Title
CRYOGENIC HEAT LEAK ESTIMATES

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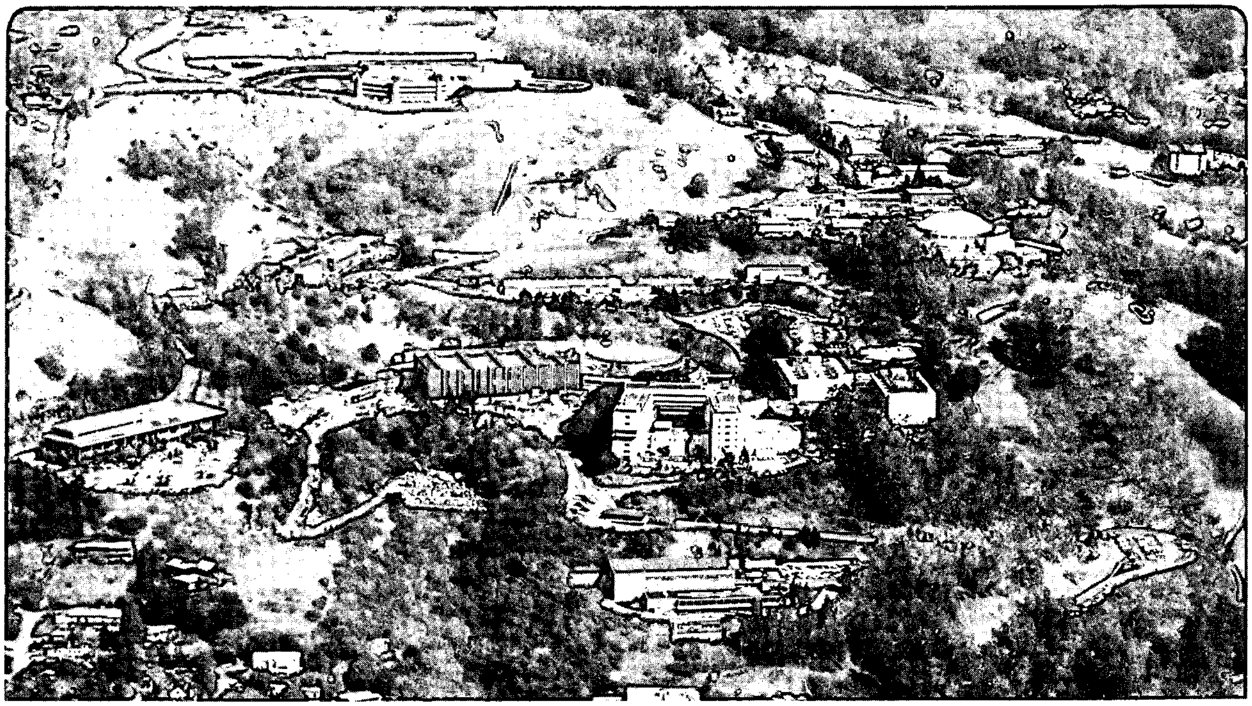

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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA **ENGINEERING NOTE**		CODE ES0510	SERIAL M4930	PAGE 1 of 11
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PROGRAM — PROJECT — JOB

ESCAR MECHANICAL FACILITIES

REFRIGERATION DISTRIBUTION

TITLE

CRYOGENIC HEAT LEAK ESTIMATES

SUMMARY. Static heat loads to LHe (and LN$_2$) are tabulated herein. No real surprises from previous estimates are found. Mass flow requirements for magnet lead cooling are also redetermined. Very little refrigeration margin for pulsing will exist if lead cooling demands exceed the 3 gm/sec refer design spec.

Tabulated in this note are crude but up to date estimates of the LHe and LN$_2$ static heat loads to the various ESCAR cryogenic sub systems (elements). Whenever they exist, the estimates are from the Engineer in Charge of detail design of that particular element, otherwise they are my own temporary crude guesses.

In most cases it can be noted (see Tables 1 and 2) that little or no other documentation exists for the estimates. Also in the case of the ring straight sections, the estimates are old and based on preliminary design layouts which have not had the benefit of critical internal engineering review, because of effort redirection in the preliminary design phase.

It is important that these heat leak estimates be periodically upgraded and distributed in a similar format to project personnel as design definition improves, so that total system trade-offs and make-or-buy component decisions can be made. We need your help on this.

We need the heat leak estimates in order to size and select the distribution lines ($1\ \phi$ and $2\ \phi$ flow pressure drop calculations) to minimize refrigerator and magnet ring impact and cost.

I've attempted to present these heat leak estimates in a format suitable for general internal information and control purposes, but needless to say, it is possible to read too much (or too little) from them, and therefore they are not suitable for outside distribution yet. The circled numbers in Column 6 are my own crude conservative estimates which I use for conservative pressure drop calculations. Better numbers will go here when we get them.

The current lead heat leak estimates, however, are not very conservative. The best real gas cooled leads conduct about 1.0 mw per amp lead to helium at the optimum current; the 1.33 figure assumed here simply totals out to 3 gms/sec (refer spec) if the 4 each 2000 A dipole pairs and 32 each 500 A quadrupole pairs are operated "self sufficient" with $(dq/d\dot{m})_p = 21.3$ J/gm. The 2400 A leads we built and tested were on the order of 20 to 40% higher heat leak, but we can't now narrow this down better, because they weren't pushed to high voltage and were masked by other system heat leaks. A limited scope retest of these leads would be desirable.

The tabulated numbers ending with .999 are also very crude; my guesses - for those who can't resist adding columns of numbers. These will be changed as soon as they are better defined.

Although M. Green got recent (informal) heat leak specs on flexible vacuum and MLI insulated helium lines of 3 sizes (modified "semiflex"), most of the heat leak numbers stated herein are for "rigid" lines with a smooth wall inner tube and strain relief bellows at suitable intervals. The flexible lines are higher heat leak and higher pressure drop. In our case, most lines can be rigid, so line heat leak estimates stated are from a recent Cryenco brochure.

So far we've used some of the heat leaks information tabulated herein to make some preliminary pressure drop calculations for distribution line type selection and sizing.

We've looked at the following circuits for 2 ϕ flow pressure drop.

A. Helium System:

1. Straight section elements (very preliminary).

B. Nitrogen System:

1. Main ring magnet elements.

These calculations were done in similar fashion to the Martinelli-Nelson pressure drop stuff in my ESCAR note of 2/13/75 which was briefly reviewed by P. Vander Arend. When the new main ring magnet element helium flow passages and static (and dynamic) helium heat leaks are specified, we will reinvestigate the helium circuit 2 ϕ flow pressure drop. With the new larger dipole magnet flow passages, there shouldn't be any surprises. Line sizes and types will dictate system operating pressure; there are several trade-offs to be considered here.

To do the above calculations, program TUFAZ2 had to be expanded to include the viscous liquid-turbulent vapor equations of Tanabe's (for nitrogen). (After these revisions, I checked the results with simpler problems against Tanabe's program, TUFAZE.) In addition a number of assumptions had to be made which I'll only briefly mention here.

A. For the straight section helium system calculations, I've assumed a circuit configuration similar to John Carrieri's schematic of 4/7/76; line physical lengths compatible with Bob Caylor's Quadrant II layout (18C9705) and element sizes consistent with Egon Hoyer's RF cavity layouts (18C3526 and 18C3536) and John Carrieri's straight section and injection line transition cryopumps (18C5596 and his sketches of 9/9/75).

B. For the main ring magnet element nitrogen system calculations, I've assumed physical dimensions compatible with R. V. Schafer's D-4 cryostat (18C7635) and R. B. Meuser's quadrupole cryostat (design study #437) with guesses about what the new dipole charge lead pot will be like.

These calculations show that there will be no pressure drop problems cooling an entire magnet quadrant with two small parallel LN_2 lines to the magnet shields. The flow regime is laminar liquid/turbulent vapor with a total magnet quadrant LN_2 heat leak of about 100 watts. These calculations will be reported in detail later.

A final word of caution. None of the heat leak numbers herein are going to be accurate to within ± 10%. Most will be in the ± 20 - 40% range and some are probably off by a factor of 2. This situation can and will improve somewhat with new information as the design progresses.

TABLE 1
ESCAR STATIC HEAT LEAK TO LHe

Element Description	Element Budget (w)	No. of Elements	Total Budget (w)	Element Estimate (w)	Total Estimate (w)	Documentation or Drg. No.	Date / Estimator	Assumptions, Comments and Basis
6 dipoles (no ends)	41.4$^{(1)}$	4	165.6	?	120$^{(2)}$ WP 5/76	See 18C7635	R.B.M.	$^{(1)}$6x1.38 m @ 5 w/m. $^{(2)}$5.0x6x4=120 (guess).
8 quads + 2 quad CLP's (no ends)	42.8$^{(3)}$	4	171.2	?	120$^{(4)}$ WP 5/76	See RBM Drg. "Design Study #437"	R.B.M.	$^{(3)}$8.16 m @ 5 w/m+1.0. $^{(4)}$30.0x4=120 (guess).
Dipole current lead pot	2.	4	8.	?	8 WP 4/15/76	?	R.W.	Guess.
Dip./quad junctions + warm ends	10.	4	40.		40 WP 5/76	See	R.B.M.	Guess.
2000A dipole lead pair	5.333 (2000A)$^{(5)}$ 3.733(0A) (6)	4	21.33 14.93		21$^{(7)}$ WP 5/76 15$^{(7)}$	See Cryogenics Apr. 1975 pg. 198	R.W.	$^{(5)}$assumes $q/_1$ = 1.33 m W/A lead. $^{(6)}$assumes $q_0/q_1 = 0.7$. $^{(7)}$rough minimum estimate.
500A quadrupole lead pair	1.333 (500A)$^{(5)}$ 0.933(0A) (6)	32	42.67 29.87		43$^{(7)}$ WP 5/76 30$^{(7)}$	"	R.W.	(same as above).
?? A cold trim coil lead pair	?	?	?	?	?	?	W.S.G./J.R.	?
Approx. magnet quadrant static heat Leak to LHe @ zero current (watts)					$Q_q \approx \frac{333}{4} \approx 83.$	None	5/11/76 W.P.	Sum of the above. Does not include lines, bayonetts, etc.

Table 1 (continued)

Element Description	Element Budget (w)	No. of Elements	Total Budget (w)	Element Estimate (w)	Total Estimate (w)	Documentation or Drg. No.	Date Estimator	Assumptions, Comments and Basis
RF cavity and drift tube cryopumps	80(9)	1	80(9)	75(8)	75	E.H. notes	4/16/76 E.H.	(8)rough re-estimate.
Ring cryopump		1		11.6	11.6	EN M4745	9/5/74 E.H.	(9)cryopump estimate in miniproject proposal (1973).
Extraction str. section cryopanel		1		4.603(10) (J.C. 9/75)	9.2 W.P.	See 18C6786	R.W.	(10)optimistic-no warm end radiation included.
Experimental str. section cryopanel		1		4.6(10, 11) (J.C. 9/75)	9.2 W.P.	"	R.W.	(11) lacking definition. Assumed to be same as extract. str. section.
Injection str. section cryopanel		1		6.616(10) (12) (J.C. 9/75)	13.2 W.P.	See 18C5596	R.W.	(12) 4.603+2.013 (J.C. 9/75).
Main distribution box + broken stem valves		1		19.999	19.999	None	4/15/76 W.P.	Crude guess.
Local distribution box + B.S.valves		3		7.999	23.999	None	4/15/76 W.P.	Crude guess.
1 1/2" cold He supply		1		22.5	22.5	None	5/11/76 W.P.	Rigid w/MLI 15 m @ 1.5 w/m.
2" cold He return		1		25.5	25.5	None	5/11/76 W.P.	Rigid w/MLI 15 m @ 1.7 w/m.

Table 1 (continued)

Element Description	Element Budget (w)	No. of Elements	Total Budget (w)	Element Estimate (w)	Total Estimate (w)	Documentation or Drg. No.	Date Estimator	Assumptions, Comments and Basis
1" cold He return		1		10.5	10.5	None	5/11/76 W.P.	Rigid w/MLI 15 m @ 0.7 w/m.
1" line to cryopanels		4		13.3	53.2	None	5/11/76 W.P.	Rigid w/MLI 19 m @ 0.7 w/m
1 1/2" local lines to magnets		8		10.8	86.4	None	5/11/76 W.P.	Rigid w/MLI & 2 bayonetts on short U. 6 m @ ≈ 1.8 w/m (Bends).
1 3/4 magnets bayonetts		16		2.0	32[13]	None	5/11/76 W.P.	[13] Crude guess @ doable. Possible to eliminate altogether.
Helium storage	?	1			?	None		
Contingency, miscellaneous, etc (w)					150	None	5/11/76 W.P.	(≈ 20% of above).
Approx. total static heat leak to LHe @ zero current (w) (no storage dewar)					875	None	5/11/76 W.P.	

Lead Cooling Requirements

The best real gas cooled current leads have a cold end heat leak of about 1.0 mW/amp lead at the optimum current (Ref. 1). The above tabulated lead heat leak estimates assume $q_o(I\ opt)/I_{opt}$ = 1.33 mW/amp lead or a 33% margin on "doability".

If the selected ESCAR magnet current leads (8 each @ 2000 A and 64 each @ 500 A) are only this good and operated "self sufficient" @ 4.5°K, the total lead mass flow required would be:

$$\dot{m}_L = \frac{\Sigma NI(q_o/I)}{(dq/d\dot{m})_p} = \frac{[8(2000) + 64\ (500)]\ (1.33 \times 10^{-3})}{21.3}$$

$$= 3.0 \text{ gm/sec}$$

Thus the assumed leads (no allowance for trim coils @ 4.5°K) just meet the CTI/FNAL/LBL 1500 W refer specification for lead cooling.

ESCAR/REFER SUPPLY-DEMAND FIT

The 1500 W refer design spec calls for 1450 watts of refrigeration at 4.5°K plus 3.0 gm/sec of lead cooling and 350 ℓ/hr (~ 11.6 gm/sec) of liquifaction (@ zero refrigeration).

The 875 watt total estimated static heat leak in Table 1 suggests we will have 1450-875 = 575 W available for pulsing. However this assumes we only extract 3.0 gm/sec for lead cooling. The above refer Liquifaction/Refrigeration is sketched in Figure 1 where a straight line interaction is assumed (which is simply a good first order guess).

It can be noted in Figure 1 that if the lead cooling demand increased 50%, to say 4.5 gm/sec, the available refrigeration @ 4.5°K would be about 1125 W leaving only 250 watts margin for pulsing.

References
Ref. 1. Cryogenics, April, 1975, pg. 198.

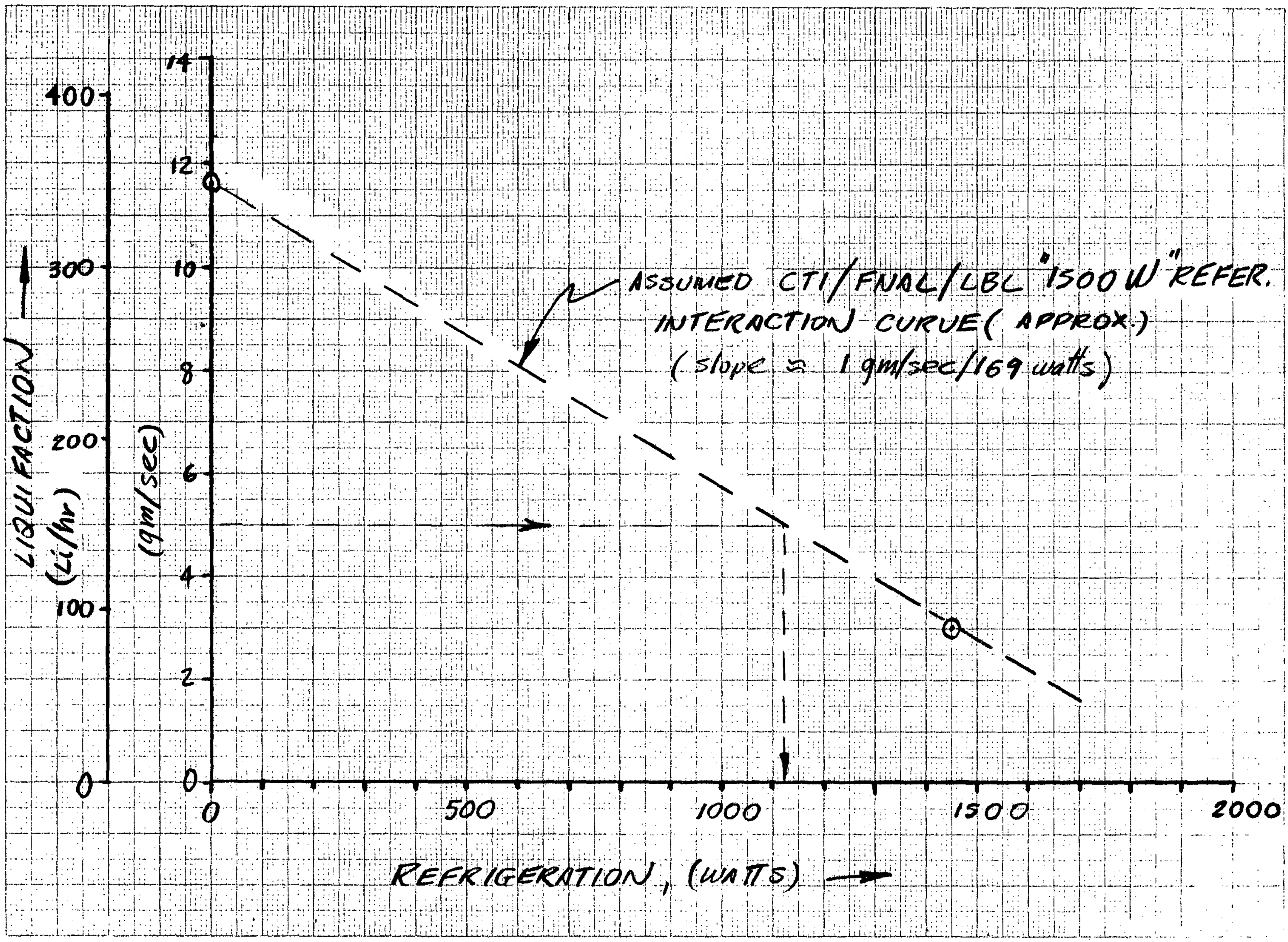
ASSUMED CTI/FNAL/LBL "1500 W" REFER.
INTERACTION CURVE (APPROX.)
(slope ≈ 1 gm/sec/169 watts)
LIQUIFACTION (Li/hr)
(gm/sec)
REFRIGERATION, (WATTS)
0
100
200
300
400
0
2
4
6
8
10
12
14
0
500
1000
1500
2000

TABLE 2

ESCAR STATIC HEAT LEAK TO LN_2

Element Description	Element Estimate (w)	No. Elements	Total Estimate (w)	Documentation or Drg. No.	Date Estimator	Assumptions, Comments and Basis
One magnet quadrant inc: 6 dipoles + CLP + 8 quads + D/Q junction + ends + quad CLP's (2)	99.3	4	397.2	TUFAZ2 07 5/7/76	5/7/76 W.P.	Detailed estimate of current configuration.
RF cavity and drift tube cryopumps	69.5[1]	1	69.5[1]	EN M4745	9/5/74 E.H.	(1)Includes local cavity dist. line losses. Preliminary design est.
Ring cryopump	453	1	453	EN M4745	9/5/74 E.H.	Preliminary design est.
Extraction str. section cryopanel	50.69	1	50.69	See 18C6786	9/18/75 J.C.	
Experimental str. section cryopanel	50.69	1	50.69	See 18C6786	9/18/75 J.C.	Lacking definition. Assumed to be similar to extr. str. section.

TABLE 2 (continued)

Element Description	Element Estimate (w)	No. Elements	Total Estimate (w)	Documentation or Drg. No.	Date / Estimator	Assumptions, Comments and Basis
Injection str. section cryopanel	77.64(2)	1	77.64(2)	See 18C5596	9/9/75 J.C.	(2)Sum of 50.69 + 26.95.
Dipole charge lead pot (CLP) (Ref.)	7.999 (Ref.)	4	⟨31.999⟩ (Ref.)	None	5/6/74 W.P.	Very crude guess (ask R.W.). Ref. only - included in quadrant above.
Main distribution box	14.999/39.999	1	14.999/39.999	None	5/6/76 W.P.	Crude guess/not in work.
Local distribution box	0./4.999	3	0./14.999	None	5/6/76 W.P.	Layout in work.
13,000 gal LN_2 storage	419.999(3)	1	419.999(3)	None	5/10/76 W.P.	(3)Crude guess based on 0.5% per day loss @ 30 psia. See Scott, Cryogenic Engineering, pg. 221.

TABLE 2 (continued)

Element Description	Element Estimate (w)	No. Elements	Total Estimate (w)	Documentation or Drg. No.	Date Estimator	Assumptions, Comments and Basis
2" VI LN$_2$ main supply line	59.999$^{(4)}$ (20.4)$^{(5)}$	1	59.999 (20.4)	Cryenco Brochure	5/6/76 W.P.	$^{(4)}$12 m @ 5 w/m-rigid w/o MLI. $^{(5)}$12 m @ 1.7 w/m-rigid w/MLI (alt.).
1" VI Ring Distribution line	83.999$^{(6)}$ (28.)$^{(7)}$	2	83.999 (28.)	"	5/10/76 W.P.	$^{(6)}$40 m @ 2.1 w/m-rigid w/o MLI. $^{(7)}$40 m @ 0.7 w/m-rigid w/MLI (alt.).
3/4" VI local distribution flex hose	20.4$^{(8)}$ (6.8)$^{(9)}$	8	163.2 (54.4)	"	5/10/76 W.P.	$^{(8)}$3 m @ 6.8 w/m-flex w/o MLI. $^{(9)}$3 m @ 2.27 w/m-flex w/MLI (alt.).
Non-vacuum insulated cold stem valves	TBD				W.P.	

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