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MAIN RING HELIUM LINE CONFIGURATION AND SIZING

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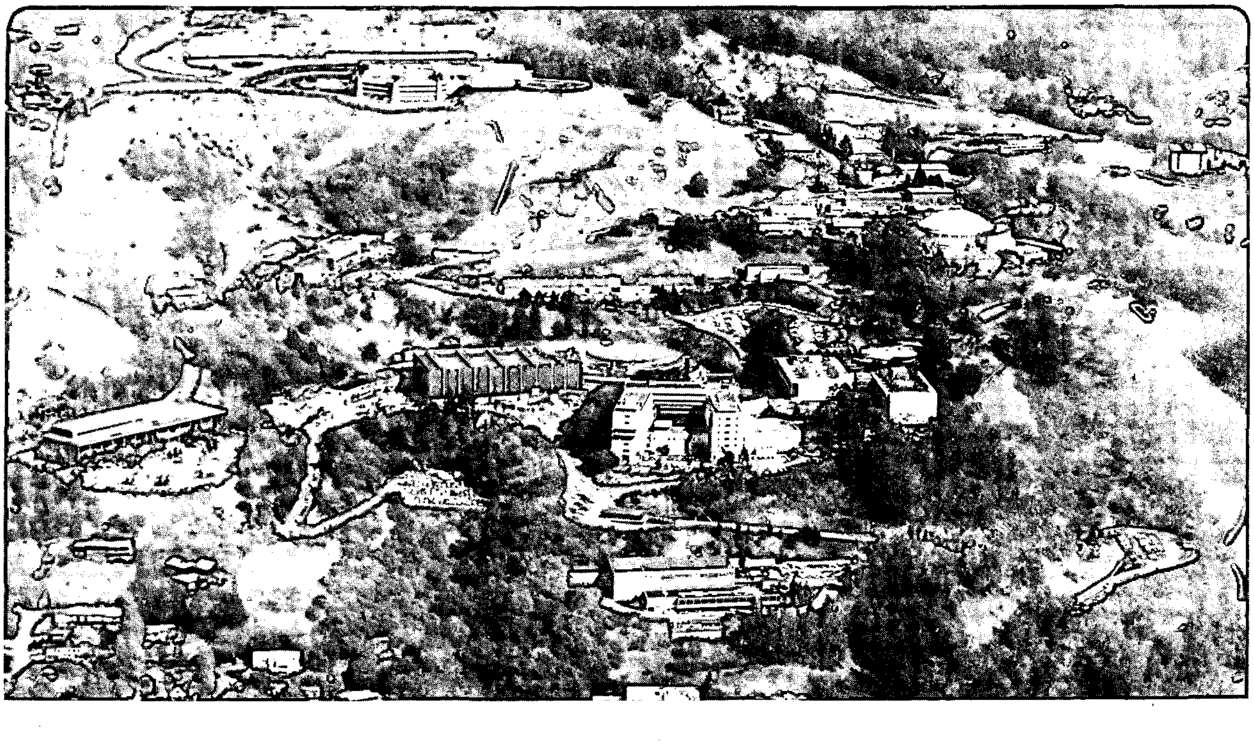

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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA **ENGINEERING NOTE**		CODE ES0510	SERIAL M4935	PAGE 1 of 16
AUTHOR W. Pope/R. Byrns	DEPARTMENT Mechanical	LOCATION Berkeley	DATE 26 May 1976	

PROGRAM — PROJECT — JOB
ESCAR MECHANICAL FACILITIES

REFRIGERATION DISTRIBUTION

TITLE
MAIN RING HELIUM LINE CONFIGURATION AND SIZING

ABSTRACT

This note discusses the results of a limited study of the ESCAR Main Magnet Ring Helium Circuit.

Presented are:

1. Proposed distribution line configuration, size, and estimated two phase helium pressure drop.
2. Proposed Cryostat/Distribution system interface hardware.

SUMMARY OF RESULTS

With the main ring helium distribution line fabricated from 2" I.D. rigid, vacuum and MLI insulated tubing, the total series ring pressure drop can be maintained at about 1.0 psi at helium mass flows up to 100 gm/sec. The minimum magnet operating temperature for the ESCAR weir cryostat helium system will be about 4.55°K dictated mainly by the return side heat exchanger Δp of the CTI/FNAL/LBL 1500 watt refrigerator with positive compressor suction pressure.

The critical current density of the Nb-Ti superconductor at this temperature (and roughly 4 1/2 Tesla) will be about 12% lower than at 4.2°K.

An "interface element" is proposed between the quadrupole cryostats and the distribution line which is simple, efficient, easily fabricated, and eliminates the need for helium bayonets. It is proposed these elements, the local distribution boxes, and this section of vacuum and MLI insulated line be fabricated in house.

DISCUSSION

The ESCAR Main Ring Magnet cryostat geometry is currently well enough defined to present new estimates of the 2kphase, diabatic helium pressure drop along with our tentative selections of the Main Ring Helium distribution system component sizes and types. Component heat leak estimates have been recently reviewed (Ref. 1).

A complete presentation herein of the pressure drop results and computation methodology, plus all the assumptions made as to local heat leak distribution and geometry will allow a critical group evaluation of the entire system to determine whether the main ring helium circuit distribution system design described meets current ESCAR requirements and is sufficiently thought out to justify detailed design and make-or-buy decisions.

An earlier note (Ref. 2), which was presented to firm up some cryostat dimensions so that dipole D-3B cryostat could be built, outlined in detail the analytical basis of the Martinelli-Nelson (M/N) semi-emperical two phase flow pressure drop calculation technique. At that time we also described the use of the M/N method in the development of a computer program, TUFAZ2, to determine the local quality and pressure distribution in a conduit consisting of several series elements each with constant but arbitrary length, cross-section, heat input per unit length, and relative roughness.

The pressure drop calculations of Ref. 2 necessarily assumed a relatively coarse conduit element mesh, and at that time we neglected all minor losses associated with local fluid resistance, i.e., elbows, tees, valves, and abrupt changes in cross-section. A relatively major simplifying assumption then also was that the flow in each element was fully established regardless of the L/D_H of the element or what preceeded it in the series circuit. This last assumption, as crude and conservative (?) as it may be, is still made, but we've recently added approximate treatments for the "minor losses" which were previously neglected. Also, to be able to look at the main ring nitrogen circuit, which will operate at considerably lower Reynolds numbers, we've expanded TUFAZ2 to include the M/N Viscous Liquid, Turbulent Vapor equations from Reference 3.

RESULTS

Table 1 shows the estimated two phase, diabatic helium pressure drop for the ESCAR ring in full series flow at 100 gm/sec. and two conditions of heat input. The Static Heat Input case assumes the dipole and quadrupole magnet elements in the circuit have a q/ℓ of 5.0 watts per meter. For pulsing at the design repetition rate, the calculations assume the magnets have a total AC loss of 25 w/dipole, and 4.0 w/quadrupole including iron hysterises losses (Ref. 4). It is assumed that this pulsed operation loss rate is comparable to the heating rates imposed during beam bunching modes.

Table 1 Design Configuration Computed Results (Full Series Ring)
See Appendix (Computer output listing) for other input details
Initial fluid state: P1 = 1.339 atm, T1 = TSAT = 4.55°K, Δh_{LV} = 18.14J/gm

RUN	$\dot{m}$	X_i	$(q/\ell)_{DIP}$	$(q/\ell)_{QUAD}$	Q_{TOT}	X_f	ΔP_{TOT}*	$\frac{\Delta P_{2\phi}}{\Delta P_{Liq.}}$
—	gm/sec	—	(WATT/m)	(WATT/m)	(WATT)	—	(psi)	(REF.)
1	100.	0.05	5.0	5.0	382.	.2637	0.74	5.77
2	"	"	25.0	15.0	1086.	.6577	1.08	8.45
3	120.	"	"	"	"	.5551	1.48	7.98

* See Output in Appendix. In actual installation, there will be only one valve in element (4,11) - two were assumed for simplicity.
Also see Ref. 2 Table 2 for similar calculations on a course element mesh, flexible lines, and no minor losses.

COMPUTATION DETAILS

A. TUFAZ2 Minor Loss Computation

The minor loss treatment is very elementary at this time, but can be improved if we feel it is important to do so, and someone has a better or faster or more accurate way. The minor losses are of two types:

Type 1: Losses associated with local flow resistance within an element of conduit.

Type 2: Losses due to abrupt area changes from element to element.

1. Type 1 Treatment

Minor losses of the first type can be considered to be things like elbows, valves, tees, etc. within an element of otherwise constant properties. To treat these a local flow resistance coefficient, k_{LR}, from single phase theory is used.

An additional equivalent length of conduit is computed for this element from $Le = K_{LR}D_H/f$, where D_H is the element hydraulic diameter and f is the local single phase liquid friction factor (function of local Reynolds number). K_{LR} (read in) is extracted from the literature, i.e., see Ref. 5. This computed additional equivalent length, iLe, is added to the actual input element length to get an effective element length and the 10 liquid pressure drop, Delto Po (I), is computed for the element. Then in ordinary M/N computation style, the two phase friction amplification factor, which is a function of local quality, is multiplied by DELTA P_o(I) to get the two phase frictional pressure drop. There is no two phase momentum term correction for this minor loss type as we presently compute it.

2. Type 2 Treatment

To compute minor losses due to abrupt changes in section from element to element we here also resort to a modified single phase, incompressible flow treatment. As the program loops over the element data, the I element hydraulic diameter is compared with the I=1 element (down stream) to determine whether the element exit is a contraction or enlargement. A single phase contraction (or enlargement) coefficient $K_D = K_{SC}$ (or K_{SE}) is computed, and then a local discharge delta p is computed from; $\Delta P_D = K_D(\dot{M}/A)^2/2\rho_M g_C$, where ρ_M is a local "mixture mean" mass density (from S. Matina and M. Green). K_D is computed internally from approximate single phase equations lifted from Ref. 6. This local element discharge pressure drop is added to the element frictional and momentum two-phase flow pressure drop (ordinary M/N method) to get the total element pressure drop.

Both the Type I and Type 2 local pressure drops as computed in TUFAZ2, then, are quite simple and crude. In neither case do we attempt to treat any local heat generation (quality change) as a result of the suddenly changing velocity distribution or eddy motion. If it can be shown that they produce serious non-conservative results, the present treatment can be improved.

B. The Main Ring Helium System Simulation

Although it is not yet complete, John Carrieri's schematic of 4/7/76 was used to define the system. For computation purposes, state point 1 is a point in the distribution line just inside the main distribution box or just downstream of the JT expansion valve in circuit, Fig. 2c in Mike Green's Cold Helium Refrigeration Distribution System note of 10/1/74, Ref. 7. This is shown schematically in simplified form in Figure 1.

C. Input Data for Pressure Drop Calculations

1. Initial Fluid Properties

The current refer contract requires that the CTI/FNAL/LBL refrigerator cold box be designed such that the return side heat exchanger total pressure drop not exceed 0.25 atm. (Ref. 8). The existing LBL drawings for the compressor plumbing (see 18K0736) and the valve leakage specs (Ref.11) require piping and valves in the compressor suction line that will be sufficiently vacuum tight that we could "consider" running the compressors with negative (sub-atmos) suction pressures without great concern of potential air contamination, however, with fixed compressor capacity and with lines and heat exchangers sized for a higher gas density, no significant reduction in suction pressure could be achieved without an attendant loss in refrigeration capacity, so I don't consider this here. This then sets the lower pressure limit for P_f (Main dist. box saturation pressure, Fig. 1) at 1.25 atm. neglecting the 1φ vapor pressure drop in the 2" cold helium return line. Allowing for a total pressure drop of 0.1 atm (max.) for the main ring series helium circuit sets the minimum supply pressure at state point 1 at 1.35 atm. TUFAZ2 currently will not handle situations with negative initial quality, and I wanted to avoid interpolation, so I selected the initial conditions for computation purposes as:

$$PI = 1.339 \text{ atm}$$

$$T_1 = T_{I(sat)} = 4.55°K$$

$$X_1 \geqq 0.0$$

An implication of this high initial temperature (which is approximately the bath temperature for the first magnets in the series) can be seen in Figs. 2 and 3. Fig. 3 was plotted from Fig. 2 which I got from W.S. Gilbert. Here we can see that the critical current density of this Nb-Ti superconducting wire will be degraded by about 12% by operating at 4.55°K (as opposed to 4.2°K) and = 4.5 tesla at the wire.

2. Element Data

Appendix 1 (Typical TUFAZ2 output) shows the series circuit element mesh assumed for a typical quadrant. It can be noted here that a relatively fine element mesh is assumed (everything but the kitchen sink) where a new element is defined virtually everywhere the conduit properties substantially change with regard to area, shape, roughness, heat leak per unit length, or internal (Type 1) local loss factor. Most of this stuff is self explanatory, but I'll expand on some of the input numbers here.

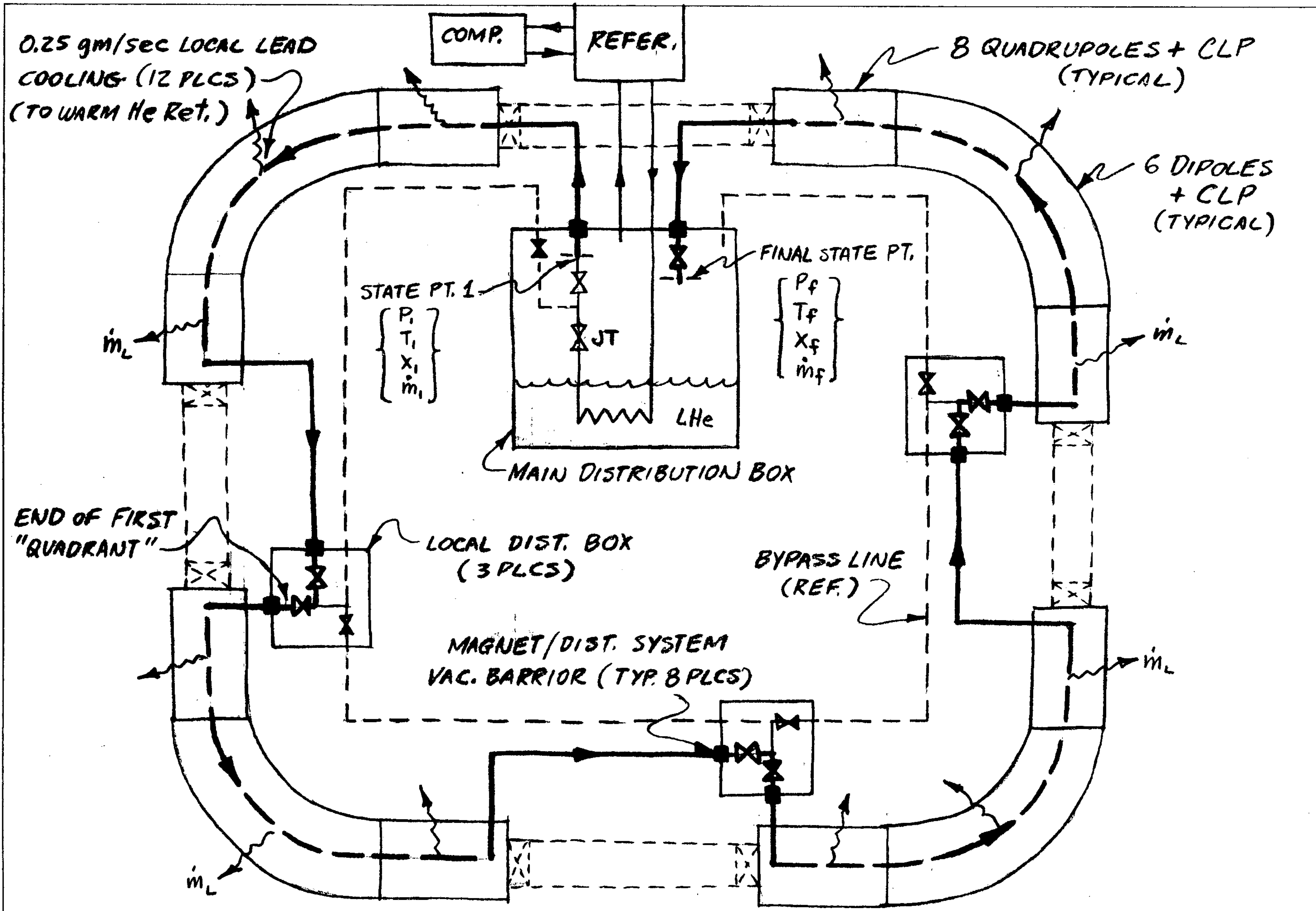

FIGURE 1 SCHEMATIC OF ESCAR MAIN RING He SYSTEM (as Configured for pressure drop calculations)

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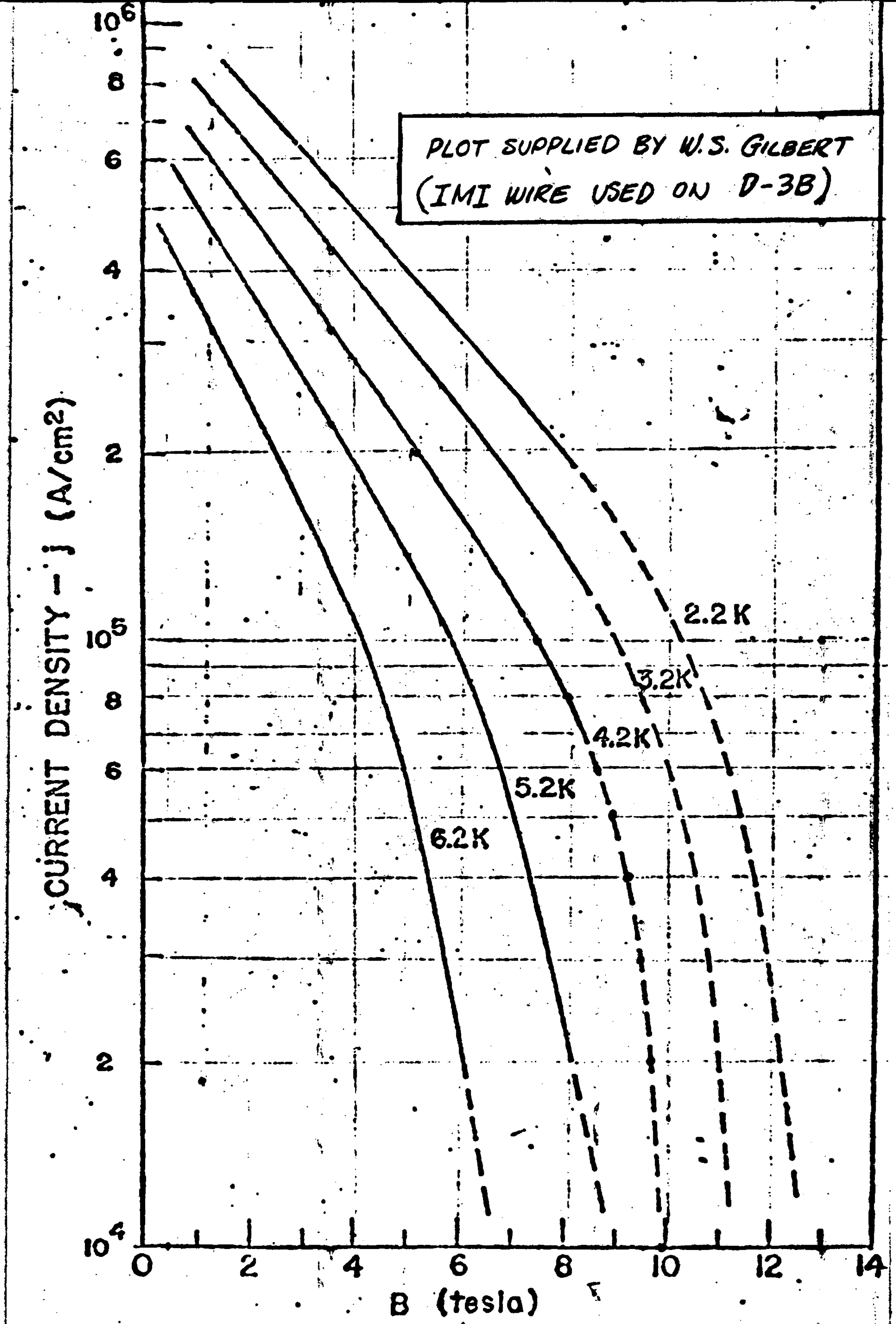


PLOT SUPPLIED BY W.S. GILBERT
(IMI WIRE USED ON D-3B)

Fig. 2 NbTi Superconductor Current Density Design Curves

SQUARE 10 X 10 TO THE CENTIMETER · AS-8014-GO

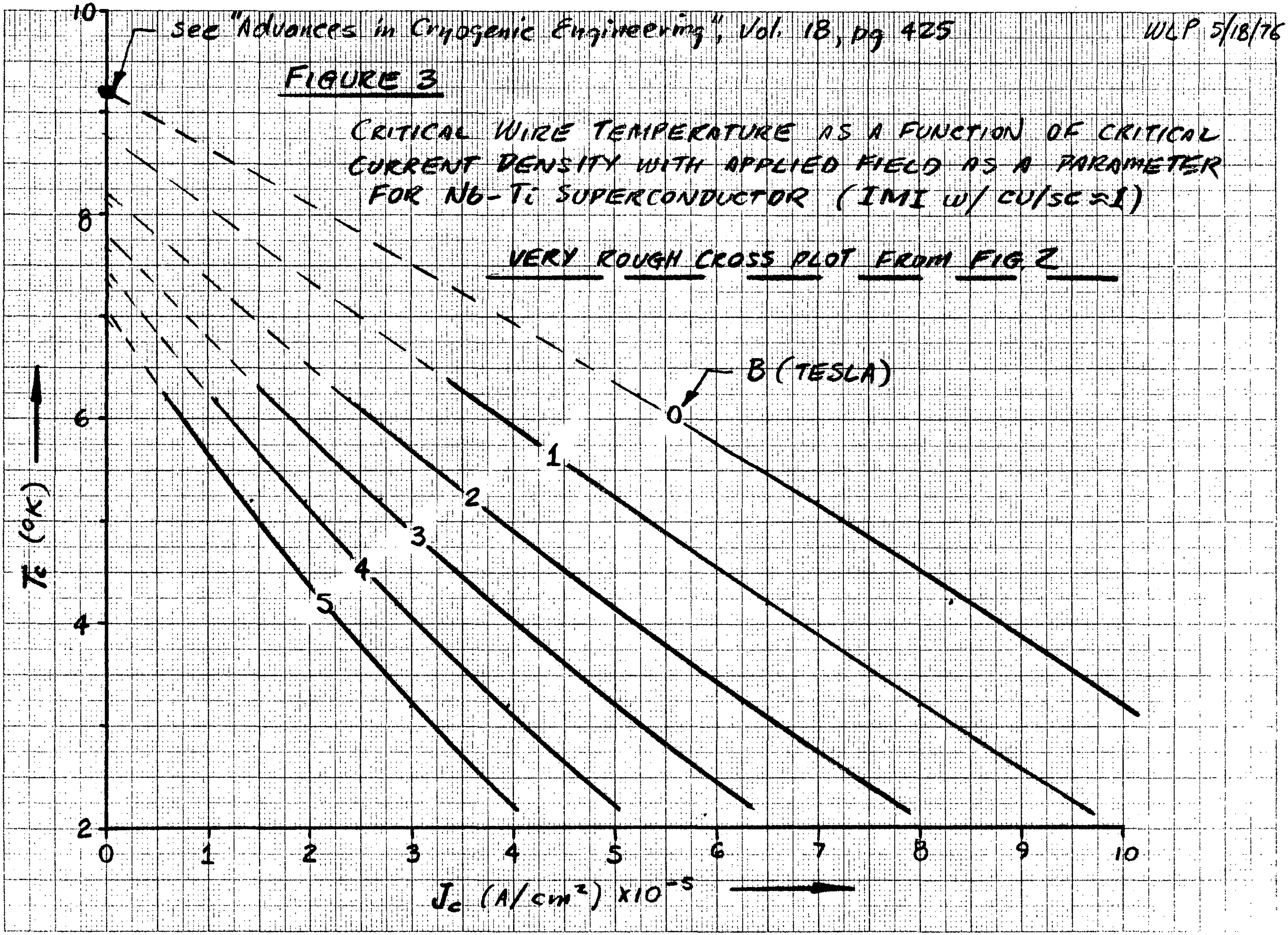
see "Advances in Cryogenic Engineering", Vol. 18, pg 425

WLP 5/18/76

FIGURE 3

CRITICAL WIRE TEMPERATURE AS A FUNCTION OF CRITICAL CURRENT DENSITY WITH APPLIED FIELD AS A PARAMETER FOR Nb-Ti SUPERCONDUCTOR (IMI w/ CU/SC ≈ 1)

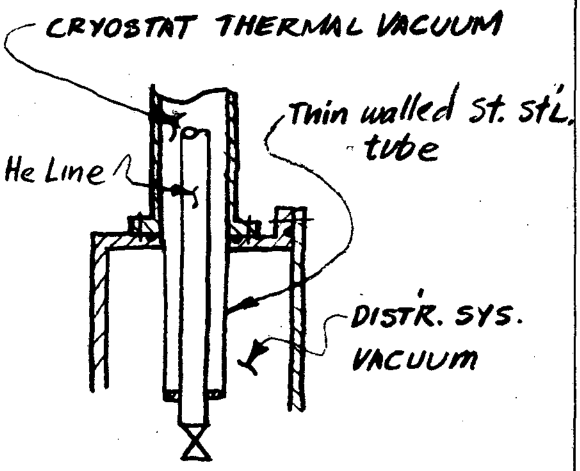
VERY ROUGH CROSS PLOT FROM FIG 2



To keep things simple, I've assumed that the whole ring consists of 4 identical quadrants starting with element type 1, a 3.0 meter long, 2" I.D., vacuum and MLI insulated, rigid local distribution line with 2 each 90° long radius elbows. The KFAC = 0.76 is simply 2x0.38, the Type I local loss factor from Ref. 5.

The heat input per unit length, for this element, 0.017 w/cm., is from Ref. 9, pg. 11 for a 2" tube line, upped roughly 6% from tabulated values to crudely account for more spacers required for the bends.

The relative roughness of .0001 is simply a guess. (For example see Ref. 10) Preceeding element type 1 in the circuit is a simulated cryostat/distribution line "vacuum barrier" which I picture as a long thin-walled stainless tube which might have a conduction heat leak of about 0.5 watts (see sketch 1). I input this as a distributed heat leak: ℓ = 10 cm., q/ℓ = 0.05 w/cm. simply to avoid computational problems. Element type 12 is 2.5" O.D. x .065"W (assumed) helium supply line within the quadruple vacuum space which has one elbow. The 1.20 KFAC here is actually the Type 1 local loss factor from Ref. 5 for flow out the side branch of a blanked off 2" tee which I guess approximates the loss factor of a mitered tube elbow. Note that a radiused commercial elbow (a wrot copper Mueller elbow or a stainless steel sched. 5 Ladish elbow) would be an improvement. The .006 w/cm. q/ℓ assumed here assumes this "bent" line has an effective surface emittance of 0.1, but part receives radiation from 300°K and part (inside the LN$_2$ shield) receives radiation from ≈ 80°K.



Sketch 1

The flow cross sections and hydraulic diameters listed for the quadrupole and dipole cryostat elements (Types 5 and 7) were computed using the formulas from Ref. 2 pages 26 and 28, with dimensions scaled from the existing cryostat drawings. Small scaling errors here would have a negligible impace on the overall ring peessure drop because the magnet channels are proportionately so large.

It can be noted that the series ring mass flow has been reduced by 0.25 gm/sec. after each current lead pot to approximate local lead cooling. This totals the budgeted 3.0 gm/sec. for the ring, not including trim coils.

The .1464 q/ℓ for elements 6 represents the 8 each 500A quadrupole lead heat leak @ q/I = 1.33 mw/A lead (Ref. 1) plus 2 watts, all divided by 50 cm., as a crude guess of the heat leak of the in-line quadrupole cryostat lead pot. This same 7.32-watt heat leak is assumed for the dipole CLP with 2 ea. 2000A leads for 6 dipoles, but a ficticious large area (9999 cm^2) is used to "fake in" the dipole CLP as part of the series flow circuit (which it is not) with a negligible pressure drop.

The KFAC of 5.4, last column, element 11, is an approximation (from Ref. 5) for two ea, 2" angle valves in series in the local distribution box. Gate valves would obviously betbetter for pressure drop purposes, but we would be hard pressed to find cheaper valves that suit our needs than the California Physics all stainless steel angle valves John Carrieri has purchased for modification and evaluation.

Our valves must be externally vacuum tight, and to avoid a whole lot of confusion during final mass spectrometer leak test/close-out of a local magnet quadrant, the valves should be mass spec tight across the seat. A Kel-F (or similar material) seat modification could make this a reality. As long as we are aware of the high loss factor of the angle valves, and pay strict attention to detail in choosing the plumbing configuration to minimize elbows, we can live with these valves. However, a larger port (if available) would help.

RECOMMENDED PLUMBING CONFIGURATION

The overall pressure drop of the ESCAR Series Helium circuit will be strongly influenced by the choice of the distribution line elements now that the flow passages within the cryostats have been enlarged. Line size and type (i.e. smooth rigid lines or flexible lines) and the number and type valves and elbows will dictate the overall circuit pressure drop (magnet operating temp.). In order to minimize heat leak and pressure drop our limited studies indicate that smooth rigid lines with expansion joints where required and with a minimum of elbows and no bayonets leads to the best overall distribution system design for ESCAR.

Figure 4 is a sketch of a cryostat-distribution line interface element that could be used to advantage for ESCAR. The unit is relatively simple and compact and little "head" room is required because no bayonets are used. A total of only 4 simple tubing joints in the main helium circuit have to be broken to install or remove a quadrant. The interface element system is easily fabricated, assembled, and insulated, and uses smooth rigid tubing with long radius elbows to minimize pressure drop. Thereiis no bayonet heat leak per se. (A long, thin-walled stainless steel "re-entrant tube" vacuum barrier separates the cryostat quadrant thermal vacuum from the distribution line vacuum which eliminates roughly half of the heat leak and half of the cost of bayonets which would be very seldom used.) The location of the distribution line local boxes is chosen to minimize elevation changes which cannot be treated in the pressure drop calculations.

The "bread Box" vacuum cover size could be judiciously chosen in the layout phase to be compatible with standard, low-cost purchasable sizes. (See Zero Mfg. Co. (deep drawn rectangular closures) brochure @ Engr. Lib.)

VALVE LOCATION DETAILS

Because the local distribution lines and their valves and elbows represent a significant part of the total circuit pressure drop, it was necessary to make "realistic assumptions" for the number of elbows, bends, etc., in the series circuit. Several sketches were made to determine ways of minimizing these minor losses.

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FIGURE 4 CRYOSTAT/DISTRIBUTION LINE INTERFACE ELEMENT

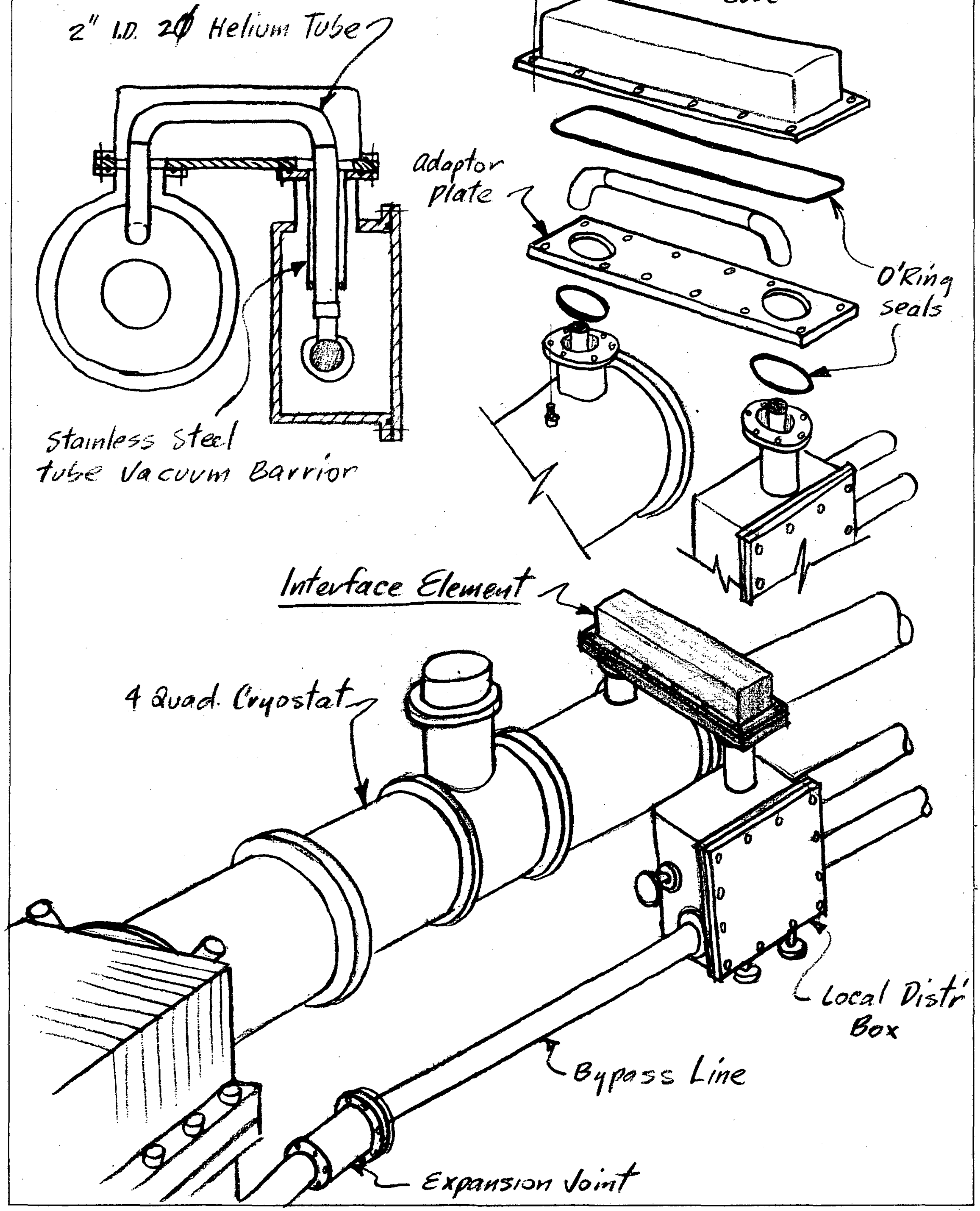

Fig. 5 is a simplified plumbing physical schematic illustrating how the existing angle valves could be oriented within the local distribution boxes to minimize Δp losses. This configuration has 5 ea. 90° bends per quadrant (minimum) not counting the 2 series angle valves and the two 90's within the cryostat quadrant. The two vacuum barrier reentrant tubes per quadrant are part of the local distribution boxes (also see Fig. 1).

The vacuum enclosure to the local lines should be large enough so that inner line radial and vertical contraction is allowed without the need for additional internal supports or bellows. This design philosophy would enable one to limit the need for distribution line thermal strain relief down to just the necessary "bent" regions in the horizontal line portions with the distribution boxes treated as fixed points for contraction purposes.

Although the angle valve handles shown here do not "exit" the local distribution box thru the same lid, implementing this valve configuration into a simple box would still be easy because the valves are "broken stem". (Stems can be different length and the stem seal bellows need not be mounted in a removable lid.)

It is important to note here that I have only shown the main ring two phase cold helium lines and valves here for simplicity. In the actual ESCAR installation it is desireable that both the Main Ring He cryogenic distribution line and the Straight Section Cryopanel Helium distribution line share the same vacuum system at the local distribution boxes. Liquid nitrogen to both systems would also cool a MLI insulated copper valve shroud within the local distribution boxes as it circulates around the ring.

CONCLUSIONS

The Main Ring He pressure drop has been investigated for a practical line configuration and size. It appears that a 2" ID smooth tube using the existing valves judiciously oriented to minimize local losses will keep the Main Ring Helium circuit Δp in the acceptable range for full series flow at high AC heating rates.

The strong influence of maximum system pressure on ESCAR magnet performance dictates the use of a low ΔP circuit. Although a larger flexible line could satisfy the ΔP requirements, it would increase the line heat input probably the order of a factor of two or more, Ref. 9. The use of a composite, rigid line will be slightly more expensive (guess 1 to 2 K $) because of the need for local thermal strain relief elements at straight section junctions, but the rigid line will be more thermally efficient allowing more refrigeration reserve for pulsed or bunched beam operation.

Although, certainly, component parts could be fabricated outside, the overall distribution line system (which consists of several individually non-sealed sections which must be field assembled) does not lend itself to outside fabrication. Because of fit-up tolerances and integration problems with other subsys systems (which currently lack definition) competing for the same space, this portion of the overall distribution system should be fabricated in house. Adequate internal skills exist; the overall cost would be comparable to a purchased line.

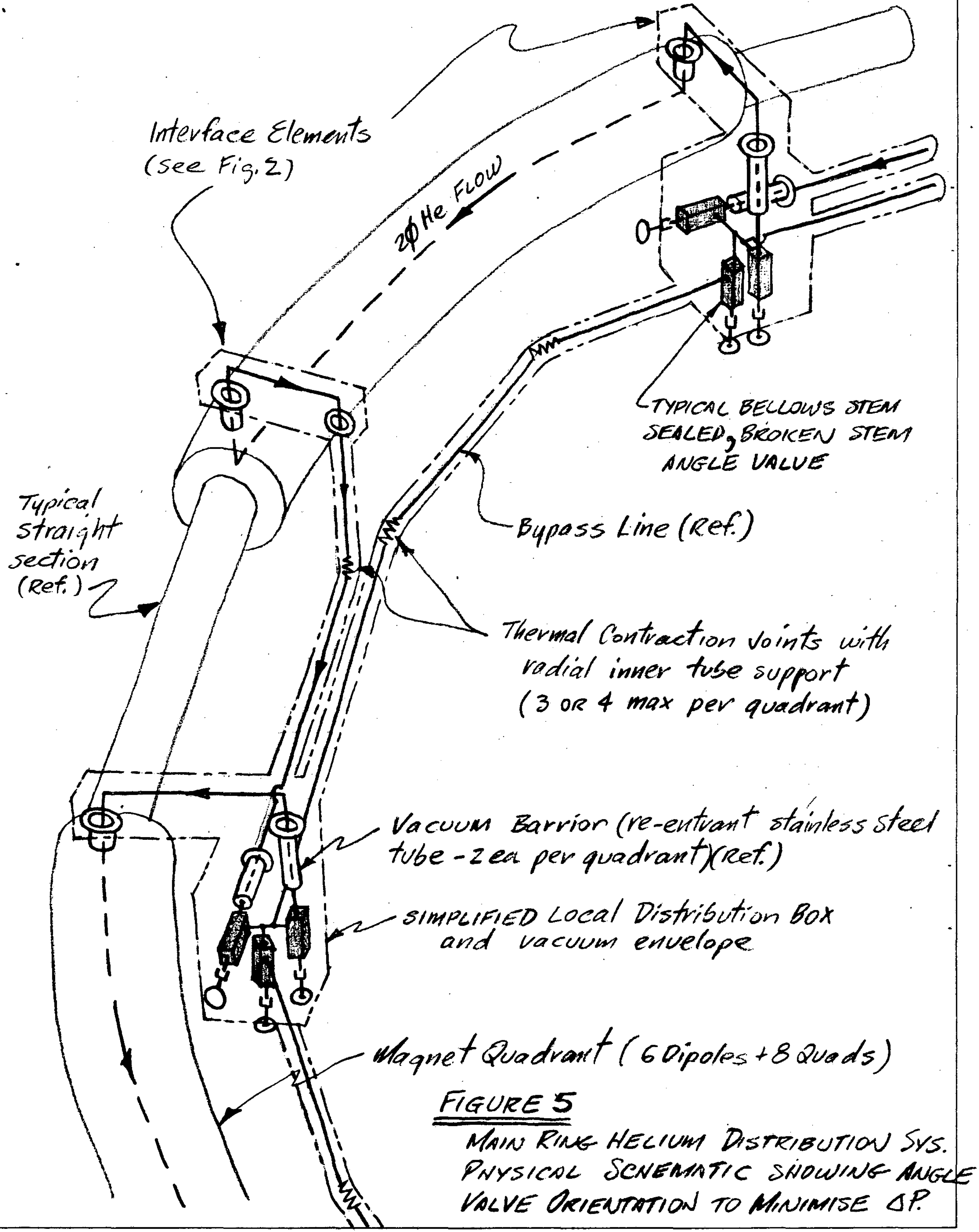

FIGURE 5

MAIN RING HELIUM DISTRIBUTION SYS. PHYSICAL SCHEMATIC SHOWING ANGLE VALVE ORIENTATION TO MINIMISE ΔP.

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APPENDIX

TUFAZZ OUTPUT FOR RUN 2, TABLE 1
(TUFS500, 5/26/76, 20118)

CRUDE MAJOR LOSS TREATMENT

```
ESCAR MAGNET RING PRESSURE DROP CALCULATIONS

HIGH AC LOSS CASE, Q/L(D) = 0.25, Q/L(0) = 0.15 W/CM

FLUID PROPERTIES AT INLET (CGS) VISCOSITY TIMES 10**6

LIQUID MASS DENSITY =     .117000 GMM/CMCUBE
LIQUID VISCOSITY   =    29.800000 GMM/CM-SEC
VAPOR MASS DENSITY  =     .023270 GMM/CMCUBE
 VAPOR VISCOSITY    =   14.000000 GMM/CM-SEC

PI(ATMOS) TI(DEG K) DELHLV(J/GM) XI   1.3390    4.5500   18.1400     .0500

MASS FLOW =  100.0000 GMM/SEC

INITIAL LIQUID REYNOLDS NUMBER = 840995.55

ELEMENT PHYSICAL CHARACTERISTICS-TYPICAL QUAURANT

TYPE  LENGTH    AREA      DHYD     LAM.GM    REL-RUF   Q OVER L    K FAC
(M=E)  (CM)    (CM SQ)    (CM)                        (WATT/CM)

  2    10.0    20.270     5.080    1.000     .00010     .0500     0.0000
  1   300.0    20.270     5.080    1.000     .00010     .0170      .7600
 12    30.0    28.460     6.020    1.000     .00010     .0060     1.2000
  4     5.0    28.460     6.020    1.000     .20000     .0008     0.0000
  5    80.0   169.950     6.944    1.170    1.00000     .1500     0.0000
  6    50.0   372.000    16.220    1.060    1.00000     .1464     0.0000
  5    80.0   169.950     6.944    1.170    1.00000     .1500     0.0000
  4     5.0    28.460     6.020    1.000     .20000     .0008     0.0000
  3    90.0    28.460     6.020    1.000     .00010     .0006     0.0000
  4     5.0    28.460     6.020    1.000     .20000     .0008     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  9     1.0  9999.000   999.000    1.000    1.00000    7.3200     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  8    20.0    28.460     6.020    1.000     .12000     .0007     0.0000
  7   120.0   128.400     7.886    1.100    1.00000     .2500     0.0000
  4     5.0    28.460     6.020    1.000     .20000     .0008     0.0000
  3    90.0    28.460     6.020    1.000     .00010     .0006     0.0000
  4     5.0    28.460     6.020    1.000     .20000     .0008     0.0000
  5    80.0   169.950     6.944    1.170    1.00000     .1500     0.0000
  6    50.0   372.000    16.220    1.060    1.00000     .1464     0.0000
  5    80.0   169.950     6.944    1.170    1.00000     .1500     0.0000
```

FROM NBS TN #631

(DESIGN FLOW RATE)

(INPUT DATA ASSUMED)

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4	5.0	20.460	6.020	1.000	.00000	.0000	0.0000
12	30.0	20.460	6.020	1.000	.00010	.0060	1.2000
10	800.0	20.270	5.080	1.000	.00010	.0170	1.1400
2	10.0	20.270	5.080	1.000	.00010	.0500	0.0000
11	60.0	13.380	4.126	1.000	.00010	.0200	5.4000

*** ELEMENT IDENTIFICATION ***

NME = 1 ASSUMES VI TUBE W/MLI AND 2 LR 90 ELS
NME = 2 MAGNT./TL VAC BARRIOR W/0.5 W COND. ML
NME = 3 QUAD/DIP CONN. TUBE (EFF = 0.1)
NME = 4 SHORT STRAIN RELIEF BELLOWS
NME = 5 QUAD DOUBLET CRYOSTAT FLOW PASSAGE
NME = 6 4 QUAD CENTER + 16 EA 500A LEADS
NME = 7 D-4 CRYOSTAT FLOW PASSAGE
NME = 8 D/D CONN. FAKE OUT, TUBE+ 1 BELLOWS
NME = 9 DIPOLE CLP + 2000A LEAD PAIR (NIS)
NME =10 ASSUMES VI TUBE W/MLI AND 3 LR 90 ELS.
NME =11 LOCAL DIST. BOX W/2 ANGL VALVE 1.02 IN PORT ← ~~(ie, CALIFORNIA PHYSICS VALVES ON HAND)~~
NME =12 QUAD IN/OUT TUBE W/1 SQ 90 EL (EFF= 0.1)

PRESSURE DROP RESULTS-LAM, OR TURB, LIQ./BUBB, VAPOR

QUADRANT	TYPE	DISTANCE (METERS)	QUALITY	FST*K	PHMST	DELTAP (PSI)	PRESSURE (PSI)	REY(L)	FF(L)	DELTA Q (WATTS)	MDOT GM/SEC
0	0	0.00	.05000	.1237	.9067	0.0000	19.6779				
1	2	.10	.05028	.1246	.9085	.0001	19.6778	840995.6	.0136	.5000	100.0000
1	1	3.10	.05309	.1342	.9265	.0082	19.6696	840995.6	.0136	5.1000	100.0000
1	12	3.40	.05319	.1344	.9271	.0033	19.6663	709815.3	.0139	.1800	100.0000
1	4	3.45	.05319	.1344	.9271	.0004	19.6659	709815.3	.1553	.0040	100.0000
1	5	4.25	.05980	.1578	.9669	.0000	19.6659	137111.0	.0200	12.0000	100.0000
1	6	4.75	.06384	.1727	.9897	.0000	19.6659	146315.9	.0180	7.3200	100.0000
1	5	5.55	.07047	.1980	1.0251	.0000	19.6659	136768.2	.0200	12.0000	99.7500
1	4	5.60	.07047	.1979	1.0251	.0004	19.6655	708040.7	.1553	.0040	99.7500
1	3	6.50	.07050	.1980	1.0252	.0006	19.6649	708040.7	.0139	.0540	99.7500
1	4	6.55	.07051	.1980	1.0252	.0005	19.6643	708040.7	.1553	.0040	99.7500
1	7	7.75	.08708	.2663	1.1045	.0001	19.6643	205583.6	.0174	30.0000	99.7500
1	8	7.95	.08709	.2662	1.1045	.0014	19.6629	708040.7	.1125	.0140	99.7500
1	7	9.15	.10367	.3410	1.1737	.0001	19.6628	205583.6	.0174	30.0000	99.7500
1	8	9.35	.10368	.3411	1.1737	.0015	19.6613	708040.7	.1125	.0140	99.7500
1	7	10.55	.12026	.4222	1.2353	.0001	19.6612	205583.6	.0174	30.0000	99.7500
1	9	10.56	.12430	.4429	1.2494	.0000	19.6612	334430.3	.0145	7.3193	99.7500
1	8	10.76	.12431	.4430	1.2494	.0015	19.6597	706266.2	.1125	.0140	99.5000
1	8	10.96	.12432	.4431	1.2494	.0016	19.6581	706266.2	.1125	.0140	99.5000
1	7	12.16	.14094	.5317	1.3041	.0001	19.6580	205068.3	.0174	30.0000	99.5000
1	8	12.36	.14095	.5318	1.3041	.0018	19.6563	706266.2	.1125	.0140	99.5000
1	7	13.56	.15757	.6261	1.3544	.0001	19.6562	205068.3	.0174	30.0000	99.5000
1	8	13.76	.15758	.6261	1.3544	.0019	19.6543	706266.2	.1125	.0140	99.5000
1	7	14.96	.17420	.7259	1.4011	.0001	19.6543	205068.3	.0174	30.0000	99.5000
1	4	15.01	.17420	.7259	1.4011	.0006	19.6537	706266.2	.1553	.0040	99.5000
1	3	15.91	.17423	.7261	1.4012	.0010	19.6527	706266.2	.0139	.0540	99.5000
1	4	15.96	.17423	.7261	1.4012	.0007	19.6520	706266.2	.1553	.0040	99.5000
1	5	16.76	.18088	.7675	1.4191	.0001	19.6520	136425.4	.0200	12.0000	99.5000
1	6	17.26	.18494	.7931	1.4298	.0000	19.6520	145584.4	.0180	7.3200	99.5000
1	5	18.06	.19160	.8360	1.4470	.0000	19.6519	136082.7	.0200	12.0000	99.2500
1	4	18.11	.19160	.8360	1.4470	.0006	19.6513	704491.6	.1553	.0040	99.2500
1	12	18.41	.19170	.8366	1.4473	.0064	19.6448	704491.6	.0139	.1800	99.2500
1	10	26.41	.19926	.8861	1.4664	.0318	19.6130	834688.1	.0137	13.6000	99.2500
1	2	26.51	.19954	.8880	1.4671	.0009	19.6121	834688.1	.0137	.5000	99.2500
1	11	27.11	.20020	.8923	1.4687	.1262	19.4859	1027537.8	.0134	1.2000	99.2500
2	2	27.21	.20048	.8942	1.4694	.0003	19.4856	834688.1	.0137	.5000	99.2500
2	1	30.21	.20331	.9131	1.4764	.0156	19.4700	834688.1	.0137	5.1000	99.2500
2	12	30.51	.20341	.9138	1.4767	.0064	19.4636	704491.6	.0139	.1800	99.2500
2	4	30.56	.20342	.9138	1.4767	.0007	19.4629	704491.6	.1553	.0040	99.2500
2	5	31.36	.21008	.9587	1.4930	.0001	19.4628	136082.7	.0200	12.0000	99.2500
2	6	31.86	.21415	.9865	1.5028	.0000	19.4628	145218.6	.0180	7.3200	99.2500
2	5	32.66	.22083	1.0328	1.5186	.0000	19.4628	135739.9	.0200	12.0000	99.0000
2	4	32.71	.22083	1.0329	1.5186	.0007	19.4621	702717.1	.1553	.0040	99.0000
2	3	33.61	.22086	1.0331	1.5187	.0011	19.4610	702717.1	.0139	.0540	99.0000
2	4	33.66	.22086	1.0331	1.5187	.0009	19.4601	702717.1	.1553	.0040	99.0000
2	7	34.86	.23757	1.1521	1.5573	.0001	19.4600	204037.8	.0174	30.0000	99.0000
2	8	35.06	.23758	1.1522	1.5573	.0023	19.4578	702717.1	.1125	.0140	99.0000
2	7	36.26	.25428	1.2757	1.5947	.0001	19.4577	204037.8	.0174	30.0000	99.0000
2	8	36.46	.25429	1.2758	1.5947	.0024	19.4553	702717.1	.1125	.0140	99.0000
2	7	37.66	.27099	1.4037	1.6310	.0002	19.4551	204037.8	.0174	30.0000	99.0000
2	9	37.67	.27507	1.4355	1.6397	.0000	19.4551	331915.7	.0145	7.3193	99.0000
2	8	37.87	.27508	1.4356	1.6398	.0022	19.4530	700942.6	.1125	.0140	98.7500
2	8	38.07	.27508	1.4356	1.6398	.0024	19.4505	700942.6	.1125	.0140	98.7500
2	7	39.27	.29183	1.5490	1.6753	.0001	19.4504	203522.6	.0174	30.0000	98.7500
2	8	39.47	.29184	1.5491	1.6753	.0025	19.4479	700942.6	.1125	.0140	98.7500
2	7	40.67	.30859	1.7064	1.7103	.0001	19.4478	203522.6	.0174	30.0000	98.7500

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
ES0510	M4935	15 OF 16

AUTHOR	DEPARTMENT	LOCATION	DATE
W. Pope/R. Burns	Mechanical	Berkeley	26 May 1976

2	8	40.87	.30860	1.7064	1.7103	.0026	19.4452	700942.6	.1125	.0140	98.7500
2	7	42.07	.32534	1.8475	1.7450	.0001	19.4451	203522.6	.0174	30.0000	98.7500
2	4	42.12	.32534	1.8476	1.7450	.0008	19.4443	700942.6	.1553	.0040	98.7500
2	3	43.02	.32537	1.8479	1.7451	.0013	19.4430	700942.6	.0139	.0540	98.7500
2	4	43.07	.32538	1.8479	1.7451	.0009	19.4421	700942.6	.1553	.0040	98.7500
2	5	43.87	.33208	1.9053	1.7589	.0001	19.4420	135397.1	.0200	12.0000	98.7500
2	6	44.37	.33616	1.9407	1.7674	.0000	19.4420	144487.0	.0180	7.3200	98.7500
2	5	45.17	.34288	1.9992	1.7812	.0001	19.4419	135054.3	.0200	12.0000	98.5000
2	4	45.22	.34288	1.9992	1.7812	.0008	19.4411	699168.0	.1553	.0040	98.5000
2	12	45.52	.34298	2.0001	1.7814	.0086	19.4325	699168.0	.0139	.1800	98.5000
2	10	53.52	.35059	2.0671	1.7972	.0422	19.3904	828380.6	.0137	13.6000	98.5000
2	2	53.62	.35087	2.0696	1.7977	.0012	19.3892	828380.6	.0137	.5000	98.5000
2	11	54.22	.35154	2.0756	1.7991	.1662	19.2230	1019773.1	.0134	1.2000	98.5000
3	2	54.37	.35182	2.0781	1.7997	.0003	19.2227	828380.6	.0137	.5000	98.5000
3	1	57.32	.35468	2.1034	1.8056	.0205	19.2021	828380.6	.0137	5.1000	98.5000
3	12	57.62	.35478	2.1043	1.8058	.0083	19.1938	699168.0	.0139	.1800	98.5000
3	4	57.67	.35478	2.1043	1.8058	.0010	19.1929	699168.0	.1553	.0040	98.5000
3	5	58.47	.36150	2.1644	1.8197	.0001	19.1928	135054.3	.0200	12.0000	98.5000
3	6	58.97	.36559	2.2012	1.8282	.0000	19.1928	144121.2	.0180	7.3200	98.5000
3	5	59.77	.37233	2.2623	1.8422	.0001	19.1927	134711.6	.0200	12.0000	98.2500
3	4	59.82	.37233	2.2624	1.8422	.0009	19.1919	697393.5	.1553	.0040	98.2500
3	3	60.72	.37236	2.2626	1.8422	.0014	19.1905	697393.5	.0139	.0540	98.2500
3	4	60.77	.37236	2.2627	1.8422	.0012	19.1893	697393.5	.1553	.0040	98.2500
3	7	61.97	.38919	2.4175	1.8774	.0001	19.1892	202492.1	.0174	30.0000	98.2500
3	8	62.17	.38920	2.4175	1.8774	.0029	19.1863	697393.5	.1125	.0140	98.2500
3	7	63.37	.40603	2.5754	1.9129	.0001	19.1862	202492.1	.0174	30.0000	98.2500
3	8	63.57	.40604	2.5755	1.9129	.0029	19.1833	697393.5	.1125	.0140	98.2500
3	7	64.77	.42288	2.7362	1.9489	.0002	19.1831	202492.1	.0174	30.0000	98.2500
3	9	64.78	.42698	2.7758	1.9578	.0000	19.1831	329401.2	.0145	7.3193	98.2500
3	8	64.98	.42699	2.7759	1.9578	.0026	19.1804	695619.0	.1125	.0140	98.0000
3	8	65.18	.42700	2.7760	1.9578	.0030	19.1774	695619.0	.1125	.0140	98.0000
3	7	66.38	.44387	2.9404	1.9947	.0001	19.1773	201976.8	.0174	30.0000	98.0000
3	8	66.58	.44388	2.9405	1.9947	.0030	19.1743	695619.0	.1125	.0140	98.0000
3	7	67.78	.46076	3.1075	2.0323	.0001	19.1742	201976.8	.0174	30.0000	98.0000
3	8	67.98	.46076	3.1076	2.0324	.0031	19.1711	695619.0	.1125	.0140	98.0000
3	7	69.18	.47764	3.2769	2.0708	.0001	19.1710	201976.8	.0174	30.0000	98.0000
3	4	69.23	.47764	3.2769	2.0708	.0009	19.1700	695619.0	.1553	.0040	98.0000
3	3	70.13	.47767	3.2772	2.0709	.0015	19.1685	695619.0	.0139	.0540	98.0000
3	4	70.18	.47768	3.2773	2.0709	.0011	19.1674	695619.0	.1553	.0040	98.0000
3	5	70.98	.48443	3.3456	2.0865	.0001	19.1673	134368.8	.0200	12.0000	98.0000
3	6	71.48	.48854	3.3875	2.0961	.0000	19.1673	143389.6	.0180	7.3200	98.0000
3	5	72.28	.49531	3.4565	2.1120	.0001	19.1672	134026.0	.0200	12.0000	97.7500
3	4	72.33	.49531	3.4565	2.1120	.0010	19.1663	693844.4	.1553	.0040	97.7500
3	12	72.63	.49541	3.4576	2.1122	.0099	19.1564	693844.4	.0139	.1800	97.7500
3	10	80.63	.50308	3.5362	2.1305	.0484	19.1080	822073.2	.0137	13.6000	97.7500
3	2	80.73	.50337	3.5391	2.1311	.0014	19.1066	822073.2	.0137	.5000	97.7500
3	11	81.33	.50404	3.5460	2.1328	.1900	18.9166	1012008.3	.0134	1.2000	97.7500
4	2	81.43	.50432	3.5489	2.1334	.0004	18.9162	822073.2	.0137	.5000	97.7500
4	1	84.43	.50720	3.5785	2.1403	.0235	18.8927	822073.2	.0137	5.1000	97.7500
4	12	84.73	.50730	3.5796	2.1406	.0095	18.8832	693844.4	.0139	.1800	97.7500
4	4	84.78	.50730	3.5797	2.1406	.0011	18.8821	693844.4	.1553	.0040	97.7500
4	5	85.58	.51407	3.6495	2.1570	.0001	18.8820	134026.0	.0200	12.0000	97.7500
4	6	86.08	.51820	3.6922	2.1670	.0000	18.8820	143023.8	.0181	7.3200	97.7500
4	5	86.88	.52499	3.7628	2.1837	.0001	18.8819	133683.2	.0201	12.0000	97.5000
4	4	86.93	.52499	3.7628	2.1837	.0010	18.8810	692069.9	.1553	.0040	97.5000
4	3	87.83	.52502	3.7631	2.1838	.0016	18.8794	692069.9	.0139	.0540	97.5000
4	4	87.88	.52502	3.7631	2.1838	.0014	18.8781	692069.9	.1553	.0040	97.5000
4	7	89.08	.54198	3.9406	2.2264	.0001	18.8779	200946.3	.0175	30.0000	97.5000
4	8	89.28	.54199	3.9406	2.2264	.0032	18.8747	692069.9	.1125	.0140	97.5000
4	7	90.48	.55895	4.1195	2.2702	.0001	18.8745	200946.3	.0175	30.0000	97.5000
4	8	90.68	.55896	4.1196	2.2702	.0033	18.8713	692069.9	.1125	.0140	97.5000
4	7	91.88	.57592	4.2998	2.3153	.0002	18.8711	200946.3	.0175	30.0000	97.5000
4	9	91.89	.58006	4.3440	2.3265	.0000	18.8711	326886.7	.0145	7.3193	97.5000
4	8	92.09	.58007	4.3440	2.3265	.0029	18.8682	690295.3	.1125	.0140	97.2500
4	8	92.29	.58008	4.3441	2.3266	.0033	18.8649	690295.3	.1125	.0140	97.2500
4	7	93.49	.59708	4.5261	2.3735	.0001	18.8648	200431.1	.0175	30.0000	97.2500
4	8	93.69	.59709	4.5262	2.3735	.0033	18.8615	690295.3	.1125	.0140	97.2500
4	7	94.89	.61410	4.7090	2.4220	.0001	18.8613	200431.1	.0175	30.0000	97.2500
4	8	95.09	.61410	4.7090	2.4220	.0033	18.8580	690295.3	.1125	.0140	97.2500
4	7	96.29	.63111	4.8926	2.4720	.0001	18.8579	200431.1	.0175	30.0000	97.2500
4	4	96.34	.63111	4.8926	2.4720	.0010	18.8569	690295.3	.1553	.0040	97.2500
4	3	97.24	.63114	4.8929	2.4721	.0016	18.8552	690295.3	.0139	.0540	97.2500
4	4	97.29	.63114	4.8929	2.4721	.0012	18.8541	690295.3	.1553	.0040	97.2500
4	5	98.09	.63795	4.9664	2.4925	.0001	18.8540	133340.4	.0201	12.0000	97.2500
4	6	98.59	.64210	5.0112	2.5051	.0000	18.8540	142292.3	.0181	7.3200	97.2500
4	5	99.39	.64892	5.0849	2.5261	.0001	18.8539	132997.7	.0201	12.0000	97.0000
4	4	99.44	.64892	5.0851	2.5261	.0010	18.8529	688520.8	.1553	.0040	97.0000
4	12	99.74	.64902	5.0862	2.5264	.0104	18.8425	688520.8	.0139	.1800	97.0000
4	10	107.74	.65675	5.1698	2.5504	.0503	18.7923	815765.7	.0137	13.6000	97.0000
4	2	107.84	.65703	5.1729	2.5513	.0016	18.7906	815765.7	.0137	.5000	97.0000
4	11	108.44	.65772	5.1802	2.5535	.1971	18.5935	1004243.5	.0134	1.2000	97.0000

TOTAL HEAT INPUT TO MAGNET RING = 1085.748 WATTS

two series valves assumed here - only one required (see Fig. 1)

TOTAL RING PRESSURE DROP = 1.8844 PSI

MOST LIKELY CONSERVATIVE - SEE ADVANCES IN CRYOGENIC ENGINEERING, VOL. 14, PG 170.

DELTA P TWO-PHASE/DELTA P LIQUID = 8.45 (REF)

2/3

REFERENCES

Ref. 1 "ESCAR...HEAT LEAK ESTIMATES", LBL Mech. Engr. Note ES0510, M4930, 5/11/76.

Ref. 2 "ESCAR...PRESSURE DROP CALCULATIONS...DIPOLE (D-3B) CRYOSTAT 20 He FLOW PASSAGE SIZING", ESCAR Note #14, 2/13/75.

Ref. 3 "BEVATRON...CRYOGENIC PUMPING SYSTEM (Note #3-Two Phase Flow)", LBL Mech. Engr. Note BEV2001, M4296, Jack Tanabe, 5/5/70.

Ref. 4 Telephone Communication with W.S. Gilbert, 5/19/76.

Ref. 5 "LOCAL RESISTANCE TO FLOW", PRODUCT ENGINEERING, 3/2/64, pg. 63-68.

Ref. 6 "FUNDAMENTALS OF HYDRAULIC LINE SELECTION", MACHINE DESIGN, 5/15/75, Pg. 69-71.

Ref. 7 "THE COLD HELIUM DISTRIBUTION SYSTEM FOR ESCAR", LBL Mech. Engr. Note ES0501, M4761 (UCID 3690), M.A. Green, 10/1/74.

Ref. 8 FNAL Specification 042809-ES 53497, 6/6/75.

Ref. 9 CRYOGENIC TRANSFER LINE EQUIPMENT", Cryogenic Engineering Company (Denver) brochure, TL668, (No date - post 3/74), page 11. R.A. Byrns file, Bldg. 90.

Ref. 10 ELEMENTARY FLUID MECHANICS, 3rd Edition, Vennard, J.K., John Wiley & Sons Inc., N.Y., 1955, pgs. 190-196.

Ref. 11 See LBL Mech. Engr. J.O. Ser. No. 332131 and 332140.

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