CRYOGENIC PERFORMANCE

D-ZERO SOLENOID COMMISSIONING

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Abstract

D-Zero installed a new 2 Tesla superconducting solenoid magnet into the central tracking region of the D-Zero detector. This report documents the cryogenic performance of the superconducting solenoid during its first cryogenic operation at Fermilab. By necessity, the liquid helium refrigerator was also operated. This was the second time the refrigerator plant has been operated. The refrigerator's performance is also documented herein.

Solenoid cool down

Figure 1 is a historical trend giving an overview of the cool down with time. Figures 2, 3, and 4 give an overview of the cryogenic and electrical system schematics associated with the solenoid system. These figures are actual operator interface pictures for the computer control system at D-Zero.

The solenoid was cooled to 90 K by passing helium gas through piping attached to the support cylinder surrounding the coil. The gas helium supplied was controlled to be 30 to 50 K colder than the support cylinder temperature. The heat exchange of the gas to the support cylinder was nearly perfect so that the exiting gas helium was at the same temperature as the support cylinder. The final cooling period of the solenoid was accomplished by using liquid helium as the coolant. The cooling (watts) supplied and received during each of the cooling periods can be calculated and tabulated.

The cooling supplied is based on the cooling gas. The average cooling = $\dot{m} * C_p * \Delta T_{out-in}$. The mass flow, $\dot{m}$, of the cooling gas was kept constant at 5 g/s. The specific heat at constant pressure, C_p , is constant = 5.194 J/g-K in the temperature range of interest. The average ΔT_{out-in} is read from historical trending data.

The cooling received by the cold mass can be determined by the change of enthalpy of the aluminum cold mass as it dropped in temperature. The average cooling rate, $Q_{(total)} = M * C_p * \Delta T / t$ or $Q_{(total)} = M * \Delta H / t$. The cold mass (includes the coil and outer support cylinder) based on volume is 1250 kg. The average specific heat and enthalpies for the temperature range are taken from the BNL data book pg. VIII-A-1.

Electrical resistance measurements added an additional heat load to the coil that cannot be neglected. At the start of cooling, a 10 amp power supply was connected to the bus work. The resistance of the coil was 1.45 ohms at 287 K. Thus the additional load was about $Q_{(elec)} = I^2 * R = 145$ watts for the first cooling period. The hand log of the resistance of the coil with temperature is included at the end of this note.

—— D0_CCRS2::D0_CCRS2:PLAT_OSC_AVE.F_CV	89.3
—— D0_CCRS2::D0_CCRS2:COILAVE3.F_CV AVERAGE TEMP FOR 3 COIL	88.3
—— D0_CCRS2::D0_CCRS2:FT-2040-H.F_CV High pressure helium to subcooler	5.0
—— D0_CCRS2::D0_CCRS2:COIL_HEOUT-IN.F_CV Solenoid He Out - He In Delta Temp.	2.4
—— D0_CCRS2::D0_CCRS2:OSC_PLAT_DELTA_T.F_CV Sol Support Cyl Delta Temp	0.9

COOLING PERIODS

9/1	13:00-23:00	10 HRS
9/2	8:30-23:00	14.5 HRS
9/3	8:00-9/5 8:00	48 HRS
9/8	13:00 - 22:00	9 HRS

TOT = 81.5 HRS

R. RUCINSKI
10/2/98

D-ZERO Helium System Cryogenic Controls

9/11/98 9:31:46 AM

Figure 2. Helium system cryogenic control page

Figure 3. Solenoid cryogenic system control page

Figure 4. Solenoid energization system control page

The liquid nitrogen cooled radiation shields were not cooled until the final period of cooling below 100 K. Therefore there is a radiation heat load from the outer vacuum jacket, to the shield, and then to the cold mass. An energy balance was made to arrive at the non-cooled shield temperature and the resulting heat load to the cold mass. See the warm up section for details of the calculation.

Table 1. Cool down data

Cooling period	Hrs.	Avg. $\Delta T_{\text{out-in}}$ of gas	Cooling supplied based on gas	Coil start temp (K)	Coil end temp (K)	Alum. avg Cp (J/g-K)	Cooling rate to Cold mass	Cooling Electrical power	Cooling radiation heat load
9/1, 13:00 – 23:00	10	26.4 K	686 watts	294.0	276.7	.888	533 watts	145 watts	45 watts
9/2, 8:30 – 23:00	14.5	38.4 K	997 watts	276.9	240.3	.867	760 watts	123 watts	40 watts
9/3, 8:00- 9/5, 8:00	48	32.9 K	854 watts	240.6	91.8	.703	757 watts	68 watts	30 watts
9/8, 12:00 – 22:00	9	N/a	N/a	100.8	8.1	N/a	685 watts	15 watts	3 watts
Total =	81.5								

Table 2. Cooling rate tabulation and summary

Cooling period	Hours	Cooling supplied based on gas	Cooling rate observed based on cold mass + Elect. Power + Radiation	Avg. DT/dt of cold mass
9/1, 13:00 – 23:00	10	686 watts	723 watts	-1.7 K/hr
9/2, 8:30 – 23:00	14.5	997 watts	923 watts	-2.5 K/hr
9/3, 8:00 – 9/5, 8:00	48	854 watts	855 watts	-3.1 K/hr
9/8, 12:00 – 22:00	9	N/a	703 watts	-10.3 K/hr
Total =	81.5 hrs			

Two cool down constraints were observed. The first was the maximum temperature difference outlet (TP3207-H) to inlet (TP3208-H) ≤ 50 K. This restriction produced an acceptable cool down during the first factory tests at Keihin, Japan. The second cool down constraint was that the maximum temperature difference at any two points on the coil and/or support cylinder ≤ 30 K. This restriction was required so the calculated stresses in the epoxy bond of the coil to support cylinder did not exceed their allowable stress. The cool down progressed based on the 50 K outlet to inlet limit. The maximum temperature differences on the support cylinder were less than 20 K during the cool down. The maximum temperature difference from the outer support cylinder to the coil was kept below 12 K.

The cool down at Fermilab took 81.5 hours of active cooling. For the first two days, the cooling was only done during the first and second shift when it could be supervised.

After the third day we had confidence to continue the cooling around the clock, monitored by the computer. The computer calls experts at home should something go awry. During the weekend, beginning at 11:30 on 9/4, the system was left unmanned with 80 K gas being supplied to the magnet. The magnet was at 110 Kelvin at that time.

Table 3. Cool down comparison to factory test

	Fermilab test	Factory test
Active cooling to get to 4.5 Kelvin	81.5 hours	60 hours
Temperature gradients on support cylinder	< 20 K	< 25 K
Temperature gradient supp. Cylinder to coil	< 12 K	< 9 K

Solenoid heat load

The heat load of the cold solenoid system was calculated by measuring the mass flow that kept the control dewar helium reservoir at a constant liquid level, a few inches below the exit piping elevation. For this condition it was assumed that the helium supplied to the solenoid from the transfer line is saturated liquid and the helium fluid leaving the solenoid via the reservoir is saturated gas. These are good assumptions because the supply transfer line is constructed with the helium supply pipe inside the helium return pipe. The supply gets little heat added, and may in fact get some cooling from the returning gas during test conditions. The supply pressure at the control dewar was 7.4 psig and the reservoir was controlled at 3.8 psig.

The heat leak of the solenoid system is a strong function of the amount of flow up the vapor cooled current leads. The flow up these leads intercepts the heat being conducted down the leads and any electrical power generated when current is present in the busses. This flow is measured and considered to be a liquefaction load. To properly describe the solenoid heat load, it is given in terms of refrigeration load (number of watts to the LHe) and the liquefaction load (# grams/second used and returned warm to the refrigerator.) The sketch of the system model and development of the equation used is included at the end of this engineering note. The technical specification required the solenoid system to be:

$$Q_{sol} \leq 18 \text{ watts} + 1 \text{ g/s (T.S. 5.7.4)}$$

Figure 5. Solenoid refrigeration vs. liquefaction load curve

Measurements made over several different days and conditions are shown in Table 4. The solenoid meets the specification since a sufficiently high lead flow reduces its refrigeration load below 18 watts. See Figure 5 for the zero current and full current operating performance curves.

Table 4. Solenoid system refrigeration and liquefaction load.

Magnet Current (amps)	Refrigeration load (watts)	Liquefaction load (g/s)
0	30.1	0.09
0	24.0	0.13
0	24.8	0.13
0	23.4	0.14
0	20.0	0.17
0	18.8	0.20
0	15.4	0.28
0	14.3	0.36
4740	20.4	0.60
4740	17.0	0.70
4740	16.0	0.76
4740	14.5	0.80
4740	14.8	0.83
4740	15.0	0.90

Additional measurements were made to try to measure the control dewar heat load separate from the chimney and magnet coil. These tests diverted the returning mass flow from the chimney and magnet out the quench recovery line. The boil off rate of the liquid inventory in the isolated helium reservoir was converted to a mass flow. The results had some scatter, probably due to the complication that there was a sub-cooling heat load on the reservoir from the mass flow that was supplied to the coil and diverted. The duration of the boil off tests was about 20 to 30 minutes, and it was difficult to balance a steady flow rate for this time period. Also, for it to be accurate, the mass flow being sub-cooled had to match the total mass flow used in the whole system test. Matching this flow and keeping it steady was difficult.

The goal of these measurements was that by subtraction, the chimney plus coil heat load would be determined. From voltage drop measurements it is suspected that a bad soldering joint at the lower field joint would be adding as much as 6 watts of electrical power to the chimney at the full current. If the chimney plus coil heat load was observed to be 6 watts higher at $I=4740$ amps than at zero current, it would affirm the electrical measurements. Figure 6 shows the results of the measurements. The linear curve fit of the subtraction is the chimney plus coil refrigeration load at the zero and full current conditions. The results although scattered, tended to show an extra 5 watts of resistive heating at full current.

Fig 6. Heat load test curves; Chimney + solenoid = Total – control dewar

Solenoid Fast dump cryogenic behavior

The solenoid was charged in successive steps to 500 amps, 1500 amps, 2500 amps, 4000 amps, and 4840 amps. After reaching the desired current, the solenoid was slow dumped to zero current and then the polarity reversed. After achieving the stable operating current the second time, a fast dump was triggered by opening the dump switch. After testing the magnet to the currents above, the magnet was typically operated at 4740 amperes for the field mapping activities. The temperature rise, pressure rise, and recovery times for these dumps are listed below in Table 6. As a comparison to the factory test, see Figure 7 and Table 5. As one would expect, the Fermilab and Keihin test results are very similar.

Table 5. Fast dump behavior at Fermilab

Current (amps)	AVG Coil rise (K)	Max Coil Temp rise (K)	AVG OSC rise (K)	Pressure rise (psi)	Recovery Time (minutes)
500	0.4	0.7	0.4	0.2	1
1500	2.9	4.0	3.5	1.9	3
2500	9.6	10.6	9.2	4.4	7
4000	20.5	25.3	20.1	4.9	17
4740	26.5	33.9	24.5	5.8	14
4812	27.0	35.0	24.6	7.8	18

Table 6. Fast dump behavior at Factory test, Keihin, Japan

Current (amps)	AVG Coil rise (K)	Max Coil Temp rise (K)	AVG OSC rise (K)
1500	2.7	2.9	1.9
3000	13.4	15.0	12.1
4000	19.8	20.0	18.8
4860	30.1	52.0	27.5

See Figures 8 through 12 for historical trend data of the higher level fast dumps during our commissioning tests. See Figures 13 and 14 for trends at Keihin dumping from 3883 amperes and 4856 amperes. It is interesting to note the north-south temperature gradient from the dumps. There are three carbon resistors mounted on the inside bottom of the coil. TR-3343-H, TR-3344-H, TR-3345-H are mounted at the south, middle, and north end respectively. The cooling pipes enter the magnet and attach to the support cylinder at the south end. For the Fermilab tests, the middle sensor saw the largest rise for dumps below 2500 amps. The north sensor saw the largest rise for 2500 amps and above. I do not know the operating conditions during the 4860 amp Keihin test dump well enough to comment on why the south sensor had such a large temperature rise compared to the middle and north end sensors.

Figure 7. Temperature rise from fast dumps, Fermilab and Keihin tests

Figure 8. Fast dump trend from 1500 A

The graph displays three data series representing different dump rates: 1000 A (top line), 1500 A (middle line), and 2000 A (bottom line). The temperature remains relatively constant for each series until approximately 16:06:00, where a sharp drop occurs. Following the dump, the temperatures for all series rise and then stabilize at new levels. The 1000 A series stabilizes at approximately 12 K, the 1500 A series at approximately 10 K, and the 2000 A series at approximately 8 K. The 1500 A series shows a small secondary peak around 16:11:00 before stabilizing.

Time (9/10/98)	1000 A (K)	1500 A (K)	2000 A (K)
15:55:00	16.0	12.0	8.0
15:59:00	16.0	12.0	8.0
16:03:00	16.0	12.0	8.0
16:06:00	16.0	12.0	8.0
16:07:00	12.0	10.0	8.0
16:11:00	12.0	10.0	8.0
16:15:00	12.0	10.0	8.0

				MAX
-----	D0_CCRS2::D0_CCRS2:TR3343H-F.F_CV	Temperature for C16825 (TR-3343-H)	RTD 4.8	7.0
-----	D0_CCRS2::D0_CCRS2:TR3344H-T.F_CV	Temperature for C16826 (TR-3344-H)	RTD 4.6	8.6
-----	D0_CCRS2::D0_CCRS2:TR3345H-T.F_CV	Temperature for C16827 (TR-3345-H)	RTD 5.0	7.6
-----	D0_CCRS2::D0_CCRS2:PT-3258-H.F_CV	Cooldown/quench He return pressure	4.0	5.9
-----	D0_CCRS2::D0_CCRS2:DC_AI28.F_CV	0-10V Analog In - ABS I Xducer (ABS I-2)	1,495	1,495
-----	D0_CCRS2::D0_CCRS2:CARB_OSC_AVE.F_CV		4.7	8.2
			↑ BEFORE DUMP VALUES	↑ MAXIMUM VALUE REACHED

Figure 9. Fast dump trend from 2500 A

——	D0_CCRS2::D0_CCRS2:TR3343H-T.F_CV Temperature for C16825 (TR-3343-H) RTD	1.9	<u>MAX</u> 12.9
——	D0_CCRS2::D0_CCRS2:TR3344H-T.F_CV Temperature for C16826 (TR-3344-H) RTD	1.7	11.9
——	D0_CCRS2::D0_CCRS2:TR3345H-T.F_CV Temperature for C16827 (TR-3345-H) RTD	5.0	15.6
——	D0_CCRS2::D0_CCRS2:PT-3258-H.F_CV Cooldown/quench He return pressure	4.0	8.4
——	D0_CCRS2::D0_CCRS2:DC_AI28.F_CV 0-10V Analog In - ABS I Xducer (ABS I-2)	2,493	2,493
——	D0_CCRS2::D0_CCRS2:CARB_OSC_AVE.F_CV	1.8	14.0
	↑	BEFORE DUMP VALUES	↑ MAXIMUM VALUE REACHED

			<u>MAX.</u>
—	D0_CCRS2::D0_CCRS2:TR3343H-T.F_CV Temperature for C16825 (TR-3343-H) RTD	5.0	23.2
—	D0_CCRS2::D0_CCRS2:TR3344H-T.F_CV Temperature for C16826 (TR-3344-H) RTD	1.7	22.7
—	D0_CCRS2::D0_CCRS2:TR3345H-T.F_CV Temperature for C16827 (TR-3345-H) RTD	5.0	30.3
—	D0_CCRS2::D0_CCRS2:PT-3258-H.F_CV Cooldown/quench He return pressure	4.0	8.9
—	D0_CCRS2::D0_CCRS2:DC_AI23.F_CV 0-10V Analog In - ABS I Xducer (ABS I-2)	3,999	3,999
—	D0_CCRS2::D0_CCRS2:CARB_OSC_AVE.F_CV	4.7	24.3
	BEFORE DUMP		↑
	VALUES		MAX. VALUE REACHED

—	D0_CCRS2::D0_CCRS2:TR3343H-T.F_CV Temperature for C16825 (TR-3343-H) RTD	5.1	<u>MAX.</u> 22.9
—	D0_CCRS2::D0_CCRS2:TR3344H-T.F_CV Temperature for C16826 (TR-3344-H) RTD	4.3	23.2
—	D0_CCRS2::D0_CCRS2:TR3345H-T.F_CV Temperature for C16827 (TR-3345-H) RTD	5.1	28.1
—	D0_CCRS2::D0_CCRS2:PT-3258-H.F_CV Cooldown/quench He return pressure	6.3	14.9
—	D0_CCRS2::D0_CCRS2:MAGCURRENT.F_CV Tag name is not defined	3,883	17,843
—	D0_CCRS2::D0_CCRS2:CYL_AVE.F_CV Tag name is not defined	4.9	23.7
	↑		↑
	BEFORE DUMP VALUES		MAXIMUM VALUES REACHED

		<u>MAX</u>
— D0_CCRS2::D0_CCRS2:TR3343H-T.F_CV Temperature for C16825 (TR-3343-H) RTD	5.0	57.2
— D0_CCRS2::D0_CCRS2:TR3344H-T.F_CV Temperature for C16826 (TR-3344-H) RTD	4.6	20.9
— D0_CCRS2::D0_CCRS2:TR3345H-T.F_CV Temperature for C16827 (TR-3345-H) RTD	5.0	26.7
— D0_CCRS2::D0_CCRS2:PT-3258-H.F_CV Cooldown/quench He return pressure	4.4	8.7
— D0_CCRS2::D0_CCRS2:MAGCURRENT.F_CV Tag name is not defined	4,856	4,856
— D0_CCRS2::D0_CCRS2:CYL_AVE.F_CV Tag name is not defined	4.8	32.3
	↑	↑
	BEFORE DUMP VALUES	MAXIMUM VALUES REACHED

Solenoid Cryogenic Operation

The D-Zero control system is very flexible and allows for automatic operation. Meaning, no operators need to be present during steady state operations. At the beginning of commissioning tests, tuning and operating parameters were determined.

Refer back to Figure 3 for the pictorial piping schematic showing the important valves and flow paths. The steady state operating parameters chosen are as follows:

D0EVMF controls the liquid helium flow through the system. It can be operated to keep a constant liquid level in the subcooler reservoir or to give a fixed mass flow measured by FT-3253-H. For most heat load testing, the liquid level control mode was chosen. However, for steady state magnet operation, mass flow control at 3.0 g/s is appropriate. This flow is sufficient for charging, steady operation, and quench recovery. This amount of flow keeps the liquid helium subcooler reservoir full and overflowing so that two phase helium returns in the transfer line to the refrigerator.

PV-3201-H and PV-3209-H are the quench recovery valves. They operate based on the temperature of the returning helium from the magnet, TR-3212-H. They are in automatic so that when the returning helium temperature rises above 7 Kelvin, PV-3201-H opens and PV-3209-H closes. This diverts flow directly to suction until the returning temperature drops below 7 Kelvin. At that point PV-3209-H opens and PV-3201-H closes putting the system back in the normal configuration. The 3.0 g/s flow replaces any lost inventory in the reservoir. The valves have overlapping set points so it is ensured that one valve is open before the other closes. PV-3201-H has a set point of 6.8 K and PV-3209-H has a set point of 7.2 K.

PV-3062-H controls the pressure in the helium reservoir. There needs to be at least 3.0 psig in the reservoir for the lead flow controllers to work reliably. The back pressure in the helium return line on the downstream side of PV-3063-H is 2.5 psig when the refrigerator is loafing and gets up to around 4.2 psig when the refrigerator is cranked up at maximum expansion engine speed and Mycom compressor loading. For PV-3062-H to control, its set point needs to be less than the back pressure in the line. I have chosen the set point to be 3.8 psig.

The lead flow controllers FTCLF1 and FTCLF2 have several bounding requirements on their set point. The flows need to be low enough so that the top of the leads do not drop below 210 K. O-rings at the top of the leads freeze at 200 K and leak if over-cooled. The flow has to be high enough to provide stable cooling of the power leads when they are energized. The flow required has to increase with the rate of electrical power generation in the lead. Power generation is proportional to the current squared. The automatic algorithm for the power leads has been chosen as:

$$\dot{M} \text{ (g/s)} = A * I^2 + B = (1.402 \text{ E-}8) * I^2 + 0.065 \text{ g/s}$$

This gives a no current flow rate of 0.065 g/s up each lead and a full current flow rate of 0.38 g/s up each lead. The temperature at the top of the leads runs around 230 K using these parameters.

The other control valve, PV-3035-N controls the liquid nitrogen flow through the nitrogen cooled radiation shield. It is desired to have enough flow that the outlet of the shield circuit, TP-3225-N is a few degrees above liquid nitrogen temperature. Automatic control was difficult due to the fact that there is at least 200 feet of tubing between the control valve and the sensor on the outlet. The response of the process variable by a valve change was on the order of 30 minutes. In the end I decided that running the valve in a fixed manual valve position was acceptable. A fixed valve position of 70% gave enough flow with the liquid nitrogen supply dewar at 29 psig.

The vacuum pressure in the insulating vacuum vessel was excellent during the test run. It was 10^{-6} Torr. The turbo pumps were pumping on the vacuum jacket until September 14. At that point I isolated the vacuum vessel. The vacuum remained flat at 10^{-6} Torr. The pumps were valved back on to the vacuum vessel during the warm up beginning October 1, 1998.

Another thing worth noting is that the calibration curve of the venturi flow meter, FT-3253-H was checked using the level in the reservoir as an independent measurement of flow rate. The indicated flow rates matched to 4%. The method was to fix the flow rate at 1.17 g/s and record the rate at which the reservoir level dropped. Then the flow rate was fixed at 2.38 g/s and the rate at which the reservoir filled was recorded. The change in flow rate, $2.38 \text{ g/s} - 1.17 \text{ g/s} = 1.21 \text{ g/s}$ was converted to a liquid rate of 35.1 liquid liters per hour. The change in reservoir level was -17.1 L/h and $+19.3 \text{ L/h}$ for the two flow rates. The net change between the two is $17.1 + 19.3 = 36.4 \text{ L/h}$. This compared nicely with 35.1 L/h.

Solenoid Warm up

The solenoid warm up began on Thursday, October 1, 1998. The method was to shut off the liquid nitrogen cooled radiation shield and circulate 90 Kelvin helium gas through the helium cooling pipes at a flow rate of 3.0 g/s. The gas was supplied from the full cool down heat exchanger at about 80 K. The gas warmed to 90 K as it passed through the transfer line and control dewar subcooler reservoir. The return gas from the magnet was diverted to suction out the cool down return line. The flow was circulated for about 24 hours at which point the coil was at 90 K. The system was then allowed to statically warm the rest of the way from a combination of radiation heat load and an electrical heat generation by the coil resistance monitoring equipment. The resistance monitoring equipment supplies 10 amps through the coil and was left on starting Monday October 5, 1998. The monitoring equipment was then shut off from October 9 until the 12th.

The characteristics of the warm up were estimated based on Toshiba's radiation heat load estimates of 2.4 watts (80 K shield to coil) and 24 watts (300 K vacuum shell to 80 K shield). [Reference TFD-026, "heat-in-leak", section 24]. Radiation heat transfer equations are used to calculate the shield temperature as a function of the coil temperature. Once that is known, the radiation heat load to the coil is known. The coil resistance is also roughly known as a function of coil temperature. This allows the electrical heating load to be calculated at each coil temperature step. The time required for the coil to warm 10 K is equal to $t = M_{\text{coil}} \cdot C_p \cdot \Delta T / Q_{\text{total}}$. The equations were put into an Excel® spreadsheet and calculated the estimated warm up as in Table 7 below. The warm up is still in progress as of the writing of this engineering note. The estimated and actual temperatures are plotted in Figure 15.

Table 7. Estimated warm up characteristics

Tcoil (K)	Tshield (K)	Qcoil Radiation (watts)	Qcoil $I^2 \cdot R$ (watts)	Qtotal Rad.+ $I^2 \cdot R$ (watts)	Timestep (days)	Cumulative Time (days)
100	152.4	25.7	26.0	51.7	1.0	1.0
110	155.7	25.9	31.0	56.9	1.3	2.3
120	159.8	26.1	40.0	66.1	1.2	3.5
130	164.6	26.3	44.0	70.3	1.0	4.5
140	170.2	26.6	0.0	26.6	1.5	6.0
150	176.3	27.0	0.0	27.0	2.7	8.6
160	183.1	27.5	56.0	83.5	1.3	9.9
170	190.4	28.0	60.0	88.0	0.8	10.7
180	198.1	28.7	67.0	95.7	0.8	11.5
190	206.2	29.5	77.0	106.5	0.7	12.2
200	214.6	30.4	85.0	115.4	0.6	12.9
210	223.2	31.5	90.0	121.5	0.6	13.5
220	232.1	32.8	95.0	127.8	0.6	14.0
230	241.2	34.2	104.0	138.2	0.5	14.6
240	250.4	35.8	110.0	145.8	0.5	15.1
250	259.7	37.7	115.0	152.7	0.5	15.6
260	269.2	39.8	125.0	164.8	0.4	16.0
270	278.7	42.1	135.0	177.1	0.4	16.4
280	288.3	44.7	140.0	184.7	0.4	16.8
290	298.0	47.6	145.0	192.6	0.4	17.2

Figure 15. Solenoid warm up

Refrigerator Performance

The refrigerator performance is defined by its capacity to provide liquid helium liquefaction and refrigeration at liquid helium temperature. Liquefaction is the rate that the refrigerator can make liquid from warm inventory. Refrigeration is the rate energy can be absorbed (watts) at liquid helium temperature given that the saturated gas at helium temperature is returned to the refrigerator.

A heater located in the liquid helium storage dewar was set to keep the dewar's liquid helium level constant. The number of watts the heater provided gives a direct reading of the refrigeration capacity of the refrigerator. During these tests, the solenoid was being operated. The solenoid heat load was measured independently and is known as a function of the lead flow. The amount of lead flow is a liquefaction load on the refrigerator. This data along with the dewar heater value were added together to plot the refrigerator's performance curve. The data was collected over long periods of time (hours) using historical trending. The refrigerator was operated in June 1997 with no heater in the dewar. Tests (D-Zero engineering note 3823.115-EN-457) gave an additional data point high on the liquefaction end. The performance curve along with the expected generic curve for a STAR is shown in Figure 16.

As shown in Figure 16, the measured performance curve falls to the left of the generic operating curve because the mass flow rate through the heat exchanger was 20 g/s less than the generic operating condition. Based on the data collected at 38 g/s flow, the refrigerator will be capable of meeting or exceeding the generic curve when the flow rate is increased to 58 g/s.

At the time of the performance testing, the motor drives on the expansion engines were running at about 1250 RPM for the dry and 580 RPM for the wet engine. Both engines at D-Zero have a 6:1 drive to engine speed ratio meaning the actual engines were running at 208 RPM and 97 RPM respectively. Knowing the thermodynamic state and characteristics of the engines, the flow rates through the dry and wet are calculated to be 17.6 g/s for the dry and 20.6 g/s for the wet. Our Mycom was fully loaded, so about 22 g/s was bypassing the heat exchanger through EVHIDIS. The valve position of EVHIDIS (about 50% open = $C_v = 0.59$) verifies this value. Figure 17 shows the historical trend of one of the testing periods.

To increase the mass flow to the design point, the wet engine speed will be operated at about twice the speed or 40 g/s through put.

Documentation of similar STAR installations such as CDF and Muon (the previous installation site of our equipment) had limits on the wet engine's motor drive speed to 600 RPM. I limited our operating speed based on this documentation. I must have misunderstood this information since design literature on the expansion engines give the operating range of either dry or wet to be 50 to 230 RPM (motor drive, 300 to 1380

Figure 16. D-Zero Refrigerator performance curve measurement

Figure 17. Refrigerator performance historical data trend

				AVG	SCALE
—	D0_CCRS2::D0_CCRS2:SPDE.F_CV Dry Engine speed	500-1500 RPM	1.325	1,236	500-1500 RPM
—	D0_CCRS2::D0_CCRS2:PT-3264-H.F_CV Control dewar Pressure transmitter	3-7 PSIG	5.0	5.2	3-7 PSIG
—	D0_CCRS2::D0_CCRS2:HE-WAT.F_CV Helium Dewar Wattage based on diff. pressure	7.27	73.0		500-1000
—	D0_CCRS2::D0_CCRS2:DEVEDEW.F_CV Helium Dewar Bypass Return Control Valve	61.3	62.8		500-1000
—	D0_CCRS2::D0_CCRS2:HEDEW_WATTS.F_CV Helium Dewar Wattage to Heater		352	422	500-1000
—	D0_CCRS2::D0_CCRS2:SPWE.F_CV Wet Engine speed	500-1500 RPM	558	586	500-1500 RPM

$$T_{WET} = 6.3 \text{ K AVG.}$$

$$T_{DRY} = 30.3 \text{ K AVG.}$$

REFRIGERATOR PERFORMANCE TEST TREND

RPM). Personnel in the expansion engine group have also assured me both wet and dry motor drives can be operated at 1400 RPM.

The back pressure through the heat exchanger is a concern at higher flow rates. At 38 g/s flow during the system performance tests, the back pressure caused the solenoid helium reservoir to operate at 5.2 psi. Suction was at about 1.2 psi, so there was 4 psi pressure drop in the heat exchanger. At higher flow rates necessary to hit the generic performance curve, the back pressure will increase. This is an area I will look into for improvement.

Also plotted on the Figure 16 is the design operating point. The design operating point included 300 watts for the visible light photon counter (VLPC) system and 33 watts plus 0.8 g/s liquefaction for the operating solenoid system. These numbers include about 18 watts of heat leak in the transfer lines. In addition to the operating point, a second point "VLPC over-budget operating point" is added reflecting the current status of the VLPC cassette design. The distance between the operating points and the generic performance curve indicate the operating margin of the system. This margin is required because of system upsets, heat due to charging the solenoid, quench recovery, and performance degradation in the refrigerator components over the length of an operating run.

APPENDIX

Solenoid cool down log sheet of coil temperatures, coil to support cylinder gradient

Solenoid resistance versus temperature hand log

Solenoid heat leak method, data, and trend example

Control dewar heat leak method, trend example

Cross calibration of FT-3253-H to liquid level probe calculation

Solenoid transfer line heat leak calculation

Summary table of Toshiba heat leak calculations

Refrigerator performance test raw data

DO SOLENOID COOLDOWN LOG SHEET

DO SOLENOID COOLDOWN LOG SHEET											

DO SOLENOID COOLDOWN LOG SHEET

A2

DO SOLENOID COOLDOWN LOG SHEET											

H 980 827A

SUBJECT

NAME

P. Hauer

DATE

REVISION DATE

Solenoid Resistance Log

Date	Time	Temp	Resistance $V_I = 0.98448$ $R = V_I / I$	Current Meter
9/1/98	17:20	Ambient	1.538	
"	18:10	~287	1.449	.9842
9/2/98	08:00	277 K 251	1.372	.9846
	12:00	273	1.354	.9850
	15:50	265	1.292	.9859
	18:15	261	1.255	.9851
	20:25	253	1.206	.9855
	22:30	248	1.163	.9860
9/3/98	08:45	251	1.1485	.9844
9/3/98	9:15		1.146	.985
	11:30	241.4	1.1072	.9866
	12:30	237	1.0836	.98665
	13:30	234	1.0602	.98695
	14:30	231.5	1.0408	.9864
	16:30	225	.9958	.9874
	18:00	220 ^{← 1700}	.953	.9866
	20:10	212	.9025	.9877
	22:10	205	.8558	.9879
09/04	08:20	180	.6708	.9883
	11:30	165	.5896	.9887
	12:30	160	.5570	.9875
	13:30	153.6	.5234	.9878
	16:40	123	.4341	.9880
	17:30	121	.4079	.9890

V_I = Voltage displayed by
Current Monitoring
Meter

V_S = Voltage displayed by
Voltage monitoring
meter.

Logger Voltage Probes on
PT's 4 & 8.

Log Temp = C/R array
of coil from Cryo guys

* ACTUAL CURRENT = READING $\times 10$
 ≈ 10 AMPS

FERMILAB

ENGINEERING NOTE

H 980827A

SUBJECT

NAME

D. Hanner

DATE

REVISION DATE

Solenoid Resistance Log

Date	Time	Temp	Resistance $V_I = 0.98448$ $R = V_I/I$	CURRENT METER
9/4	19:30	118	.3612	.9879
	22:30	109	.3073	.9885
	23:45		.2810	.9863
9/7	09:30		.2698	.9863
9/8	8:30	98.7	.2555	.9893
	11:45	100	.2635	.9946
	12:30		.2648	.9939
	16:30		.1773	.9945
	18:16		.1728	.9942
	18:40		.0991	.994
	18:50		.0770	"
	19:00		.0571	.9940
	19:35		0.0580	.9942
	20:35		0.0171	.9940
	20:40	33	0.0150	.9940
	21:05		0.00582	.9950
	21:15	29	0.00419	.9933
	21:25	29	0.00312	.9931
	21:35	21	0.00190	.9929
	21:42		0.00149	.9928
	21:45		0.00130	.9928
	21:47		0.00120	.9928
	21:48		0.0007	.9927
	21:48	8	.0003	.9927
			.0002	.9927

V_I = Voltage displayed by
Current Monitoring
Meter

V_S = Voltage displayed by
Voltage monitoring
meter.

LHe started on @ 12 ~

$$\leftarrow RRR = \frac{1.999}{.0150} \times 10^2$$

$$= 258$$

$$= 357$$

$$= 480$$

$$= 789$$

$$= 1006$$

$$= 1153$$

$$= 1249$$

$\leftarrow SC!!$

A4

SUBJECT

SOLENOID HEAT LEAK METHOD

NAME RUSS RUKINSKI

DATE 10/2/98

REVISION DATE

1ST LAW OF THERMODYNAMICS FOR FIXED CONTROL VOLUME

$$\frac{dE_{cv}}{dt} = \sum \dot{m}_i \left(h + \frac{V^2}{2} + gz \right)_i - \sum \dot{m}_e \left(h + \frac{V^2}{2} + gz \right)_e + \dot{Q}_{cv} + \dot{W}_w$$

ASSUMPTIONS: MASS IS FIXED (i.e. LHC RESERVOIR LEVEL FIXED)
PROPERTIES UNIFORM ACROSS INLET & OUTLET

$$\frac{dE_{cv}}{dt} = 0 \text{ SINCE TEMPERATURES ARE NOT CHANGING, } \frac{V^2}{2} \text{ \& } gz \text{ ARE NEGLIGIBLE}$$

$$\dot{W}_w = 0 \quad \dot{m}_L - \text{READ FROM FT3253H}$$

$$\dot{m}_i = \dot{m}_{e1} + \dot{m}_{e2} \quad \text{OR} \quad \dot{m}_{e2} = \dot{m}_L - \dot{m}_{LEADS}$$

$$Q_{cv} = \underbrace{\dot{m}_{e2} (h_{e2} - h_{i1})}_{\text{REFRIGERATION}} + \underbrace{\dot{m}_{e1} (h_{e3} - h_{i1})}_{\text{LIQUEFACTION LOAD}}$$

THE SECOND TERM, THE LIQUEFACTION LOAD IS LEFT IN TERMS OF $\dot{m}_{e1} = \dot{m}_{LEADS}$ SINCE IT IS UNDERSTOOD THAT $h_{e3} \approx$ ROOM TEMP GAS RETURNED TO THE REFRIGERATOR AND h_{i1} IS LIQUID STATE.

$$Q_{SYSTEM} = (\dot{m}_{FT3253} - \dot{m}_{LEADS}) \left[h_{GAS}^{SAT} - h_{LIQ}^{SAT} \right] + \dot{m}_{LEADS}$$

P=3.8 PSIG.   P=7.4 PSIG.

20.0
100.00
5.00
0.500
5,000.00
275
0.500

EXAMPLE: SOLENOID HEAT LEAK METHOD

2

10.0
50.00
2.50
0.250
2,500.00
225
0.250

0.0
0.00
0.00
0.000
0.00
175
0.000

07:50:00
9/21/98

07:56:00
9/21/98

08:02:00
9/21/98

08:08:00
9/21/98

08:14:00
9/21/98

08:20:00
9/21/98

DO_CCRS2::DO_CCRS2:LL-3250A-B.F.CV Liq.Level Subcooler of Control Dewar	14.8	15.0
DO_CCRS2::DO_CCRS2:DOEVMF.F.CV Solenoid Re-supply Valve	0.00	0.00
DO_CCRS2::DO_CCRS2:PT151-H.F.CV Solenoid Re-supply Valve	0.00	0.00
DO_CCRS2::DO_CCRS2:FTULF18.F.CV Solenoid Lead Flow Controller	0.063	0.063
DO_CCRS2::DO_CCRS2:DC_A128.F.CV 0-15V Analog I/O - ABS i Reader (A53 I-7)	0.00	0.00
DO_CCRS2::DO_CCRS2:TP3269H-T.F.CV Temperature for TP-3269-H	234	234
DO_CCRS2::DO_CCRS2:FTULF28.F.CV Solenoid Lead Flow Controller	0.00	0.00

$$I=0 \quad \dot{m} = 2.263 \text{ g/s} =$$

SYSTEM HEAT LEAK

$$\dot{m}_{TOTAL} = 1.43 \text{ g/s}$$

$$Q_{SL} = (1.43 \text{ g/s} - 2.263 \text{ g/s}) (17.896 \text{ J/g}) = -126 \text{ J/s}$$

$$= 23.96 \text{ W} \pm 0.26 \text{ J/s}$$

Heat Load tests - RAW DATA

Current (amps)	One Lead flow (g/s)	Total Refrigeration load (watts)	Date of total test	Control dewar Refrigeration (watts)	Date of CD test	Solenoid+Chimney Refrigeration (watts) Total - CD	FT3253H Mass flow, system test (g/s)	FT3253H Mass flow, CD test (g/s)	Lead temp (K)	Pseudo total load (Watts)
0	0.045	30.08	9/17, 10:00				1.79		240	43.571
0	0.063	24.00	9/21, 7:50	21.6	9/21, 8:35	2.4	1.48	1.48	234	42.8874
0	0.065	24.80	9/17, 24:00	25.5	9/18, 8:34	-0.7	1.53	0.90	236	44.287
0	0.068	23.40	9/22, 22:00							
0	0.085	20.00	9/13, 16:00	14	9/17, 16:14	6	1.30	0.70	206	45.483
0	0.1	18.80	9/17, 8:15	17	9/18, 13:04	1.8	1.26	1.00	200	48.78
0	0.14	15.40	9/17, 12:30	12.2	9/18, 9:17	3.2	1.15	0.72	<200	57.372
0	0.18	14.30	9/17, 11:05	12.3	9/18, 9:56	2	1.18	0.80	<200	68.264
4740	0.3	20.40	9/16, 19:45	13.3	9/18, 16:00	7.1	1.75	0.89	270	110.34
4740	0.35	17.00	9/16, 16:00	13.6	9/18, 14:33	3.4	1.66	0.88	240	121.93
4740	0.38	16.00	9/22, 12:45	3.3	9/22, 14:03	12.7	1.68	1.69		
4740	0.4	14.50	9/16, 18:20	10.3	9/17, 15:17	4.2	1.62	0.67	215	134.42
4740	0.413	14.75	calc avg	7	9/18, 14:58	7.75		0.74		138.5674
	0.42								195	
4740	0.45	15.00	9/16, 18:52				1.75		<200	149.91

Pseudo load=Refrig.load+(lead flow)x 150 W/(g/s)

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	Magnet Current (amps)	Refrigeration load (watts)	Liquefaction load (g/s)	One Lead flow (g/s)	CD boil off test (watts)	Subtraction Chimney+solenoid (watts)
0.09	0	30.1	0.09	0.045		
0.13	0	24.0	0.13	0.063	21.6	2.4
0.13	0	24.8	0.13	0.065	25.5	-0.7
0.14	0	23.4	0.14	0.068		
0.17	0	20.0	0.17	0.085	14	6.0
0.20	0	18.8	0.20	0.1	17	1.8
0.28	0	15.4	0.28	0.14	12.2	3.2
0.36	0	14.3	0.36	0.18	12.3	2.0
0.00						
0.60	4740	20.4	0.60	0.3	13.3	7.1
0.70	4740	17.0	0.70	0.35	13.6	3.4
0.76	4740	16.0	0.76	0.38	3.3	12.7
0.80	4740	14.5	0.80	0.4	10.3	4.2
0.83	4740	14.8	0.83	0.413	7	7.8
0.90	4740	15.0	0.90	0.45		

SUBJECT

CONTROL DEWAR HEAT LEAK
METHOD

NAME

RUSS RUCINSKI

DATE

10/5/98

REVISION DATE

$$\dot{m}_{\text{TOTAL BOIL-OFF}} = \text{ROR} \left(\frac{1}{4} \text{ HR} \right) \times \frac{1 \text{ HR}}{3600 \text{ s}} \times \frac{1 \text{ M}^3}{1000 \text{ L}} \times 119.5 \frac{\text{kg}}{\text{M}^3} \times \frac{1000 \text{ g}}{1 \text{ kg}}$$

$$= .0332 \frac{\text{g/s}}{\text{L/HR}} \cdot \left[\text{ROR} \left(\frac{1}{4} \text{ HR} \right) \right]_{\text{MEASURED}}$$

SOME MASS REMAINS AS VAPOR;

$$\dot{m}_{\text{LEAVING}} = \dot{m}_{\text{TOTAL BOIL-OFF}} \left(\frac{P_f - P_v}{P_f} \right) = \dot{m}_{\text{TOTAL BOIL-OFF}} \left(\frac{119.5 - 21.5 \frac{\text{kg}}{\text{M}^3}}{119.5 \frac{\text{kg}}{\text{M}^3}} \right)$$

$$= \dot{m}_{\text{TOTAL BOIL-OFF}} (.320)$$

$$= \text{ROR} \left(\frac{1}{4} \text{ HR} \right) [.027227 \frac{\text{g/s}}{\text{L/HR}}]$$

$$Q_{\text{CD}} = (\dot{m}_{\text{LEAVING}} - \dot{m}_{\text{VCL}})(h_v - h_f)$$

$$= (\dot{m}_{\text{LEAVING}} - \dot{m}_{\text{VCL}})(30.52 \frac{\text{J}}{\text{g}} - 11.48 \frac{\text{J}}{\text{g}})$$

$$= (\dot{m}_{\text{LEAVING}} - \dot{m}_{\text{VCL}})(19.04 \frac{\text{J}}{\text{g}})$$

EXAMPLE = CONTROL DEWAR BOIL-OFF TEST

2

$$25 \times \frac{20L}{31.5} = 15.37 L$$

DO_CCRS2::DO_CCRS2:LL-3250A-H.F.CV Lq.Level Subcooler of Control Dewar	12.3	12.8
DO_CCRS2::DO_CCRS2:DOEVME.F.CV Solenoid He supplyline control valve	49.50	54.17
DO_CCRS2::DO_CCRS2:TP3253-H.F.CV Solenoid He Control Dewar Mixe Flow	20	1.25
DO_CCRS2::DO_CCRS2:FTCLF18.F.CV Solenoid Lead Flow Controller	0.299	0.300
DO_CCRS2::DO_CCRS2:DC_AT28.F.CV 0-10V Analog 16 - ABS 1 Xducer (ABS 1-2)	4,740.21	4,740.29
DO_CCRS2::DO_CCRS2:TP3269H-T.F.CV Temperature for TP-3269-H	225	225
DO_CCRS2::DO_CCRS2:FTCLF28.F.CV Solenoid Lead Flow Controller	294	0.29

$$ROR = 47.62 \text{ } ^\circ\text{L/HR}$$

MEASURED.

FULL CURRENT, $I = 4740 \text{ A.}$

$$\begin{aligned} \dot{m}_{\text{LEAVING}} &= ROR(^{\circ}\text{L/HR}) [0.27227 \text{ } ^{\circ}\text{L/HR}] \\ &= 1.29655 \text{ } ^{\circ}\text{L/HR} \end{aligned}$$

$$\begin{aligned} Q_{\text{CD}} &= (\dot{m}_{\text{LEAVING}} - \dot{m}_{\text{VCL}})(h_{\text{fg}}) \\ &= (1.29655 \text{ } ^{\circ}\text{L/HR} - .30 \text{ } ^{\circ}\text{L/HR} \cdot 2)(19.04 \text{ } ^{\circ}\text{L/HR}) \\ &= 13.3 \text{ W REFRIGERATION LOAD} \\ &\quad + \\ &\quad 0.6 \text{ } ^{\circ}\text{L/HR LIQUEFACTION LOAD} \end{aligned}$$

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CRYO IMPROVEMENTS

CROSS CALIBRATION OF FT3253H, VENTURI

$$(\dot{m}_{VCL} = .05 \frac{g}{s} \times 2 = .10 \frac{g}{s})$$

9/14/98 10:40:02 14.92 LITERS $\dot{m} = 1.18 \frac{g}{s}$ 66.7%
14.94

10:57:38 9.92 L $\dot{m} = 1.17 \frac{g}{s}$

$$RISE = \frac{9.92 L - 14.94 L}{17 \text{ MIN} + 36 S} = \frac{-5.02 L}{17.6 \text{ MIN}} = -0.28523 \frac{L}{\text{MIN.}}$$

9/14/98 11:05:58 10.88 L. $\dot{m} = 2.38 \frac{g}{s}$ 85%

11:16:46 17.41 L $\dot{m} = 2.49 \frac{g}{s}$

$$\frac{17.41 - 10.88 L}{10 \text{ MIN} + 48 S} = \frac{3.47 L}{10.8 \text{ MIN}} = 0.321296 \frac{L}{\text{MIN.}}$$

$$\Delta \text{RISE RATE} = 0.6065 \frac{L}{\text{MIN.}} = 36.39 \frac{L}{\text{HR.}}$$

$$\Delta \dot{m} = 2.38 - 1.17 \frac{g}{s} = 1.21 \frac{g}{s} \times \frac{29 \frac{L}{\text{HR}}}{1 \frac{g}{s}} = 35.09 \frac{L}{\text{HR}}$$

2.06 ^{NMR} @ 1 FLOW

20 LITERS

3.6

— D0_CCRS2::D0_CCRS2:FT3253-H.F_CV Solenoid Re Control Dewar Mass Flow 2.49
 — D0_CCRS2::D0_CCRS2:FT3253-H.DIFF.F_CV Solenoid Re Control Dewar Diff Pressure 35.0
 — D0_CCRS2::D0_CCRS2:D0EVMF.F_CV Solenoid Re supply control valve 1.41
 — D0_CCRS2::D0_CCRS2:IL-1053A-H.F_CV Sig. Level Submerged in Control Dewar 4.67
 — D0_CCRS2::D0_CCRS2:TR3027H-T.F_CV Temperature for X03536 (TR-3027-H) RTD 4.67

VENTURI CROSS CALIBRATION WITH
LEVEL PROBE.

All

ESTIMATE SOLENOID X-FER LINE HEAT LEAK TO LHE.

PREV. DATA, JUNE 1997 REFRIG. TEST MEASURED

$$Q_{\text{LINE}} = 39 \text{ WATTS.} \quad Q_{\text{EXPECTED}} = 18 \text{ WATTS.}$$

USE 10/2/98

8:30 WARMUP CONDITIONS, STABLE SUPPLY, NO RETURN.

TR3027H-T He SUPPLY TEMP INTO X-FER LINE

TR3061H-T H₂ TEMP @ OUTLET X-FER LINE

NO GOOD, LN₂ SHIELD IS OFF. RAD. LOAD INCREASING TO H₂.

USE CASE WHEN STEADY KNOWN ^{1 ϕ} GAS FLOW IS RETURNED FROM SOLENOID. AT KNOWN $\dot{m}$,

9/19/98 0:00:00 TO 8:00

$$\dot{m}_{\text{SOLENOID}} = 1.52 \frac{\text{g}}{\text{s}}$$

$$\dot{m}_{\text{LEADS}} = .063 \frac{\text{g}}{\text{s}} + .062 \frac{\text{g}}{\text{s}}$$

$$\text{TR 3027H} = 4.63 \text{ K}$$

$$\text{TR 3061H} = 4.66 \text{ K}$$

$$\text{TR 3007H} = 5.11 \text{ K}$$

$$\text{PT-3006-H} - \text{ASSUMED } 2.5 \text{ MPa} = .12 \text{ MPa}$$

$$Q_{\text{X-FER LINE}} = (1.52 \frac{\text{g}}{\text{s}} - .063 \frac{\text{g}}{\text{s}} - .062 \frac{\text{g}}{\text{s}}) (36.33 \frac{\text{J}}{\text{g}} - 24.60 \frac{\text{J}}{\text{g}})$$

$$= 16.4 \text{ WATTS}$$

Steady State Thermal Loads for the Coil

Component	300 to 80 K (W)		80 to 4 K (W)	
	Fermilab.	Toshiba	Fermilab.	Toshiba
Radiation	130.0	24.0	9.3	2.4
Conduction				
Shield Standoffs	12.0	2.0	-	-
6 Axial Supports	6.6	1.2	0.5	0.1
12 Radial Supports	16.7	2.2	2.7	0.1
Gas convection	-	0.1	-	0.1
Total	165.3	29.5	12.5	2.7
Eddy Currents(Charging)	0.0	-	20.0	6.0
Total (including eddy Curr.)	165.3	29.5	32.5	8.7

Heat Loads for the Control Dewar

item	300 to 80 K		80 to 4 K	
	Fermilab.	Toshiba	Fermilab.	Toshiba
Bayonets	2.4W	4.0W	2.6W	4.6W
Control Valve Stem	-	-	0.5W	1.6W
Radiation	0.8W	3.6W	0.1W	0.1W
Relief Lines	negligible	-	0.6W	0.5W
Miscellaneous Conduction	-	-	0.1W	-
Intercepts	5.0W	8.4W	-	-
Current Leads	-	-	28.8L/h	28.8L/h
Gas Convection	-	0.1W	-	0.1W
Supports	-	2.2W	-	0.1W
Total	8.2W	18.3W	3.9W + 28.8L/h	7.0W + 28.8L/h

Heat Loads for the Service Chimney

item	300 to 80 K (W)		80 to 4 K (W)	
	Fermilab.	Toshiba	Fermilab.	Toshiba
Radiation, Obround Section	13.6	8.5	0.12	0.02
Radiation, Circular Section	86.4	33.0	0.78	0.09
Field Joints	-	-	0.10	0.0
Conduction (total Spiders)	7.6	-	0.44	-
Conduction (Obround Spiders)	-	6.0	-	0.56
Conduction (Circular Spiders)	-	8.2	-	0.69
Total	107.6	55.7	1.4	1.4

Total Heat Loads for the Magnet Sysytem

item	300 to 80 K (W)		80 to 4 K (W)	
	Fermilab.	Toshiba	Fermilab.	Toshiba
Coil	165.3W	29.5W	12.5W+20W	2.7W+6W
Control Dewar	8.2W	18.3W	3.9W + 28.8L/h	7.0W + 28.8L/h
Service Chimney	107.6W	55.7W	1.4W	1.4W
Total	281.1W	103.5W	17.8W + 20W	11.1W + 6W
			28.8L/h	28.8L/h

RAW data - Refrigerator Performance tests

HTRDEW Refrigeration load	solenoid load	Solenoid transfer line load	Total Refrigeration load (W)	Liquifaction load (g/s)	Average HiDis open (%)	
17.3			17.3	3.95		June 1997 test
422	22	17	461	0.143	49.7	9/23, 23:00, 9/24, 11:00
447.6	22	17	486.6	0.1285	46.2	9/25, 5:00-8:00
360	16	17	393	0.758	51.8	9/24, 15:30-17:30

Estimated flow bypassing HX= 22.5 g/s

Expected
VLPC
system
(watts)

HTRDEW Refrigeration load	solenoid load	Solenoid transfer line load	Total Refrigeration load (W)	Liquifaction load (g/s)	
325	0	16	359	0.758	Operating Data pt. for curve
300	0	16	334	0.758	Operating Data pt. for curve

Refrigeration load (W)	Liquifaction load (g/s)	Liquifaction load (L/hr)	
0	4.34	125	Generic refrigerator pt. For curve
630	0	0	Generic refrigerator pt. For curve

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