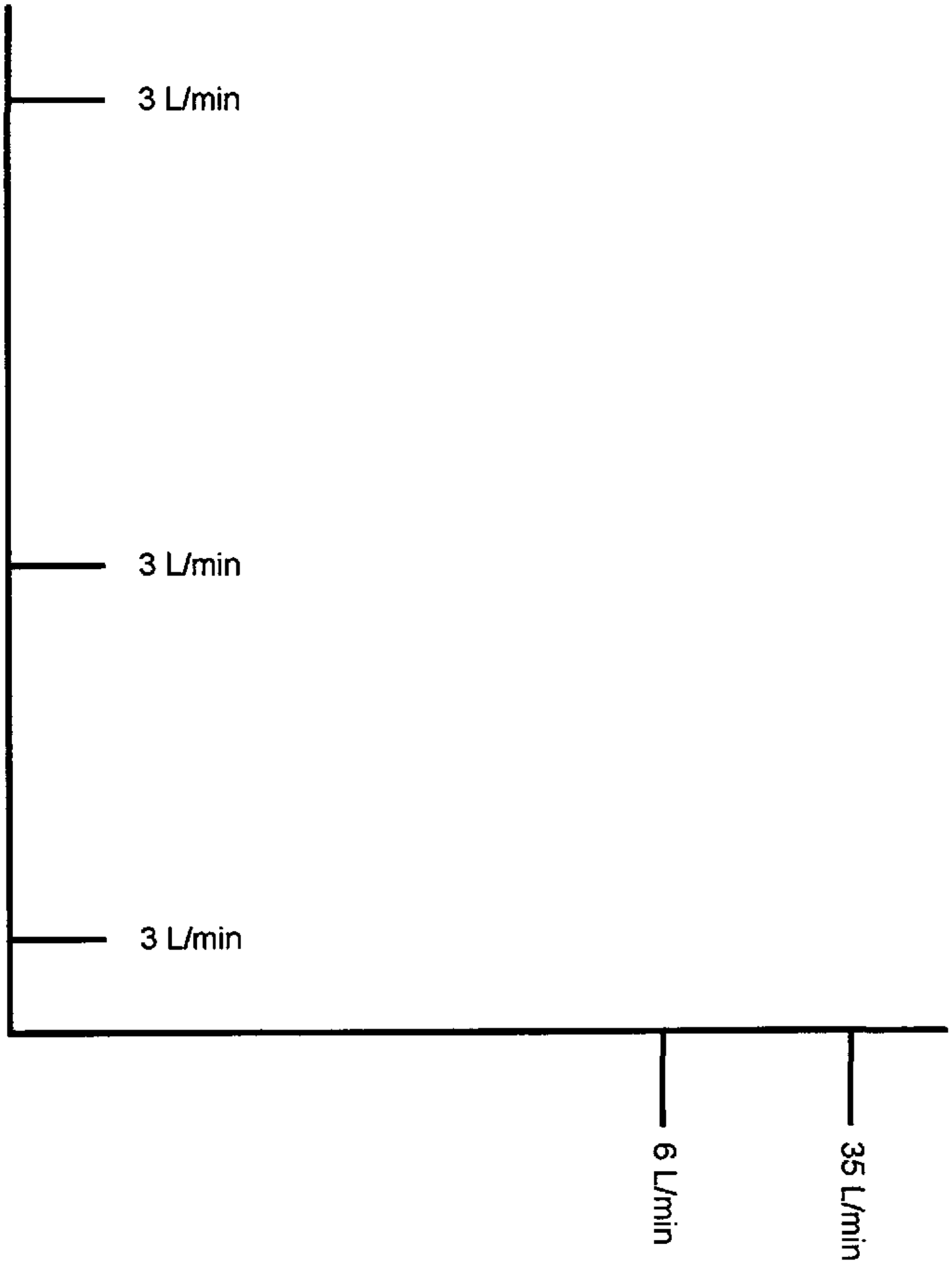
PROJECT: LIGO R.THAN
PROJECT NO: V59049 4/12/96
TITLE: COOLING WATER LINES SIZING



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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                            BY: R. THAN
 PROJECT NO:V59049                                          DATE: 4/12/**
 TITLE:     COOLING WATER LINES SIZING  COPPER TYPE L       PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES END/MID STATION

 PRESSURE:        72.5 PSIA          57.810 PSIG
 TEMPERATURE:   518.400 R          58.400 F
 DENSITY :       62.390 LBS/FT^3       0.624E+02 LBS/FT^3
 QUALITY :         1.000

ITEMNAME              FLOWRATE  I.D.     K / DO    CV      LENGTH  PRESSURE  Z1       Z2       DP-F     DP-Z     DP-T     DP-SUM  DENSITY VELOCITY RE NO
                         Lbs/S  in                         FT      PSI       FT       FT       PSI      PSI      PSI      PSI     Lbs/ft^3   ft/S

1/2" TUBE LENGTH     0.220E+00  0.5450                     164.00    68.29     0.00     0.00     4.21     0.00     4.21     4.21 0.624E+02      2.181 0.923E+04
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      68.190    0.00     0.00     0.10     0.00     0.10     4.31 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      68.094    0.00     0.00     0.10     0.00     0.10     4.41 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      67.998    0.00     0.00     0.10     0.00     0.10     4.50 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      67.902    0.00     0.00     0.10     0.00     0.10     4.60 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      67.806    0.00     0.00     0.10     0.00     0.10     4.69 0.624E+02
1/2" TUBE .035WT     0.220E+00  0.5450                      16.40    67.38     0.00     0.00     0.42     0.00     0.42     5.12 0.624E+02      2.181 0.923E+04
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      67.288    0.00     0.00     0.10     0.00     0.10     5.21 0.624E+02
EQUIPMENT DP         0.220E+00  0.5450                               32.285    0.00     0.00    35.00     0.00    35.00    40.21 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      32.189    0.00     0.00     0.10     0.00     0.10    40.31 0.624E+02
1/2" TUBE .035WT     0.220E+00  0.5450                      16.40    31.77     0.00     0.00     0.42     0.00     0.42    40.73 0.624E+02      2.181 0.923E+04
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      31.672    0.00     0.00     0.10     0.00     0.10    40.83 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      31.576    0.00     0.00     0.10     0.00     0.10    40.92 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      31.480    0.00     0.00     0.10     0.00     0.10    41.02 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      31.383    0.00     0.00     0.10     0.00     0.10    41.12 0.624E+02
1/2" ELBOW LR-90     0.220E+00  0.5450   3.0000                      31.287    0.00     0.00     0.10     0.00     0.10    41.21 0.624E+02
1/2" TUBE LENGTH     0.220E+00  0.5450                     164.00    27.07     0.00     0.00     4.21     0.00     4.21    45.43 0.624E+02      2.181 0.923E+04

                                                                                   TOTAL      45.4265   0.0000           45.4265
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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                                BY: R. THAN
 PROJECT NO:V59049                                              DATE: 4/12/**
 TITLE:     COOLING WATER LINES SIZING  COPPER TYPE L           PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES END/MID STATION

 PRESSURE:        72.5 PSIA          57.810 PSIG
 TEMPERATURE:   518.400 R          58.400 F
 DENSITY :       62.390 LBS/FT^3      0.624E+02 LBS/FT^3
 QUALITY :        1.000

ITEMNAME              FLOWRATE  I.D.      K / DO     CV      LENGTH   PRESSURE  Z1       Z2       DP-F     DP-Z     DP-T     DP-SUM   DENSITY VELOCITY RE NO
                         Lbs/S  in                           FT        PSI      FT       FT       PSI      PSI      PSI      PSI      Lbs/ft^3  ft/S

1/2" TUBE LENGTH     0.176E+00  0.5450                       164.00     69.69     0.00     0.00     2.81     0.00     2.81     2.81 0.624E+02    1.745 0.739E+04
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        69.626    0.00     0.00     0.06     0.00     0.06     2.87 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        69.565    0.00     0.00     0.06     0.00     0.06     2.94 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        69.503    0.00     0.00     0.06     0.00     0.06     3.00 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        69.442    0.00     0.00     0.06     0.00     0.06     3.06 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        69.380    0.00     0.00     0.06     0.00     0.06     3.12 0.624E+02
1/2" TUBE .035WT     0.110E+00  0.5450                        16.40     69.26     0.00     0.00     0.12     0.00     0.12     3.24 0.624E+02    1.090 0.462E+04
1/2" ELBOW LR-90     0.110E+00  0.5450    3.0000                        69.235    0.00     0.00     0.02     0.00     0.02     3.27 0.624E+02
EQUIPMENT DP         0.110E+00  0.5450                                  34.232    0.00     0.00    35.00     0.00    35.00    38.27 0.624E+02
1/2" ELBOW LR-90     0.110E+00  0.5450    3.0000                        34.208    0.00     0.00     0.02     0.00     0.02    38.29 0.624E+02
1/2" TUBE .035WT     0.110E+00  0.5450                        16.40     34.09     0.00     0.00     0.12     0.00     0.12    38.41 0.624E+02    1.090 0.462E+04
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        34.025    0.00     0.00     0.06     0.00     0.06    38.47 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        33.964    0.00     0.00     0.06     0.00     0.06    38.54 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        33.902    0.00     0.00     0.06     0.00     0.06    38.60 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        33.841    0.00     0.00     0.06     0.00     0.06    38.66 0.624E+02
1/2" ELBOW LR-90     0.176E+00  0.5450    3.0000                        33.779    0.00     0.00     0.06     0.00     0.06    38.72 0.624E+02
1/2" TUBE LENGTH     0.176E+00  0.5450                       164.00     30.97     0.00     0.00     2.81     0.00     2.81    41.53 0.624E+02    1.745 0.739E+04


                                                                                 TOTAL         41.5330  0.0000             41.5330
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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                            BY: R. THAN
 PROJECT NO:V59049                                          DATE: 4/12/**
 TITLE:     COOLING WATER LINES SIZING  COPPER TYPE L       PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES END/MID STATION

 PRESSURE:        72.5 PSIA          57.810 PSIG
 TEMPERATURE:   518.400 R          58.400 F
 DENSITY :        62.390 LBS/FT^3        0.624E+02 LBS/FT^3
 QUALITY :         1.000

ITEMNAME               FLOWRATE   I.D.      K / DO     CV       LENGTH    PRESSURE  Z1        Z2        DP-F      DP-Z      DP-T      DP-SUM   DENSITY VELOCITY RE NO
                          Lbs/S   in                            FT         PSI      FT        FT        PSI       PSI       PSI       PSI      Lbs/ft^3 .  ft/S

3/4" TUBE LENGTH      0.176E+00   0.7800                        164.00     72.01     0.00      0.00      0.49      0.00      0.49      0.49 0.624E+02     0.852 0.516E+04
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         71.995    0.00      0.00      0.01      0.00      0.01      0.51 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         71.980    0.00      0.00      0.01      0.00      0.01      0.52 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         71.965    0.00      0.00      0.01      0.00      0.01      0.53 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         71.951    0.00      0.00      0.01      0.00      0.01      0.55 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         71.936    0.00      0.00      0.01      0.00      0.01      0.56 0.624E+02
1/2" TUBE .035WT      0.110E+00   0.5450                         16.40     71.81     0.00      0.00      0.12      0.00      0.12      0.69 0.624E+02     1.090 0.462E+04
1/2" ELBOW LR-90      0.110E+00   0.5450    3.0000                         71.790    0.00      0.00      0.02      0.00      0.02      0.71 0.624E+02
EQUIPMENT DP          0.110E+00   0.5450                                   36.787    0.00      0.00     35.00      0.00     35.00     35.71 0.624E+02
1/2" ELBOW LR-90      0.110E+00   0.5450    3.0000                         36.763    0.00      0.00      0.02      0.00      0.02     35.74 0.624E+02
1/2" TUBE .035WT      0.110E+00   0.5450                         16.40     36.64     0.00      0.00      0.12      0.00      0.12     35.86 0.624E+02     1.090 0.462E+04
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         36.627    0.00      0.00      0.01      0.00      0.01     35.87 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         36.613    0.00      0.00      0.01      0.00      0.01     35.89 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         36.598    0.00      0.00      0.01      0.00      0.01     35.90 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         36.583    0.00      0.00      0.01      0.00      0.01     35.92 0.624E+02
3/4" ELBOW LR-90      0.176E+00   0.7800    3.0000                         36.569    0.00      0.00      0.01      0.00      0.01     35.93 0.624E+02
3/4" TUBE LENGTH      0.176E+00   0.7800                        164.00     36.08     0.00      0.00      0.49      0.00      0.49     36.42 0.624E+02     0.852 0.516E+04


                                                                                   TOTAL             36.4221    0.0000              36.4221
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PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:    LIGO                                                  BY: R. THAN
 PROJECT NO:V59049                                                 DATE: 4/12/**
 TITLE:      COOLING WATER LINES SIZING  COPPER TYPE L             PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:COOLING WATER LINES END/MID STATION

 PRESSURE:        72.5 PSIA            57.810 PSIG
 TEMPERATURE:   518.400 R            58.400 F
 DENSITY :       62.390 LBS/FT^3       0.624E+02 LBS/FT^3
 QUALITY :        1.000

ITEMNAME              FLOWRATE  I.D.      K / DO     CV        LENGTH   PRESSURE  Z1        Z2        DP-F      DP-Z      DP-T      DP-SUM   DENSITY VELOCITY RE NO
                          Lbs/S  in                             FT        PSI     FT        FT        PSI       PSI       PSI       PSI      Lbs/ft^3  ft/S

1" TUBE LENGTH       0.132E+01  1.0000                          65.60     70.26     0.00      0.00      2.24      0.00      2.24      2.24 0.624E+02    3.886 0.302E+05

                                                                                  TOTAL          2.2430    0.0000              2.2430
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CLEAN AIR.
COMPRESSOR

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Copper Water Tube/engineering data

				TYPE "K"						TYPE "L"					
				Hard Drawn—20 Ft. Straight Lengths Soft Annealed—20 Ft. Straight Lengths or 40 Ft. and 60 Ft. Length Coils (to and including 1⅛")						Hard Drawn—20 Ft. Straight Lengths Soft Annealed—20 Ft. Straight Lengths or 40 Ft. and 60 Ft. Length Coils (to and including 1⅛")					
				Use: For Underground Service and General Plumbing and Heating Installations under Severe Conditions.						Use: For General Plumbing and Heating Installations.					
						HARD DRAWN		SOFT ANNEALED				HARD DRAWN		SOFT ANNEALED	
Nominal Tube Size in inches	Outside Diameter in inches	TOLERANCE Tubing O. D. in inches		Nom. Wall Thickness in inches	Weight per Foot in Lbs.	Bursting Pressure in Lbs. *	Safe Working Stress in Lbs. § ●	Bursting Pressure in Lbs. *	Safe Working Stress in Lbs. ☆ ●	Nom. Wall Thickness in inches	Weight per Foot in Lbs.	Bursting Pressure in Lbs. *	Safe Working Stress in Lbs. § ●	Bursting Pressure in Lbs. *	Safe Working Stress in Lbs. ☆ ●
		Max.	Min.												
¼"	.375	.376	.374	.035	.145	6720	1060	5600	930	.030	.126	5760	900	4800	800
⅜"	.500	.501	.499	.049	.269	7100	1170	5900	980	.035	.198	5000	800	4200	700
½"	.625	.626	.624	.049	.344	5600	920	4700	780	.040	.285	4600	740	3800	630
⅝"	.750	.751	.749	.049	.418	4700	760	3900	650	.042	.362	4000	650	3400	560
¾"	.875	.876	.874	.065	.641	5300	880	4500	750	.045	.455	3700	590	3100	510
1"	1.125	1.1265	1.1235	.065	.839	4200	680	3500	580	.050	.655	3200	510	2700	450
1¼"	1.375	1.3765	1.3735	.065	1.04	3400	550	2800	465	.055	.884	2900	460	2400	400
1½"	1.625	1.627	1.623	.072	1.36	3200	520	2700	450	.060	1.14	2700	430	2200	360
2"	2.125	2.127	2.123	.083	2.06	2800	450	2300	380	.070	1.75	2400	370	2000	330
2½"	2.625	2.627	2.623	.095	2.93	2600	420	2200	360	.080	2.48	2220	350	1800	300
3"	3.125	3.127	3.123	.109	4.00	2500	410	2100	350	.090	3.33	2100	330	1700	280
3½"	3.625	3.627	3.623	.120	5.12	2400	380	2000	330	.100	4.29	2000	320	1700	280
4"	4.125	4.127	4.123	.134	6.51	2300	370	1900	320	.110	5.38	1900	300	1600	260
5"	5.125	5.127	5.123	.160	9.67	2200	360	1900	320	.125	7.61	1800	280	1500	250
6"	6.125	6.127	6.123	.192	13.87	2300	370	1900	320	.140	10.20	1600	260	1400	230
8"	8.125	8.127	8.121	.271	25.90	2400	390	2000	330	.200	19.29	1800	280	1500	250
10"	10.125	10.127	10.119	.338	40.3	2400	390	2000	330	.250	30.1	1800	290	1500	250
12"	12.125	12.127	12.119	.405	57.8	2400	400	2000	330	.280	40.4	1700	270	1400	230

ID

1.025

1.505

Note: Information and data contained in these charts as taken from ASTM Specifications No. B-88, Federal Specification WW-T-799, and various Copper Tube Mill chart standards.

§ From Cabra based on 150°F. with an allowable stress of 6000 P.S.I.

* Bursting pressures are calculated from the following Formula for thin, hollow cylinders under tension:

$$P = \frac{2tS}{D}$$

Where P = Bursting pressure, Lb. per Sq. In.
t = Wall thickness, Inches
D = Outside tube diameter, Inches
S = Tensile strength (36,000 Lb. per Sq. In. for hard tubes and 30,000 for soft tubes)

☆ With safety factor of 6, maximum safe working pressure allowable by common usage up to 150°F. can be taken at 1/6 the above bursting pressure

● Rated internal pressure for copper water tube based on the strength of the tube alone and applicable to systems using suitable mechanical joints.

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LIGO Vacuum Equipment Instrument Air Requirements

Preliminary Instrument Air Requirements D. A. McWilliams
Reference: P&ID V049-0-001 Rev 0 Feb 1,1996
Supply Pressure: 80 to 120 psig
Dewpoint - 60 C

		Air Consumption (SCFM)		
		Continuous	Intermittent (5 minute duration)	Peak
Corner Stations				
WA	LA			
80 K Pumps				
WCP1	LCP1	1.5		
WCP2	LCP2	1.5		
Gate Valves				
WGV5	LGV3		0.6	
WGV6	LGV4		0.6	
WGV7	LGV5		0.6	
WGV8	LGV6		0.6	
Roughing Carts				
WRC1	LRC1	0.7	0.6	
WRC2	LRC2	0.7	0.6	
Turbo Carts				
WTC1	LTC1	0.7	0.6	
WTC2	LTC2	0.7	0.6	
Station Total		**5.8**	**4.8**	**10.6**
WA Midstations				
80 K Pumps				
WCP3 or 5		1.5		
WCP4 or 6		1.5		
Turbo Carts				
WTC3 or 4		0.7	0.6	
Station Total		**3.7**	**0.6**	**4.3**
End Stations				
WA	LA			
80 K Pumps				
WCP7 or 8	LCP3 or 4	1.5		
Turbo Carts		1.5		
WTC5 or 6	LTC3 or 4	0.7	0.6	
Station Total		**3.7**	**0.6**	**4.3**

Table 3-1: VE Power Required[a] at Load Centers
Corner Station

Prepared By: RW **Date:** 4-26-96
Approved By: FAB **Date:** 4-26-96

Voltage	*208Y/120V, 3φ*							*480Y/277V, 3φ*						
Location[b]	*# C[c]*	*φ*	*KVA[d]*	*CB (A)*	*# R[e]*	*Recepticle (NEMA)*	*nominal use*	*# C*	*φ*	*KVA*	*CB (A)*	*# R*	*Recepticle[f] (NEMA)*	*nominal use*
VEAC-01	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-02	1	3	2.0	30		L21-60R	Turbo Pump	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1					L22-60R	
VEAC-03	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
								1	3	39.9	60		L22-60R	
VEAC-04	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
								1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-05	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	20.0	30		Direct	Regen Heater
VEAC-06	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	3	2.0	30		L21-60R	Turbo Pumps	1	3	20.0	30		Direct	Regen Heater
VEAC-07	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room

Table 3-1: VE Power Required[a] at Load Centers
Corner Station

Voltage	*208Y/120V, 3φ*							*480Y/277V, 3φ*						
Location b	***# C[c]***	***φ***	***KVA d***	***CB (A)***	***# R[e]***	***Recepticle (NEMA)***	***nominal use***	***# C***	***φ***	***KVA***	***CB (A)***	***# R***	***Recepticle[f] (NEMA)***	***nominal use***
VEAC-08	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
								1	3	7.5	20		L22-60R	Roughing Pump
VEAC-09	1	3	2.0	30		L21-60R	Turbo Pump	1	3	7.5	20		L22-60R	Roughing Pump
	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	39.9	60		L22-60R	Bakeout/Clean Room
			2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
			2.9	30		L5-30R	Bakeout Control	1	3	13.3	20		Direct	Gate Valve
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	13.3	20		Direct	Gate Valve
VEAC-10	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-11	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
								1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-12	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	3	2.0	30		L21-60R	Turbo Pumps	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	7.5	20		L22-60R	Roughing Pump
								1	3	13.3	20		Direct	Gate Valve
								1	3	7.5	20		L22-60R	Roughing Pump
VEAC-13	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room

Table 3-1: VE Power Required[a] at Load Centers

Corner Station

Voltage	*208Y/120V, 3φ*							*480Y/277V, 3φ*						
Location b	*# C[c]*	*φ*	*KVA d*	*CB (A)*	*# R e*	*Recepticle (NEMA)*	*nominal use*	*# C*	*φ*	*KVA*	*CB (A)*	*# R*	*Recepticle[f] (NEMA)*	*nominal use*
VEAC-14	1	1	2.9	30		L5-30 R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	13.3	20		Direct	Gate Valve
								1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-15	1	1	1.9	20		Direct	VE Control Xformer							
VEAC-16	1	1	1.9	20		Direct	VE Control Xformer							
VEAC-17	1	1	1.9	20		L5-20R	ION Pump	1	3	61.0	175		Direct	Air Compressor
	1	1	1.9	20		5-20R	ION Pump	1	3	15.0	40		Direct	Rough Backing
	1	1	1.9	20		5-20R	ION Pump	1	3	15.0	40		Direct	Rough Backing
	1	1	1.9	20		5-20R	ION Pump							
	1	1	1.9	20		5-20R	ION Pump							
	1	1	1.9	20		5-20R	ION Pump							
	1	1	1.9	20		5-20R	ION Pump							
	1	1	1.9	20		5-20R	ION Pump							
	1	1	1.9	20		Direct	VE Control Xformer							
	1	3	4.0	30		L15-30R	Turbo Backing							
	1	3	4.0	30		L15-30R	Turbo Backing							

Mid Station

Table 3-1: VE Power Required[a] at Load Centers

Voltage	*208Y/120V, 3φ*							*480Y/277V, 3φ*						
Location **[b]**	***# C***[c]	***φ***	***KVA*** **[d]**	***CB (A)***	***# R*** [e]	***Recepticle (NEMA)***	***nominal use***	***# C***	***φ***	***KVA***	***CB (A)***	***# R***	***Recepticle***[f] ***(NEMA)***	***nominal use***
VEAC-01	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	13.3	20		Direct	Gate Valve
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	13.3	20		Direct	Gate Valve
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	20.0	30		Direct	Regen Heater
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-02	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	13.3	20		Direct	Gate Valve
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	13.3	20		Direct	Gate Valve
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	20.0	30		Direct	Regen Heater
								1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-03	1	1	1.9	20		Direct	VE Control Xformer							
VEAC-04	1	1	1.9	20		5-20R	ION Pump	1	3	25.0	80		Direct	Air Compressor
	1	1	1.9	20		Direct	VE Control Xformer							
	1	3	4.0	30		L15-30R	Turbo Backing							

End Station

Table 3-1: VE Power Required[a] at Load Centers

Voltage	*208Y/120V, 3φ*							*480Y/277V, 3φ*						
Location ***b***	***# C[c]***	***φ***	***KVA d***	***CB (A)***	***# R e***	***Recepticle (NEMA)***	***nominal use***	***# C***	***φ***	***KVA***	***CB (A)***	***# R***	***Recepticle[f] (NEMA)***	***nominal use***
VEAC-01	1	1	1.9	20		5-20R L5-20R	General/ION Pumps/ Aux. Turbo	1	3	13.3	20		Direct	Gate Valve
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	13.3	20		Direct	Gate Valve
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	20.0	30		Direct	Regen Heater
	1	3	2.0	30		L21-60R	Turbo Pump	1	3	39.9	60		L22-60R	Bakeout/Clean Room
	1	1	2.9	30		L5-30R	Bakeout Control	1	3	39.9	60		L22-60R	Bakeout/Clean Room
VEAC-03	1	1	1.9	20		Direct	VE Control Xformer							
VEAC-04	1	1	1.9	20		5-20R	ION Pump	1	3	25	80		Direct	Air Compressor
	1	1	1.9	20		Direct	VE Control Xformer							
	1	3	4.0	30		L15-30R	Turbo Backing							

a. All power to the VE is "facility power". Electronics racks used for CDS control of VE are provided with technical power and covered under the Detector-CC ICD.

b. Locations are indicated in drawing PSI-V049-3-124, V049-3-305 and V049-3-505
where in this case, C= corner station, CC = Civil Construction, PD = Power Distribution, VEAC_n = n'th Vacuum Equipment AC location.

c. Number of separate circuits and circuit breaker.

d. Maximum continuous KVA per circuit.

e. Number per receptacles (duplex receptacles for single phase locations).

f. TBR Recepticles (TBD-VE)

PROCESS SYSTEMS INTERNATIONAL, INC.
WESTBOROUGH, MA

ENGINEERING CALCULATIONS

NO: V049-1-093
PAGE 1 OF 4

REV	DEO#	DATE	BY:	CHECK
0	0126	04/12/96	R. Than	D. McW

TITLE:
INSTRUMENT AIR LINES SIZING
CORNER STATION

BY: R. THAN
DEPT: 744

PROJECT: LIGO
PROJECT NO: V59049

PURPOSE:
Determine instrument air lines / header sizes requirements

METHOD:
Turbulent flow: Cole brook formula, "Moody chart"
Laminar flow: Hagen-Poiseuille Flow

ASSUMPTIONS: Line leng of 300 ft

INPUTS:
Corner station: Air 20 SCFM @ 70 psig
End/Mid station: Air 10 SCFM @ 70 psig

REFERENCE:

CALCULATIONS:

see Attachments

CONCLUSIONS:
0.5 inch ID copper lines gives for Corner station a pressure drop of 18 psi
0.5 inch ID copper lines gives for Mid/End station a pressure drop of 4 psi

NOTES:

CORNER STATIONS

	Qty'	SCFM	Total SCFM
Cryopump valve	**2**	**1.5**	**3**
Roughing cart purge	**2**	**1.5**	**3**
Turbocart purge	**2**	**1.5**	**3**
44/48 gatevalves	**4**	**0.6**	**2.4**
Total			**11.4**

END/MID STATION

	Qty'	SCFM	Total SCFM
Cryopump valve	**2**	**1.5**	**3**
Turbocart purge	**1**	**1.5**	**1.5**
Total			**4.5**

With a margin of 2 the pressure drop thru a 0.5 inch ID line are the following:

	I.D.	Flowrate	Flowrate	ΔP	ΔP
	inch	SCFM	kg/s	psi	bar
CORNER STATION	**0.500**	**20**	**0.01**	**18**	**1.2**
END/MID STATION	**0.500**	**10**	**0.005**	**4**	**0.3**

```
PROCESS SYSTEMS INTERNATIONAL, INC     20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                                   BY: R. THAN
 PROJECT NO:V59049                                                 DATE: 4/12/**
 TITLE:     CORNER STATION INSTRUMENT AIR  SYS.                    PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:INSTRUMENT AIR HEADER  20 SCFM

 PRESSURE:      600000.0 Pa             6.000 BAR
 TEMPERATURE:    293.000 K            293.000 K
 DENSITY :         6.910 KG/M^3         0.691E+01 KG/M^3
 QUALITY :         1.000

ITEMNAME                FLOWRATE   I.D.     K / DO    CV      LENGTH PRESSURE     Z1       Z2      DP-F      DP-Z      DP-T     DP-SUM  DENSITY VELOCITY  RE NO     Knunsen
                           KG/S   METER                        M        Pa      METER    METER    Pa        Pa        Pa        Pa     KG/M^3    M/S

1/2" TUBE              0.100E-01   0.013                      25.0  573240.0    0.00     0.00 26760.00 0.00E+00 0.27E+05 0.27E+05 0.691E+01      11.42  0.57E+05  0.86E-0
1/2" TUBE              0.100E-01   0.013                      25.0  545229.6    0.00     0.00 28010.42 0.00E+00 0.28E+05 0.55E+05 0.660E+01      11.96  0.57E+05  0.90E-0
1/2" TUBE              0.100E-01   0.013                      25.0  515778.8    0.00     0.00 29450.76 0.00E+00 0.29E+05 0.84E+05 0.628E+01      12.57  0.57E+05  0.94E-0
1/2" TUBE              0.100E-01   0.013                      25.0  484644.9    0.00     0.00 31133.89 0.00E+00 0.31E+05 0.12E+06 0.594E+01      13.29  0.57E+05  0.10E-0
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  484086.5    0.00     0.00   558.40 0.00E+00 0.56E+03 0.12E+06 0.558E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  483527.5    0.00     0.00   559.05 0.00E+00 0.56E+03 0.12E+06 0.557E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  482967.8    0.00     0.00   559.69 0.00E+00 0.56E+03 0.12E+06 0.557E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  482407.5    0.00     0.00   560.34 0.00E+00 0.56E+03 0.12E+06 0.556E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  481846.5    0.00     0.00   560.99 0.00E+00 0.56E+03 0.12E+06 0.555E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  481284.8    0.00     0.00   561.65 0.00E+00 0.56E+03 0.12E+06 0.555E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  480722.5    0.00     0.00   562.30 0.00E+00 0.56E+03 0.12E+06 0.554E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  480159.6    0.00     0.00   562.96 0.00E+00 0.56E+03 0.12E+06 0.553E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  479595.9    0.00     0.00   563.62 0.00E+00 0.56E+03 0.12E+06 0.553E+01
1/2" ELBOW LR-90       0.100E-01   0.013     1.000                  479031.6    0.00     0.00   564.29 0.00E+00 0.56E+03 0.12E+06 0.552E+01

                                                                     TOTAL     120968.35      0.00   120968.35   =   17.5404 PSI
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1/2 I.D.

5/8 O.D.

REVISION: 0
DOC NO: V049-1-093
PAGE 3 OF 4

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PROCESS SYSTEMS INTERNATIONAL, INC    20 Walkup Drive, Westborough, MA 01581

 PROJECT:   LIGO                                                BY: R. THAN
 PROJECT NO:V59049                                              DATE: 4/12/**
 TITLE:     END/MID STATION INSTRUMENT AIR  SYS.                PAGE: 1 OF

PRESSURE DROP ROUTE OR LINE ID:INSTRUMENT AIR HEADER  10 SCFM

 PRESSURE:      600000.0 Pa          6.000 BAR
 TEMPERATURE:     293.000 K        293.000 K
 DENSITY :          6.910 KG/M^3      0.691E+01 KG/M^3
 QUALITY :          1.000

ITEMNAME              FLOWRATE   I.D.     K / DO      CV       LENGTH PRESSURE      Z1       Z2       DP-F      DP-Z      DP-T     DP-SUM   DENSITY VELOCITY  RE NO     Knunsen
                          KG/S   METER                           M       Pa        METER    METER     Pa        Pa        Pa        Pa      KG/M^3    M/S

1/2" TUBE            0.500E-02   0.013                          25.0  592955.9     0.00     0.00  7044.06 0.00E+00 0.70E+04 0.70E+04 0.691E+01      5.71  0.28E+05  0.86E-0
1/2" TUBE            0.500E-02   0.013                          25.0  585828.1     0.00     0.00  7127.81 0.00E+00 0.71E+04 0.14E+05 0.683E+01      5.78  0.28E+05  0.87E-0
1/2" TUBE            0.500E-02   0.013                          25.0  578613.5     0.00     0.00  7214.59 0.00E+00 0.72E+04 0.21E+05 0.675E+01      5.85  0.28E+05  0.88E-0
1/2" TUBE            0.500E-02   0.013                          25.0  571308.9     0.00     0.00  7304.62 0.00E+00 0.73E+04 0.29E+05 0.666E+01      5.92  0.28E+05  0.89E-0
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      571190.5     0.00     0.00   118.40 0.00E+00 0.12E+03 0.29E+05 0.658E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      571072.1     0.00     0.00   118.43 0.00E+00 0.12E+03 0.29E+05 0.658E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570953.6     0.00     0.00   118.45 0.00E+00 0.12E+03 0.29E+05 0.658E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570835.2     0.00     0.00   118.48 0.00E+00 0.12E+03 0.29E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570716.7     0.00     0.00   118.50 0.00E+00 0.12E+03 0.29E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570598.1     0.00     0.00   118.52 0.00E+00 0.12E+03 0.29E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570479.6     0.00     0.00   118.55 0.00E+00 0.12E+03 0.30E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570361.0     0.00     0.00   118.57 0.00E+00 0.12E+03 0.30E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570242.4     0.00     0.00   118.60 0.00E+00 0.12E+03 0.30E+05 0.657E+01
1/2" ELBOW LR-90     0.500E-02   0.013     1.000                      570123.8     0.00     0.00   118.62 0.00E+00 0.12E+03 0.30E+05 0.657E+01

                                                                           TOTAL       29876.20      0.00     29876.20  =    4.3320 PSI
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REVISION: 0
DOC NO: V049-1-093
PAGE 4 OF 4

Title: HAZARDS ANALYSIS

HAZARDS ANALYSIS

FOR

LIGO VACUUM EQUIPMENT

Hanford, Washington
and
Livingston, Louisiana

PREPARED BY Stephen F. Totty

TECHNICAL DIRECTOR D. A. McWilliams

PROJECT MANAGER

Information contained in this specification and its attachments is proprietary in nature and shall be kept confidential. It shall be used only as required to respond to the specification requirements and shall not be disclosed to any other party.

0	SFT 4/11/96	RES 5/1/96	Issue for FDR per DEO # 0119
REV LTR	BY—DATE	APPD—DATE	DESCRIPTION OF ACTION

PROCESS SYSTEMS INTERNATIONAL, INC					**SPECIFICATION**	
INITIAL APPROVALS	PREPARED BY SFT	DATE 4-11-96	APPROVED BY RES	DATE 5/1/96	Number **A** V049-2-093	Rev 0

LIGO Vacuum Equipment Hazards Analysis

Below is a release of the PHA sheets that constitute the Hazards Analysis required by the LIGO System Safety Plan. The major types of equipment and operations were analyzed with respect to hazards that result in damage to equipment or the environment or injury to personnel. The principal engineers were involved in the review of equipment and operations for which they are responsible. The analysis rates the hazards according to hazard probability and severity using the guides found in MIL-STD-882C section 4.5.1 and 4.5.2 which are also found in Tables 3.1, 3.2, and 3.3 of the LIGO Project System Safety Plan. The relevant definitions are referenced in the lower left hand corner of the PHA sheets. The Hazard Risk Index is given below for convenience. No hazards were found which fall in the Unacceptable or Undesirable categories.

Hazard Risk Index

Hazard Risk Index	Risk Code Criteria
1A, 1B, 1C, 2A, 2B, 3A	Unacceptable
1D, 2C, 2D, 3B, 3C	Undesirable (Project Manager Decision Required)
1E, 2E, 3D, 3E, 4A, 4B	Acceptable with review by Project Manager
4C, 4D, 4E	Acceptable without review

The PHA sheets completed are listed in the index below. This is a complete set of those sheets we anticipate being required. PSI will provide any other PHA sheets as needed.

Index of PHA sheets completed

Equipment:
1. An isolatable section
2. Beam Splitter Chamber
3. Horizontal Access Module
4. Roughing Pumps
5. Turbomolecular Pumps
6. Auxiliary Turbo Cart
7. Ion Pumps
8. Annulus Ion Pumps
9. 80 K Cryopumps
10. Large Gate Valves
11. Small Gate Valves
12. Blanket Bake Out System
13. Clean Rooms
14. Clean Air System
Operations:
1. Bake Out
2. Back to Air (Repressurization)
3. Cryopump Regeneration
4. Roughing
5. Turbo/Roughing
6. High Vacuum Operation

Rev. 0
Prepared by: JET
Reviewed by: RDL

EQUIPMENT ITEM OR PROCESS: **An Isolatable Section**

Each isolatable section includes at least 1) a large gate valve for isolation and 2) a beam splitter. It may also contain a HAM or a cryopump.
A cryopump in itself is an isolatable section.
The individual hazards associated with each individual piece are considered on the individual equipment hazard sheets.

The one hazard that must be addressed for any isolatable section not containing a cryopump is overpressure.
These is no pressure relief for the vacuum shells except for the cryopumps. There also is no source of overpressure except for the following three causes:

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overpressurization	Failure of back to air controller, failure of the pressure letdown valve to 1 psig, accidental change in setpoint	Loss of containment, flange leak.	RV on the back to air supply header	LIGO - Configure pressure alarm and shutdown of the back to air supply on the back to air pressure controller. *	1	E	1E
Overpressurization	Air Showers or purge air in use with the vessel closed and at atmospheric pressure	Loss of containment, flange leak.	RV on the back to air supply header. Procedures: Lockout on air shower supply until the chamber is opened and under purge.	Make part of operating procedures.	1	E	1E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Overpressure of section being baked out.	Initiation of bakeout with the system closed at atmospheric pressure.	Loss of containment: flange rupture, seam failure, etc.	Procedures: Heating an enclosed volume of gas from ambient to 200 C increases the pressure by 60 %. The operating procedures for bakeout must ensure that the section is at least rough pumped before heat is added.	Ensure this potential hazard is spelled out in the bakeout procedures.	2	E	2E

* This must be done on the back to air pressure controller because it is the only gauge accurate enough to be meaningful
The addition of a portable pressure control/transmitter for each site is an important feature to allow accurate gauging and control in the near atmospheric range.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: SET
Reviewed by: ROC

LIGO Vacuum Equipment
Hazards Analysis

Process Systems International, Inc.

EQUIPMENT ITEM OR PROCESS: **Beam Splitter Chamber**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overpressure	Failure to control pressure during back to ambient repressurization step	Loss of containment, Excess pressure on large flanged opening when the door is opened.	The purge air is controlled at 1 psig with a 2 psig relief valve setting limiting the source pressure.		3	E	3E
			Change to an accurate pressure gauge for control in the near atmospheric range.				
Loss of vacuum containment	Opening of a valve from an atmospheric pressure source.	Contamination, injury to personnel being sucked in, damage to equipment.	All valves larger than 2-1/2" have physical locking devices to prevent them being inadvertently being opened or closed. This is true of both manual and automatic valves. Personnel procedures governing their use and the breaking of vacuum.	None	1	E	1E
Loss of vacuum	"O"-Ring failure, flange leak, bellows leak, flex hose leak.	Operational upset, loss of on-stream time	Pressure gauges register leak, RGA identifies source as air. Clean Room can be put in place, the BSC isolated by the large gate valves, the leak found and repaired.	None	3	E	3E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: JFT
Reviewed by: DAC

EQUIPMENT ITEM OR PROCESS: **Horizontal Access Modules**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overpressure	Failure to control pressure during back to ambient repressurization step	Loss of containment, Excess pressure on large flanged opening when the door is opened.	The purge air is controlled at 1 psig with a 2 psig relief valve setting limiting the source pressure.		3	E	3E
			Change to an accurate pressure gauge for control in the near atmospheric range.				
Loss of vacuum containment	Opening of a valve from an atmospheric pressure source.	Contamination, injury to personnel being sucked in, damage to equipment.	All valves larger than 2-1/2" have physical locking devices to prevent them being inadvertently being opened or closed. This is true of both manual and automatic valves. Personnel procedures governing their use *and the breaking of* vacuum.	None	1	E	1E
Loss of vacuum	"O"-Ring failure, flange leak, bellows leak, flex hose leak.	Operational upset, loss of on-stream time	Pressure gauges register leak, RGA identifies source as air. Clean Room can be put in place, the BSC isolated by the large gate valves, the leak found and repaired.	None	3	E	3E

The HAM's are not isolatable from the BSC's. Repressureization is done through the BSC associated with that HAM.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Analysis (HRI)

EQUIPMENT ITEM OR PROCESS: **80 K Cryopumps**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overpressure of LN2 side	Blocked vent line	Rupture of LN2 annular section and N2 leak into chamber	RV-133 on the vent line. The RV will be sized for the maximum flow when the vent is iced up. One case would be maximum flow through the supply valve wide open.	PSI will develop and review both flows and pressure setting for RV-133.	2	E	2E
Overheating Aluminum LN2 Reservoir	1) Misoperation of heater, 2) Failure to monitor TE on warm vent gas	Rupture of LN2 annular section due to loss of aluminum strength	Procedures, TI-102 on vent gas	Ask Ligo to add alarm to TI-102 with shutdown of Electrical heater. Design temperature of LN2 reservoir set to 400 F to provide margin for regeneration at design pressure above maximum back pressure during regeneration.	3	D	3D
Rupture of LN2 Reservoir	Overpressure, over temperature, material defect.	Overpressure of cryopump due to vaporization of the LN2 reservoir in the hot (happens during regeneration) pump.	Pressure relief device - double "O" Ring sealed lift plate will be added to shell.	None	1	E	1E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Overfilling cryopump	Failure of level control, failure to put level control back in operation on refill.	Spill LN2 out vent to atmosphere	Locate in safe location both in regard to liquid nitrogen and to build up of N2 vapor causing reduced O2 content.	None	4	D	4D
LN2 or GN2 leak into chamber	Defect or minor rupture of a weld or piping	Loss of vacuum, Pump would be valved off, repressurized, and the leak found and repaired	Pressure gauges, RGA will determine leak to be nitrogen	None	4	E	4E
Overpressure during back to air	Design pressure is close to clean air supply pressure	Vessel rupture or flange leak. The contained energy is too small to cause injury or damage beyond the vessel itself.	Three safety features are provided: 1) Relief valve on supply air set at 2 psig, 2) back to air valve will be controlled from a gauge accurate at atmospheric	None	4	E	4E
			3) a pressure relief device expected to be a specially designed rupture disk will be installed on the shell.				
Loss of liquid level in cryopump reservoir	Blocked supply line, empty dewar, failure of level control	Loss of effectiveness of cryopump, possible release of adsorbed water vapor.	None	Suggest LIGO add low level alarm to level control LIC-100.	4	E	4E

* The LN2 supply dewar, pressure building coil, and ambient vaporizer are all protected by the standard safety controls. The same is true for the electric heater which has overheat protection to avoid burning out the elements.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Ion Pump**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Operation at too high pressure	1) Leak, 2) Turbomolecular pump failure, 3) Cryopump Failure, 4) Premature operation during pump down - operator error	Excessive current draw with pump damage or shortened pump life.	Large pumps have current trips built into the controllers. The gate valves separating the ion pump from the system are physically lockable. Procedures before valve is opened.	None	4	D	4D
	Pump restart after power failure	Excessive current draw with pump damage or shortened pump life.	The MultiVac controller will be set not to restart on return of power.	None	4	E	4E
Electrical Shock	Improper Contact with High Voltage Equipment	Injury or death	High voltage clearly marked, high voltage power cable run in cable tray marked high voltage. Design to applicable electrical codes.	None	1	E	1E
Ion Pump Failure	Defect, Electrical failure	Loss of pumping capacity.	Pump power controls and high amperage trip. Pump can be valved off and replaced without breaking the system vacuum. Short does not release materials into the chamber.	None	4	D	4D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Analysis (HRI)

Rev. 0
Prepared by:
Reviewed by: FMB

EQUIPMENT ITEM OR PROCESS: **Annulus Ion Pumps**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Operation at too high pressure	1) "O" Ring Leak, 2) Turbomolecular pump failure, 3) Premature operation during pump down - operator error	Excessive current draw with pump damage or shortened pump life.	The 75 torr-liter/sec pumps and 25 torr-liter/sec pumps are fuse protected. The gate valves separating the ion pump from the system are physically lockable. Procedures before valve is opened.	None	4	D	4D
	Pump restart after power failure	Excessive current draw with pump damage or shortened pump life.	The MiniVac controllers return to their original state on power return so they will power up.	Make it part of procedure for extended power outage to shutoff ion pumps.	4	C	4C
Electrical Shock	Improper Contact with High Voltage Equipment	Injury or death	High voltage clearly marked. Care in locating controller and running power cables. Design to applicable electrical codes.	None	1	E	1E
Ion Pump Failure	Defect, Electrical failure	Loss of pumping capacity.	Pump power controls and high amperage trip. Pump can be valved off and replaced without breaking the system vacuum. Annulus space can be turbopumped to an acceptable vacuum.	None	4	D	4D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: SET
Reviewed by: FAB

EQUIPMENT ITEM OR PROCESS: **Blanket Bake Out System**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Electrical short circuit	Breakdown in insulation, moisture	damage to heating mantel, possible short to vessel, personnel injury	Blankets are designed specifically for each item of equipment. Construction of the blanket protects the heating elements. Each blanket is protected by a fuse. The power supply on the control cart has a circuit breaker.	None	3	E	3E
			Design to all applicable electrical standards. Blankets are not grounded, the equipment being baked and the control carts are grounded. Proper maintenance and storage of blankets and power cords.				
Accident	Assembly of blankets around the system is a manually intensive operation	Personnel injury, probably minor	Personnel training and written procedures.	Make part of training both for PSI manufacturing personnel and also LIGO operating personnel.	3	D	3D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Non-uniform heating and cooling	Misoperation or set-up of the blanket system and controls	Excessive temperature differences in the equipment	Procedures for wiring the carts to the blankets must be rigorously followed. Incorrect setup will cause the control system to shutdown on temperature difference prematurely. The system is safe against excessive delta T's.	Make part of training both for PSI manufacturing personnel and also LIGO operating personnel.	4	C	4C
Loss of control	PC Failure	No hazard - Loss of ability to view system operations but the PLC's maintain control.	PLC's maintain control.	None	4	C	4C
	PLC Failure	No hazard	System shutdown - PLC failure trips the breaker on the cart	None	4	C	4C
	Thermal data acquisition system failure	No hazard	Erroneous signal shutdown the system on out of range temperature - similar to miswiring. No signal causes shutdown based on loss of timing signal.	None	4	C	4C
Overheat Equipment attached to the Main System	Auxiliary equipment such as Turbopumps which are close coupled to the system have lower acceptable temperatures than the design bakeout temperature of the main system.	Damage to auxiliary equipment components or electronics.	Bakeout procedure must address this problem.	Analyze the thermal conduction to the auxiliary equipment, whether it should be baked out separately so the insulation on the auxiliary section can be removed, etc.	4	C	4C

EQUIPMENT ITEM OR PROCESS: **Turbomolecular Pump Cart**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Pump vents to vacuum chamber	1) backing pump failure, 2) magnetic bearing failure, 3) power failure	Contamination of chamber, possible damage to equipment in the chamber	Automatic shutoff valve on Turbo pump discharge interlocked to close on pump or power failure.	None	3	D	3D
Turbomolecular pump mechanical failure	Bearing failure, material failure of blades	Large amount of momemtum to dissipate - possibly causing pump mounting failure.	The frame to which the Turbo Cart is bolted is designed for this load. The bolts for anchoring the cart are also designed for this load.	Make sure other users of the TurboCart, i.e., the Beam Tube Contractor is informed and correct bolts are always used - LIGO responsibility.			
Turbopump emergency shutdown	Power Failure	Damage to Turbopump.	The controller which controls the active magnetic bearings is supplied with battery backup. Procedures must ensure that the batteries are good and that they have sufficient charge.	Make sure information is passed to LIGO.	2	E	2E
			This is especially true if there is a series of power failures without enough up time to recharge.				

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

	Controller failure, control cable failure	Damage to Turbopump.	Auxiliary bearings are provided to allow the pump to shutdown safely. They are only good for a limited number of "crash landing."	None	2	E	2E
Turbopump shutdown	Seal gas failure, seal failure. cooling water failure.	Pump damage, leakage into the vacuum system, contamination of the vacuum system	Seal gas is from the clean air system so there is no contamination.	None	3	E	3E
			Only the backing pump uses seal gas, loss of seal gas purge causes a pump shutdown. There is an automatic shutoff valve between the turbo and the backing pump actuated on pump shutdown..	None	3	E	3E
			Cooling water failure will trip the turbopump on high temperature, the backing pump also has TSH protection,	None	3	E	3E
Cart Mechanical Failure	Lifting the two parts of the cart together	Damage to equipment, injury to personnel	The carts will be clearly marked. Training and procedures. LIGO to enforce compliance by beam tube contractor.	None	2	E	2E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Overheating during bakeout	Too high temperature in the vacuum section to which the turbopump is coupled causing overheat by conduction.	Damage to electronics, components. Damage to turbopump (if running).	Temperature alarms and shutdowns on the blankets designed for heating the turbopump. This could terminate the bakeout if the condition cannot be alleviated. The turbopump is also TSH protected.	Investigate the bakeout scenario and determine whether this is a real problem. If so, it may be necessary to bakeout the pump first and then remove the pump blanket or bakeout everything to 120 C together and then remove the pump blanket and continue.	2	E	2E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: SFT
Reviewed by:

EQUIPMENT ITEM OR PROCESS: **Auxiliary Turbo Cart**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Pump vents to vacuum chamber	1) backing pump failure, 2) magnetic bearing failure, 3) power failure	Contamination of chamber, possible damage to equipment in the chamber	Automatic shutoff valve on turbo inlet interlocked to close on pump or power failure. An automatic vent valve lets air into the turbo to keep flow in the direction of the backing pump under normal shutdown.	None	3	D	3D
Turbopump emergency shutdown	Power Failure, Controller failure, Control Cable Failure	Damage to Turbopump.	The system is designed for safe shutdown with all the required interlocks and safeties.	None	3	E	3E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Roughing Pumps**

The roughing pump system consists of a roughing pump cart with a roots blower (10 hp) and a backing pump cart with a mechanical backing pump (20 hp) connected by a flex hose.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Pump vents to vacuum chamber	1) backing pump failure, 2) roots blower failure 3) power failure	Contamination of chamber, possible damage to equipment in the chamber	Automatic shutoff valve on roots blower cart inlet interlocked to close on pump failure or power failure.	None	3	D	3D
Roughing pump shutdown	Seal gas failure, seal failure.	Pump damage, leakage into the vacuum system, contamination of the vacuum system	Seal gas is from the clean air system so there is no contamination.	None	3	E	3E
			Loss of seal gas purge causes a pump shutdown which closes the automatic shutoff valve on the roughing pump inlet.	None	3	E	3E
	Loss of cooling water flow		Loss of cooling water shuts down backing pump on high temperature switch				

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Excessive Stress on Vacuum Equipment or Beam Tube	Improper Mounting and mate up to the roughing port.	Possible damage to equipment	The carts are designed to mate with the vacuum equipment. The carts must be bolted down. The beam tube contractor must provide suitable safe and stable means to attach to the beam tube.	LIGO to provide proper instructions and oversight to the beam tube contractor.	3	E	3E

Hazard Severity Categories (HSC): 1=*Catastrophic*, 2=*Critical*, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Large Gate Valves**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Valve closes with laser on	Operator initiated valve closure	Damage to gate valve and possibly other equipment.	Procedures and computer interlock (LIGO) to prevent large gate valve closure in the line of the beam with the laser powered.	Convey this requirement to LIGO.	1	D	1D
Valve not fully open or close	misoperation	system not isolated or valve impinges on beam path.	Positive indication of valve closure or valve opening is provided. Electric actuators have gear driven switches, pneumatic valves have limit switches on the actuators.	None	3	E	3E
Valves Fail to Close (Electrically operated valves)	Electrical system failure - motor or electrical supply	Failure to isolate section on demand.	All electrical components can be replaced or repaired without compromising vacuum system. These valves are not designed for emergency isolation.	None	4	D	4D
			Failure to close in combination with a system leak would be considered double jeopardy.				

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Valves Fail to Close (Pneumatically operated valves)	Instrument Air Failure	Failure to isolate section on demand.	Failure to close in combination with a system leak would be considered double jeopardy.	None	4	D	4D
Valves Fail to Open	Electrical system failure - motor or electrical supply	Delay in bringing system back on-line	All electrical components can be replaced or repaired without compromising vacuum system.	None	4	D	4D
Valve Opens Unexpectedly	Operator or Control system failure	Section containing equipment or personnel exposed to rapid depressurization with damage to equipment and personnel injury or death.	Control system lockout procedure and physical lockout on valve to prevent opening. Personnel training and procedures	None	1	E	1E
Damage to "O" Ring Gaskets	Excessive temperature on bake out	Inability to reach vacuum, contamination by products of decomposition. The products generated by heating over 200 C are both toxic and dangerous (HF).	Blanket bake out system controls	None	2	E	2E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Small Gate Valves**

The small gate valves, 14 inches and smaller, are manually operated valves. The small valves use metal gasket conflat flanges rather than double "O" ring seals.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Valve Opened Inadvertently.	Misoperation	Vacuum system opened to atmosphere with damage to equipment and contamination. Injury to personnel or damage to equipment sucked into the valve.	Physical lockout on valve to prevent opening. Personnel training and procedures.	LIGO to establish personnel training procedures in regard to opening system to atmosphere.	1	E	1E

There do not appear to be any hazards not addressed by the lockout devices and procedures.

Small valves in the 1-1/2" to 2-1/2" range have no lockout protection. These will have to be protected by personnel procedures.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: 3FT
Reviewed by: TS

EQUIPMENT ITEM OR PROCESS: **Clean Room**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI

There do not appear to be any significant hazards inherent in clean room operation other than those normally associated with operating a small air compressor and physically setting up the pieces of the portable equipment. See attached HAZNOTES.

These would be handled by proper storage and maintenance of the clean rooms and training of the personnel who will set them up and operate in them.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev.
Prepared by: SET
Reviewed by: TS

LIGO Vacuum Equipment
Hazards Analysis
HAZNOTES

Subject Area: Clean Rooms

Date: 20-Mar-96

Meeting Attendance: Stephen Toth, Tom Starr

Notes:	Safety aspects of the clean rooms and their usage were discussed.
Description:	Each clean room consists of an enclosure made up of a frame covered by 40 mil sheets of polyethylene, a blower providing air, and an air filter. Each room will have electrical outlets and lighting. An anteroom will be provided for gowning prior to entry.
Usage	The clean rooms will be used to provide a clean (low particulate level) environment for the following operations: Final Assembly, Installation, and Opening of the Vacuum System to atmosphere. The air will be filtered but not dehumidified. No welding will take place in a clean room.
Hazards:	
Asphyxiation	The clean room is a partially enclosed space with a high air flow. At site there will be no welding (Argon Source) or use of nitrogen for drying so there can be no reduction in oxygen content. Purge air will be Class 100 clean air. Air for the air showers will be class 100 air but also dehumidified to -60 C dew point.
Flammability	The 40 mil sheets of polyethylene are considered to be flame retardant. With no ignition sources in the clean room and flame retardant walls there is no apparent fire hazard.
Other hazards	There are no other hazards inherent in clean room operation other that normally associated with operating a small air compressor and physically setting up the several pieces of the portable system.

Rev. 0
Prepared by: SFT
Reviewed by: TS

EQUIPMENT ITEM OR PROCESS: **Clean Air System - Vent and Purge**

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI

There do not appear to be any hazards other than those involved in operating small air compressors.
See attached HAZNOTES.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: SFT
Reviewed by: TS

LIGO Vacuum Equipment
Hazards Analysis
HAZNOTES

Subject Area: Clean Air Supply, Vent and Purge

Date: 20-Mar-96

Meeting Attendance: Tom Starr, Stephen Toth

Notes:	The vent and purge compressors and the clean air supply to the air showers was discussed from a safety viewpoint.
Description:	Vent and Purge clean air is provided as a manifolded utility to the various stations as required. The air is compressed either by two stage screw compressors or by parallel scroll compressors. Both types are oil free compressors. The air is compressed to around 90 psig, dried in a two-bed heatless mole sieve drier, filtered and then let down in two stages to 1 psig for supply to the vacuum equipment. The 1 psig supply header is protected by a relief valve set at approximately 2 psig.
Hazards:	There are no hazards other than those involved in operating small air compressors. Hazards or operational issues resulting from loss of instrument air or loss of purge air will be addressed in regard to the equipment being investigated or in the FMEA of the particular P&ID.

Rev. C
Prepared by: SFT
Reviewed by: RDC

EQUIPMENT ITEM OR PROCESS: **Operation: Bake Out**

Most of the possible system hazards are covered in the Blanket Bake Out Equipment Hazard sheets.
The additional hazards associated with the overall operation are covered below.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overpressure of section being baked out.	Initiation of bakeout with the system closed at atmospheric pressure.	Loss of containment: flange rupture, seam failure, etc.	Procedures: Heating an enclosed volume of gas from ambient to 200 C increases the pressure by 60 %. The operating procedures for bakeout must ensure that the section is at least rough pumped before heat is added.	Ensure this potential hazard is spelled out in the bakeout procedures.	2	E	2E
			The low ramp rate of the blanket system allows time to respond should the blankets be turned on before rough pumping is initiated.				
Failure of vessel walls or flanges	Stress induced by thermal expansion of large system.	Loss of containment	These stresses are addressed in the design of the equipment, expansion joints are incorporated in the design.	None	2	E	2E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Overheating equipment	Some of the components of the system are more heat sensitive than others.	Damage to equipment, release of toxic gases or liquids, contamination.	The control system is available to monitor and protect the equipment.	Ensure this potential hazard is spelled out in the bakeout procedures.	2	E	2E
			Procedures are required to ensure that the limitations of the few heat sensitive components are understood and that the bakeout is done in a methodical manner.				
			That adequate time and oversight is provided.				

The remaining hazards of overheating and the like are covered on the blanket bakeout equipment section.
There are sufficient controls, safeties, and interlocks to protect the system against overheating.

Rev. <>
Prepared by: SFT
Reviewed by: TS

EQUIPMENT ITEM OR PROCESS: **Operation Back to Air (Repressuization)**

Most of the possible system hazards are covered in the Clean Air, BSC, HAM, and cryopump hazard sheets. The additional hazards associated with the overall operation are covered below.

Isolation:

The first action required is to isolate the section to be repressurized. This requires closing the large gate valves. The hazard associated with this is listed below

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Valve closes with laser on	Operator initiated valve closure	Damage to gate valve and possibly other equipment.	Procedures and computer interlock (LIGO) to prevent large gate valve closure in the line of the beam with the laser powered.	Convey this requirement to LIGO.	1	D	1D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Repressurization:

Once the section is isolated, the back to air connections are made.
The back to air process is initiated with the controller gradually pressurizing the system with the pressure signal from the Pirani gauge.
When the pressure is back to within two decades of atmospheric a portable pressure gauge/transmitter accurate in the near atmospheric range will be attached to one of the 1-1/2 inch conflat ports (the RGA port for example) and the control switched to this transmitter for the final stage of repressurization. The hazard associated with these actions are listed below

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Damage to equipment in the section being repressurized, i.e., optics0	Too rapid a flow of repressuization gas, gas flow into a sensitive section.	Repairs, realignment necessary.	Change to an accurate pressure gauge for control in the near atmospheric range.	PSI-None, all necessary equipment and instrumentation is provided.	2	E	2E
			Procedures, low ramp rate near atmospheric.	LIGO-Develop the philosophy and parameters necessary to prevent disruption of the interferometer.			
Overpressurization	Failure of back to air controller, failure of the pressure letdown valve to 1 psig, accidental change in setpoint	Loss of containment, flange leak.	RV on the back to air supply header	LIGO - Configure pressure alarm and shutdown of the back to air supply on the back to air pressure controller. *	1	E	1E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, *D=Remote*, E=Improbable
Hazard Risk Index (HRI)

Vessel Entry:

Presumably the section was isolated and brought back to atmospheric pressure in order for work to be done in that section. Once it has been confirmed that the system is pressurized to near atmospheric, one or more clean rooms are put in place and preparations made to open the chamber. One or more small valves are opened to equalize to atmosphere, the purge air and air showers started, and the vessel opened up.
The hazard associated with these actions are listed below

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Moisture intrusion into chamber	Failure to start purge flow or insufficient purge flow	Might require a bakeout, or a longer pumpdown. Loss of onstream time.	Procedures	None	4	E	4E
Moisture on optics	Failure to start air shower flow or insufficient air shower flow	Need to redry optics	Procedures	None	4	E	4E
Vessel is opened to section under vacuum	Misoperation of large gate valve	Damage and loss of life	Procedures: See physical lockout of gate valves.	None	1	E	1E
Laser is energized	Misoperation	Probable destruction of gate valve opening section to the beam tube vacuum. Death and damage	Procedures	LIGO to provide both computer interlock and physical lockout of laser power when either the large gate valves are closed or vessel entry made.	1	E	1E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Operation: Cryopump Regeneration**

Most of the possible hazards associated with regeneration of the cryopumps were covered in the cryopump hazard sheets. Listed below are mostly the same hazards but broken out into which portion of the process they are most likely to occur in.

Isolation:

Once it has been determined that the cryopump needs to be regenerated, the first step is to turn off the laser and isolate the cryopump with it's two large gate valves. The turbopump cart is attached to the 10" gate valve and the pump started to maintain vacuum and evacuate the water vapor during regeneration. The one immediate hazard is:

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Valve closes with laser on	Operator initiated valve closure	Damage to gate valve and possibly other equipment.	*Procedures and computer interlock (LIGO) to prevent large gate valve closure in the line of the beam with the laser powered.*	*Convey this requirement to LIGO.*	*1*	D	1D

Initiate Regeneration:

The LN2 supply block valve is shut to the cryopump at the supply dewar and the level control valve LV-100 is closed and taken off automatic. The block valve to the ambient vaporizer opened. The operator opens the flow control valve slowly sending gas to the bottom of the reservoir in the cryopump while watching the vent line pressure gauge to make sure that the pressure did not get too high, and that liquid was not coming out of the vent line. The control room and the local operator will monitor the vent gas temperature until it warmed to within approximately 40 C of ambient.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Too much regeneration nitrogen to the reservoir	Manually opening flow valve to quickly	Carryover of LN2 out the vent or if back pressure is too high lifting of relief valve with LN2 going out the relief valve.	Locate in safe location both in regard to liquid nitrogen and to build up of N2 vapor causing reduced O2 content.	None	4	D	4D
			Procedures: Operator to monitor nitrogen gas flow and vent pressure				
Break in regeneration feed line in Cryopump	Thermal Stress	Both vapor (from regen side) and liquid from reservoir into the shell side.	Vessel protected from over pressure by special rupture disk.	None	4	E	4E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: JFT
Reviewed by: BM

Finish Regeneration:

The heater blankets will be installed and the ramp up in temperature initiated.
The control room will set the ramp rate on the electric heater and turn it on. Flow rate will be adjusted to both warm up at the desired rate and also to stay within the pressure limits of the reservoir. When the temperature of the vent gas reaches the desired 150 C, the controller will be set to hold temperature for some period of time.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overheating Aluminum LN2 Reservoir	1) Misoperation of heater, 2) Failure to monitor TE on warm vent gas	Rupture of LN2 annular section due to loss of aluminum strength	Procedures, TI-102 on vent gas. Design temperature of LN2 reservoir set to 400 F to provide margin for regeneration at design pressure above maximum back pressure during regeneration. .	Ask Ligo to add alarm to TI-102 with interlock to shutdown of Electrical heater.	3	D	3D
Overpressure of Shell	Failure of Turbopump so there is no evacuation. Automatic valve closes protecting turbopump but blocking in shell side.	If there is sufficient water content still in the shell the vaporizing water will drive the pressure above design.	Special rupture disk on the shell.	LIGO - Configure pressure alarm on Pirani gauge at a pressure safely below relief pressure indicating loss of vacuum. Operator would then have time to shutdown electric nitrogen heater and have blankets turned off.	2	D	2D
Break in regeneration feed line in Cryopump	Thermal Stress	Both vapor (from regen side) and liquid from reservoir into the shell side.	Vessel protected from over pressure by special rupture disk.	None	4	E	4E

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Cool Down and Restart

The whole sequence of operations will be reversed.
The electric nitrogen gas heater turned off and the blankets turned off, allowed to cool down and removed. Nitrogen gas flow will be maintained but cut back to maintain a purge flow through the nitrogen vent line to prevent air and water vapor intrusion.
The LN2 block valve opened, the block valve to ambient vaporizer closed, and LV-100 opened slightly from the control room to cool down the reservoir.
When the reservoir is cooled down as evidenced by the vent gas temperature approaching 80 K, the flow rate can be increased and the reservoir filled.
When the level approaches the desired level, LV-100 can be put back in automatic. The turbopump can be turned off, valved off and disconnected.
The large gate valves opened, locked open, and the laser restarted.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Overfilling cryopump	Failure of level control, failure to put level control back in operation on refill.	Spill LN2 out vent to atmosphere	Locate in safe location both in regard to liquid nitrogen and to build up of N2 vapor causing reduced O2 content.	None	4	D	4D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Operation: Roughing**

The hazards associated with the roughing pumps are mostly covered on the roughing pump cart equipment hazard sheets.
The additional hazards associated with the overall operation are covered below.

The volume to be roughed first must be closed. The open flanges are closed and bolted and valves are closed.
The roughing pump cart is put in place, aligned with its port, and bolted down. The backing pump cart is permanently installed in the mechanical room.
The flex hose is attached to the manifold connecting the two carts. The control cable linking the two is connected and power brought to the roughing pump. Cooling water and instrument air are attached and started. Once the overall setup is verified the suction gate valve on the chamber is opened and the automatic block valve on the cart is opened. The roughing pump and its backing pump can then be started.
Pump down is monitored with the Pirani gauge sets on the volume to be roughed. When the desired pressure is reached the gate valve is closed and locked. The roughing pump can then be shutdown which automatically closes its suction valve.
The roughing pump cart is disconnected from their utilities and removed.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Failure to close gate valve before disconnecting roughing pump.	Operator error	Rapid repressurization, contamination, damage to interferometer optics, personal injury.	Procedures and training	Detailed check list of setup and disassembly is required.	1	E	1E
Failure to close gate valve before performing repairs or maintenance on the roughing/backing pumps.	Operator error	Rapid repressurization, contamination, damage to interferometer optics, personal injury.	Procedures and training	Sign off before working around an open gate valve is required.	1	E	1E

The roughing pump and backing pump are self protecting. The hazard involves working around a large vacuum volume until it is closed off and locked.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Rev. 0
Prepared by: ST-T
Reviewed by: Jm

EQUIPMENT ITEM OR PROCESS: **Operation: Turbo Roughing**

The hazards associated with turbo roughing are mostly covered on the turbomolecular pump cart equipment hazard sheets.
The additional hazards associated with the overall operation are covered below.

The volume to be turbo roughed has been rough pumped. The turbo cart is put in place, aligned with its port, and bolted down. The flex hose connecting the turbo exhaust to the manifold connecting the turbo to its backing pump in the mechanical room is attached.
Power is connected to the turbo cart and the control cable linking the two is connected.
Cooling water, instrument air, and seal gas are attached and started. Once the overall setup is verified the suction gate valve on the chamber is opened. The turbo pump and its backing pump can then be started.
Pump down is monitored with the gauge sets on the volume to be turbo pumped. When the desired pressure is reached the gate valve on the chamber is closed and locked. The turbo pump can then be shutdown.
The turbo pump cart is disconnected from utilities and removed.

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Failure to close gate valve before disconnecting the turbo pump.	Operator error	Rapid repressurization, contamination, damage to interferometer optics, personal injury.	Procedures and training	Detailed check list of setup and disassembly is required.	1	E	1E
Failure to close gate valve before performing repairs or maintenance on the turbo pumps or the backing pump.	Operator error	Rapid repressurization, contamination, damage to interferometer optics, personal injury.	Procedures and training	Sign off before working around an open gate valve is required.	1	E	1E
Turbocart breaks free from chamber	Failure to properly bolt down the turbo cart and the turbo seizes up.	Rapid repressurization, contamination, damage to interferometer optics, personal injury.	Procedures, maintenance and house keeping.	Detailed assembly and setup procedures required. Keep bolts with the turbo pumps and mark them as special material.	1	E	1E

Once the turbo pump is up and running the turbo and its backing pump are self protecting. The hazards involved are those involved with working around a large vacuum volume until it is closed off and locked and properly mounting an elevated piece of high speed equipment.

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

EQUIPMENT ITEM OR PROCESS: **Operation: High Vacuum Operation**

Once the system is turbo pumped the next stage is to reach high vacuum and initialize operation of the interferometer.
The pressure and setup of the system are verified as being ready for high vacuum operation. The pumped double "O" ring seals are pumped down with the auxiliary turbo pump and the annulus ion pumps started.
The 80 K cryopump which has been kept purged with nitrogen vapor on the nitrogen side is cooled down and then filled with liquid nitrogen.
The level control for liquid nitrogen makeup is put on automatic operation.
The gate valves on the main ion pumps are opened and the ion pumps started.
Pressure is monitored in the system with the cold cathode and RGA.
The laser interferometer operation is initialized.

Most of the hazards associated with the 80 K cryopumps, ion pumps, large gate valves, and other equipment have been handled on the individual equipment hazard sheets. Additional hazards associated with overall operation are listed below:

HAZARD	CAUSE	CONSEQUENCES	SAFEGUARD	ACTION ITEM	HSC	HP	HRI
Opening the chamber to atmosphere	Misoperation	Rapid repressurization, damage to interferometer optics, contamination, personal injury	All valves over 2 1/2 inches are provided with lockable devices. Procedures:	Operations must establish the absolute prohibition against breaking vacuum without approval at the highest level.	1	E	1E
Gradual loss of vacuum	Flange leak, leak in any joint or weld	Reduction in accuracy of interferometer, contamination	Monitoring of RGA, vacuum gauges	None	3	D	3D

Hazard Severity Categories (HSC): 1=Catastrophic, 2=Critical, 3=Marginal, 4=Negligible
Hazard Probability (HP): A=Frequent, B=Probable, C=Occasional, D=Remote, E=Improbable
Hazard Risk Index (HRI)

Title: **FAILURE MODES and EFFECTS ANALYSIS**

FAILURE MODES and EFFECTS ANALYSIS

FOR

LIGO VACUUM EQUIPMENT

Hanford, Washington
and
Livingston, Louisiana

PREPARED BY S. F. Toth

TECHNICAL DIRECTOR D. A. McWilliams

PROJECT MANAGER

Information contained in this specification and its attachments is proprietary in nature and shall be kept confidential. It shall be used only as required to respond to the specification requirements and shall not be disclosed to any other party.

1	SFT - 7/3/96	D. MW 8-6-9	Revised per LIGO TDM No. 10, ISSUE PER DEO 0239
0	SFT - 4/19/96	REB	Issue for FDR per DEO # 0120
REV LTR	BY—DATE	APPD—DATE	DESCRIPTION OF ACTION

PROCESS SYSTEMS INTERNATIONAL, INC		**SPECIFICATION**	
INITIAL APPROVALS	PREPARED BY SF Toth DATE 4-19	APPROVED BY D. MW DATE 5-1-96	Number A V049-2-094	Rev 1

Following is a general revision of the Failure Modes and Effects Analysis with an emphasis on:

1. Reliability
2. System Wide Effects (Listed as "Ultimate Effect" on the FMEA sheets)

To: Dave McWilliams

From: Stephen Toth

Date: July 2, 1996

Subject: Revised LIGO FMEA

Attached is the revised LIGO FMEA sheets for your review.

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

Process Systems International, Inc.

P&I Number: V049-0-002
Node: 1
System: Annulus Vacuum System
Date: 6/24/96

Node 1 is the Annulus ion pump and the connections from the double "O" rings seals on the 104" and 4 - 60" flanges.
This P&I represents 11 BSC's, Washington BSC 2,4,5,6,7,8,9, and Louisiana BSC 2,4,5. The numbers below reflect WBSC2.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
1		75 liter/second ion pump	1A: Ion pump shuts down on high current caused by premature operation on pumpdown.	Pump down ceases. Restart turbopump, complete pump down to acceptable pressure for ion pump, and restart ion pump.	No significant effect.
			1B: Ion pump fails mechanically or electrically	Loss in Annulus Vacuum Pumping. Indication of loss of pump operation by current readings on LIGO control system.	Increase in leakage from atmosphere into the LIGO vacuum equipment until the annulus ion pump is replaced. The ion pump can be replaced, turbopumped, and brought back online without the chamber vacuum being broken. No significant effect.
			1C: Ion pump shuts down due to high pressure caused by annulus leak from atmosphere.	Once the ion pump fails to restart due to high current, an auxiliary turbocart can be attached to the 2 1/2" AVHV and the turbocart pressure gauges used to confirm the loss of vacuum.	LIGO Operations will determine the timing of helium leak checking the annulus "O" ring seal. If the seal cannot be fixed externally by tightening bolts, etc. The BSC will have to be isolated and the "O" ring repaired or replaced.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the BSC and other chambers in the isolatable section back to vacuum.

					Estimated leakage rate per "O" ring seal from atmospheric pressure is 1 x 10-5 Torr-liter/sec. This would be the rate if either the inner or outer ring failed.

P&I Number: V049-0-002
Node: 2
System: Beam Splitter Chamber
Date: 6/24/96

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
3	WBSC2	Beam Splitter Chamber	3A: Any flange leak or leak in a feed through	Loss in vacuum is indicated on the Cold Cathode or Pirani gauge.	LIGO Operations will determine the timing of helium leak checking the chamber and repairing the leak.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the BSC and other chambers in the isolatable section back to vacuum.
			3B: During manual "Back to Air" operation the operator fully opens the larger supply valve.	The pressure will rise to the "Back to Air" supply header pressure of 1 psig. The supply header pressure is further limited by a relief valve set at 2 psig. The pressure can be bled out of the system by *opening the* 1 1/2" Aux. Turbo Pumpout Port.	None
			3C: Opening of the 2 1/2" RGA Port valve, the 1 1/2" Aux. Turbo Pumpout Port valve, or the 14" Air Shower Connection with the BSC under vacuum.	The BSC and other sections of the vacuum enclosure connected to it would rapidly pressurize with contamination of the vacuum enclosure. The rapid air flow into the open valve might cause injury to personnel nearby.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

4	Gauge Pair on WBSC2	A Gauge Pair consists of a Cold Cathode gauge and a Pirani gauge both with local and remote readouts.	4A: Either gauge can fail during pumpdown	There are two options: 1. The section can be isolated, brought back to atmospheric pressure and the gauge replaced, or 2. The gauges on the Turbo Cart could be used to monitor pressure during pumpdown.	Minor loss in operating time with no long term effects.

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

P&I Number: V049-0-003
Node: 3
System: Annulus Vacuum System
Date: 6/25/96

Node 3 is the Annulus ion pump and the *connections from the* double "O" rings seals on the 104" and 4 - 60" flanges. and Louisiana BSC 1 and 3. The numbers below reflect WBSC1.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
5		75 liter/second ion pump	5A: Ion pump shuts down on high current caused by premature operation on pumpdown.	Pump down ceases. Restart turbopump, complete pump down to acceptable pressure for ion pump, and restart ion pump.	No significant effect.
			5B: Ion pump fails mechanically or electrically	Loss in Annulus Vacuum Pumping. Indication of loss of pump operation by current readings on LIGO control system.	Increase in leakage from atmosphere into the LIGO vacuum equipment until the annulus ion pump is replaced. The ion pump can be replaced, turbopumped, and brought back online without the chamber vacuum being broken. No significant effect.
			5C: Ion pump shuts down due to high pressure caused by annulus leak from atmosphere.	Once the ion pump fails to restart due to high current, an auxiliary turbocart can be attached to the 2 1/2" AVHV and the turbocart pressure gauges used to confirm the loss of vacuum.	LIGO Operations will determine the timing of helium leak checking the annulus "O" ring seal. If the seal cannot be fixed externally by tightening bolts, etc. The BSC will have to be isolated and the "O" ring repaired or replaced.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the BSC and other chambers in the Corner Vertex Section back to vacuum.

					Estimated leakage rate per "O" ring seal from atmospheric pressure is 1 x 10-5 Torr-liter/sec. This would be the rate if either the inner or outer ring failed.
6		"O" Ring Seals on the 104" top section and the 4 - 60" ports and interconnecting piping.	6A: "O" Ring seals fails, or leakage in a piping item (flex hose, flange)	Same as Failure Mode 5C above	Same as Failure Mode 5C above

P&I Number: V049-0-003
Node: 4
System: Beam Splitter Chamber
Date: 6/24/96

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
7	WBSC1	Beam Splitter Chamber	7A: Any flange leak or leak in a feed through	Loss in vacuum is indicated on the Cold Cathode or Pirani gauge located on adjacent BSC (WBSC2).	LIGO Operations will determine the timing of helium leak checking the chamber and repairing the leak.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the BSC and the other chambers in the Corner Vertex Section back to vacuum.
			7B: Opening of the 2 1/2" RGA Port valve, the 1 1/2" Aux. Turbo Pumpout Port valve, or the 14" Air Shower Connection with the BSC under vacuum.	The BSC and other sections of the vacuum enclosure connected to it would rapidly pressurize with contamination of the vacuum enclosure. The rapid air flow into the open valve might cause injury to personnel nearby.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

Process Systems International, Inc.

P&I Number: V049-0-004
Node: 5
System: Annulus Vacuum System
Date: 6/25/96

Node 5 is the Annulus ion pump and the connections from the double "O" rings seals on the 2 - 84" and 2 - 60" flanges.
This P&I represents all 19 HAM's, Washington 1-13, and Louisiana 1-6. The numbers below reflect WHAM1.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
8		75 liter/second ion pump	8A: Ion pump shuts down on high current caused by premature operation on pumpdown.	Pump down ceases. Restart turbopump, complete pump down to acceptable pressure for ion pump, and restart ion pump.	No significant effect.
			8B: Ion pump fails mechanically or electrically	Loss in Annulus Vacuum Pumping. Indication of loss of pump operation by current readings on LIGO control system.	Increase in leakage from atmosphere into the LIGO vacuum equipment until the annulus ion pump is replaced. The ion pump can be replaced, turbopumped, and brought back online without the chamber vacuum being broken. No significant effect.
			8C: Ion pump shuts down due to high pressure caused by annulus leak from atmosphere.	Once the ion pump fails to restart due to high current, an auxillary turbocart can be attached to the 2 1/2" AVHV and the turbocart pressure gauges used to confirm the loss of vacuum.	LIGO Operations will determine the timing of helium leak checking the annulus "O" ring seal. If the seal cannot be fixed externally by tightening bolts, etc. The HAM will have to be isolated and the "O" ring repaired or replaced.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the HAM and other chambers in the isolatable section back to vacuum.

					Estimated leakage rate per "O" ring seal from atmospheric pressure is 1 x 10-5 Torr-liter/sec. This would be the rate if either the inner or outer ring failed.
9		"O" Ring Seals on the 2 - 84" and the 2 - 60" ports and interconnecting piping.	9A: "O" Ring seals fails, or leakage in a piping item (flex hose, flange)	Same as Failure Mode 8C above	Same as Failure Mode 8C above

Rev.
Prepared by:
Reviewed by:

P&I Number: V049-0-004
Node: 6
System: Horizontal Access Module
Date: 6/26/96

Node 6 is the Horizontal Access Module.
This P&I represents all 19 HAM's, Washington 1-13, and Louisiana 1-6. The numbers below reflect WHAM1.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
10	WHAM1	Horizontal Access Module	10A: Any flange leak or leak in a feed through	Loss in vacuum is indicated on the Cold Cathode or Pirani gauge located BSC in the same isolatable section (WBSC2).	LIGO Operations will determine the timing of helium leak checking the chamber and repairing the leak.
					The overall repair operation will result in a loss of operating time to effect the repairs and bring the HAM and the other chambers in the Isolatable Section back to vacuum.
			10B: Opening of the 2 1/2" RGA Port valve, the 1 1/2" Aux. Turbo Pumpout Port valve, or the 14" Air Shower Connection with the HAM under vacuum.	The HAM and other sections of the vacuum enclosure connected to it would rapidly pressurize with contamination of the vacuum enclosure. The rapid air flow into the open valve might cause injury to personnel nearby.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

P&I Number: V049-0-005
Node: 7
System: Large Gate Valves
Date: 6/26/96

This P&ID depicts the pneumatic and motor driven 44" and 48" gate valves.
There are 8 - 44" pneumatic gate valves, Washington 5-8, and Louisiana 3-6.
There are 8 - 48" and 16 - 44" electric gate valves, Wasnington 1-4, and 9-20. and Louisiana 1,2 and 7-12.
The equipment and instrument numbers reflect WGV5 for pneumatic and WGV1 for electric.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
11		25 liter/second ion pump on one of the Pneumatic Gate Valves	11A: Ion pump shuts down on high current caused by premature operation on pumpdown.	Pump down ceases. Restart turbopump, complete pump down to acceptable pressure for ion pump, and restart ion pump.	No significant effect.
			11B: Ion pump fails mechanically or electrically	Loss in Annulus Vacuum Pumping. Indication of loss of pump operation by current readings on LIGO control system.	Increase in leakage from atmosphere into the LIGO vacuum equipment until the annulus ion pump is replaced. The ion pump can be replaced, turbopumped, and brought back online without the chamber vacuum being broken. No significant effect.
			11C: Ion pump shuts down due to high pressure caused by annulus leak from atmosphere.	Once the ion pump fails to restart due to high current, an auxiliary turbocart can be attached to the 1 1/2" AVHV and the turbocart pressure gauges used to confirm the loss of vacuum.	LIGO Operations will determine the timing of helium leak checking the annulus "O" ring seal. If the seal cannot be fixed externally by tightening bolts, etc., the gate valve will have to be isolated and the "O" ring repaired or replaced.
					This operation requires closing the gate valve and the next large gate valve on the side where the leak is detected.

					The overall repair operation will result in a loss of operating time to effect the repairs and bring the HAM and other chambers in the isolatable section back to vacuum.
					Estimated leakage rate per "O" ring seal from atmospheric pressure is 1 x 10-5 Torr-liter/sec. This would be the rate if either the inner or outer ring failed.

P&I Number: V049-0-005
Node: 8
System: Large Gate Valves
Date: 6/27/96

The large gate valves, whether pneumatic or electric are driven from the computer. Since the opening of one of these valves exposes an atmospheric section to high vacuum and vice versa we recommend and plan to configure the controls such that they can only be operated from the control room. At the valve itself there is a lockout with a keyed padlock which prevents opening even if the computer initiates it. LIGO operating procedures will stress the critical nature of the lockout / tagout function.
The lockout feature of the valves is also used in the open position.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
12	WGV5	44" Pneumatic Gate Valve	12A: Valve Fails to Close, caused by instrument air failure, failure of drive mechanism, or failure to open lockout.	Failure to isolate a section when desired - causes a delay in isolating a section either for pumpdown to vacuum, repressurization, or cryopump regeneration.	Minor loss in operating time - No long term effect.
			12B: Valve Fails to Open, caused by instrument air failure, failure of drive mechanism, damage to drive mechanism caused by excessive differential pressure, failure to open lockout, or failure of the latching mechanism to release.	Failure to open a section when desired - causes a delay in opening a section either for work to be performed at atmospheric pressure or return to operation of the interferometer and cryopump.	Minor loss in operating time - No long term effect.
			12C: Valve is Closed with the Laser on	Damage to the valve and possibly other equipment	Major loss in operating time to remove the valve for repair or replacement, repair instrument damage and remove contamination from the adjacent area followed by a bakeout of a large section of the vacuum enclosure.

			12D: Valve fails to fully close or open as indicated by limit switches, or false signal from limit switches indicating failure to open or close.	Same as 12A and 12B	Minor loss in operating time - No long term effect.
			12E: Valve is opened at an inappropriate time	Section containing equipment and personnel under atmospheric pressure is exposed to vacuum causing injury or death and damage to equipment on both sides of valve.	Major loss in operating time to repair instrument damage followed by a bakeout of a large section of the vacuum enclosure.

P&I Number:	V049-0-005
Node:	9
System:	Large Gate Valves
Date:	6/27/96

This P&ID depicts the pneumatic and motor driven 44" and 48" gate valves.
There are 8 - 44" pneumatic gate valves, Washington 5-8, and Louisiana 3-6.
There are 8 - 48" and 16 - 44" electric gate valves, Wasnington 1-4, and 9-20. and Louisiana 1,2 and 7-12.
The equipment and instrument numbers reflect WGV5 for pneumatic and WGV1 for electric.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
13		25 liter/second ion pump on one of the Electric Gate Valves	13A: Ion pump shuts down on high current caused by premature operation on pumpdown.	Pump down ceases. Restart turbopump, complete pump down to acceptable pressure for ion pump, and restart ion pump.	No significant effect.
			13B: Ion pump fails mechanically or electrically	Loss in Annulus Vacuum Pumping. Indication of loss of pump operation by current readings on LIGO control system.	Increase in leakage from atmosphere into the LIGO vacuum equipment until the annulus ion pump is replaced. The ion pump can be replaced, turbopumped, and brought back online without the chamber vacuum being broken. No significant effect.
			13C: Ion pump shuts down due to high pressure caused by annulus leak from atmosphere.	Once the ion pump fails to restart due to high current, an auxiliary turbocart can be attached to the 1 1/2" AVHV and the turbocart pressure gauges used to confirm the loss of vacuum.	LIGO Operations will determine the timing of helium leak checking the annulus "O" ring seal. If the seal cannot be fixed externally by tightening bolts, etc., the gate valve will have to be isolated and the "O" ring repaired or replaced.
					This operation requires closing the gate valve and the next large gate valve on the side where the leak is detected.

					The overall repair operation will result in a loss of operating time to effect the repairs and bring the HAM and other chambers in the isolatable section back to vacuum.
					Estimated leakage rate per "O" ring seal from atmospheric pressure is 1 x 10-5 Torr-liter/sec. This would be the rate if either the inner or outer ring failed.

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

Process Systems International, Inc.

P&I Number: V049-0-005
Node: 10
System: Large Gate Valves
Date: 6/27/96

The large gate valves, whether pneumatic or electric are driven from the computer. Since the opening of one of these valves exposes an atmospheric section to high vacuum and vice versa we recommend and plan to configure the controls such that they can only be operated from the control room. At the valve itself there is a lockout with a keyed padlock which prevents opening even if the computer initiates it. LIGO operating procedures will stress the critical nature of the lockout / *tagout function.*
The lockout feature of the valves is also used in the open position.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
14	WGV1	48" Electric Gate Valve	14A: Valve Fails to Close, caused by power failure, failure of drive mechanism, or failure to open lockout.	Failure to isolate a section when desired - causes a delay in isolating a section either for pumpdown to vacuum, repressurization, or cryopump regeneration.	Minor loss in operating time - No long term effect.
			14B: Valve Fails to Open, caused by power failure, failure of drive mechanism, damage to drive mechanism caused by excessive differential pressure, failure to open lockout, or failure of the latching mechanism to release.	Failure to open a section when desired - causes a delay in opening a section either for work to be performed at atmospheric pressure or return to operation of the interferometer and cryopump.	Minor loss in operating time - No long term effect.
			14C: Valve is Closed with the Laser on	Damage to the valve and possibly other equipment	Major loss in operating time to remove the valve for repair or replacement, repair instrument damage and remove contamination from the adjacent area followed by a bakeout of a large section of the vacuum enclosure.

			14D: Valve fails to fully close or open as indicated by limit switches, or false signal from limit switches indicating failure to open or close.	Same as 14A and 14B	Minor loss in operating time - No long term effect.
			14E: Valve is opened at an inappropriate time	Section containing equipment and personnel under atmospheric pressure is exposed to vacuum causing injury or death and damage to equipment on both sides of valve.	Major loss in operating time to repair instrument damage followed by a bakeout of a large section of the vacuum enclosure.

P&I Number: V049-0-006
Node: 11
System: 80K Cryopump LN2 and GN2 Supply
Date: 6/27/96

At each cryopump there is a dedicated LN2 supply dewar located outside the building. The cryopump regeneration system consists of an ambient vaporizer also located outside the building, a hand control valve, a flow indicator, and an electric heater to warm the gas.
The storage dewar includes a pressure building coil and all the normal pressure relief protection.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
15	LV-100	LN2 Level Control Valve	15A: Valve fails closed	Failure to make up liquid to the cryopump with loss of effectiveness and eventual release of adsorbed water vapor.	None
				LAL-100 indicates problem, valve can either be repaired or HV-194 can be used to supply make-up manually.	
			15B: Valve fails open	The cryopump reservoir overfills spilling LN2 out the vent.	None
				LAH-100 indicates problem, the manual block valve closed and LV-100 repaired or HV-194 can be used to supply make-up manually.	
16	WDW1	LN2 Dewar and associated vendor supplied valving and pressure building coil.	16A: Vessel or line rupture caused by overpressure	Vessel is protected against rupture by RV 106 and rupture disk RD 106. Potentially blocked in liquid lines are protected by RV 108, 112, 132, and 136.	None - Vessel rupture can be eliminated as a failure mode

			16B: RV fails to reseat after relief	Partial loss of LN2 inventory. Block valve can be closed and valve repaired. Makeup rate to the Cryopump is low enough that it can be cut off for a short period of time without detrimental effects to the system.	None
17		Ambient Vaporizer	17A: Outside surface covered with ice limiting effectiveness.	Inability to vaporize sufficient LN2 for regeneration. Regeneration can be stopped until the vaporizer can be derimed or regeneration can be done at a lower rate.	None
18		Electric Heater	18A: Heater burns out. Protection is by hard wired TSH-103.	Inability to heat the gas above ambient. This would slow regeneration.	None
			18B: JC-103 fails with low output.	Inability to heat the gas above ambient. This would slow regeneration.	None
			18C: TIC-103 fails with high output	TAH-103 alerts LIGO operators who can the cut the power to the heater.	Although the inner annulus may be heated above its' design temperature, there is no source of significant overpressure since the annulus is open to the atmosphere so vessel rupture caused by overheat is not a failure mode. None

P&I Number: V049-0-006
Node: 12
System: 80K Cryopump
Date: 6/27/96

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
19	WCP1	80 K Cryopump	19A: Leakage from atmosphere, either through a faulty weld or through the Relief Valve.	Failure to maintain vacuum, each cryopump has a gauge pair which will indicate loss of vacuum. The leak can either be repaired with the cryopump in service or the cryopump can be isolated and the leak repaired.	Minor loss in operating time to isolate the Cryopump, leak check, and bring the cryopump back online since each cryopump is designed to be isolated for regeneration.
			19B: Rupture or leak from LN2 reservoir into the cryopump while the cryopump is isolated for regeneration.	Overpressure of the cryopump shell. Protection is provided by relief device on the cryopump shell.	Major loss in operating time to isolate the cryopump, effect repairs on the internal annulus, clean and decontaminate the repaired area, rebake the isolatable section containing the cryopump and return to vacuum.
			19C: Rupture or leak from LN2 reservoir into the cryopump during normal operation	Failure to maintain vacuum, each cryopump has a gauge pair which will indicate loss of vacuum.	Major loss in operating time to isolate the cryopump, effect repairs on the internal annulus, clean and decontaminate the repaired area, rebake the isolatable section containing the cryopump and return to vacuum.

P&I Number: V049-0-010
Node: 13
System: Washington Site Left End Station
Date: 6/27/96

Node 13 includes all the normally connected equipment. The BSC chamber covered on P&ID V049-0-002, WIP11, and WCP7.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
20	WIP11	2500 liter/sec ion pump and its' associated 14" gate valve.	13A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			13B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
21	WCP7	80 K Cryopump (Short)	21A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-424 A or B will indicate leak. The cryopump can be isolated with WGV17 and 18 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
22	PI 424 A or B	Gauge Pair on Cryopump	22A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

23	WGV18	Large Motor Operated Gate Valve	23A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			23B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			23C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			23D:Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
24	WGV17	Large Motor Operated Gate Valve	24A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			24B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			24C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			24D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

P&I Number: V049-0-010
Node: 14
System: Washington Site Left End Station
Date: 6/27/96

Node 14 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing Pump Cart are self-protected. See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
25	WTC5	Turbopump cart and associated connections	25A:Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
26	HV 420 / 421	10" Pump out port valve	26A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
27	WTC5B	Turbo pump backing cart	27A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

28	WCA400	Class 100 Clean Air Supply System	28A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
29	PCV-426	First stage letdown valve	29A: Fail open	Increase downstream pressure to PCV-427. If PCV-427's response is not fast enough the clean air supply header pressure will increase limited by PSV-425 which will relieve at 2 psig.	None
			29B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
30	PCV-427	Second stage letdown valve	30A: Fail open	The clean air supply header pressure will increase limited by PSV-425 which will relieve at 2 psig.	None
			30B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-011
Node: 15
System: Washington Left Mid Station
Date: 6/27/96

Node 15 includes all the normally connected equipment; WCP4, WBSC6, WIP9, WCP3, and WGV 9,10,11, and 12.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
31	WIP9	2500 liter/sec ion pump and its' associated 14" gate valve.	31A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			31B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
32	WCP4	80 K Cryopump (Short)	32A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-245 A or B will indicate leak. The cryopump can be isolated with WGV11 and 12 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
33	PI 245 A or B	Gauge Pair on Cryopump	33A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

34	WCP3	80 K Cryopump (Short)	34A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-244 A or B will indicate leak. The cryopump can be isolated with WGV9 and 10 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
35	PI 244 A or B	Gauge Pair on Cryopump	35A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None
36	WGV12	Large Motor Operated Gate Valve	36A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			36B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			36C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			36D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
37	WGV11	Large Motor Operated Gate Valve	37A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			37B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			37C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			37D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
38	WGV10	Large Motor Operated Gate Valve	38A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			38B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			38C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			38D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

39	WGV9	*Large Motor Operated Gate Valve*	39A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			39B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			39C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			39D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

P&I Number: V049-0-011
Node: 16
System: Washington Left Mid Station
Date: 6/28/96

Node 16 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing Pump Cart are self-protected. See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
40	WTC3	Turbopump cart and associated connections	40A:Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
41	HV 240 / 241 / 242	10" Pump out port valves	41A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
42	WTC3B	Turbo pump backing cart	42A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

43	WCA200	Class 100 Clean Air Supply System	43A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
44	PCV-261	First stage letdown valve	44A: Fail open	Increase downstream pressure to PCV-284. If PCV-284's response is not fast enough the clean air supply header pressure will increase limited by PSV-260 which will relieve at 2 psig.	None
			44B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
45	PCV-284	Second stage letdown valve	45A: Fail open	The clean air supply header pressure will increase limited by PSV-260 which will relieve at 2 psig.	None
			45B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-012
Node: 17
System: Washington Site Left Beam Manifold
Date: 6/28/96

Node 17 includes all the normally connected equipment; WCP1, WBSC8, WIP5, and WGV 5 and 6.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
46	WIP5	2500 liter/sec ion pump and its' associated 14" gate valve.	46A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			46B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
47	WCP1	80 K Cryopump (Long)	47A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-114 A or B will indicate leak. The cryopump can be isolated with WGV5 and 6 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
48	PI 114 A or B	Gauge Pair on Cryopump	48A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

49	WGV5	Large Pneumatic Gate Valve	49A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			49B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			49C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			49D:Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
50	WGV6	Large Pneumatic Gate Valve	50A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			50B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			50C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

			50D:Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
51	HV 146 / 147 / 148	10" Pump out port valves	51A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

1 of 4
Process Systems International, Inc.

P&I Number: V049-0-013
Node: 18
System: Washington Site Vertex Section
Date: 6/28/96

Node 18 is the entire P&ID. The vertex section is one large isolatable section with only two large gate valves. There are no cryopumps in the vertex section. The FMEA information for the HAM's and BSC's is found on the FMEA sheets for P&ID's V049-0-002, 003 and 004.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
52	WIP1	2500 liter/sec ion pump and its' associated 14" gate valve.	52A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			52B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
53	WIP2	2500 liter/sec ion pump and its' associated 14" gate valve.	53A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect

			53B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
54	WIP3	2500 liter/sec ion pump and its' associated 14" gate valve.	54A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			54B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
55	WIP4	2500 liter/sec ion pump and its' associated 14" gate valve.	55A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			55B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replace without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.

56	HV 109	10" Pump out port valves	56A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
57	HV 145	6" Pump out port valve	57A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
58	WGV1	Large Motor Operated Gate Valve	58A: Valve fails to close	Inability to isolate vertex section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			58B: Valve fails to open	Inability to return vertex section to operation. Valve can be repaired and the valve	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			58C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			58D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
59	WGV2	Large Motor Operated Gate Valve	59A: Valve fails to close	Inability to isolate vertex section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			59B: Valve fails to open	Inability to return vertex section to operation. Valve can be repaired and the valve	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			59C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			59D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
60	WTC2	Turbopump cart and associated connections	60A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
61	WRC2	Roughing pump cart and associated connections	61A: Pump shuts down for any of a number of reasons.	Delay in rough pumping the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

P&I Number: V049-0-014
Node: 19
System: Washington Site Diagonal Section
Date: 6/28/96

Node 19 is the entire P&ID. The diagonal section is one large isolatable section with only two large gate valves. There are no cryopumps in the diagonal section. The FMEA information for the HAM's and BSC's is found on the FMEA sheets for P&ID's V049-0-002 and 004.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
62	WIP7	2500 liter/sec ion pump and its' associated 14" gate valve.	62A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			62B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
63	WIP8	2500 liter/sec ion pump and its' associated 14" gate valve.	63A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect

			63B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
64	HV 174	10" Pump out port valves	64A: Valve opened to atmosphere with vacuum in the tube. This is a manual gate valve with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of this valve.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
65	HV 160	6" Pump out port valves	65A: Valve opened to atmosphere with vacuum in the tube. This is a manual gate valve with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of this valve.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
66	WGV3	Large Motor Operated Gate Valve	66A: Valve fails to close	Inability to isolate diagonal section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			66B: Valve fails to open	Inability to return diagonal section to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			66C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			66D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
67	WGV4	Large Motor Operated Gate Valve	67A: Valve fails to close	Inability to isolate diagonal section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			67B: Valve fails to open	Inability to return diagonal section to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			67C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			67D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
68	WCT1	Turbopump cart and associated connections	68A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

69	WRC1	Roughing pump cart and associated connections	69A: Pump shuts down for any of a number of reasons.	Delay in rough pumping the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

P&I Number: V049-0-015
Node: 20
System: Washington Site Right Beam Manifold
Date: 6/28/96

Node 20 includes all the normally connected equipment; WCP2, WBSC7, WIP6, and WGV 7 and 8.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
70	WIP6	2500 liter/sec ion pump and its' associated 14" gate valve.	70A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			70B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
71	WCP2	80 K Cryopump (Long)	71A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-134 A or B will indicate leak. The cryopump can be isolated with WGV7 and 8 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
72	PI 134 A or B	Gauge Pair on Cryopump	72A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

73	WGV7	Large Pneumatic Gate Valve	73A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			73B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			73C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			73D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
74	WGV8	Large Pneumatic Gate Valve	74A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			74B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			74C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

			74D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
75	HV 176 / 177 / 178	10" Pump out port valves	75A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

P&I Number: V049-0-016
Node: 21
System: Washington Site Right Mid Station
Date: 6/28/96

Node 21 includes all the normally connected equipment; WCP5, WBSC5, WIP10, WCP6, and WGV 13,14,15, and 16.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
76	WIP10	2500 liter/sec ion pump and its' associated 14" gate valve.	76A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			76B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
77	WCP5	80 K Cryopump (Short)	77A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-344 A or B will indicate leak. The cryopump can be isolated with WGV13 and 14 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
78	PI 344 A or B	Gauge Pair on Cryopump	78A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

79	WCP6	80 K Cryopump (Short)	79A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-345 A or B will indicate leak. The cryopump can be isolated with WGV15 and 16 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
80	PI 345 A or B	Gauge Pair on Cryopump	80A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None
81	WGV13	Large Motor Operated Gate Valve	81A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			81B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			81C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			81D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
82	WGV14	Large Motor Operated Gate Valve	82A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			82B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			82C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			82D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
83	WGV15	Large Motor Operated Gate Valve	83A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			83B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			83C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			83D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

84	WGV16	Large Motor Operated Gate Valve	84A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			84B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			84C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			84D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

P&I Number: V049-0-016
Node: 22
System: Washington Site Right Mid Station
Date: 6/28/96

Node 22 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing Pump Cart are self-protected. See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
85	WTC4	Turbopump cart and associated connections	85A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
86	HV 340 / 341 / 342	10" Pump out port valves	86A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
87	WTC4B	Turbo pump backing cart	87A; Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

88	WCA300	Class 100 Clean Air Supply System	88A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
89	PCV-361	First stage letdown valve	89A: Fail open	Increase downstream pressure to PCV-384. If PCV-384's response is not fast enough the clean air supply header pressure will increase limited by PSV-360 which will relieve at 2 psig.	None
			89B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
90	PCV-384	Second stage letdown valve	90A: Fail open	The clean air supply header pressure will increase limited by PSV-360 which will relieve at 2 psig.	None
			90B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-017
Node: 23
System: Washington Site Right End Station
Date: 6/28/96

Node 23 includes all the normally connected equipment. The BSC chamber covered on P&ID V049-0-002, WIP12, WCP8, WGV19 and WGV20.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
91	WIP12	*2500 liter/sec ion pump* and its' associated 14" gate valve.	91A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			91B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
92	WCP8	80 K Cryopump (Short)	92A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-524 A or B will indicate leak. The cryopump can be isolated with WGV19 and 20 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
93	PI 524 A or B	Gauge Pair on Cryopump	93A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

94	WGV19	Large Motor Operated Gate Valve	94A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			94B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			94C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			94D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
95	WGV20	Large Motor Operated Gate Valve	95A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			95B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			95C; Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			95D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

P&I Number:	V049-0-017
Node:	24
System:	Washington Site Right End Station
Date:	6/28/96

Node 24 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing *Pump Cart are self-protected.* See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
96	WTC6	Turbopump cart and associated connections	96A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
97	HV 520 / 521	10" Pump out port valve	97A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
98		Turbo pump backing cart	98A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	*Shutdown of turbo cart and* delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

99		Class 100 Clean Air Supply System	99A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
100	PCV-526	First stage letdown valve	100A: Fail open	Increase downstream pressure to PCV-527. If PCV-527's response is not fast enough the clean air supply header pressure will increase limited by PSV-525 which will relieve at 2 psig.	None
			100B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
101	PCV-527	Second stage letdown valve	101A: Fail open	The clean air supply header pressure will increase limited by PSV-525 which will relieve at 2 psig.	None
			101B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-018
Node: 25
System: Washington Site Corner Station Mechanical Room
Date: 6/28/96

Node 25 includes the turbo and roughing backing pump carts and the clean air supply system equipment in the mechanical room. The Turbo Backing Pump Cart and Roughing Backing pump cart are self-protected. See Hazards Analysis sheets for the Turbo Carts and Roughing Pump Carts. The units shut down on loss of seal gas to the backing cart, loss of cooling water flow shuts them down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart or roughing pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
102	WRC1B	Roughing pump backing cart	102A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of roughing pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
103	WRC2B	Roughing pump backing cart	103A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of roughing pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
104	WTC1B	Turbo pump backing cart	104A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

105	WTC2B	Turbo pump backing cart	105A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
106	WCA100	Class 100 Clean Air Supply System	106A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
107	PCV-184	First stage letdown valve	107A: Fail open	Increase downstream pressure to PCV-198. If PCV-198's response is not fast enough the clean air supply header pressure will increase limited by PSV-175 which will relieve at 2 psig.	None
			107B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

108	PCV-198	Second stage letdown valve	108A: Fail open	The clean air supply header pressure will increase limited by PSV-175 which will relieve at 2 psig.	None
			108B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-020
Node: 32
System: Louisiana Site Left End Station
Date: 7/2/96

Node 32 includes all the normally connected equipment. The BSC chamber covered on P&ID V049-0-002, LIP5, and LCP3.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
147	LIP5	2500 liter/sec ion pump and its' associated 14" gate valve.	147A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			147B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
148	LCP3	80 K Cryopump (Short)	148A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-724 A or B will indicate leak. The cryopump can be isolated with LGV9 and 10 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
149	PI 724 A or B	Gauge Pair on Cryopump	149A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

150	LGV9	Large Motor Operated Gate Valve	150A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			150B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			150C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			150D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
151	LGV10	Large Motor Operated Gate Valve	151A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			151B:Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			151C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			151D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

Process Systems International, Inc.

P&I Number: V049-0-020 Rev. 1
Node: 33
System: Louisiana Site Left End Station
Date: 4/17/96

Node 33 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing Pump Cart are self-protected. See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
152	LTC3	Turbopump cart and associated connections	152A:Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
153	HV 720 / 721	10" Pump out port valve	153A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
154	LTC3B	Turbo pump backing cart	154A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

155	LCA700	Class 100 Clean Air Supply System	155A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
156	PCV-726	First stage letdown valve	156A: Fail open	Increase downstream pressure to PCV-727. If PCV-727's response is not fast enough the clean air supply header pressure will increase limited by PSV-725 which will relieve at 2 psig.	None
			156B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
157	PCV-727	Second stage letdown valve	157A: Fail open	The clean air supply header pressure will increase limited by PSV-725 which will relieve at 2 psig.	None
			157B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

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Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

P&I Number: V049-0-021
Node: 26
System: Louisiana Site Left & Right Mid Joints
Date: 6/28/96

Node 26 is just the large gate valve at the mid joint connecting two beam tubes for both the left and right arms. The instrumentation (4 gauge pairs) and four pumpout ports are on the beam tube sections.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
109	LGV8	Large Motor Operated Gate Valve	109A: Valve fails to close	Inability to isolate beam tube for pump down or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			109B:Valve fails to open	Inability to return beam tube to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			109C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			109D: Valve opened with pressure on one side.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
110	LGV7	Large Motor Operated Gate Valve	110A: Valve fails to close	Inability to isolate beam tube for pump down or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			10B: Valve fails to open	Inability to return beam tube to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			110C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			110D: Valve opened with pressure on one side.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

Rev.
Prepared by:
Reviewed by:

P&I Number: V049-0-022
Node: 27
System: Louisiana Site Left Beam Manifold
Date: 6/28/96

Node 27 includes all the normally connected equipment; LCP1, LGV 3 and 4. as well as the turbo cart (LTC1) and roughing pump cart (LRC1).

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
111	LCP1	80 K Cryopump (Long)	111A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-614 A or B will indicate leak. The cryopump can be isolated with LGV3 and 4 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
112	PI 614 A or B	Gauge Pair on Cryopump	112A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None
113	PI 680 A or B	Gauge Pair on 72" Beam Tube	113A: Either gauge fails electrically	Loss in the ability to read the vacuum level when this section is isolated from the	None
114	LGV3	Large Pneumatic Gate Valve	114A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			114B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

			114C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			114D: Valve opened with pressure on one side or BSC open to clean room (BSC in Vertex section).	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
115	LGV4	Large Pneumatic Gate Valve	115A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			115B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			115C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			115D: Valve opened with pressure on one side or BSC open to clean room (BSC in Vertex section).	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

116	HV 647 / 648	10" Pump out port valves	116A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
117	HV 646	6" Pump out port valve	117A: Valve opened to atmosphere with vacuum in the tube. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
118	LTC1	Turbopump cart and associated connections	118A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
119	LRC1	Roughing Pump cart and associated connections	119A: Pump shuts down for any of a number of reasons.	Delay in rough pumping the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

P&I Number: V049-0-023 Rev. 1
Node: 28
System: Louisiana Site Vertex Section
Date: 4/16/96

Node 28 is the entire P&ID. The vertex section is one large isolatable section with only two large gate valves. There are no cryopumps in the vertex section. The FMEA information for the HAM's and BSC's is found on the FMEA sheets for P&ID's V049-0-002, 003 and 004.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
120	LIP1	2500 liter/sec ion pump and its' associated 14" gate valve.	120A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			120B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
121	LIP2	2500 liter/sec ion pump and its' associated 14" gate valve.	121A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect

			121B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
122	LIP3	*2500 torr-liter/sec ion* pump and its' associated 14" gate valve.	122A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			122B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
123	LIP4	2500 torr-liter/sec ion pump and its' associated 14" gate valve.	123A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			123B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.

124	HV 609	10" Pump out port valve	124A: Valve opened to atmosphere with vacuum in the tube. This is a manual gate valve with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of this valve.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
125	HV 645	6" Pump out port valve	125A: Valve opened to atmosphere with vacuum in the tube. This is a manual gate valve with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of this valve.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
126	LGV1	Large Motor Operated Gate Valve	126A: Valve fails to close	Inability to isolate vertex section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			126B: Valve fails to open	Inability to return vertex section to operation. Valve can be repaired and the valve	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			126C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			126D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

127	LGV2	Large Motor Operated Gate Valve	127A: Valve fails to close	Inability to isolate vertex section for pumpdown or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			127B: Valve fails to open	Inability to return vertex section to operation. Valve can be repaired and the valve	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			127C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			127D: Valve opened with pressure on one side or one of the BSC's or HAM's open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
128	LTC2	Turbopump cart and associated connections	128A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
129	LRC2	Roughing pump cart and associated connections	129A: Pump shuts down for any of a number of reasons.	Delay in rough pumping the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

			133C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			133D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
134	LGV6	Large Pneumatic Gate Valve	134A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			134B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			134C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			134D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

Rev.
Prepared by:
Reviewed by:

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

1 of 3
Process Systems International, Inc.

P&I Number: V049-0-024
Node: 29
System: Louisiana Site Right Beam Manifold
Date: 7/2/96

Node 29 includes all the *normally connected* equipment; LCP2, LGV 5 and 6.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
130	LCP2	80 K Cryopump (Long)	130A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-634 A or B will indicate leak. The cryopump can be isolated with LGV5 and 6 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
131	PI 634 A or B	Gauge Pair on Cryopump	131A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None
132	PI 670 A or B	Gauge Pair on 72" Beam Tube	132A: Either gauge fails electrically	Loss in the ability to read the vacuum level when this section is isolated from the	None
133	LGV5	Large Pneumatic Gate Valve	133A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"
			133B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 8) "Large Gate Valves"

135	HV 676 / 677 / 678	10" Pump out port valves	135A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.

P&I Number: V049-0-025
Node: 30
System: Louisiana Site Right End Station
Date: 7/2/96

Node 30 includes all the normally connected equipment. The BSC chamber covered on P&ID V049-0-002, LIP6, and LCP4.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
136	LIP6	2500 liter/sec ion pump and its' associated 14" gate valve.	136A: Ion pump shutsdown on high current caused by premature operation during pumpdown of the pump itself or the chamber. The ion pump controller protects the pump from damage due to high current draw.	Pumpdown ceases. Restart Turbopump, complete pumpdown to acceptable pressure for ion pump, and restart ion pump.	No significant effect
			136B: Ion pump fails mechanically or electrically.	Loss in ion pumping capacity. Ion pump failure will be indicated by current and voltage indication sent to the LIGO control system. System pressure will begin to rise.	The 14" GVHV can be closed and the Ion pump replaced without breaking system vacuum. The new ion pump can then be turbopumped, started, and brought online.
137	LCP4	80 K Cryopump (Short)	137A: Leakage from atmosphere or LN2 side.	Loss of vacuum, possible contamination. PI-824 A or B will indicate leak. The cryopump can be isolated with LGV11 and 12 and repaired.	Major or minor loss in operating time depending on source of leak. See Node 12 "80 K Cryopump" for details.
138	PI 824 A or B	Gauge Pair on Cryopump	138A: Either gauge fails electrically	Loss in the ability to read the vacuum level. Either an RGA can be attached to read the pressure or operation may continue without this information until it's convenient to isolate the cryopump and replace the gauges.	None

139	LGV11	Large Motor Operated Gate Valve	139A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			139B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			139C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			139D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
140	LGV12	Large Motor Operated Gate Valve	140A: Valve fails to close	Inability to isolate cryopump for regeneration or back to air operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			140B: Valve fails to open	Inability to return pump to operation. Valve can be repaired and the valve closed.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"
			140C: Valve closed with laser in operation	Damage to equipment and/or valve. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

			140D: Valve opened with pressure on one side or BSC open to clean room.	Damage to equipment, personnel injury or death. Protection is by "two-key" lockout with both computer and physical lockout covered in operating procedures.	See Sheet V049-0-005 (Node 10) "Large Gate Valves"

LIGO Vacuum Equipment
Failure Modes and Effects Analysis

P&I Number: V049-0-025
Node: 31
System: Louisiana Site Right End Station
Date: 7/2/96

Node 31 includes the turbo pumping equipment and the clean air supply system equipment.
The Turbo Cart and its' Turbo Backing Pump Cart are self-protected. See Hazards Analysis sheets for the Turbo Carts.
The unit shuts down on loss of seal gas to the backing cart, loss of cooling water flow shuts it down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
141	LTC4	Turbopump cart and associated connections	141A: Pump shuts down for any of a number of reasons; loss of utility, suction pressure above allowable due to leak or insufficient roughing.	Delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
142	HV 820 / 821	10" Pump out port valve	142A: Valve opened to atmosphere with vacuum in the tube or cryopump. These are manual gate valves with a pad lock for both lock open and lock closed. LIGO procedures will regulate the opening or closing of these valves.	Loss of vacuum, damage to equipment in the tube, contamination, injury or loss of life to personnel near the valve.	Major loss in operating time as the contaminated section might have to be baked out as well as pumped down.
143	LTC4B	Turbo pump backing cart	143A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

144	LCA800	Class 100 Clean Air Supply System	144A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of the Turbo Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
145	PCV-826	First stage letdown valve	145A: Fail open	Increase downstream pressure to PCV-827. If PCV-827's response is not fast enough the clean air supply header pressure will increase limited by PSV-825 which will relieve at 2 psig.	None
			145B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None
146	PCV-827	Second stage letdown valve	146A: Fail open	The clean air supply header pressure will increase limited by PSV-825 which will relieve at 2 psig.	None
			146B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

P&I Number: V049-0-026
Node: 34
System: Louisiana Site Corner Station Mechanical Room
Date: 7/2/96

Node 34 includes the turbo and roughing backing pump carts and the clean air supply system equipment in the mechanical room. The Turbo Backing Pump Cart and Roughing Backing pump cart are self-protected. See Hazards Analysis sheets for the Turbo Carts and Roughing Pump Carts. The units shut down on loss of seal gas to the backing cart, loss of cooling water flow shuts them down on high temperature, power failure, etc.

An intrinsically safe wiring setup has been designed such that it is physically impossible to operate more than one turbo pump cart or roughing pump cart with a single backing pump.

ITEM:	IDENTIFICATION	DESCRIPTION	FAILURE MODES	IMMEDIATE EFFECTS	ULTIMATE EFFECT
158	LRC1B	Roughing pump backing cart	158A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of roughing pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
159	LRC2B	Roughing pump backing cart	159A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of roughing pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
160	LTC1B	Turbo pump backing cart	160A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.

161	LTC2B	Turbo pump backing cart	161A: Pump shuts down for any of a number of reasons; loss of utility, signal from turbo cart controller.	Shutdown of turbo pump cart and delay in pumping out the system. The cause of pump shutdown needs to be corrected and the process restarted.	Minor loss in operating time. No long term effect.
162	LCA600	Class 100 Clean Air Supply System	162A: System shutdown, either compressor out or drier beds won't switch. Three signals go to the LIGO computer for monitoring, Compressor running signal, Compressor Common Alarm, Drier Beds Common Alarm.	A-1: During turbo pumping this would cause shutdown of *the Turbo* Backing Pump on loss of seal air.	Minor loss in operating time. No long term effect.
				A-2: During back to air operation the receiver could be sucked down to vacuum damaging it.	Loss in operating time. This would require replacement of receiver. A vacuum relief valve should be included on the receiver to avoid this situation.
				A-3: During purge operation through air showers loss of flow would allow contamination of optics with moisture should the outage persist long enough to drop the receiver pressure.	None
163	PCV-684	First stage letdown valve	163A: Fail open	Increase downstream pressure to PCV-698. If PCV-698's response is not fast enough the clean air supply header pressure will increase limited by PSV-675 which will relieve at 2 psig.	None
			163B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None

164	PCV-698	Second stage letdown valve	164A: Fail open	The clean air supply header pressure will increase limited by PSV-675 which will relieve at 2 psig.	None
			164B: Fail closed	Loss of clean air flow tripping the turbo or cutting off air shower flow.	None