AD/RHIC/RD–71

RHIC PROJECT

Brookhaven National Laboratory

Safety Relief for RHIC Vacuum Tank

K. C. Wu

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SAFETY RELIEF FOR RHIC VACUUM TANK

K. C. Wu

1). INTRODUCTION

The relief systems are required to prevent overpressure in both the pressure vessel containing cold helium and the vacuum tank for the RHIC cryostats. The pressure relief system for the helium vessel has been designed for a catastrophic loss of the insulating vacuum.[1] In this report, the relief system for the vacuum tank is considered. Unlike the helium vessel, the vacuum tank is designed for low pressure. The tank relief is typically set at 3 to 4 psi (0.2 to 0.3 atm) differential and will be of a disc type supported by three or four springs. The venting capacity for a 2 inch relief valve along with the associated longitudinal pressure drops have been calculated. Results suggest that a safe relief system for RHIC could be achieved provided there is one relief valve on every other magnet cryostat.

2). PHENOMENON

The maximum credible accident (MCA) for the vacuum tank assumes a serious failure occurs in the helium system and cold helium is released into the vacuum tank. Because the tank volume is approximately fifty times that of the helium vessel, the initial pressure in the vacuum tank will be considerably lower than the ambient pressure as cold helium expands in the tank. The pressure and temperature then increase through a constant density heating process. When the pressure reaches the relief setting, helium will be vented outside and the process becomes a constant pressure heating process as illustrated in Fig. 1.

FAILURE OCCURS IN HELIUM SYSTEM

-----> COLD HELIUM EXPANDS INTO VACUUM TANK

-----> HEATING AT CONSTANT DENSITY

-----> REACHES 1 ATM AT ABOUT 15 K

-----> PRESSURE INCREASES FURTHER

-----> VENTING WITH HEATING AT CONSTANT PRESSURE

Figure 1. Heating and venting process with relief valve of the vacuum tank

3). HEAT LOAD

The heat load associated with the type of accident under consideration is rather complicated because of the transient processes of conduction and convection in the vacuum space. In an earlier study using warm helium to spoil the vacuum of a RHIC dipole cryostat[2], a 13 kW heat load from the vacuum tank into the cryostat was identified. In principle, the heat transferred from the tank to cold helium in the vacuum space is more. In this study, calculations have been performed to obtain the amount of heat that can be removed by the venting process as a function of the venting pressure for a 2 inch diameter relief valve. For the conditions here, 25 kW is estimated as the heat load for a magnet cryostat. Should the real heat load exceed 25 kW, it will be shown that the pressure inside the vacuum tank will still be lower than one atmosphere differential for heat loads up to three times estimated.

4). VENTING OF HELIUM

When the upstream pressure is less than two times the downstream pressure the flow is at subsonic conditions. The amount of helium $\dot{m}$ (lb/hr) that can be vented through an orifice of area A (in^2) connected to a large volume is given by equation 1. In equation 1, the constant 600 is obtained with an assumed flow resistance coefficient of 1.5 through the orifice.

$$\frac{\dot{m}_{vent}}{A} = 600 \times Y \times \frac{\sqrt{\Delta P \times P}\,\sqrt{M}}{\sqrt{T}} \qquad (1)$$

$$Y = \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}} \sqrt{\frac{k}{k-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}\right] / \left(1 - \frac{P_2}{P_1}\right)} \qquad (2)$$

where Y is the expansion factor given by equation 2.
P is the upstream pressure, lb/in^2.
ΔP is the differential pressure, lb/in^2.
M is the molecular weight of the gas, 4 for helium.
T is the inlet temperature, in degree R.
k is the specific heat ratio, 5/3 for helium.
subscript *vent* refers to the helium vented through the relief valve.
1 and 2 refer to upstream and downstream of the orifice.

For upstream pressures greater than two times the downstream pressure, the sonic formula given by equation 3 should be used instead

$$\frac{\dot{m}_{vent}}{A} = \frac{C\ K\ P\ \sqrt{M}}{\sqrt{T}} \tag{3}$$

where C is the gas constant, 377 for helium.
K is the valve coefficient of discharge = 0.816.

5). CONSTANT DENSITY HEATING PROCESS

In RHIC, the magnets contain more cold helium than any other helium lines. The failure of a magnet helium containment is considered as the worst accident in sizing the vacuum tank relief. A dipole magnet vacuum tank is about 3000 liters in volume and there are 67 liters of supercritical helium in the dipole magnet. When 67 liters of supercritical helium are released into the 3000 liter vacuum tank, the initial pressure and temperature in the vacuum tank become 0.27 atms and 4.5 K. The constant density heating process will heat the helium to higher temperatures and pressures as shown in Table 1. From Table 1, the temperature at which the relief valve opens can be determined from the set pressure of the valve.

Table 1. Pressure and temperature for the constant density heating process

Pressure - atm	Temperature - K
1.2	19.1
1.4	22.2
1.6	25.4
1.8	28.5
2.0	31.7
2.5	39.5

6). CONSTANT PRESSURE HEATING PROCESS

Although the Table 1 tank pressure (1.2 to 2 atms) at which the relief valve opens is less than the critical pressure of helium, the temperature is greater than the critical temperature. Therefore no phase change occurs when the relief opens. The heating process from thermodynamic state 1 to state x at a higher temperature with helium venting through a relief valve can be illustrated by Fig. 2.[3]

m_1		m_x		(m_1-m_x)
P_1	$\rightarrow$	P_x	+	$P_x=P_1$
T_1		T_x		$T_1 \rightarrow T_x$
h_1		h_x		$h_1 \rightarrow h_x$
ρ_1		ρ_x		$\rho_1 \rightarrow \rho_x$
State 1		*State x*		*Helium Relieved Through Safety Device*

Fig. 2 Heating process from state 1 to x with helium venting through relief valve.

where P is the pressure
T is the temperature
m is the mass of helium
h is the enthalpy
ρ is the density
and subscripts 1 and x refer to thermodynamic states 1 and x.

The heat absorbed by the helium vapor for any such incremental step can be approximated by equation 4. The heat absorbed per unit mass of helium leaving the container is given in equation 5.

$$q = m_x (h_x - h_1) + (m_1 - m_x) \frac{(h_x - h_1)}{2} \tag{4}$$

$$L' = \frac{q}{(m_1-m_x)} = \frac{(h_x-h_1)\ (m_1+m_x)}{2\ (m_1-m_x)} \tag{5}$$

where m , h , 1 and x are as defined above
and q is amount of heat absorbed
L' is the heat absorbed per unit mass of helium leaving the container

The heating rate $\dot{Q}$ during the constant pressure venting process equals the amount of helium to be vented multiplied by the heat absorbing capability as shown in equation 6. In equation 4 through 6, the specific heats from the magnet and other components of the magnet are neglected.

$$\dot{Q} = \dot{m}_{vent} \times L' \tag{6}$$

7). HEAT REMOVING CAPACITY

Based on the initial conditions and the parameters of the cryogenic system, the relief requirements have been calculated for relief pressures from 1.2 to 2.5 atms absolute, i.e. 0.2 to 1.5 atm differential. The detailed results including the constant density and constant pressure heating processes are given in the appendix. A summary of the heat removing capacity for a 2 inch diameter relief as a function of relief pressure is given in Table 2. As one can see, the heat removing capacity increases from about 50 kW to over 200 kW when the relief pressure is increased from 1.2 to 2.5 atms. The pressure difference between the inside of the vacuum tank and the ambient is 0.2 to 1.5 atm. As a general rule, the pressure rating for a vacuum vessel should be at least 1 atm differential. Simple calculation shows that the 1/4" wall 24" O.D. RHIC cryostat can sustain an internal pressure of 5 atm. However, the exact pressure rating for other components of the cryostat can not be obtained as easily.

Table 2. Heat removing capability as a function of relief pressure for the vacuum tank

Pressure atm absolute	Total Area of Relief in^2	Temp. Relief Opens K	Max. Mass Flow g/s	Heat. Removing Capacity kW
1.2	3.14	19.1	523	53
1.4	3.14	22.2	687	81
1.6	3.14	25.4	803	108
1.8	3.14	28.5	863	130
2.0	3.14	31.7	936	157
2.5	3.14	39.5	1035	216

8). SYSTEM INTEGRATION

As can be seen from Table 2, the heat removing capacity for a 2 inch diameter relief valve set at 1.2 atms is 53 kW. This is about twice the 25 kW estimated heat load. Therefore a 2 inch relief is suitable for two magnets. The heat load would have to be three times greater than the estimate before the differential pressure seen by the vacuum tank reaches one atmosphere.

While the cross section of the cryostat is 24 inch in diameter, there are superinsulations, heat shield and cold helium lines inside. Identification of equivalent diameter for pressure drop calculation is required. In Table 3, the longitudinal helium conductances and the equivalent round conduit are given by Kimo Welch[4] from measurements in Full Cell #2.

Table 3. Conductance and equivalent diameter for RHIC cryostats

Cryostat	Conductance	Equivalent Diameter
Dipole Cryostat:	89 L/s	14.0 cm
Standard CQS Cryostat:	152 L/s	13.3 cm
CQS Cryostat w/ Recooler:	307 L/s	16.8 cm

The pressure drop that may occur longitudinally is calculated for a 10 meter dipole cryostat with different venting condition. The results are given in Table 4. As one can be, the longitudinal pressure is not a concern if there is one relief for one or two magnets. Since there are multiple relief valves installed in RHIC, there is no need to install redundant relief valve.

Table 4. Pressure drop for a RHIC dipole cryostat at venting condition shown in Table 2

Pressure atm	Temperature K	Flow Rate g/s	Pressure Drop atm
1.2	19.1	523	0.002
1.4	22.2	687	0.003
1.6	25.4	803	0.003
1.8	28.5	863	0.004
2.0	31.7	936	0.005
2.5	39.5	1035	0.006

REFERENCES

1. K. C. Wu, "Pressure relief for RHIC cryogenic system", RHIC Project Tech. Note AD/RHIC/RD-64, Dec. 1993.
2. R. H. Kropschot, B. W. Birmingham and D. B. Mann, "Technology of Liquid Helium", National Bureau of Standards, Monograph 111, Oct. 1968.
3. K. C. Wu, D. P. Brown, J. Sondericker and D. Zantopp, "An experimental study of catastrophic loss of vacuum for RHIC dipole in MAGCOOL", in "Advances in Cryogenic Engineering", Vol. 39A, p987, Plenum Press, New York (1993).
4. Kimo Welch, "Cryostat Longitudinal Helium Conductances", Memo to K. C. Wu, Dec. 16, 1993.

APPENDIX:

Requirements and operating conditions for the relief valves of the RHIC vacuum tank

Please enter remarks
Chenk the heat absorbing capability for a 2 inch vent in RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.2
qheat-kW
53

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.36	5.96	.003	9.2	32.60	.79
.45	7.42	.003	9.2	37.13	.79
.55	8.89	.003	9.2	41.72	.80
.64	10.35	.003	9.2	46.25	.79
.73	11.81	.003	9.2	50.81	.79
.83	13.27	.003	9.2	55.33	.79
.92	14.74	.003	9.2	59.93	.80
1.01	16.20	.003	9.2	64.46	.79
1.11	17.65	.003	9.2	68.99	.79
1.20	19.10	.003	9.2	73.52	.79

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
19.1	.003	113.1	20.1	.003	118.4	101.4	43.7	22.	523.	3.13	.89	606.
20.1	.003	118.4	21.1	.003	123.6	106.7	46.0	21.	497.	3.05	.85	590.
21.1	.003	123.6	22.1	.003	128.9	112.0	48.2	21.	473.	2.98	.81	575.
22.1	.003	128.9	23.1	.003	134.1	117.2	50.5	20.	452.	2.91	.77	562.
23.1	.003	134.1	24.1	.002	139.4	122.5	52.8	20.	433.	2.84	.74	549.
24.1	.002	139.4	25.1	.002	144.6	127.7	55.0	19.	415.	2.78	.70	537.
25.1	.002	144.6	26.1	.002	149.8	133.0	57.3	19.	398.	2.72	.68	526.
26.1	.002	149.8	27.1	.002	155.1	138.2	59.6	18.	383.	2.67	.65	516.
27.1	.002	155.1	28.1	.002	160.3	143.5	61.8	18.	369.	2.62	.63	506.
28.1	.002	160.3	30.1	.002	170.7	151.3	65.2	18.	350.	2.57	1.19	497.
30.1	.002	170.7	32.1	.002	181.2	161.8	69.7	17.	328.	2.48	1.11	480.
32.1	.002	181.2	34.1	.002	191.6	172.3	74.2	16.	308.	2.40	1.04	464.
34.1	.002	191.6	36.1	.002	202.0	182.7	78.7	16.	290.	2.33	.98	451.
36.1	.002	202.0	38.1	.002	212.5	193.1	83.2	15.	274.	2.27	.93	438.
38.1	.002	212.5	40.1	.001	222.9	203.6	87.7	15.	260.	2.21	.88	426.
40.1	.001	222.9	42.1	.001	233.3	214.0	92.2	15.	248.	2.15	.84	415.
42.1	.001	233.3	44.1	.001	243.7	224.4	96.7	14.	236.	2.10	.80	405.
44.1	.001	243.7	46.1	.001	254.1	234.8	101.2	14.	226.	2.05	.76	396.
46.1	.001	254.1	48.1	.001	264.5	245.3	105.7	13.	216.	2.00	.73	387.
48.1	.001	264.5	50.1	.001	274.9	255.7	110.2	13.	207.	1.96	.70	379.

C:\FORTRAN\NBSDIST>tkrelief

Please enter remarks
Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.4
qheat-kW
81

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.38	6.28	.003	9.2	33.59	.63
.49	8.05	.003	9.2	39.08	.62
.61	9.83	.003	9.2	44.63	.63
.72	11.61	.003	9.2	50.17	.63
.83	13.39	.003	9.2	55.72	.63
.95	15.14	.003	9.2	61.17	.62
1.06	16.92	.003	9.2	66.73	.63
1.17	18.70	.003	9.2	72.28	.63
1.29	20.48	.003	9.2	77.83	.63
1.40	22.23	.003	9.2	83.29	.62

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
22.2	.003	129.5	23.2	.003	134.7	117.9	50.8	20.	687.	3.11	.58	856.
23.2	.003	134.7	24.2	.003	140.0	123.2	53.1	20.	658.	3.04	.56	837.
24.2	.003	140.0	25.2	.003	145.2	128.4	55.3	19.	631.	2.98	.54	819.
25.2	.003	145.2	26.2	.003	150.5	133.7	57.6	19.	606.	2.92	.51	802.
26.2	.003	150.5	27.2	.003	155.7	139.0	59.9	18.	583.	2.86	.49	786.
27.2	.003	155.7	28.2	.002	160.9	144.2	62.1	18.	562.	2.81	.48	772.
28.2	.002	160.9	29.2	.002	166.2	149.5	64.4	18.	542.	2.75	.46	758.
29.2	.002	166.2	30.2	.002	171.4	154.7	66.7	17.	524.	2.71	.44	744.
30.2	.002	171.4	31.2	.002	176.6	159.9	68.9	17.	506.	2.66	.43	732.
31.2	.002	176.6	33.2	.002	187.1	167.8	72.3	17.	483.	2.62	.82	719.
33.2	.002	187.1	35.2	.002	197.5	178.2	76.8	16.	454.	2.54	.77	697.
35.2	.002	197.5	37.2	.002	207.9	188.7	81.3	16.	429.	2.46	.73	677.
37.2	.002	207.9	39.2	.002	218.4	198.8	85.6	15.	408.	2.40	.69	660.
39.2	.002	218.4	41.2	.002	228.8	209.6	90.3	15.	387.	2.33	.65	642.
41.2	.002	228.8	43.2	.002	239.2	220.0	94.8	14.	368.	2.28	.62	626.
43.2	.002	239.2	45.2	.002	249.6	230.4	99.3	14.	352.	2.22	.59	611.
45.2	.002	249.6	47.2	.001	260.0	240.9	103.8	14.	336.	2.17	.57	598.
47.2	.001	260.0	49.2	.001	270.4	251.9	108.5	13.	322.	2.12	.54	583.
49.2	.001	270.4	51.2	.001	280.8	261.7	112.7	13.	310.	2.08	.52	573.
51.2	.001	280.8	53.2	.001	291.3	272.1	117.2	13.	298.	2.04	.50	561.

C:\FORTRAN\NBSDIST>tkrelief

Please enter remarks
Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.6
qheat-kW
108

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.40	6.59	.003	9.2	34.55	.56
.53	8.68	.003	9.2	41.05	.55
.67	10.77	.003	9.2	47.56	.55
.80	12.86	.003	9.2	54.07	.55
.93	14.95	.003	9.2	60.58	.55
1.07	17.02	.003	9.2	67.03	.55
1.20	19.13	.003	9.2	73.61	.56
1.33	21.20	.003	9.2	80.06	.55
1.47	23.31	.003	9.2	86.65	.56
1.60	25.38	.003	9.2	93.11	.55

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
25.4	.003	145.9	26.4	.003	151.2	134.5	57.9	19.	803.	3.15	.44	1066.
26.4	.003	151.2	27.4	.003	156.4	139.7	60.2	18.	773.	3.09	.42	1045.
27.4	.003	156.4	28.4	.003	161.6	145.0	62.5	18.	745.	3.03	.41	1026.
28.4	.003	161.6	29.4	.003	166.9	150.3	64.7	18.	719.	2.98	.39	1007.
29.4	.003	166.9	30.4	.003	172.1	155.5	67.0	17.	695.	2.92	.38	990.
30.4	.003	172.1	31.4	.002	177.3	160.7	69.3	17.	672.	2.87	.37	973.
31.4	.002	177.3	32.4	.002	182.6	165.4	71.3	17.	653.	2.84	.35	960.
32.4	.002	182.6	33.4	.002	187.8	171.2	73.8	16.	631.	2.78	.34	942.
33.4	.002	187.8	34.4	.002	193.0	176.4	76.0	16.	612.	2.74	.33	928.
34.4	.002	193.0	36.4	.002	203.5	184.3	79.4	16.	586.	2.70	.64	914.
36.4	.002	203.5	38.4	.002	213.9	194.7	83.9	15.	555.	2.62	.60	888.
38.4	.002	213.9	40.4	.002	224.3	205.2	88.4	15.	526.	2.55	.57	865.
40.4	.002	224.3	42.4	.002	234.7	215.6	92.9	14.	501.	2.49	.54	843.
42.4	.002	234.7	44.4	.002	245.2	226.1	97.4	14.	478.	2.43	.52	823.
44.4	.002	245.2	46.4	.002	255.6	236.5	101.9	14.	457.	2.38	.50	804.
46.4	.002	255.6	48.4	.002	266.0	246.9	106.4	13.	437.	2.32	.48	786.
48.4	.002	266.0	50.4	.002	276.4	257.4	110.9	13.	420.	2.27	.46	770.
50.4	.002	276.4	52.4	.001	286.8	267.8	115.4	13.	403.	2.23	.44	755.
52.4	.001	286.8	54.4	.001	297.2	278.2	119.9	13.	388.	2.19	.42	740.
54.4	.001	297.2	56.4	.001	307.6	288.6	124.3	12.	374.	2.15	.41	726.

C:\FORTRAN\NBSDIST>tkrelief

Please enter remarks
Chekk the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
1.8
qheat-kW
130

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.42	6.90	.003	9.2	35.52	.53
.57	9.30	.003	9.2	43.00	.53
.73	11.71	.003	9.2	50.48	.53
.88	14.11	.003	9.2	57.96	.53
1.03	16.51	.003	9.2	65.45	.53
1.19	18.91	.003	9.2	72.93	.53
1.34	21.34	.003	9.2	80.49	.54
1.49	23.72	.003	9.2	87.93	.53
1.65	26.14	.003	9.2	95.49	.54
1.80	28.52	.003	9.2	102.92	.53

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
28.5	.003	162.3	29.5	.003	167.6	150.6	64.9	18.	863.	3.09	.36	1212.
29.5	.003	167.6	30.5	.003	172.8	156.3	67.3	17.	832.	3.03	.35	1188.
30.5	.003	172.8	31.5	.003	178.1	161.5	69.6	17.	805.	2.98	.34	1168.
31.5	.003	178.1	32.5	.003	183.3	166.8	71.9	17.	780.	2.93	.33	1149.
32.5	.003	183.3	33.5	.003	188.5	172.0	74.1	16.	756.	2.88	.32	1131.
33.5	.003	188.5	34.5	.003	193.7	177.3	76.4	16.	733.	2.84	.31	1114.
34.5	.003	193.7	35.5	.002	199.0	182.5	78.6	16.	712.	2.80	.30	1098.
35.5	.002	199.0	36.5	.002	204.2	187.7	80.9	16.	692.	2.76	.29	1082.
36.5	.002	204.2	37.5	.002	209.4	193.0	83.1	15.	674.	2.72	.28	1067.
37.5	.002	209.4	39.5	.002	219.8	200.8	86.5	15.	647.	2.68	.55	1052.
39.5	.002	219.8	41.5	.002	230.3	211.3	91.0	15.	615.	2.61	.52	1025.
41.5	.002	230.3	43.5	.002	240.7	221.7	95.5	14.	586.	2.55	.50	1000.
43.5	.002	240.7	45.5	.002	251.1	232.1	100.0	14.	560.	2.49	.47	977.
45.5	.002	251.1	47.5	.002	261.6	242.6	104.5	14.	536.	2.43	.45	955.
47.5	.002	261.6	49.5	.002	272.0	253.0	109.0	13.	514.	2.38	.43	935.
49.5	.002	272.0	51.5	.002	282.4	263.4	113.5	13.	493.	2.33	.42	916.
51.5	.002	282.4	53.5	.002	292.8	273.9	118.0	13.	475.	2.29	.40	898.
53.5	.002	292.8	55.5	.002	303.2	284.3	122.5	12.	457.	2.25	.39	881.
55.5	.002	303.2	57.5	.002	313.6	294.7	127.0	12.	441.	2.20	.37	865.
57.5	.002	313.6	59.5	.001	324.0	305.1	131.5	12.	426.	2.17	.36	850.

C:\FORTRAN\NBSDIST>tkrelief

```
 Please enter remarks
 Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
2
qheat-kW
157
```

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.44	7.22	.003	9.2	36.51	.50
.61	9.94	.003	9.2	44.97	.50
.79	12.66	.003	9.2	53.43	.50
.96	15.38	.003	9.2	61.90	.50
1.13	18.09	.003	9.2	70.38	.50
1.31	20.81	.003	9.2	78.86	.50
1.48	23.53	.003	9.2	87.34	.50
1.65	26.25	.003	9.2	95.83	.50
1.83	28.97	.003	9.2	104.31	.50
2.00	31.69	.003	9.2	112.79	.50

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
31.7	.003	178.9	32.7	.003	184.1	167.7	72.2	17.	936.	3.15	.30	1384.
32.7	.003	184.1	33.7	.003	189.3	172.9	74.5	16.	908.	3.10	.29	1362.
33.7	.003	189.3	34.7	.003	194.6	178.2	76.8	16.	881.	3.05	.28	1342.
34.7	.003	194.6	35.7	.003	199.8	183.4	79.0	16.	856.	3.01	.28	1322.
35.7	.003	199.8	36.7	.003	205.0	188.7	81.3	15.	832.	2.96	.27	1303.
36.7	.003	205.0	37.7	.003	210.3	193.9	83.5	15.	810.	2.92	.26	1285.
37.7	.003	210.3	38.7	.003	215.5	199.1	85.8	15.	788.	2.88	.25	1268.
38.7	.003	215.5	39.7	.002	220.7	204.4	88.1	15.	768.	2.85	.25	1251.
39.7	.002	220.7	40.7	.002	225.9	209.6	90.3	15.	749.	2.81	.24	1235.
40.7	.002	225.9	42.7	.002	236.3	217.4	93.7	14.	722.	2.77	.46	1220.
42.7	.002	236.3	44.7	.002	246.8	227.9	98.2	14.	689.	2.71	.44	1191.
44.7	.002	246.8	46.7	.002	257.2	238.3	102.7	14.	659.	2.65	.42	1164.
46.7	.002	257.2	48.7	.002	267.6	248.8	107.2	13.	631.	2.59	.41	1138.
48.7	.002	267.6	50.7	.002	278.0	259.2	111.7	13.	606.	2.54	.39	1115.
50.7	.002	278.0	52.7	.002	288.5	269.6	116.2	13.	582.	2.49	.37	1093.
52.7	.002	288.5	54.7	.002	298.9	280.0	120.7	12.	561.	2.44	.36	1072.
54.7	.002	298.9	56.7	.002	309.3	290.5	125.1	12.	541.	2.39	.35	1052.
56.7	.002	309.3	58.7	.002	319.7	300.9	129.6	12.	522.	2.35	.34	1033.
58.7	.002	319.7	60.7	.002	330.1	311.3	134.1	12.	504.	2.31	.32	1016.
60.7	.002	330.1	62.7	.002	340.5	321.7	138.6	12.	488.	2.27	.31	999.

```
C:\FORTRAN\NBSDIST>tkrelief
```

Please enter remarks
Check the heat absorbing capability for a 2 inch vent on RHIC cryostat
Enter initial pressure, temperature, liquid volume, tank volume,
relief pressure and heating rate.
pi-atm
5
ti-K
4.5
liquid helium vol-L
67
vacuum tank volume -L
3000
pvent-atm
2.5
qheat-kW
216

Constnat density heating process

p atm	t K	rho g/cc	M kg	u j/g	d-time sec.
5.00	4.50	.137	9.2	8.42	
.27	4.50	.003	9.2	28.03	
.49	8.00	.003	9.2	38.94	.47
.71	11.50	.003	9.2	49.83	.46
.94	15.00	.003	9.2	60.73	.46
1.16	18.49	.003	9.2	71.60	.46
1.38	21.99	.003	9.2	82.52	.47
1.61	25.49	.003	9.2	93.44	.47
1.83	28.99	.003	9.2	104.37	.47
2.05	32.49	.003	9.2	115.28	.47
2.28	35.99	.003	9.2	126.20	.47
2.50	39.49	.003	9.2	137.13	.47

Constant pressure venting process

t1 K	rho1 g/cc	h1 j/g	tx K	rhox g/cc	hx j/g	heatl j/g	L B/lb	Gi	mout g/s	Area in**2	dtime sec	Air SCFM
39.5	.003	219.6	40.5	.003	224.9	208.8	89.9	15.	1035.	3.10	.22	1702.
40.5	.003	224.9	41.5	.003	230.1	214.0	92.2	14.	1009.	3.06	.21	1681.
41.5	.003	230.1	42.5	.003	235.3	219.2	94.5	14.	985.	3.02	.21	1660.
42.5	.003	235.3	43.5	.003	240.5	224.5	96.7	14.	962.	2.99	.20	1640.
43.5	.003	240.5	44.5	.003	245.7	229.7	99.0	14.	940.	2.95	.20	1621.
44.5	.003	245.7	45.5	.003	251.0	234.9	101.2	14.	919.	2.92	.20	1603.
45.5	.003	251.0	46.5	.003	256.2	240.2	103.5	14.	899.	2.89	.19	1585.
46.5	.003	256.2	47.5	.003	261.4	245.4	105.7	13.	880.	2.85	.19	1568.
47.5	.003	261.4	48.5	.003	266.6	250.6	108.0	13.	862.	2.82	.18	1552.
48.5	.003	266.6	50.5	.002	277.0	258.4	111.3	13.	836.	2.79	.36	1535.
50.5	.002	277.0	52.5	.002	287.5	268.9	115.8	13.	803.	2.74	.34	1505.
52.5	.002	287.5	54.5	.002	297.9	279.3	120.3	13.	773.	2.69	.33	1476.
54.5	.002	297.9	56.5	.002	308.3	289.7	124.8	12.	746.	2.64	.32	1448.
56.5	.002	308.3	58.5	.002	318.7	300.2	129.3	12.	720.	2.59	.31	1423.
58.5	.002	318.7	60.5	.002	329.1	310.6	133.8	12.	695.	2.54	.30	1398.
60.5	.002	329.1	62.5	.002	339.5	321.0	138.3	12.	673.	2.50	.29	1375.
62.5	.002	339.5	64.5	.002	350.0	331.4	142.8	11.	652.	2.46	.28	1353.
64.5	.002	350.0	66.5	.002	360.4	341.8	147.3	11.	632.	2.42	.27	1332.
66.5	.002	360.4	68.5	.002	370.8	352.2	151.8	11.	613.	2.39	.26	1312.
68.5	.002	370.8	70.5	.002	381.2	362.7	156.3	11.	596.	2.35	.25	1293.

C:\FORTRAN\NBSDIST>type tkrelief.lst

```
Calculation of pressure drop for
helium flowing in a round pipe
Enter mass flow rate in gm/s
523
Enter pressure in atm
1.2
Enter inlet temperature in degree k
19.1
Enter outlet temperature in degree k
19.1
Enter length of pipe in meter
10
Enter pipe diameter in cm
14
```

PROGRAM DPROUND

INPUT DATA

FIN G/S	PIN ATM	TIN K	TOUT K	LENGTH M	D CM
523.00	1.20	19.10	19.10	10.00	14.00

```
Do you satisfy this input data (y/n) ?
y
```

CALCULATED DATA

FLOW AREA(SQ CM) 153.938
ABSOLUTE ROUGHNESS(CM) .152E-03
RELATIVE ROUGHNESS .109E-04

seg.	p atm	t k	rho g/cc	v cm/s	visc g/cm-s	rey	fric	segdp atm	vel head atm
1	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.50E-04	1.86E-03
2	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.50E-04	1.86E-03
3	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.50E-04	1.86E-03
4	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
5	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
6	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
7	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
8	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
9	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03
10	1.20	19.10	3.07E-03	1.11E+03	3.49E-05	1.36E+06	1.14E-02	1.51E-04	1.86E-03

TOTAL PRESSURE DROP IS .002 ATM

```
Do you want another pressure drop calculation (y/n) ?
y
```