CHAPTER III

DESIGN OF CRYOSTAT ASSEMBLY (see Drwg MICE-0000)

III-1. Helium Vessel

Engineering Drawing for 4.2K vessel is shown in Appendix II-1-1.
The vessel will be made of ½" thick 6061T6 aluminum half cylinder halves as shown in Drwg MICE-C002. It will be welded with full penetration weld between two halves. At both end, it will be welded with ½"x½" 4043Al weld.

The helium vessel is designed with 45 psi pressure rating. The rupture disc pressure is set at 32 psig to 35 psig. The relief pressure will be 29 psig or lower.

The helium vessel is designed to satisfy pressure vessel code. It will be tested to pressure vessel code. The pressure vessel code design calculation is shown in Table III-1-1.

The total liquid helium volume is 200 liters.

The complete helium vessel component drawing is shown in Drwg MICE-C0000.
The helium vessel will be insulated with 15 layers of superinsulation.

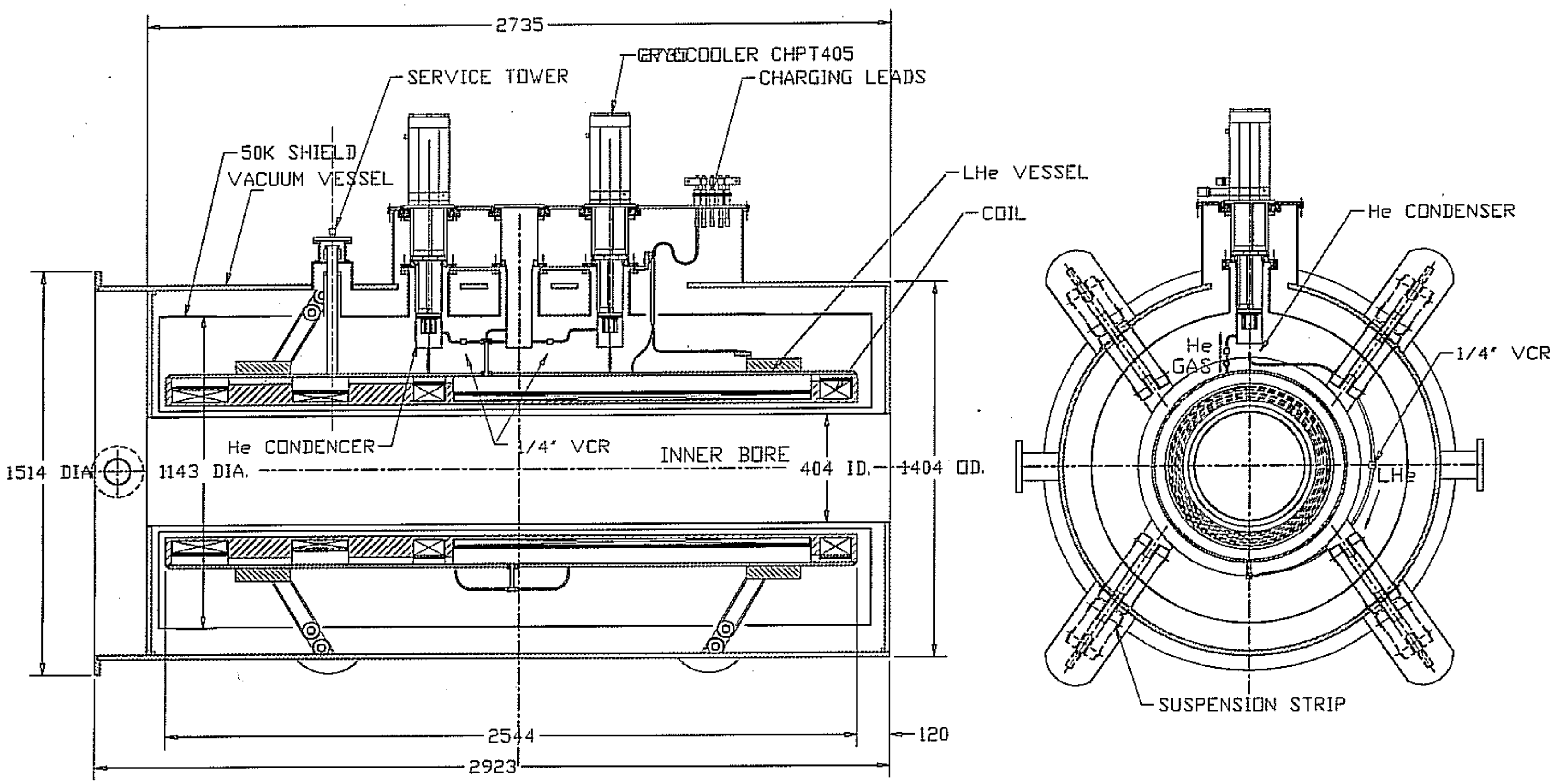
III-2. Design of Conduction-Cooled Thermal Shield

Engineering Drawing for 60K shield system is shown in Appendix III-2-1.
The thermal shield assembly is shown in Drwg MICE-6000. The 70K shield will be made of 6061T6. It is estimated that the shield will be operated at 60K with two coolers.

The shield is cooled by conduction from the first stage of cryocooler. It will be made of 6061T6. Thickness of the shield is sized so that the (hottest) maximum temperature of shield does not exceed 80K.

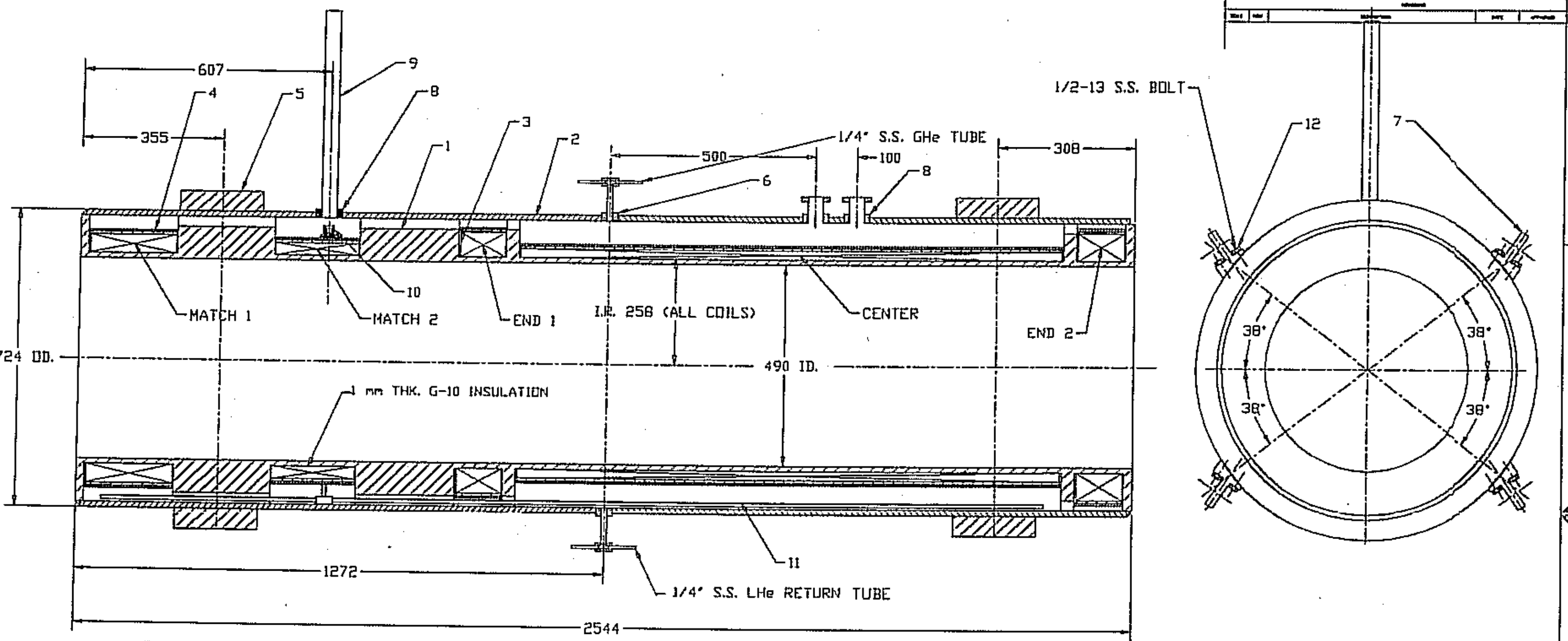
(A) The outer cylinder

The OD of the shield will be 45" Φ. It will be made of 0.188" thick 6061T6 Al. The length will be 103.11". The engineering drawing is shown in Drwg MICE-6100.



NOTES:
1) DIMENSIONS ARE IN mm

WANG NMR, INC.
550 North Canyons Parkway, Livermore, CA 94550
MICE TRACKER MODULE
4.5T TRACKER
SOLENOID MAGNET
D
MICE-0000



QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
32	12	MICE-C012	WASHER	304 S.S.
1	11	MICE-C011	PRECOOL LINE	304 S.S.
1	10	MICE-C010	PRECOOL NUZZLE	304 S.S.
1	9	MICE-C009	NECK TUBE	304 S.S.
2	8	MICE-C008	BI-METAL COUPLING	AL- S.S.
8	7	MICE-C007	COLD MASS SUPPORT BLACKET	316 S.S.
2	6	MICE-C006	BI-METAL COUPLING	AL- S.S.
2	5	MICE-C005	SUSPESION RING	6061T6
5	4	MICE-C004	REINFORCEMENT	6061T6
10	3	MICE-C003	SIDE INSULATION	G-10
2	2	MICE-C002	LHe VESSEL	6061T6
1	1	MICE-C001	COIL FORM	6061T6

NOTES:
1) DIMENSIONS ARE IN mm
2) REQD. VACUUM TIGHT (LEAK CHECK)

WANG NMR, INC.

MICE TRACKER MOUDLE
COIL STRUCTURE

D MICE-C0000

(B) <u>The inner cylinder shield</u>

The OD of the inner shield will be 18.228" OD. It is made of rolled and welded 6061T6 aluminum plate with a thickness of 3/16". The length will be 103.11".

(C) <u>The end disc shield</u>

The disc will have an I.D. of 18.228", an OD of 44.625", and a thickness of 0.188".

III-3. Vacuum Vessel and its support assembly

Engineering Drawing for 300K vacuum vessel is shown in Appendix III-3-1.
The vacuum vessel will be made of 304SS. The non-magnetic vessel will be tested to satisfy the ASME pressure vessel code to sustain a pressure rating of 1 atmosphere pressure. Engineering Drawing for magnet support system is shown in Appendix III-3-2. The support system will be made of 304SS.

III-4. Design of Neck Tube for Cryogen Feed and Quench Vent

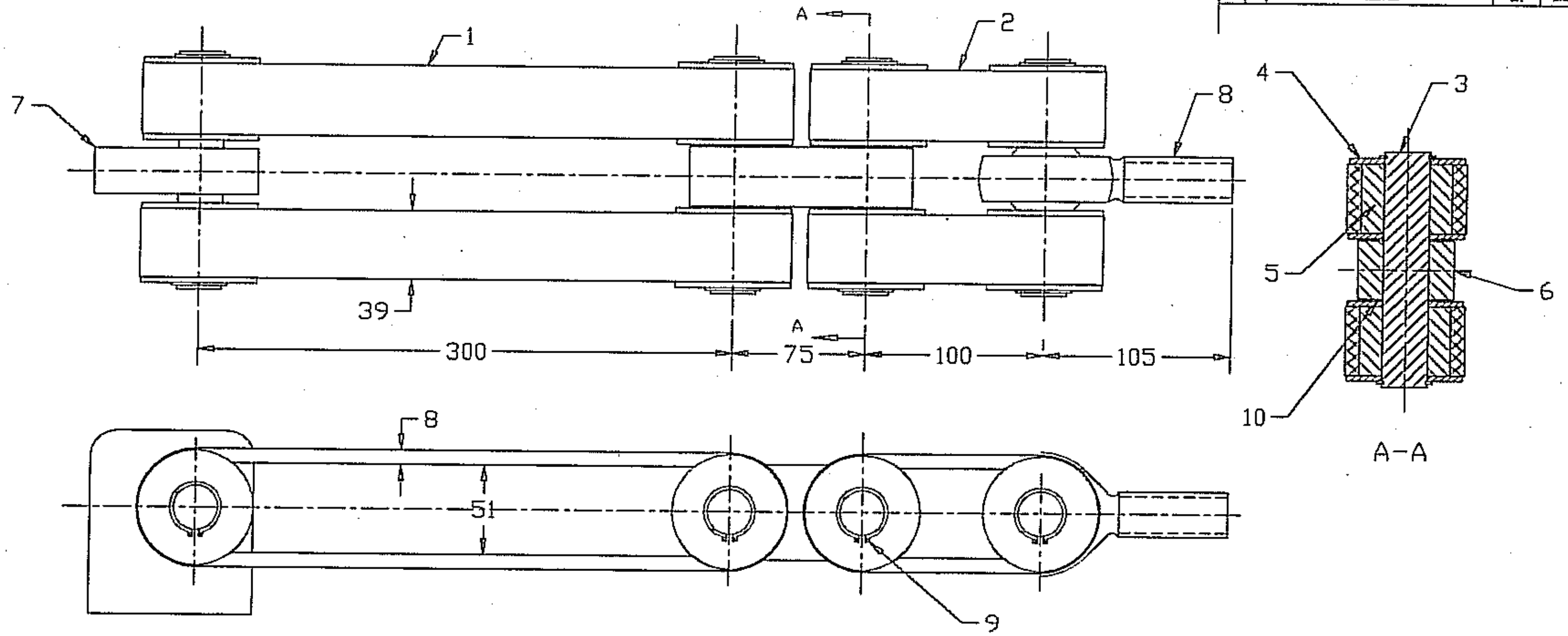
From instrument wire support (G-10), all instrumentation wires will be routed upwards through a G-10 tube, employing 0.005 Cu Ni wire Teflon insulated. These wires will be ended to a multiple pin feedthru at the top of helium neck tube.

Drwg MICE-C009 shows the 38.1mm OD neck tube with 36.32mm ID. The OD is machined to 36.82 mm to cut down solid conduction to 4.2 K and to 64 K. It is made from 1.5" OD x 0.035" wall 304LSS seamless tube.
At bottom of the neck tube we install precool nozzle (Drwg MICE-C010) and precool line (Drwg MICE-C011) to allow cooldown evenly along the length.
At top the neck tube, we install bellow to take care thermal contraction. In addition a rupture disc, a relief valve and a transfer line quick connect/ disconnect are installed. There are one 38 mm diameter neck tubes with thermal intercept to the first stage of the cooler. The intercept will be keep below 70K.

PRESSURE RATING AND PRESSURE RELIEF

The neck tube is part of helium vessel. Thus, the design internal working pressure is 44 psig and the design external working pressure must be 15 psig. The relief valve which is attached to the neck tube is set at 29 psig or lower. The rupture disc pressure is set between 32 psig and 44 psig. The rupture disc is connected to the bottom of the neck tube.

The neck tubes are also served as quench vent. The neck tubes must be designed to satisfy ASME pressure vessel code.



QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
6	10	MICE-L007	SPACER	304 S.S.
8	9		1" RETAIMAIN RING	
1	8		1" HIGH STRENTH ROD END	
1	7	MICE-C007	4.2K BRACKET	304 S.S.
1	6	MICE-L006	50K BRACKET	304 S.S.
8	5	MICE-L005	BUSHER	304 S.S.
16	4	MICE-L004	WASHER	304 S.S.
4	3	MICE-L003	PIN	INCONEL
2	2	MICE-L002	50K-300K FIBER GLASS STRIP	S2 GLASS
2	1	MICE-L001	4.2K-50K FIBER GLASS STRIP	S2 GLASS

NOTES:
1) DIMENSIONS ARE IN mm
2) QTY. 8 SET

WANG NMR, INC.
MICE TRACKER MODULE
25T COLD MASS
SUPPORT
D
MICE-L000

III-5. Cold Shippable Cold Mass Support Design

Engineering Design Drawings for cold mass support are shown in Appendix III-11-1. The 4.2K cold mass will be supported with a low heat leak, proprietary designed unidirectional fiberglass laminate. The suspension system will be configured so that it provides rotational restraint. As shown in Figure I-2, the support strength will be such that the dynamic shipping g-load will be satisfied (ie. up 1g, down 3g, transverse 2.5g). Therefore, the system is cold shippable after the magnet is discharged to zero field. The proprietary design features includes but not limited to a special angles such that the cold end when it is cooled down will trace through a path that will neither increase nor decrease the stress of links. The 60K is suspended in a G-10 rod. The 4.2K cold mass suspension subsystem is shown in Drwg MICE-L-000.

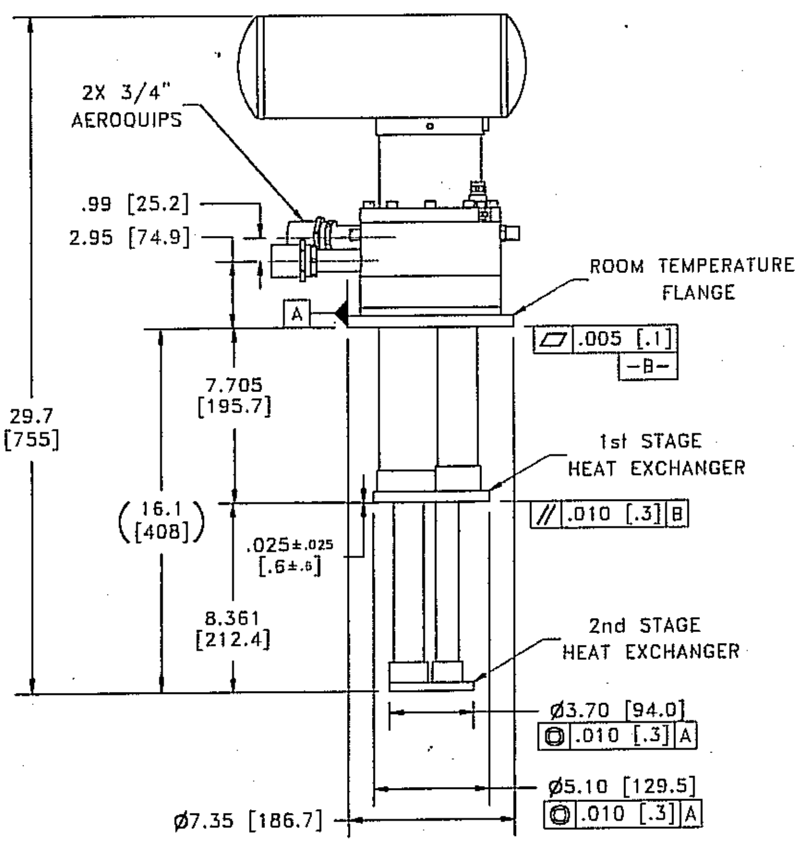
III-6. Cryogen Free Cryogenic Design, Hi-Tc Current Leads and Crycooler Specifications (see Drwg MICE-crycool-001)

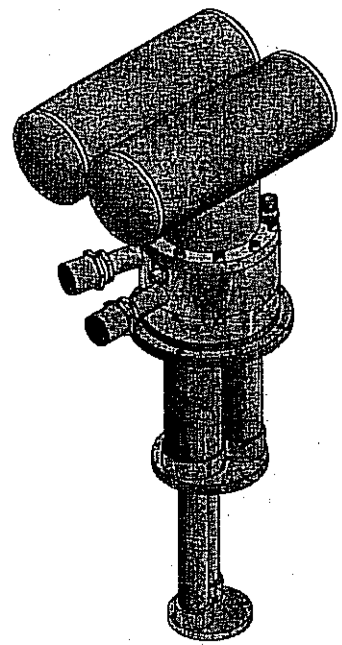
The major heat leak to 4.2K are the power leads (350A, 6 ea and 50A, 2 ea). In order to be cryogen free, Hi-Tc leads must be employed. We have developed specifications for the Hi-Tc leads and the normal leads with vacuum feedthru as shown in Table III-6-1. It is seen that the Hi-Tc leads will still have a heat leak of 0.85W to 4.2K. Furthermore, the normal leads will generate 12W per lead or 72W total to the 50-60K thermal shields system.

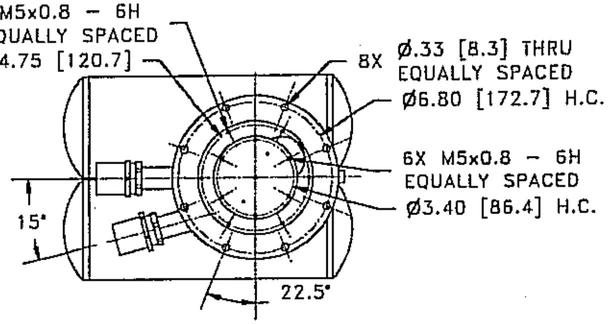
The detail heat leak tabulation due to current leads is shown in Table III-6-1. Magnet cryostat contributes 0.495W to 4.2K and 18.4W to thermal shields (50 to 64K). For each tracker solenoid, two Cryomech 1.5W pulse tube cryocoolers (model PT415) are proposed to provide cryogen-free refrigeration for the Hi-Tc leads, normal leads, and cryostat heat leak. The combined refrigeration power will be 3.0W at 4.2K and 120W at 60K.

Each Cryomech Model PT415 will have 1.5W cryocooler capability. The cooler specification is shown in Table III-6-2. PT415 cold head dimensions and PT 415 first stage and second stage performance are attached for reference.

CHPT415 | REV –







** SPECIAL NOTE: COLD HEAD MUST BE OPERATED COLD END DOWN **

THIRD ANGLE PROJECTION

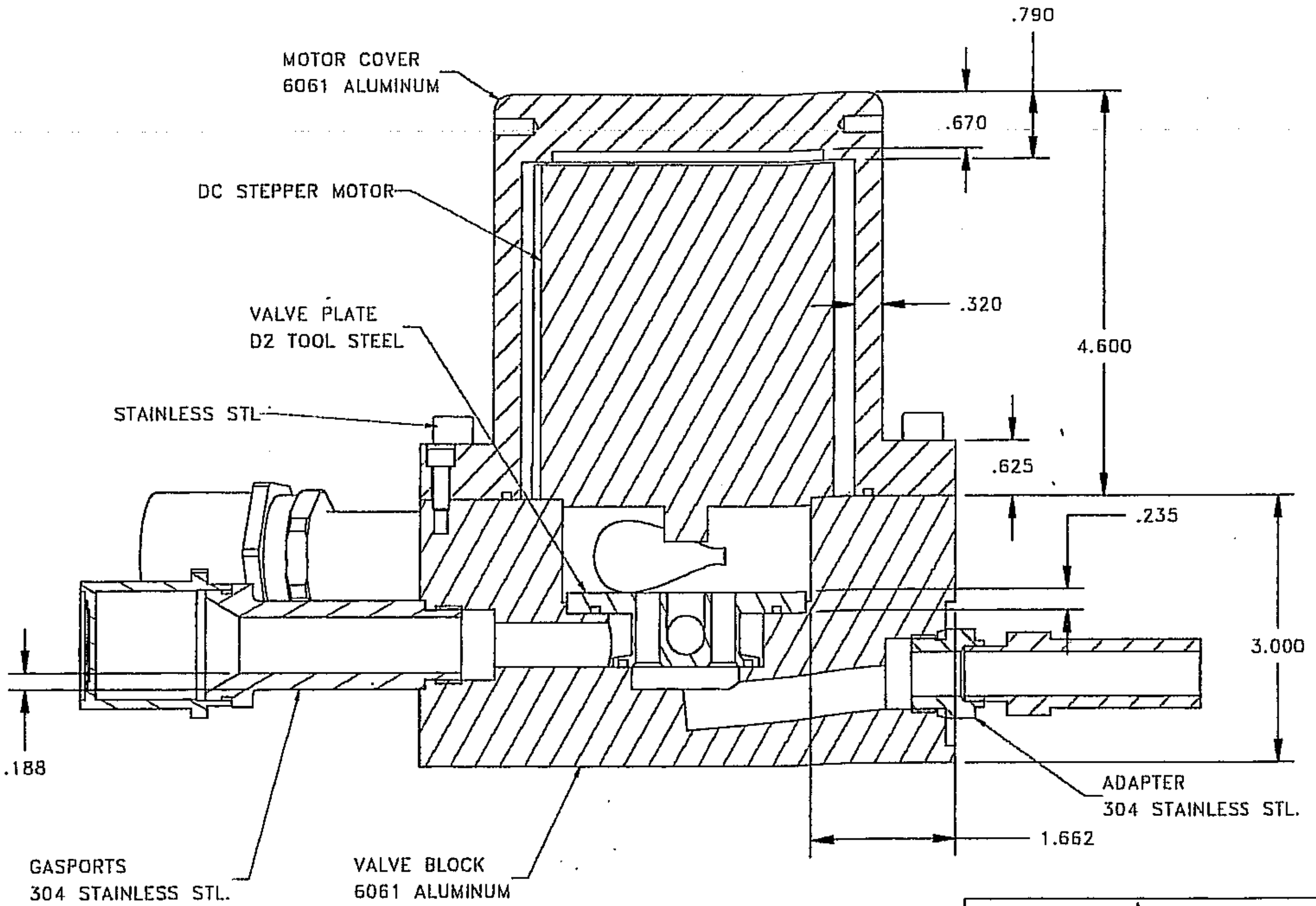
CRYOMECH,INC

113 FALSO DRIVE SYRACUSE N.Y. 13211
Tel:(315)455-2555 Fax:(315)455-2544

ALL DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±1/64 DECIMALS XXX=±.005 XX=±.01 X=±.1
ANGLES =.5° ALLOVER FINISH 25 Ra
CONCENTRICITY .005 TOTAL INDICATOR RUN OUT
PERPENDICULARITY ±.002 (UNLESS OTHERWISE SPECIFIED)

NAME: CHPT415 OUTLINE DRAWING			
PART #: CHPT415		SHT 1 OF 1	
MATERIAL: PT415			
DWN BY: AO	DATE: 02NOV05	SCALE: .150	DWG SIZE: A
1ST CHK:	DATE:	2ND CHK:	DATE:

968	–	–	INITIAL RELEASE	02NOV05



THIRD ANGLE PROJECTION

CRYOMECH,INC
113 FALSO DRIVE SYRACUSE N.Y. 13211
Tel:(315)455-2555 Fax:(315)455-2544

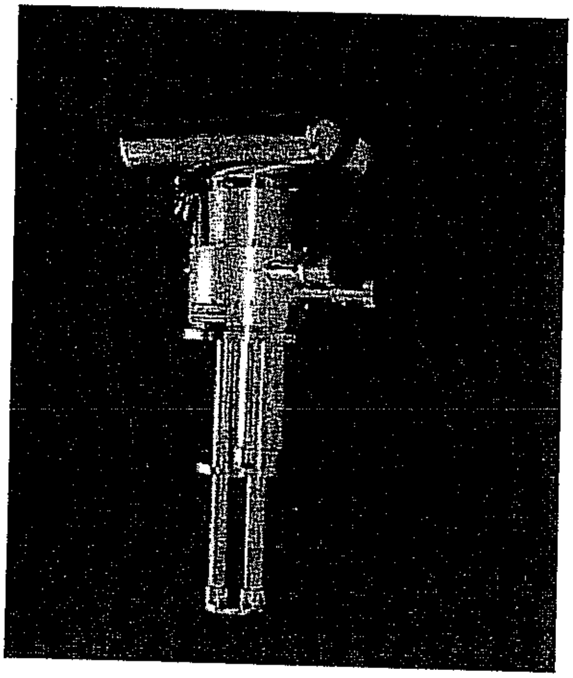
ALL DIMENSIONS ARE IN INCHES
TOLERANCES: FRACTIONS ±1/64 DECIMALS XXX=±.005 XX=±.01 X=±.1
ANGLES ±.5° ALLOVER FINISH 20 Ra
CONCENTRICITY .005 TOTAL INDICATOR RUN OUT
PERPENDICULAR ±.002 (UNLESS OTHERWISE SPECIFIED)

NAME:			
DWG #:		SHT OF	
MATERIAL:			
DWN BY:	DATE:	SCALE:	DWG SIZE:
1ST CHK:	DATE:	2ND CHK:	DATE:
CUST:			

NEW PRODUCT!

CRYOMECH

PT415



The PT415 is the largest 4K Pulse Tube yet!

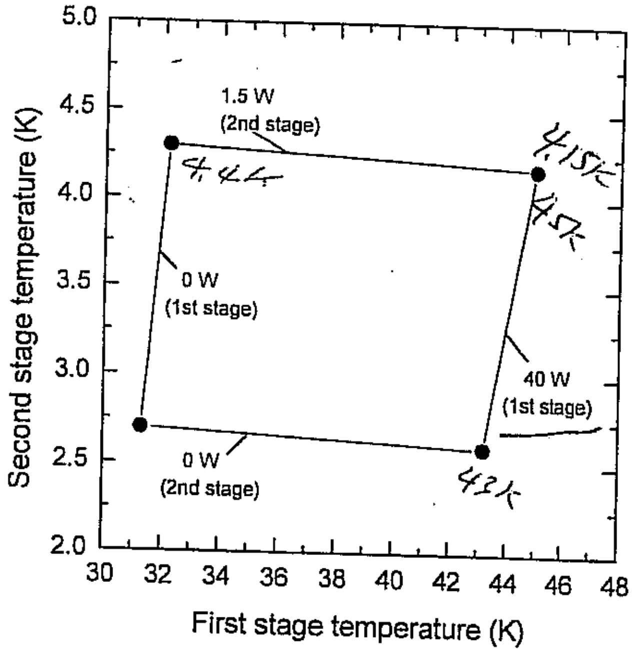
Cryomech newest 2 stage pulse tube is designed to provide 1.5 W at 4.2K and operates with the CP1010, our latest line of compressor packages.

The PT415 is available with our standard vibration elimination options such as remote motor, bellows assembly, and low vibration assembly.

Certified Performance
(50Hz and 60Hz)
2nd Stage: 1.5W @ 4.2K
1st Stage: 40W @ 45K

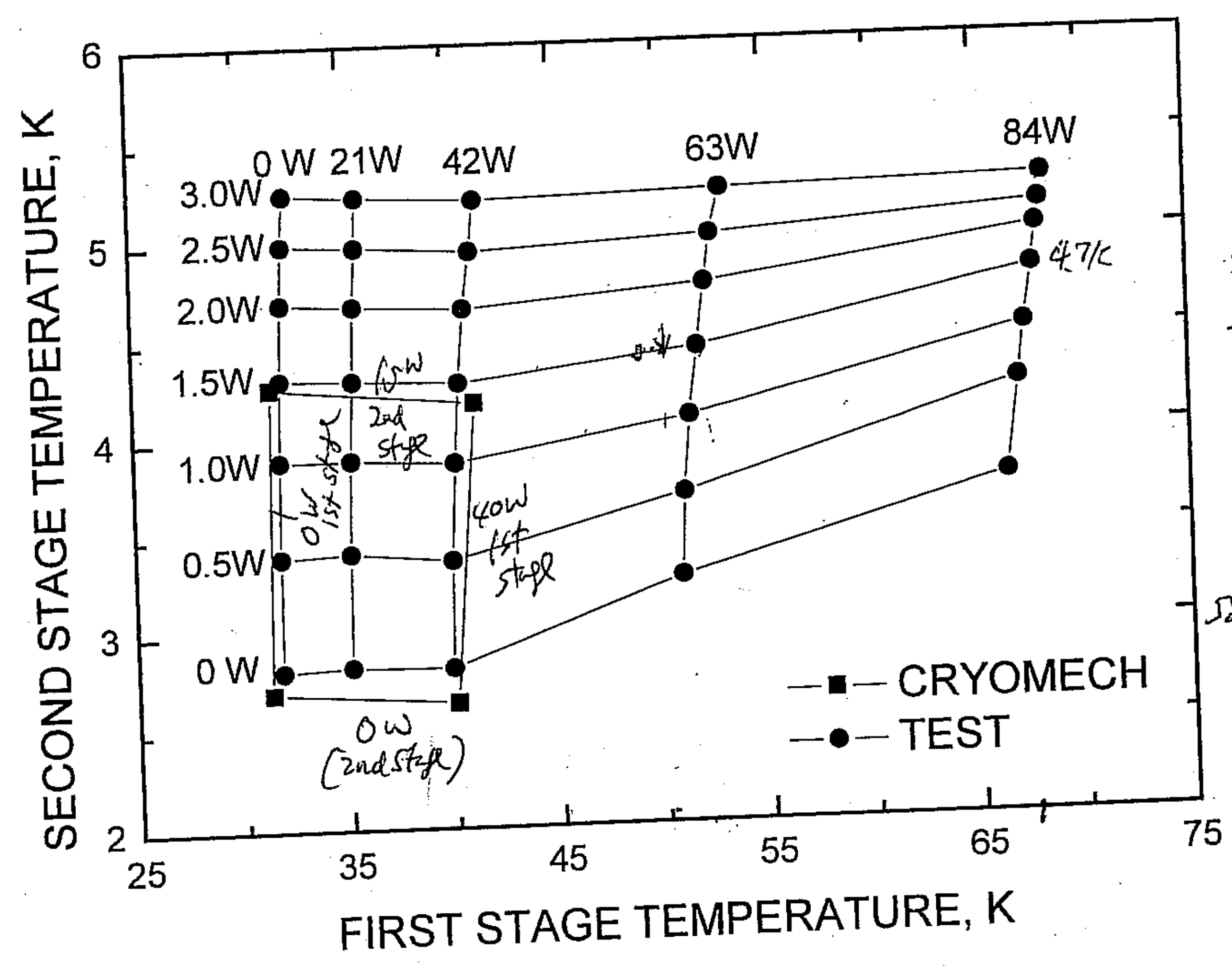
Cool down time to 4.2K:
< 60 min

CP1010 Compressor
(Water cooled only)
Input power: 11kW



PT Warranty: 3 years or 12,000 hours (whichever comes first) on all parts and materials

CRYOMECH 113 Falso Drive, Syracuse, New York 13211 USA
Ph. 315-455-2555 | Fax. 315-455-2544
www.cryomech.com sales@cryomech.com



50K
58W

58×2

2 PT415
1st stage 70K 63W
2nd 4.5K 1.5W

2EA
70K 63×2=
4.5K 1.5×2

70K 84W

TABLE III-6-1
Hi-Tc LEADS, VACUUM FEEDTHRU, AND NORMAL LEADS SPECIFICATION

A. 350A Lead – Hi-Tc (6 ea), Total Heat Leak = 0.25W/ pair at 4.2K and 28W at 60K

A-1 Specification – 500A at 64 K@ OG, 450A at 64 K@ 1000 G parallel field, 475A at 77K @ 100 G perpendicular field.

A-2 Normal Operation – Hot end at 60K or colder at $I \leq 350A$

A-3 Emergency Operation – Hot end at 80K or colder at $I \leq 350A$

A-4 Total Heat Leak at 60K at I = 300A 12W x 6 = 72W

A-5 Total Heat Leak to 4.2K at I = 300A .125W x 6 = 0.750W

A-6 Vacuum Feed Thru for 350A

A-7 Normal Leads for 350A

B. 50A Lead – Hi-Tc (2 ea) Total Heat Leak for 2 leads = 0.1W at 4.2K and 15W at 60-70K

B-1 Specification –150A at 64 K@ OG, 135A at 64 K@ 1000 G parallel field

50A at 80K @ 100 G perpendicular field

B-2 Normal Operation – Hot end at 60K or colder $I \leq 50A$

B-3 Emergency Operation – Hot end at 80K or colder $I \leq 50A$

B-4 Total Heat Leak to 60K at I = 50A 3.75W per lead or 7.5W total

B-5 Total Heat Leak to 4.2K at I = 50A 0.025W x 2 = 0.05W for 2 leads

B-6 Vacuum Feedthru for 50A

B-7 Normal Leads for 50A

TABLE III-6-2
1.5W CRYOMECH MODEL (PT 415)
PULSE TUBE CRYOCOOLER SPECIFICATION

CRYOCOOLER OUTPUT –
1.5W at 4.2K
45W at 50K (Max. 84W at 70K, 63W at 55K, or 40W at 45K)
Coldhead weight 25 kg, dimension 186.7 mm D x 389 mm L x 670 mm H)

COMPRESSOR MODEL CP1010 (WEIGHT 214 KG)
580W x 610 L x 910 mm H
Power Input – AC 220/ 230V or 460 VAC/ 60Hz, 3 phases
Max. 11.0KW
Cooling water – flow rate $\geq$ 11.5 liter/ min @27°C
Accessories – Input power cable 5 m
- Flexible gas line – 20 m

III-7. Heat leak calculations of 80k shield

Heat Leak Analyses of 80K Shield

(i.) Heat leak through one neck tubes of the Helium Vessel

The neck tube will be 1.5" OD, a 0.010" wall and a length from 300K to 70K of 8.73 cm

$$Q_{ss} = A/L \int_{70} kdT = [(0.304)/(8.73)] \times 27.12 = 0.944W$$

(ii.) Heat leak through 300K to 80K Radiation

We compute the 80K surface area $A \approx 149{,}468\ cm^2$. For 60 layers of superinsulation in a vacuum gap, $X = 2.54$ cm, the measured effective thermal conductivity of superinsulation is:

(iii.) Heat leak through LN2 cold mass suspension

The magnet coil cryostat 80K shield is suspended by eight S-2 fiberglass links which have a crosssection of 0.03125 in^2 (0.2016 cm^2) each. The length of the link will be about 7.62 cm or 3 inches. Since

$$\int_{80}^{300} kdT = 0.642 \text{ W/ cm}^2$$

we have $Q = 8\,(A/L) \int_{80}^{300} kdT = 8[(0.2016 \times 0.642)]/ 7.62] = 0.136W$.

(iv.) The heat intercept (from 300K to 80K) to the shield through the 4.2K coil cold mass suspension system

The 4.2K cold mass suspension system consists of eight supports. Each support consists of a pair of S-2 glass unidirectional race track which have 0.8 cm x 3.9 cm crossection of 3.12 cm^2. The length of the link is 10.0 cm. Since

$$\int_{80}^{300} kdT = 0.642 \text{ W/ cm}^2,$$

The total heat intercept is:

$$8 \times [(3.12 \times 4)/ 10] \times 0.642 = 6.41W$$

The total sum of steady heat leak to the LN_2 system is :

$$72W + 8W + 1.082W + 10.745W + 0.136W + 6.4W = 98.373W$$

80K shield has a total heat leak of 98.373W without sleeve, or 105.37W with sleeve. This is to compare total cryocooler capacity of 116W at 64 K.

Each Cryomech 415 pulse tube cooler will have a capacity of 40W at 45K or 58W at 64K or 63W at 70K for 1st stage while the second stage producing 1.5W at 4.2K.

III-8. Heat Leak to the 4.2K Coil Helium Vessel

(i.) Heat leak from 80K through the 1.5" diameter with a 0.010" wall

The quench vent neck tube will be 1.5" OD tubes with 0.010" wall and a length of 37.4 cm from 60K to 4.2K.

The heat leak through the S.S. tube is:

$$Q_{ss1} = A/L \int_{4.2}^{60} kdT = [(\pi \times 1.5 \times 0.010 \times 6.452)/ 37.4] \times 3.5 \text{ W/cm} = 0.028W$$

(ii.) Heat leak through the radiation from 80K to 4.2K

The total surface area of the 4.2K magnet helium vessel is 101436 cm^2. The measures effective heat transfer through 15 layers of superinsulation is 3.1 x 10^{-7} W/ cm^2. Therefore,

$$Qr(4.2K) = 3.1 \times 10^{-7} \times 101{,}436 = 0.0314W = 31.4\ mW$$

(iii.) The heat leak through Hi-Tc leads – 0.85W

(a) Six 300A Hi-Tc leads – 0.125W x 6 = 0.75W

(b) Two 50A Hi-Tc leads – 0.05W x 2 = 0.10W

(iv.) The heat leak through fifty-five permanently connected instrument wires

We shall have 55 wires for instrumentation leads, between 4.2 K and 300 K. The heat leak through 55 wires from 300K to 4.2K using 0.005" dia. cupronickel wire of 40 cm length is 8.25 mW total.

(v.) Heat leak through the cold mass suspension system

The cold mass suspension system is designed for the dynamic shipping loads of the cold mass. There are a total of eight cold mass supports. Each support consists of a pair of links with a crossection of 3.12 cm^2 x 4 or 12.48 cm^2. The length of the link from the 77K intercept to the 4.2K is 30 cm. Since :

$$\int_{4.2}^{80} kdT = 0.0926\ W/cm^2,$$

the total heat leak through the eight cold mass suspension system is :

$$8 \times (A/L) \int_{4.2}^{80} kdT = 8 \times [(3.12 \times 4)/30] \times 0.0926 = 0.308W.$$

Summing up (i) to (v), we have

4.2K Total Sum
= 0.028W + 0.0314W + 0.85W + 0.00825W + 0.308W = 1.225W (without sleeve)
= 1.436W (with sleeve)

III-9 Additional heat leak estimation if sleeve tube is used to assemble / disassemble a pulse tube cryocooler

(i) solid conduction from 300 k to 60 k = 3.2W

ASME code calculation shows the tube OD 5.24" will need a wall of 0.020" thick to support 45 psi, therefore

$$Q = A/L \int_{60}^{300} kdt = 0.122 \times 28.6 = 3.2 \text{ W}$$

Where $A = \pi DT = 3.14 \times 5.87 \times 0.020 \times 6.425 = 2.378 \text{ cm}^2$
$L = 7.705 \times 2.54 = 19.572$

(ii) solid conduction from 60 k to 4.2 k = 0.108 W

ASME code calculation shows the tube OD 3.83" will need a wall of 0.015" in thickness to support 45 psi, therefore

$$Q = A/L \int_{4.2}^{60} kdt = 1.164/30.48 \text{ X } 1.98 = 0.108 \text{ W}$$

Where $A = \pi DT = 3.14 \times 3.83 \times 0.015 \times 6.425 = 1.164 \text{ cm}^2$
$L = 8.36" = 8.36 \times 2.54 = 21.23\text{cm}$

(ii) gas conduction from 60 k to 4.2 k = 0.103 W (gas conduction from 300k - 60k?)

Summary
For two cryocooler with 2 sleeve tube

Additional heat load to 4.2K is (0.108+0.103) x 2 = 0.211W x 2 = 0.422W
Additional heat load to 60K 3.5W x 2 = 7.0 W

14

(iii) Gas conduction from 300 K to 60 K = ~~0.336 W~~ 0.5 W

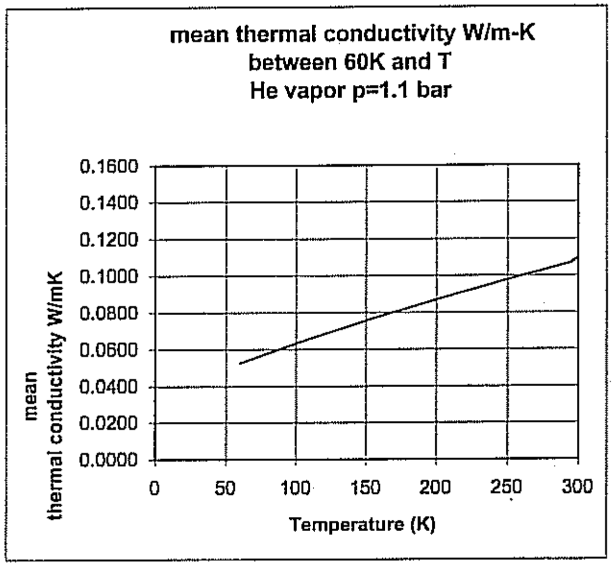
Thermal conduction in annular vapor space between stages 1 & 300 K for PT405 Cryocooler

0.6 W

OD in.	5.3		
ID1 in	1.59		
ID2 in	2.036		
area sq i	16.8206	rea sq m	0.01085
L in	7.7	L m	0.19558
		k W/m-K	0.1102
dT	20	Q W	0.336

He at 1.1 bar -Mean thermal conductivity

dT	Temperature (K)	Therm. Cond. (W/m*K)		mean Therm. Cond. 5 to T (W/m*K)
5	60	0.052562	0.26281	0.0526
5	65	0.055391	0.276955	0.0540
5	70	0.058158	0.29079	0.0554
5	75	0.060868	0.30434	0.0567
5	80	0.063527	0.317635	0.0581
5	85	0.066138	0.33069	0.0594
5	90	0.068706	0.34353	0.0608
5	95	0.071232	0.35616	0.0621
5	100	0.073721	0.368605	0.0634
5	105	0.076174	0.38087	0.0646
5	110	0.078594	0.39297	0.0659
5	115	0.080982	0.40491	0.0672
5	120	0.083341	0.416705	0.0684
5	125	0.085671	0.428355	0.0696
5	130	0.087974	0.43987	0.0709
5	135	0.090252	0.45126	0.0721
5	140	0.092506	0.46253	0.0733
5	145	0.094737	0.473685	0.0745
5	150	0.096945	0.484725	0.0757
5	155	0.099133	0.495665	0.0768
5	160	0.1013	0.5065	0.0780
5	165	0.10345	0.51725	0.0792
5	170	0.10558	0.5279	0.0803
5	175	0.10769	0.53845	0.0814
5	180	0.10978	0.5489	0.0826
5	185	0.11186	0.5593	0.0837
5	190	0.11392	0.5696	0.0848
5	195	0.11596	0.5798	0.0859
5	200	0.11799	0.58995	0.0870
5	205	0.12	0.6	0.0881
5	210	0.12201	0.61005	0.0892
5	215	0.12399	0.61995	0.0903
5	220	0.12596	0.6298	0.0914
5	225	0.12793	0.63965	0.0925
5	230	0.12987	0.64935	0.0935
5	235	0.13181	0.65905	0.0946
5	240	0.13373	0.66865	0.0957
5	245	0.13564	0.6782	0.0967
5	250	0.13754	0.6877	0.0978
5	255	0.13943	0.69715	0.0988
5	260	0.14131	0.70655	0.0998
5	265	0.14318	0.7159	0.1009
5	270	0.14504	0.7252	0.1019
5	275	0.14688	0.7344	0.1029
5	280	0.14872	0.7436	0.1039
5	285	0.15055	0.75275	0.1050
5	290	0.15237	0.76185	0.1060
5	295	0.15418	0.7709	0.1070
5	300	0.15598	0.7799	0.1102
5	300	0.15598	0.7799	-0.4539



0.24 W

(vi) Gas Conduction from 60 K to 4.2 K = 0.~~103W~~

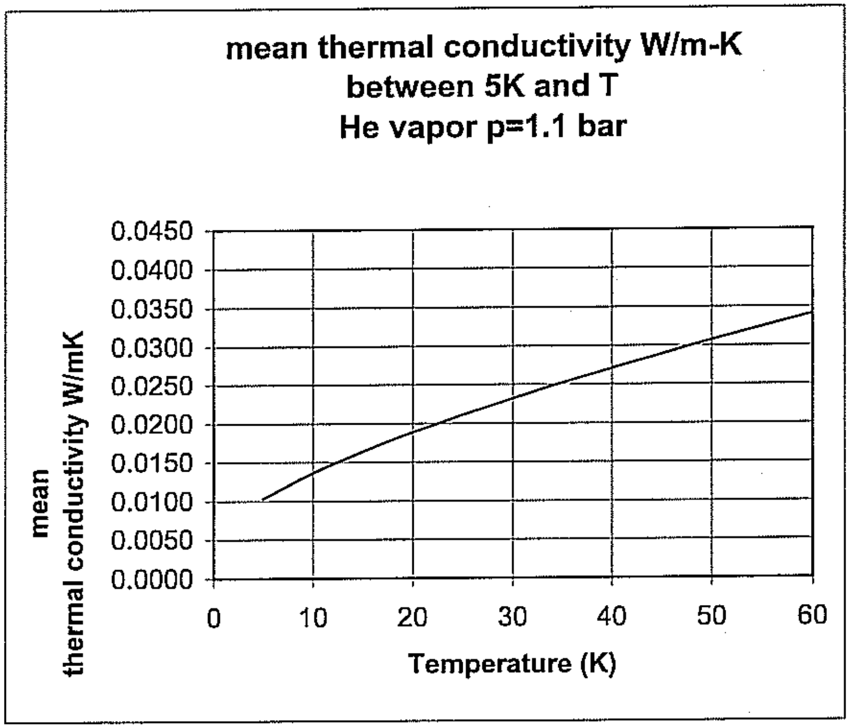
13 W

Thermal conduction in annular vapor space between stages 1 & 2 for PT415 Cryocooler

OD in.	3.8		
ID in	1		
area sq in	10.55575	area sq m	0.00681
L in	7.5	L m	0.1905
		k W/m-K	0.0526
dT	5	Q W	0.103

He at 1.1 bar -Mean thermal conductivity

dT	Temperature (K)	Therm. Cond. (W/m*K)		mean Therm. Cond. 5 to T (W/m*K)
5	5	0.010331	0.051655	0.0103
5	10	0.016925	0.084625	0.0136
5	15	0.021934	0.10967	0.0164
5	20	0.026216	0.13108	0.0189
5	25	0.030102	0.15051	0.0211
5	30	0.033729	0.168645	0.0232
5	35	0.037166	0.18583	0.0252
5	40	0.040455	0.202275	0.0271
5	45	0.043623	0.218115	0.0289
5	50	0.046687	0.233435	0.0307
5	55	0.049663	0.248315	0.0324
5	60	0.052562	0.26281	0.0341
5	65	0.055391	0.276955	0.0358
5	70	0.058158	0.29079	0.0402
	70	0.058158	0	



III-10 Estimation of Required Cryogens For Cooldown

(i.) Calculation of 80K and 4.2K Cold Mass Weight

A. Compute Cold Mass of 80K shield = 500 lb or 250 kg

B. Compute Cold Mass of 4.2K Vessel

1. Aluminum mass :
   Al Coil Bobbin= 883 lb
   Al He Shell = 428 lb
   Al Banding = 132 lb
   Reinforce Al Cylinder = 200 lb
   Total Al. Mass = 1,643 lb

2. Coil (Copper/ Superconductor) – 2,931 lb

Subtotal 4.2K System Weight = 4574 lb or 2079 kg

(ii.) Enthalpy Change of Cold Mass Material per LB

	ΔT (K)	
Material	300 - 80K	80 - 4.5K
Aluminum	69.24 BTU/LB	3.8953 BTU/LB
Copper (Superconductor Composite)	31.64 BTU/LB	2.756 BTU/LB

(iii.) Total Heat Removal From 300K to 80K

(1) Total for 80K System – AL, 69.24 BTU/LB x 550 LB = 38082 BTU

(2) Total for LHe System –

For LHe Vessel System – AL, 69.24 BTU/LB x 1643 LB = 113761 BTU

For Coil – 31.64 BTU/LB x 2931 = 92737 BTU

Therefore, total hear removal from 300K to 80K for LHe system is :

113761 BTU + 92737 BTU = 206498 BTU

(iv.) To cooldown He can from 300K to 80K, we need to transfer LN2.

Since 20648 BTU/ 365.7 BTU/LB = 565 liters LN2

(v.) Total Heat Removal from 80K to 4.2K for He Vessel

For He I (4.2K) System :
Al. (weight 7.12 LB) 3.8953 BTU/LB x 1643 LB = 6340 BTU

For S.C. Coils in He Vessel :
2.756 BTU/ LB x 2931 LB = 8078 BTU

Subtotal 14418 BTU

(vi.) Estimation of Required LHe for Cooldown from 80K to 4.2K

Again, assume exit gas at 80K, then one LB of liquid helium will remove 189.42 BTU from 80K to 4.2K, then, the required liquid helium is :

14418 BTU/ 189.42 BTU/LB = 76.1 LB, or 9.79 Ft^3 or 277 liters

Past experiences show that the exit gas temperature will be at an average temperature around 40K, one LB of liquid helium will remove 91.34 BTU, then, required helium will be

277 x 2.07 = 57.3 liters

To fill up the vessels of He, we need an additional 400 liters. Therefore, the required liquid helium per cooldown is estimated at 1000 liters.

Note: Density of liquid nitrogen is 50.46 LB/ Ft^3

Density of liquid helium is 7.798 LB/ Ft^3 and 1 Ft^3 = 28.317 liters

III-11 Design and Calculation of Cold Shippable Requirement for Cold Mass Suspension (See Fig. III-11-1)

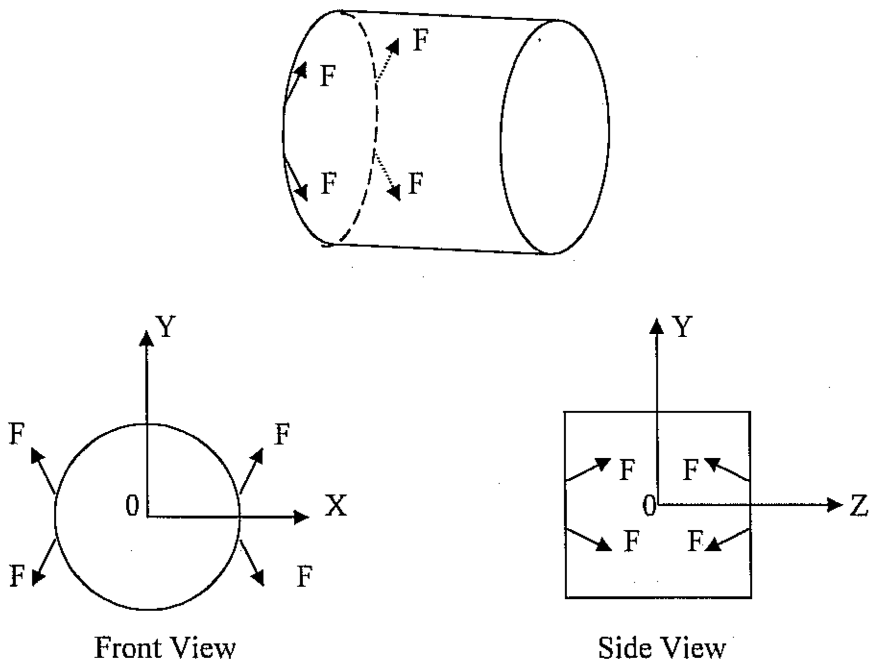


Figure III-11-1 Cold Mass Suspension

(A) Design load requirement

Design for Shipping Dynamic Load are: 1g up, 3g down and 2.5g transverse where g for 4.2K is estimated at 4574 lb and for 80K mass is estimated at 500 lb.

(B) Cold mass suspension

Engineering design drawing for cold mass support is shown in Appendix III-11-1

Cold attachment point coordination (in mm)

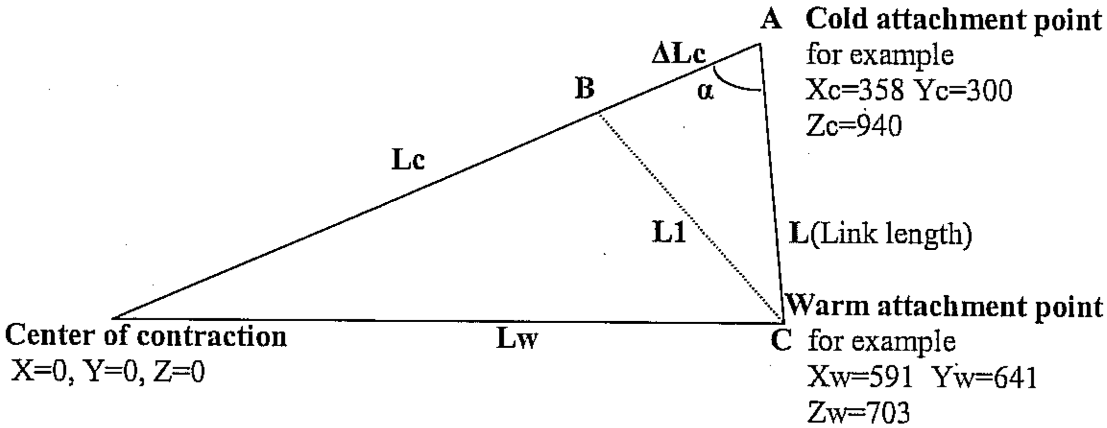
Xc = ±358 Yc = ±300 Zc = ±940

Warm attachment point coordination (in inches)

Xw = ±591 Yw =±641 Zw = ±703

8 suspension links restrict cold mass movement in X, Y, Z and X rotate, Y rotate, Z rotate direction

The tilting angle α (between link and cold attachment point to center of contraction) to avoid stress or loosed or in links, due to the thermal contraction is illustration in the following figure



$Lc = \sqrt{358^2 + 300^2 + 940^2} = 1050$ mm

$Lw = \sqrt{591^2 + 641^2 + 703^2} = 1120$ mm

$L = \sqrt{(358-591)^2 + (300-641)^2 + (940-703)^2} = 475$ mm

Cold attachment point moves from A to B due to thermal contraction so a required tile angle α

$\Delta Lc = 4.32 \times 10^{-3} \times Lc = 4.54$ mm

Link contraction: $L_1 = L - L \times 1.08 \times 10^{-3} = 474.487$ mm

$\cos \alpha = (\Delta Lc^2 + L^2 - L1^2) / (2 \times \Delta Lc \times L) = 0.118 \quad \alpha = 83.24°$

Actual angle of 88° is selected:

$\cos \alpha = (Lc^2 + L^2 - Lw^2) / (2 \times Lc \times L) = 0.074 \quad \alpha = 85.8°$

This will assure that links will tighten up after it is cooldown.

III-12 Design of liquid helium recondensing system for MICE

III-12-1 INTRODUCTION: helium vapor from cryostat boiloff is condensed on surfaces cooled by a cryocooler; and condensed liquid flows back to the magnet. The flow is driven by gravity so the condenser is positioned above the maximum level of liquid in the cryostat .

Drwg MICE-CON-000 shows the design of recondenser assembly. Drwg MICE-CON-001 shows the OFHC recondensing unit. The vacuum tight enclosure is made of 316SS which are shown in Drwg MICE-CON-002 and MICE-CON-003.

III-12-2 Design Formula for condensing surface

Theory of Eckert is used for calculation of condenser area. Heat transfer across downward-flowing liquid film determines condensation rate. In most cases of interest, liquid film is laminar. $Nu_x = \left[\frac{g\rho(h_v - h_l)x^3}{4\mu k(T_v - T_s)}\right]^{\frac{1}{4}}$ and N_{uave} = 4/3 Nu_x

$Nu_x = H_x x/k$

x = distance from top of condensing surface (m)
H_x = local heat transfer coefficient at x (W/m_2K)
k = thermal conductivity of liquid (W/mK)

$H_{ave} = \frac{4}{3} H_L$

H_{ave} = average heat transfer coefficient from x=0 to x=L (W/m_2K)
L = height of condensing surface (m)
g = acceleration of gravity (9.8 m/s_2)
ρ = density (kg/m_3)
h_v = enthalpy of vapor (J/kgK)
h_l = enthalpy of liquid (J/kgK)
μ = viscosity of liquid (Pa s)
T_v = vapor temperature (K)
T_s = surface temperature (K)

Pressure drop in tube for flow of liquid or vapor

$$\Delta P = \frac{\rho V^2}{2} f \frac{L}{D_h} \quad \text{(Pa)}$$

V = average fluid velocity (m/s)
f = friction factor
for laminar flow (Re < 2200) f = 64/Re
for turbulent flow (Re > 2200) $f = 0.316/(Re)^{0.25}$
Re = Reynolds number = $\rho V D_h/\mu$
L = tube length (m)
D_h = hydraulic diameter (m)
for a tube, D_h = inner tube diameter (m)
Difference in height between ends of tubes required to balance friction pressure drop $\Delta P_{total} = \Delta P_{liq} + \Delta P_{vap}$

liquid "head" = h (m) = $\Delta P_{tot} /(\rho_{liq}-\rho_{vap})g$ $\quad \frac{\Delta P_{tot}}{(\rho_{liq} - \rho_{vap})g}$

III-12-3 – Calculation Results

We assume the maximum case of three PT 415 cryocoolers installed and operating simultaneously. Piping is sized to accommodate the resulting helium flow. Each cryocooler has a He condenser bolted to the second stage flange.

Condenser design.

Material: OFHC copper
Helium: saturated vapor at 1.1 bar
Height of condenser fins = 2.0 inch
ΔT between vapor and plate temperature = 0.05 K
calculated heat transfer coefficient (average over the 2-inch long fin) is 1200 $W/m^2 K$
calculated required surface area: 40 sq. inch
construction:

10 slots are cut across a 2.18 inch diameter cylindrical section of copper. Each slot is 1/8 inch wide and 2 inches deep leaving a copper fin about 0.06 inch wide remaining between each slot. The resulting area exposed to He vapor is about 68 sq inches. In operation, the ΔT between vapor and fin temperature will automatically adjust to accommodate the actual head load.

The one-piece copper condenser has a flange that bolts directly to the cryocooler. A 2.5 inch OD stainless steel tube encloses the finned section and is brazed to the copper just below the flange. This tube forms a container, closed on the bottom by a stainless-steel plate.

¼-inch stainless steel tubes lead from the main He vapor vent line to the top of each condenser. Condensed liquid, (which is slightly subcooled below the saturation temperature of the vapor), drops from the tip of the fins into a space at the bottom and from this space flows into the ¼-inch liquid exit tube. ¼- inch liquid tubes lead from each condenser to the common liquid down-tube which carries liquid to the bottom of the magnet He volume. Liquid level in the down-tube is slightly higher (about 1.4 inches) than the level of the liquid He surface in the magnet.

Pressure drop:

If it is assumed the each ¼-inch line is at least 48 inches long, and the main down tube is at least 3/8-inch OD x 0.035 inch wall x 48 inch long, with three cryocoolers operating, the total pressure drop due to fluid friction is about 5.5 Pa requiring at total liquid "head" of only about 1.2 inches.

The tubes will probably be much shorter than 48 inches, so achieving the required "head" will be assured.

9/5/2006 4:02:14 PM CET

Example calculation of pressure drop: 20.31

For He at 4.3 K, h_{vap}= 20.7 kJ/kg, h_{liq} =0 .388 J/g,(h_{vap}- h_{liq}) = 30.31 J/g

Mass flow rate = 1.5 W/30.31 J/g = .0737 g/s

For vapor tube: 20.31 = .0739 OK

V_{vap} = 0.25 m/s;

$\frac{\rho V^2}{2}$ = 0.563 Pa; ρ = 17.2 kg/m3, μ = 1.28x10^{-6} Pa*s; D = 0.18 inch = 0.00457 m

Re =ρVD/ μ = 16,100 (flow is turbulent); f= 0.028;

$\Delta P/L = \frac{\rho V^2}{2} f \frac{1}{D_h}$ = 3.45 Pa/m; for 48 inches = 1.22 m, dP = 4.2 Pa

Similarly, for liquid tube:

V_{liq}= 0.364 m/s;

$\frac{\rho V^2}{2}$ = 0.63 Pa; ρ = 123 kg/m3, μ =3.12x10^{-6} Pa*s; D = 0.18 inch = 0.00457 m

Re =ρVD/ μ = 6570 (flow is turbulent); f= 0.035;

$\Delta P/L = \frac{\rho V^2}{2} f \frac{1}{D_h}$ = 0.63 Pa/m; for 48 inches = 1.22 m, dP = 0.77 Pa

Note that most of the pressure drop is in the vapor tube.

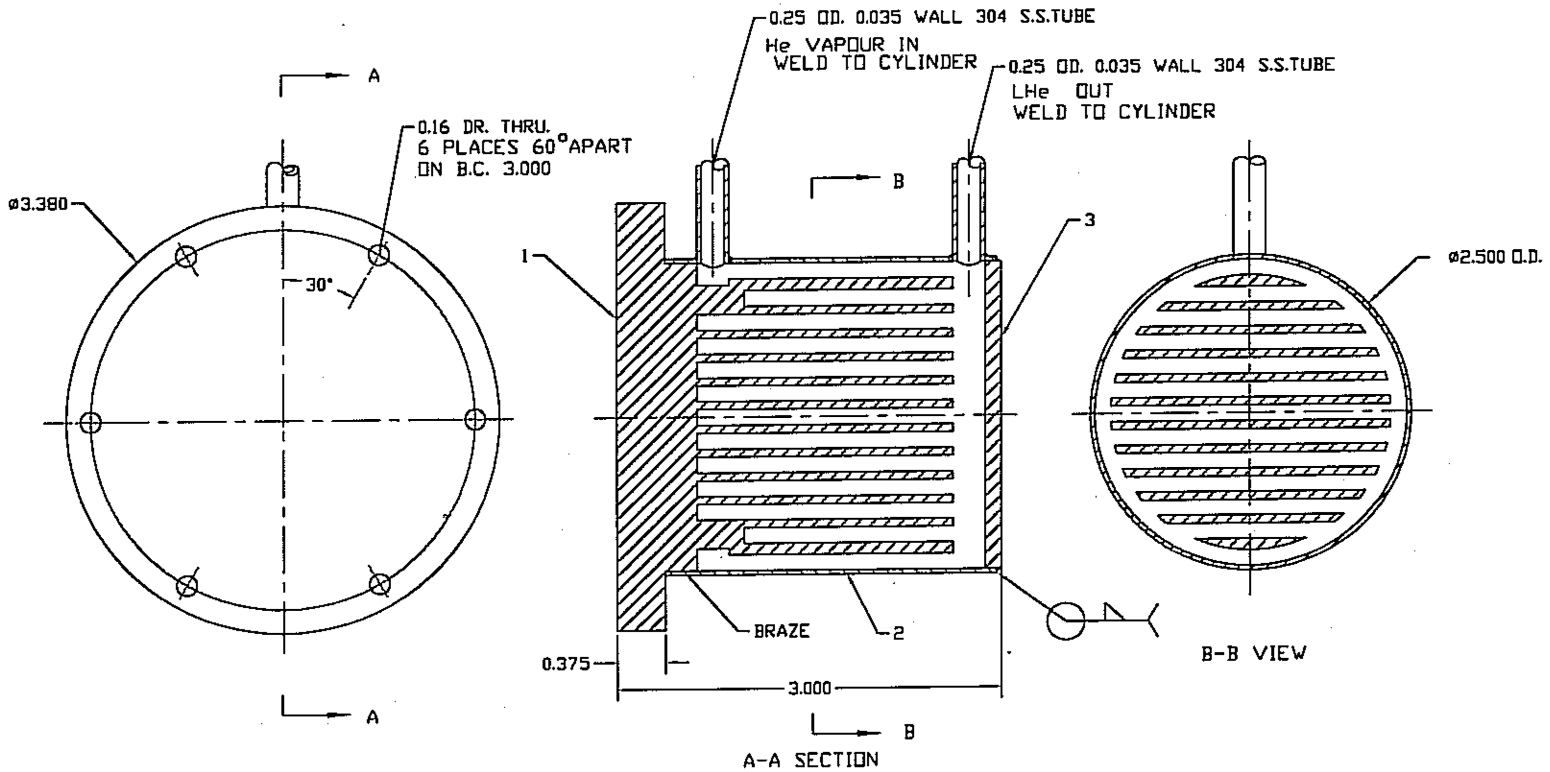
If we assume a 3/8x 0.035 wall down tube with flow from three condensers, with length = 48 inches, it's pressure drop is less than 0.5 Pa

Total pressure loss tubes is about 5.5 Pa

Equivalent liquid helium "head" is h = ΔP / ρ g where g = 9.8 m/s

h = 4.54 mm ≠ 1.15 inches

= 0.17"



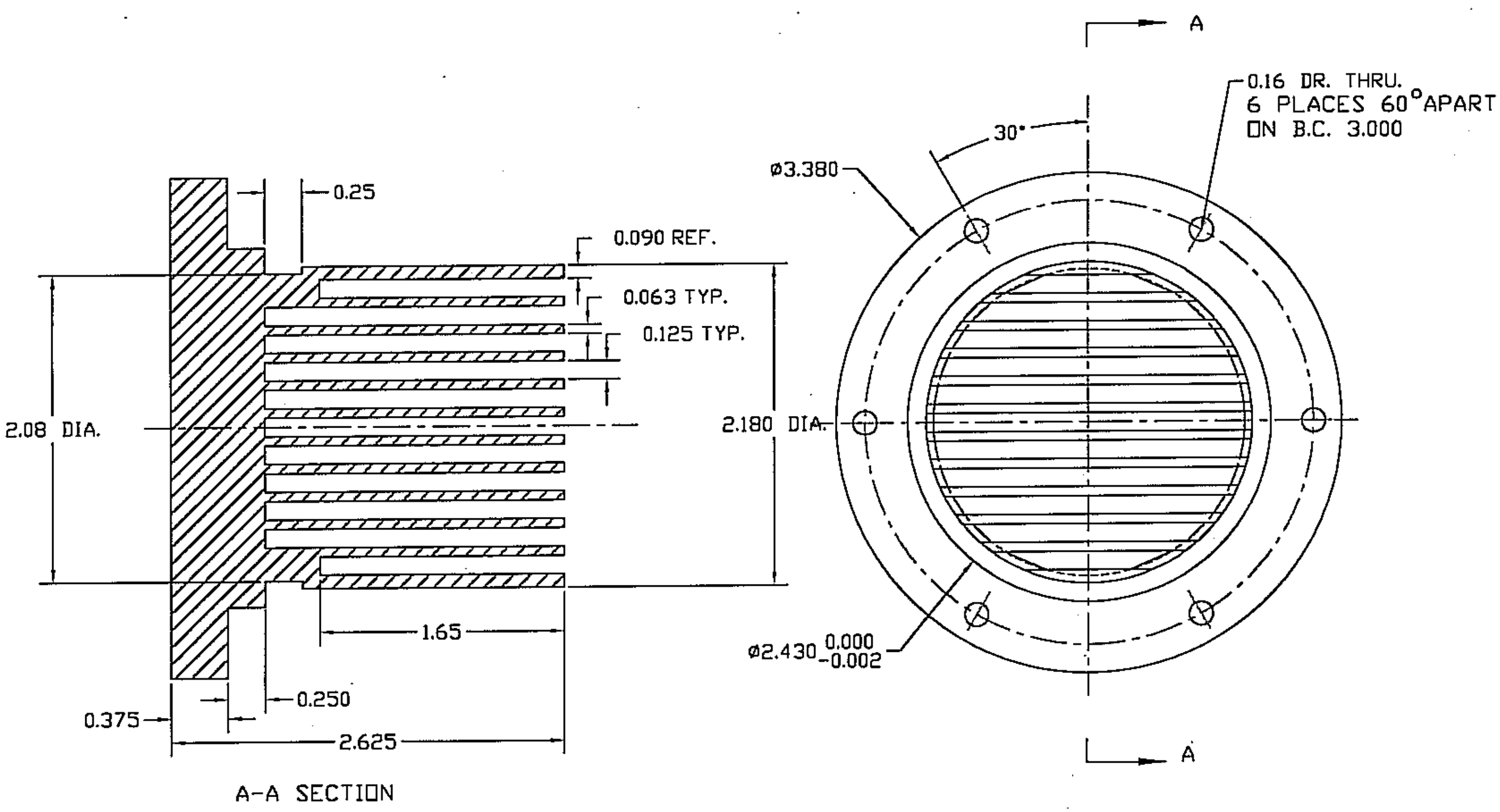
NOTES:
1) DIMENSIONS ARE IN INCHES
2) QTY. REQD. 3 SETS

QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
1	3	MICE-CON-003	VACUUM DISC	304 S.S.
1	2	MICE-CON-002	VACUUM CYLINDER	304 S.S.
1	1	MICE-CON-001	CONDENSING FINS.	OFHC

WANG NMR, INC.

LHe CONDENCE
HEAT EXCHANGE

D MICE-CON-000



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 3.50 O.D. OFHC ROD
3) QTY. 1

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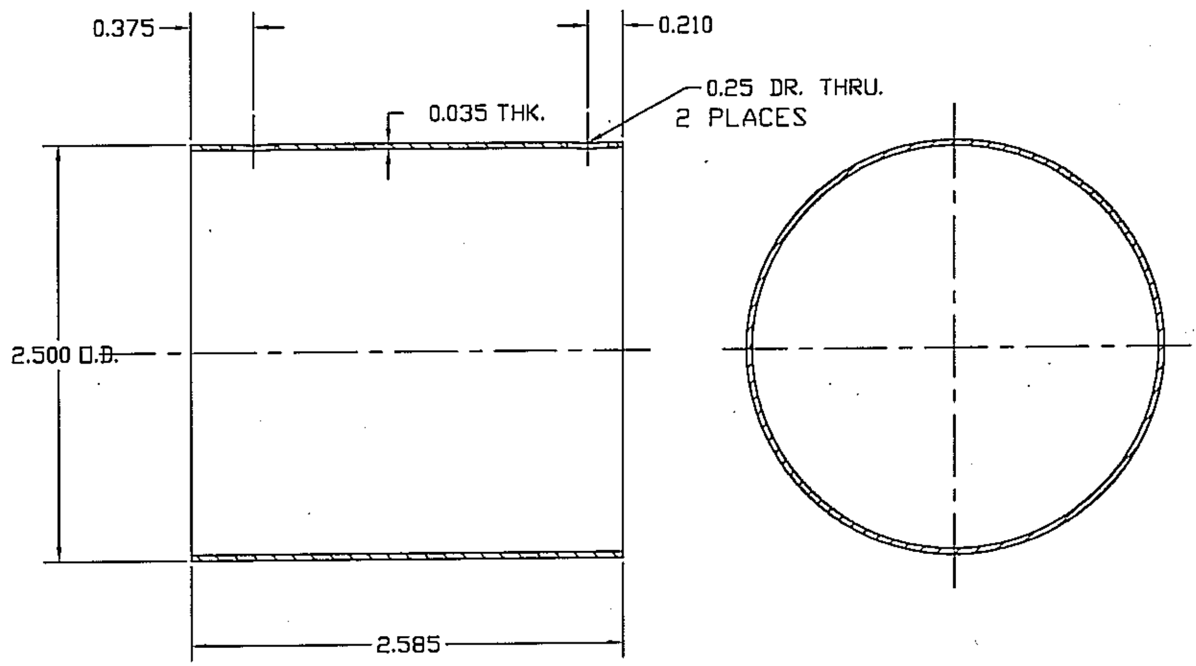
HEAT EXCHANGE FINS.

D

MICE-CON-001



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 2.5 O.D. 0.035 WALL 304 S.S. TUBE
3) QTY. 1

ZONE	REV	DESCRIPTION	DATE	APPROVED

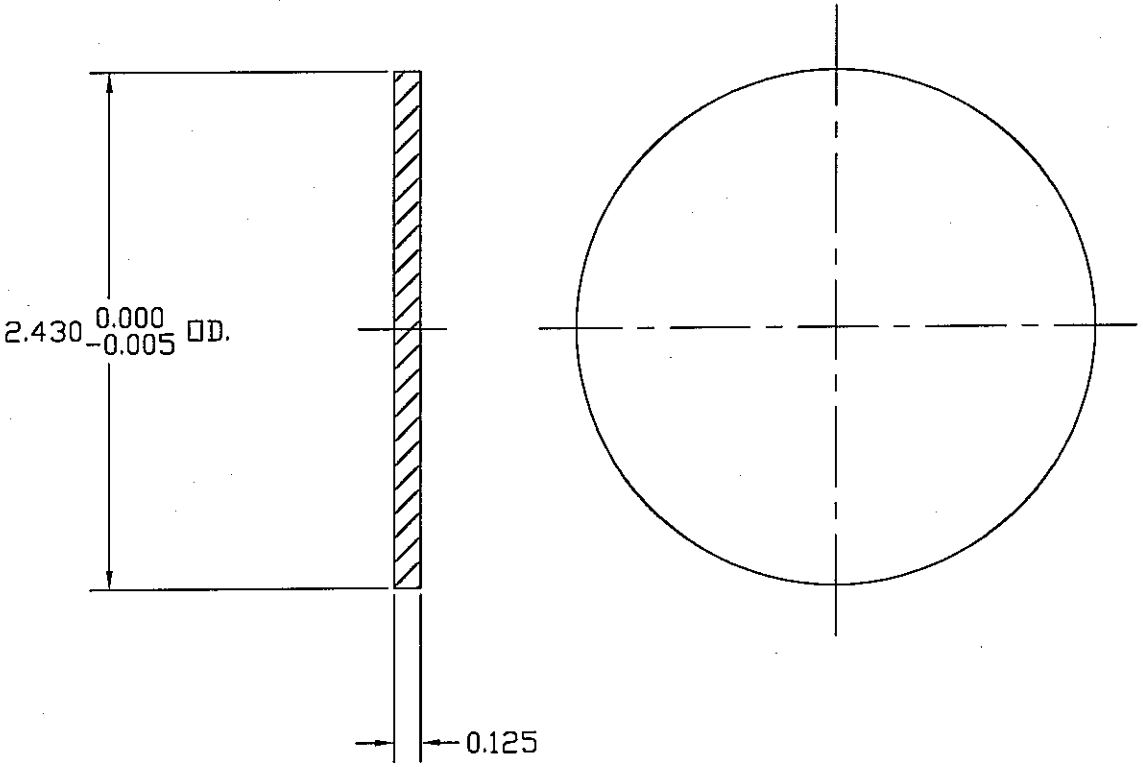
UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

TITLE: VACUUM CYLINDER

SIZE: C
DWG NO: MICE-CON-002

DO NOT SCALE



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 1/8 THK. 304 S.S. PLATE
3) QTY. 1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

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550 North canyons Parkway, Livermore, CA 94550

VACUUM DISC

C | MICE-CON-003

DO NOT SCALE

III-13 Instrumentation Design and Feed through for each Tracker

The following Table, III-13A, lists the sensors, location, and wiring from the magnet through the helium vent. Two feed through connector are used.
Connector J1 is 27 contact, Fischer P/N DEE 105A1
Connector J2 is 11 contact, Fischer P/N DEE104A056

TABLE III-13A

SENSOR TYPE	SENSOR DESIGNATION	LOCATION	NO. OF WIRES	FEED-THROUGH J01-
Temperature PT 100	TRP01	Bottom of pre-cool line	4	1,2,3,4
Temperature CERNOX	TRX 01	Match Coil #1	4	5,6,7,8
	TRX 02	End Coil #2	4	9,10,11,12
Helium level 600 mm	LHE 01	Lower level	7	13,14,15,16,17, 18,19
	LHE 02	Upper Level		
				FEED-THROUGH J02-
Voltage Tap	VTM 01	End Coil #2, Start	9	1
	VTM 02	End Coil #2 & Center Coil		2
	VTM 09	Center Coil Tap		9
	VTM 03	Center Coil & Coil #1		3
	VTM 04	End Coil #1, Finish		4
	VTM 05	Match Coil #2, Start		5
	VTM 06	Match Coil #2, Finish		6
	VTM 07	Match Coil #1, Start		7
	VTM 08	Match Coil #1, Finish		8

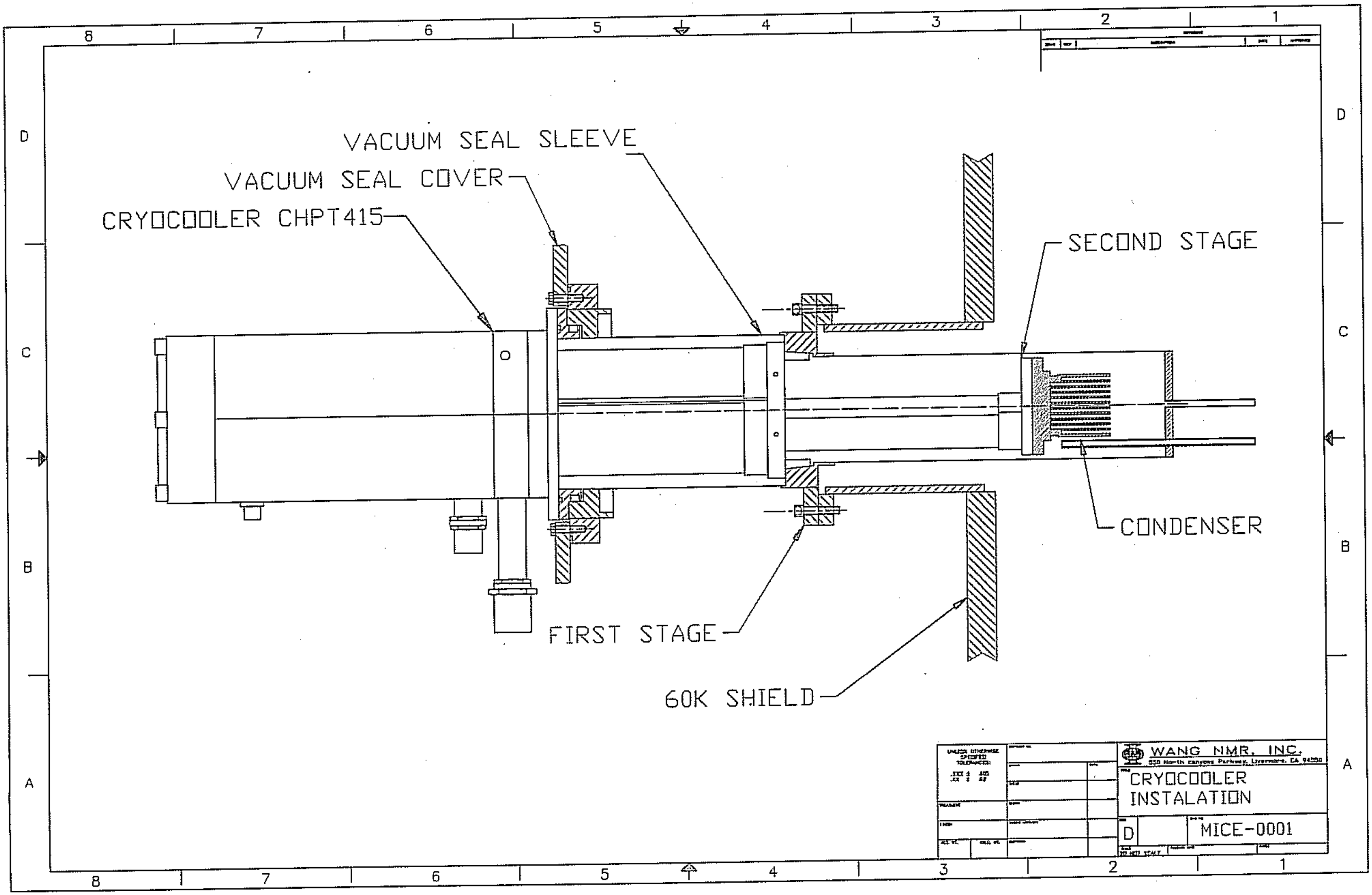
The following table, III-13B, lists the sensors, location, and wiring from the magnet through the vacuum wall. Two feed through connector are used.
Connector J3 is 11 contact, Fischer P/N DEE104A056
Connector J4 is 40 contact, Fischer P/N DEE 107A52

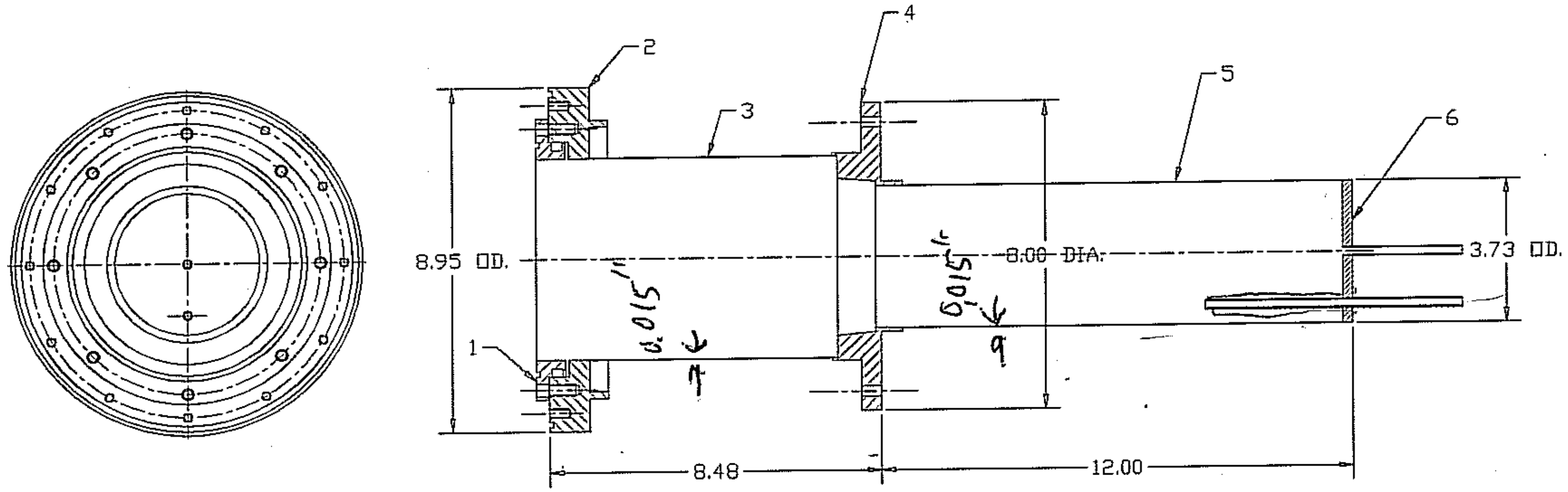
TABLE III-13B

SENSOR TYPE	SENSOR DESIGNATION	LOCATION	NO. OF WIRES	FEED-THROUGH J02-
Voltage Tap	VTL 01	Bottom of HTS Lead (F)	8	1
	VTL 02	Bottom of HTS Lead (H)		2
	VTL 03	Bottom of HTS Lead (G)		3
	VTL 04	Bottom of HTS Lead (E)		4
	VTL 05	Bottom of HTS Lead (D)		5
	VTL 06	Bottom of HTS Lead (C)		6
	VTL 07	Bottom of HTS Lead (B)		7
	VTL 08	Bottom of HTS Lead (A)		8
				FEED-THROUGH J03-
Temperature PT 100	TRP 02	64 K shield	4	1, 2, 3, 4,
Temperature PT 100	TRP 03	Cryocooler #1, Stage 2	4	5, 6, 7, 8,
	TRP 04	Cryocooler #2, Stage 2	4	9, 10, 11, 12
Temperature PT 100	TRP 05	HTC Lead #1, Warm End	4	13, 14, 15, 16,
	TRP 06	HTC Lead #2, Warm End	4	17, 18, 19, 20
Temperature CERNOX	TRX 03	Cryocooler #1, Stage 1	4	21, 22, 23, 24
	TRX 04	Cryocooler #2, Stage 1	4	25, 26, 27, 28
Temperature CERNOX	TRP 05	HTC Lead #1, Cold End	4	29, 30, 31, 32
	TRP 06	HTC Lead #2, Cold End	4	33, 34, 35, 36

III-14 Design of sleeve and Installation of cryocooler

Drwg MICE-0001 shows the cryocooler installation with sleeve. The first stage is indirectly cooled through OFHC cone contact. This might create imperfection in heat transfer. In additional two sleeves tubes will contribute at least 7.0W heat load to first stage and 0.422W to the second stage.


VACUUM SEAL SLEEVE
VACUUM SEAL COVER
CRYOCOOLER CHPT415
SECOND STAGE
CONDENSER
FIRST STAGE
60K SHIELD
WANG NMR, INC.
CRYOCOOLER INSTALATION
D
MICE-0001



NOTES:
1) DIMENSIONS ARE IN INCHES

QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
1	6	MICE-C007		
1	5	MICE-C006		
1	4	MICE-C005		
1	3	MICE-C004		
1	2	MICE-C003		
1	1	MICE-C002		

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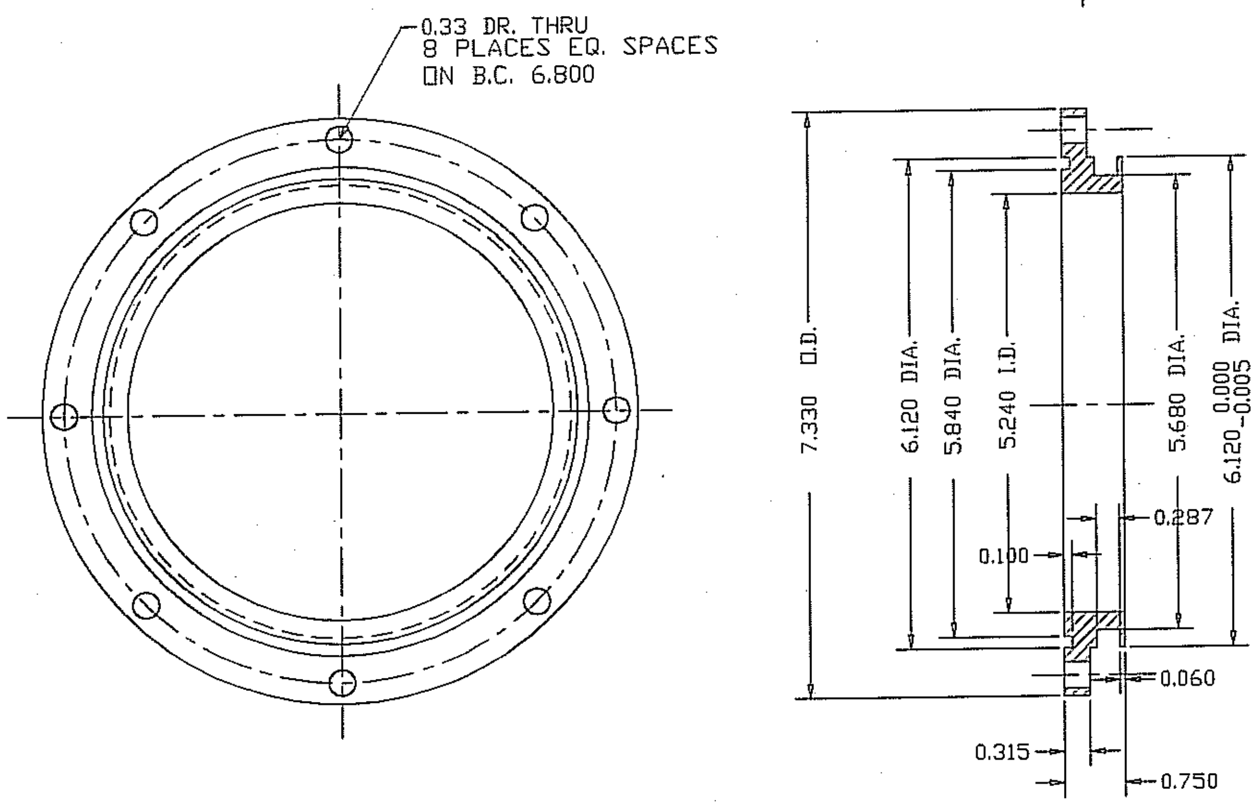
D MICE-C001



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 304 S.S.
3) QTY. 1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

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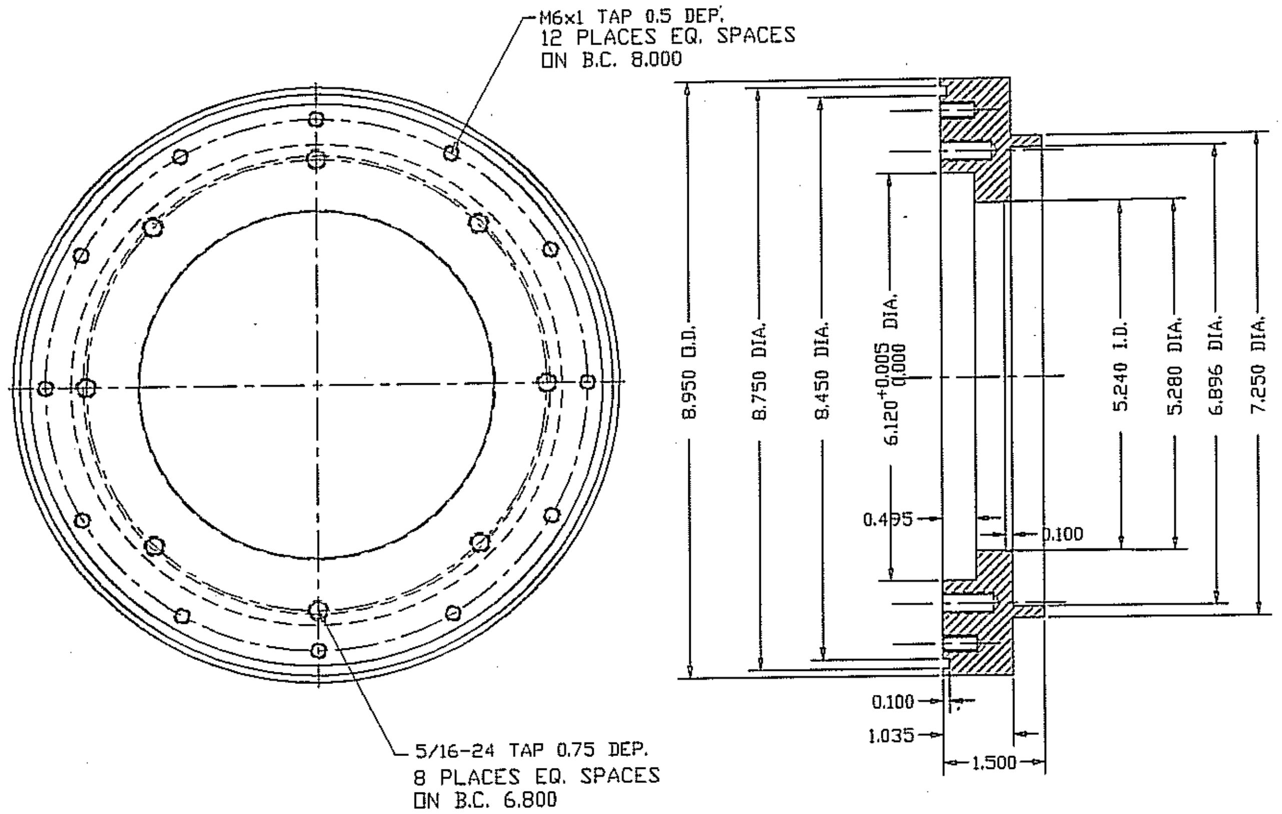
SIZE C
MICE-CD02
DO NOT SCALE



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 304 S.S.
3) QTY. 1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

WANG NMR, INC.
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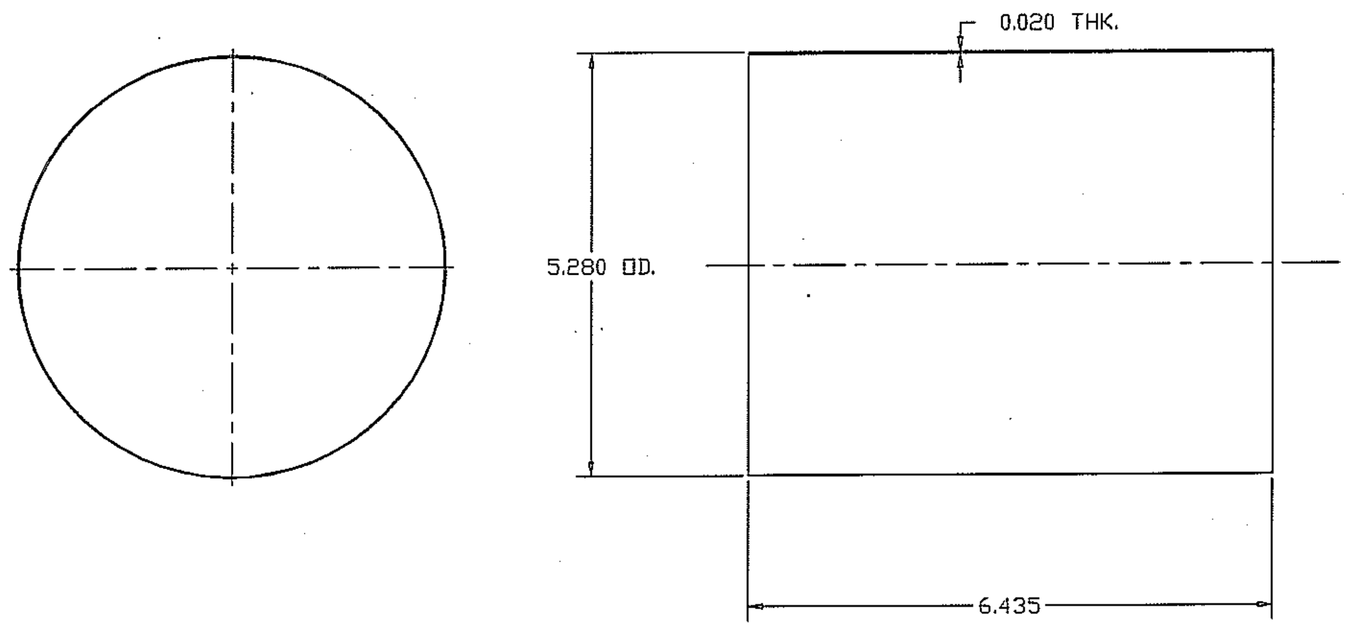
SIZE	DWG NO.
C	MICE-C003

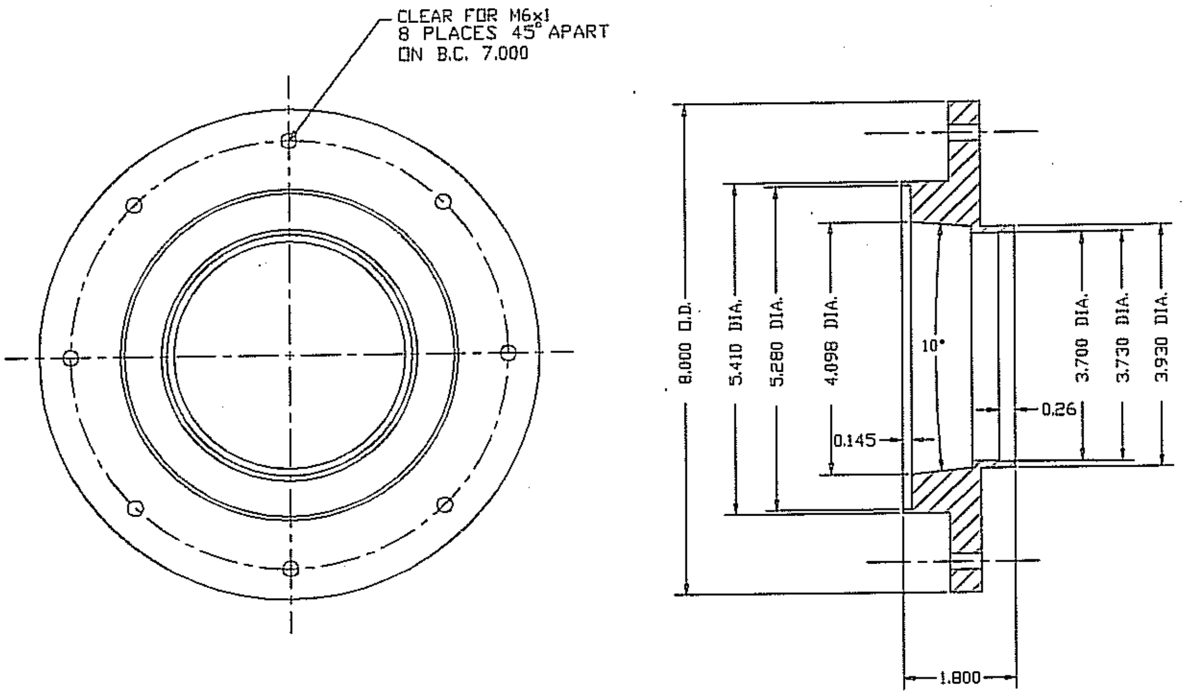
DO NOT SCALE



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 304 S.S.
3) QTY. 1

UNLESS OTHERWISE SPECIFIED TOLERANCES: .XXX ± .005 .XX ± .02	CONTRACT NO.	WANG NMR, INC. 550 North canyons Parkway, Livermore, CA 94550
TREATMENT	DESIGN	TITLE
FINISH	DESIGN ACTIVITY	SIZE C — DWG NO. MICE-C004
ACT. WT. / CALC. WT.	CUSTOMER	SCALE DO NOT SCALE — RELEASE DATE — SHEET

REVISIONS: ZONE | REV | DESCRIPTION | DATE | APPROVED



NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS OFHC
3) QTY. 1

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.XXX ± .005
.XX ± .02

WANG NMR, INC.
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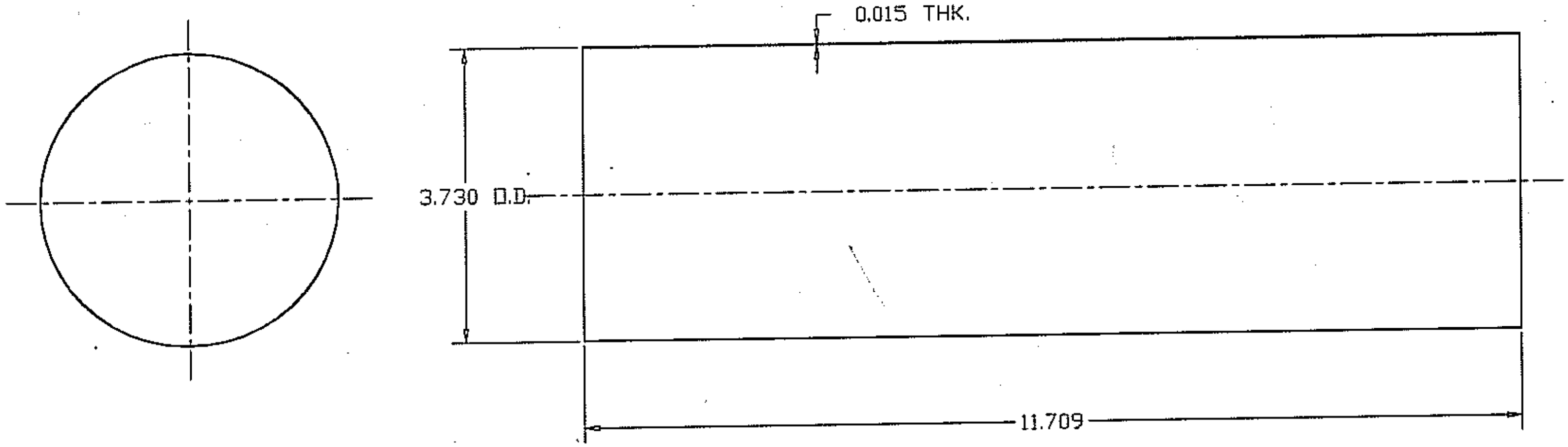
SIZE: C
DWG NO: MICE-C005
DO NOT SCALE

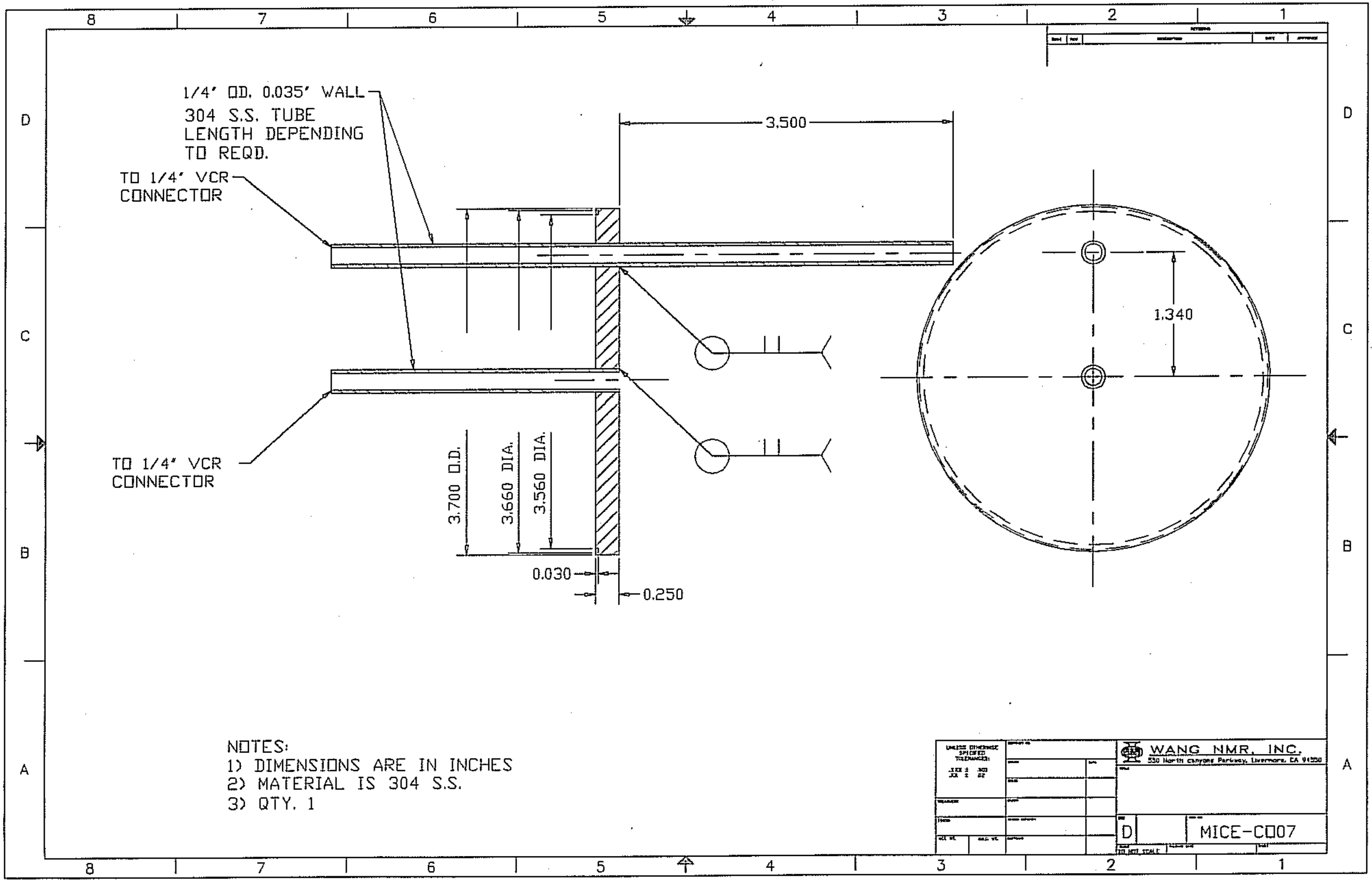


NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 304 S.S.
3) QTY. 1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

SIZE: C
DWG NO: MICE-C006
DO NOT SCALE



1/4" OD. 0.035" WALL
304 S.S. TUBE
LENGTH DEPENDING
TO REQD.
TO 1/4" VCR
CONNECTOR
TO 1/4" VCR
CONNECTOR
3.500
1.340
3.700 O.D.
3.660 DIA.
3.560 DIA.
0.030
0.250
NOTES:
1) DIMENSIONS ARE IN INCHES
2) MATERIAL IS 304 S.S.
3) QTY. 1
WANG NMR, INC.
550 North Canyons Parkway, Livermore, CA 94550
D
MICE-C007
DO NOT SCALE

APPENDIX III-1-1

ASME Code Calculation

For MICE Cryostat

Wang NMR, Inc.

550 North Canyons Parkway , Livermore, Ca. 94551

SUMMARY ON ASME CODE ANALYSIS OF MICE SOLENOID CRYOSTAT DESIGN

ASME code for shell stress and end disc.(end plate) are employed to verify the ASME stress and thickness requirement and then compare with design thickness.

Design internal working stress for He Vessel is 45 psi. Design stress for vacuum vessel is 15 psi.

4.2 K shell thickness and stress were examined for He shell, bobbin tube and He neck tube. 300 K shell thickness and stress were examined for outer shell and inner bore tube. In each case, we found our design satisfy ASME code. All designs are very conservative.

Stresses on 4.2 K cylinder plate of bobbin and on 300 K vacuum end plate were also examined. They also satisfy ASME code with very conservative margin.

Fault conditions such as quench pressure (45 psi) and vacuum break (15 psi above atmosphere pressure or 30 psi absolute) as well as required normal operations such as leak check were also examined. Again, they satisfy ASME code with good safety margin.

SHELL STRESS ANALYSIS

ASME Code Verfication Calculation

For MICE TRACKER MAGNET SYSTEM, LBL

(Bobbin, He Vessel and Vacuum Vessel)

Date: July 7, 2006

I. Design Dimension:(inch)	ID	OD	THICK	LENGTH
Bobbin (Al 6061-T6)	19.291	20.236	0.473	100.160
He Shell (Al 6061-T6)	27.500	28.500	0.500	100.160
End Closure (Al 6061-T6)	19.291	28.500	0.800	100.160
Inner Vessel (304 Stain Steel)	15.787	16.023	0.125	107.680
Outer Vessel (304 Stain Steel)	54.094	55.275	0.625	107.677
End Flange (304 Stain Steel)	16.023	51.732	0.750	107.677

II. Under External Pressure	(Leak Ck) Outer Vessel	(Quench) Bobbin	(Leak Ck) He Shell	(Vac. Break) Inner Vessel
Material	S. S.-304	Al- 6061T	Al- 6061T	S. S.-304
Shell Thickness (in) *(thk)*	dwg? .75 ~~0.625~~	0.473	0.500	0.125
Length (in) *(lgh)*	107.677	100.160	100.160	107.680
Outside Diameter (in) *(OD)*	55.275	20.236	28.500	16.023
D/t *(D =OD / thk)*	88.440	42.782	57.000	128.184
L/D *(L = lgh / OD)*	1.948	4.950	3.514	6.720
Factor A (UGO-28.0)** *(UGO)*	0.00200	0.00340	0.00250	~~0.00030~~
Factor B (UHA-28.1) *(UHA)*	12000.00	5400.00	5000.00	~~4300.00~~
Max. allowable P (psi) * *MAP*	180.46	167.87	116.67	44.62
* *MAP = 1.33 * UHA/ D*				
Actual Working P (psi) *AWP*	15.00	45.00	15.00	15.00
Circumf. Stress (psi) *Cstress= AWP*OD/4/thk*	331.65	481.30	213.75	480.69
Longitud. Stress (psi) *Lstress= AWP*OD/2/thk*	663.30	962.60	427.50	961.38

III. Under Internal Pressure	(Vac. Break) Outer Vessel	(Leak Ck) Bobbin	(Quench) He Shell	(Leak Ck) Inner Vessel
Design Pres. (psi) *DPres*	15.00	15.00	45.00	15.00
Inside Radius (in) *IR*	27.047	9.65	13.75	7.89
Stress Limit (psi) *SLtd*	17500.00	10000.00	10000.00	17500.00
Joint Efficiency *JE*	0.70	0.70	0.70	0.70
Thickness Req. (in) *ThkR=DPres*IR/(SLtd*JE-0.6**	0.033	0.021	0.089	0.010
Actural Design Thick(in) *ADThk*	0.625	0.473	0.500	0.125
Circumf. Stress (psi) *Cstress=Dpres*2*IR/4/ADT*	324.56	152.94	618.75	473.64
Longitud. Stress (psi) *Lstress=Dpres*2*IR/2/ADTh*	649.13	305.88	1237.50	947.28

**FACTOR A IS INDEPENDENT OF MATERIAL

Note: Stress Limit=Yield Strength/S.F.=35000/2=17500psi

Ref.: Pressure Vessel Handbook, Eugene F. Megyesy, 1977

SHELL STRESS ANALYSIS
ASME Code Verfication Calculation- He Neck tube
For MICE TRACKER MAGNET SYSTEM

Date: July 7, 2006

I. Design Dimension:(inch)	ID	OD	THICK	LENGTH
He Neck Tube (304 S S)	0.930	1.000	0.035	20.300

II. Under External Pressure	Neck Tube /	S tube		
Material	S. S.-304	"		
Shell Thickness (in) *(thk)*	~~0.035~~	.010		
Length (in) *(lgh)*	20.300			
Outside Diameter (in) *(OD)*	1.000	1.5		
D/t *(D =OD / thk)*	28.571			
L/D *(L = lgh / OD)*	20.300			
Factor A (UGO-28.0)** *(UGO)*	0.00025			
Factor B (UHA-28.1) *(UHA)*	3500.00			
Max. allowable P (psi) * *MAP*	162.93			
* *MAP = 1.33 * UHA/ D*				
Actual Working P (psi) *AWP*	15.00			
Circumf. Stress (psi) *Cstress= AWP*OD/4/thk*	107.14			
Longitud. Stress (psi) *Lstress= AWP*OD/2/thk*	214.29			

III. Under Internal Pressure	(Quench) He Neck Tube			
Design Pres. (psi) *DPres*	45.00			
Inside Radius (in) *IR*	0.930			
Stress Limit (psi) *SLtd*	17500.00			
Joint Efficiency *JE*	0.70			
Thickness Req. (in) *ThkR=DPres*IR/(SLtd*JE-0.6**	0.003			
Actural Design Thick(in) *ADThk*	0.035			
Circumf. Stress (psi) *Cstress=Dpres*2*IR/4/ADT*	597.86			
Longitud. Stress (psi) *Lstress=Dpres*2*IR/2/ADTh*	1195.71			

**FACTOR A IS INDEPENDENT OF MATERIAL

Note: Stress Limit=Yield Strength/S.F.=35000/2=17500psi

Ref.: Pressure Vessel Handbook, Eugene F. Megyesy, 1977

Cylinder Side Plate
Stress Analysis - ALUMINUM
For MICE TRACKER MAGNET SYSTEM

Date: July 7, 2006

(6061-T6 ALUMINUM FOR BOBBIN)

		End Plate of Aluminum Bobbin
Pressure Load (psi)	*(PL)*	45.00
--this is the design limit		
Outer Radius (in)		13.75
Offset (in)		0.00
Outer Radius+offset (in)	*(ORO)*	13.750
--outer radius is enlarged due to offset.		
Disk Inner Radius (in	*(DIR)*	10.118
Thichness (in)	*(t)*	0.800
--this is the thickness should be in design.		
E (AL, 6061T6) (ps	*E(al)*	1.00E+07
Use Table on P341, Roark to determine coefficients :		
Ri/Ro	*(DIR / ORO)*	0.74
Poisson Ratio	(v)	0.30
Ky,max (p341 Roark)	*(Kymax)*	-0.0004
Km,rb (case 2h.)	*(Kmrb)*	-0.0410
Kq,b	*(kqb)*	0.4240
D=Et^3/12(1-v^2)	*D = E(al)t^3 *(1 -v^2)/ 12*	388266.67

For the thickness in design, under the pressure indicated, the disk is having :

Deflection,max (in)	*(Kymax *PL* ORO^4/ D)*	-0.0017
Moment (in-# per inc	*(M = Kmrb *PL*ORO^2)*	-348.82
Shear (psi)	*(kqb *PL*ORO)*	262
Max. Stress by Mt. (ps	*Max Str= (6 * M / t^2)*	-3270

Compare the max. stress due to bending to the max. allowable stress of that material:

18000 psi for S.St.

10000 psi for AL6061-T6

The thickness in the design is adequate.

Cylinder Side Plate- Vacuum Vessel
Stress Analysis - Stainless Steel
For MICE TRACKER MAGNET SYSTEM

Date: Ju

304 Stainless Steel		**End Plate of Vacuum Vessel**
Pressure Load (psi) *(PL)*		15.00
--this is the design limit		
Outer Radius (in)		25.87
Offset (in)		0.00
Outer Radius+offset (in) *(ORO)*		25.866
--outer radius is enlarged due to offset.		
Disk Inner Radius (in *(DIR)*		8.0115
Thichness (in) *(t)*		0.750
--this is the thickness should be in design.		
E (S. St. 3xxx) (psi *E(ss)*		2.80E+07

Use Table on P341, Roark to determine coefficients :

Ri/Ro	*(DIR / ORO)*	0.31
Poisson Ratio	(v)	0.30
Ky,max (p341 Roark)	*(Kymax)*	-0.0006
Km,rb (case 2h.)	*(Kmrb)*	-0.0570
Kq,b	*(kqb)*	0.5414
D=Et^3/12(1-v^2)	*D = E(ss)t^3 *(1 -v^2) / 12*	895781.25

For the thickness in design, under the pressure indicated, the disk is having :

Deflection,max (in)	*(Kymax *PL* ORO^4/ D)*	-0.0045
Moment (in-# per inc	*(M = Kmrb *PL*ORO^2)*	-572.04
Shear (psi)	*(kqb *PL*ORO)*	210
Max. Stress by Mt. (ps	*Max Str= (6 * M / t^2)*	-6102

Compare the max. stress due to bending to the max. allowable stress of that material:

18000 psi for S.St.

10000 psi for AL6061-T6

The thickness in the design is adequate.

SHELL STRESS ANALYSIS
ASME Code Verfication Calculation- He Neck tube
For MICE TRACKER MAGNET SYSTEM

Date: July 7, 2006

I. Design Dimension:(inch)	ID	OD	THICK	LENGTH
He Neck Tube (304 S S)(vent)	0.980	1.000	0.010	20.300
Cooler Neck Tube (4.2 K)	3.800	3.830	0.015	12.000
Cooler Neck Tube (77 K)	5.200	5.240	0.020	8.800

II. Under External Pressure		Neck Tube	Cooler Neck Tube (4.2 K)	Cooler Neck Tube (77 K)	
Material		S. S.-304L	S. S.-304L	S. S.-304 L	
Shell Thickness (in)	*(thk)*	0.010	0.010	0.010	
Length (in)	*(lgh)*	20.300	12.000	8.800	
Outside Diameter (in)	*(OD)*	1.000	3.830	5.240	
D/t	*(D =OD / thk)*	100.000	383.000	524.000	
L/D	*(L = lgh / OD)*	20.300	3.133	1.679	
Factor A (UGO-28.0)**	*(UGO)*	0.00025	0.00025	0.00025	
Factor B (UHA-28.1)	*(UHA)*	3500.00	3500.00	3500.00	
Max. allowable P (psi) *	*MAP*	46.55	12.15	8.88	
*MAP = 1.33 * UHA/ D					
Actual Working P (psi)	*AWP*	15.00	15.00	15.00	
Circumf. Stress (psi)	*Cstress= AWP*OD/4/thk*	375.00	1436.25	1965.00	
Longitud. Stress (psi)	*Lstress= AWP*OD/2/thk*	750.00	2872.50	3930.00	

III. Under Internal Pressure		(Quench) He Neck Tube	Cooler Neck Tube (4.2 K)	Cooler Neck Tube (77 K)	
Design Pres. (psi)	*DPres*	45.00	45.00	45.00	
Inside Radius (in)	*IR*	0.980	3.800	5.200	
Stress Limit (psi)	*SLtd*	17500.00	17500.00	17500.00	
Joint Efficiency	*JE*	0.70	0.70	0.70	
Thickness Req. (in)	*ThkR=DPres*IR/(SLtd*JE-0.6**	0.004	0.014	0.019	
Actural Design Thick(in)	*ADThk*	0.010	0.015	0.020	
Circumf. Stress (psi)	*Cstress=Dpres*2*IR/4/ADT*	2205.00	5700.00	5850.00	
Longitud. Stress (psi)	*Lstress=Dpres*2*IR/2/ADTh*	4410.00	11400.00	11700.00	

**FACTOR A IS INDEPENDENT OF MATERIAL

Note: Stress Limit=Yield Strength/S.F.=35000/2=17500psi

Ref.: Pressure Vessel Handbook, Eugene F. Megyesy, 1977

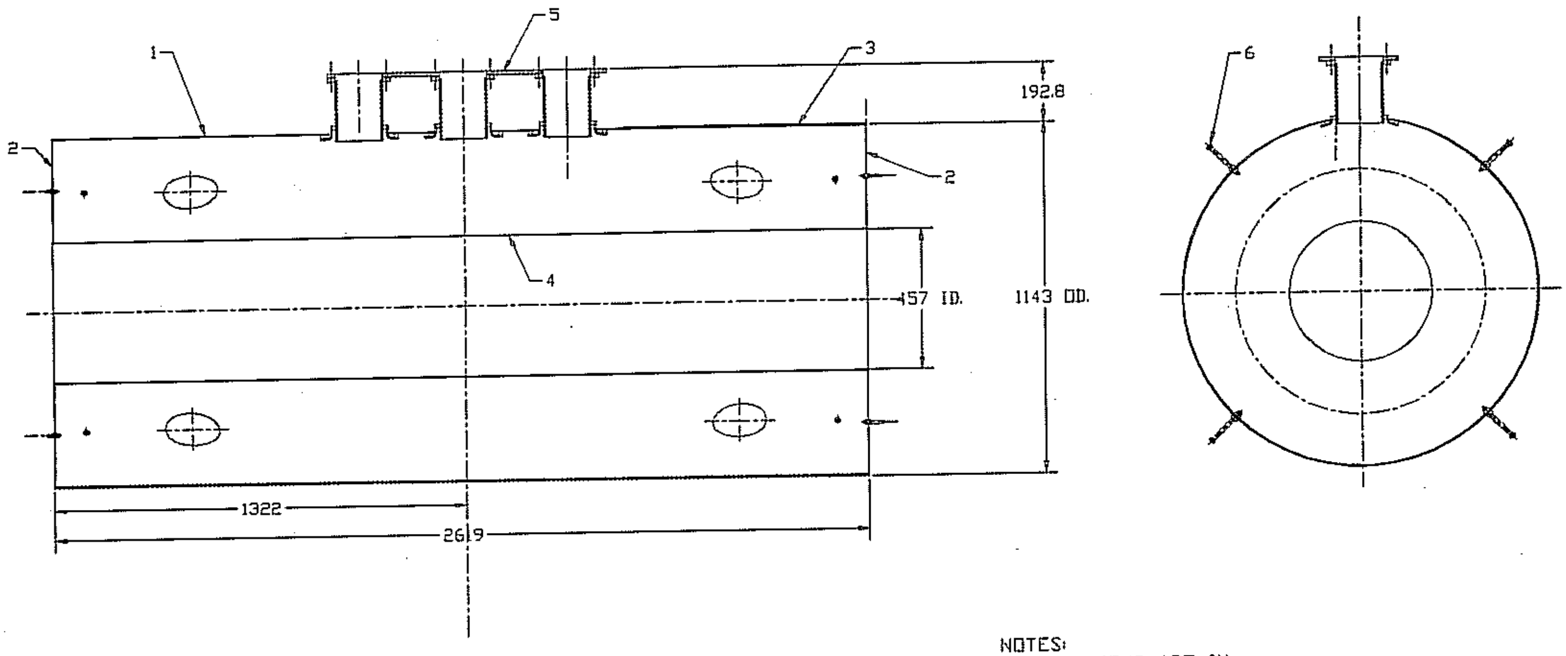
Appendix III-2-1

Engineering Design Drawing For

60 K Thermal Shield

Wang NMR Inc.

• 550 North Canyons Parkway • Livermore, CA 94551



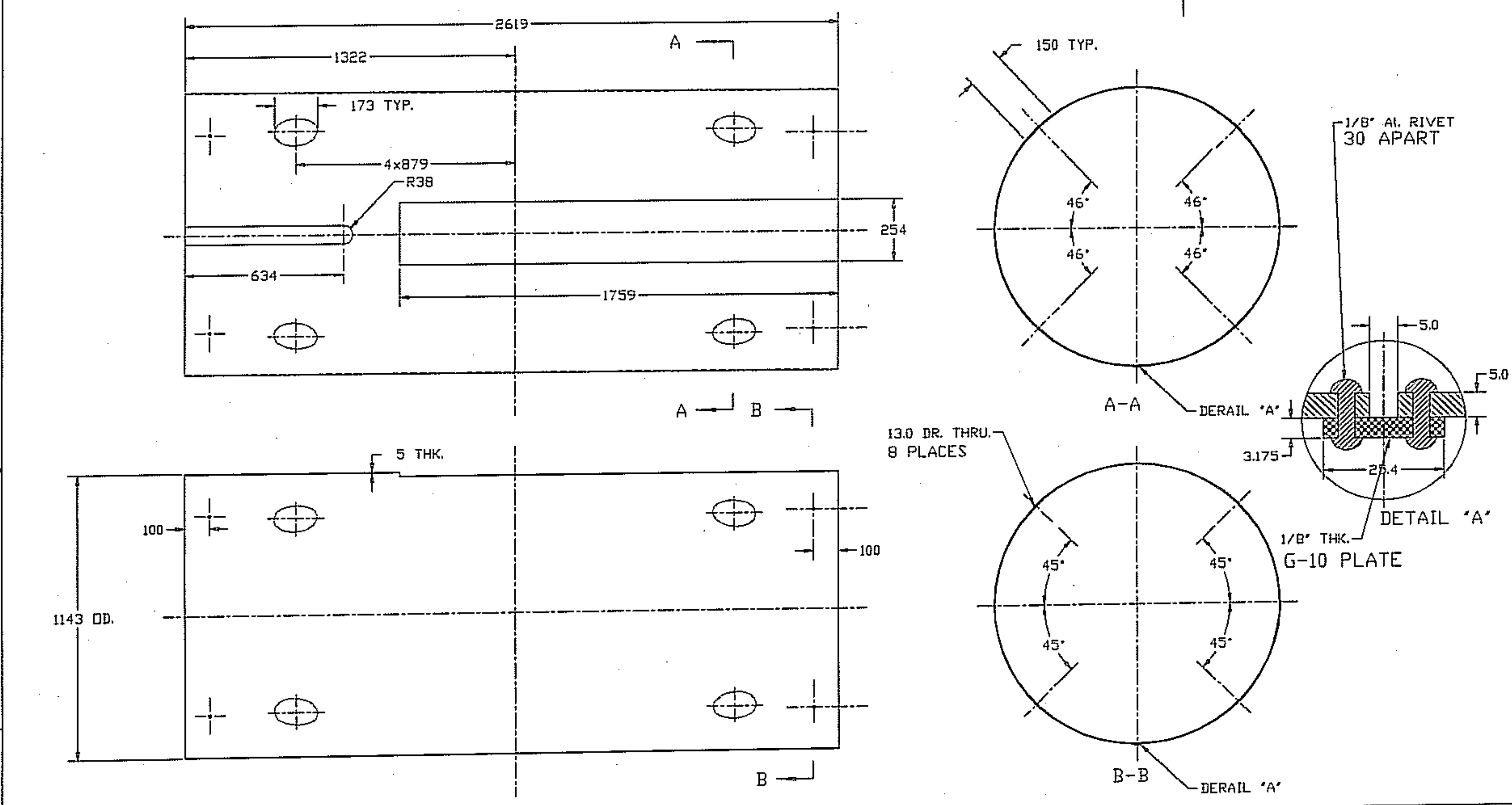
NOTES:
1) DIMENSIONS ARE IN mm

QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
16	6	MICE-6600	THERMAL BUMPER	G-10
1	5	MICE-6500	CRYOCOOLER FIRST STAGE MOUTING PORT	6061 T6
1	4	MICE-6400	INNER CYLINDER	6061 T6
1	3	MICE-6300	REMOVABLE COVER	6061 T6
2	2	MICE-6200	END PLATE	6061 T6
1	1	MICE-6 100	OUTER CYLINDER	6061 T6

WANG NMR, INC.
550 North Canyons Parkway, Livermore, CA 94550

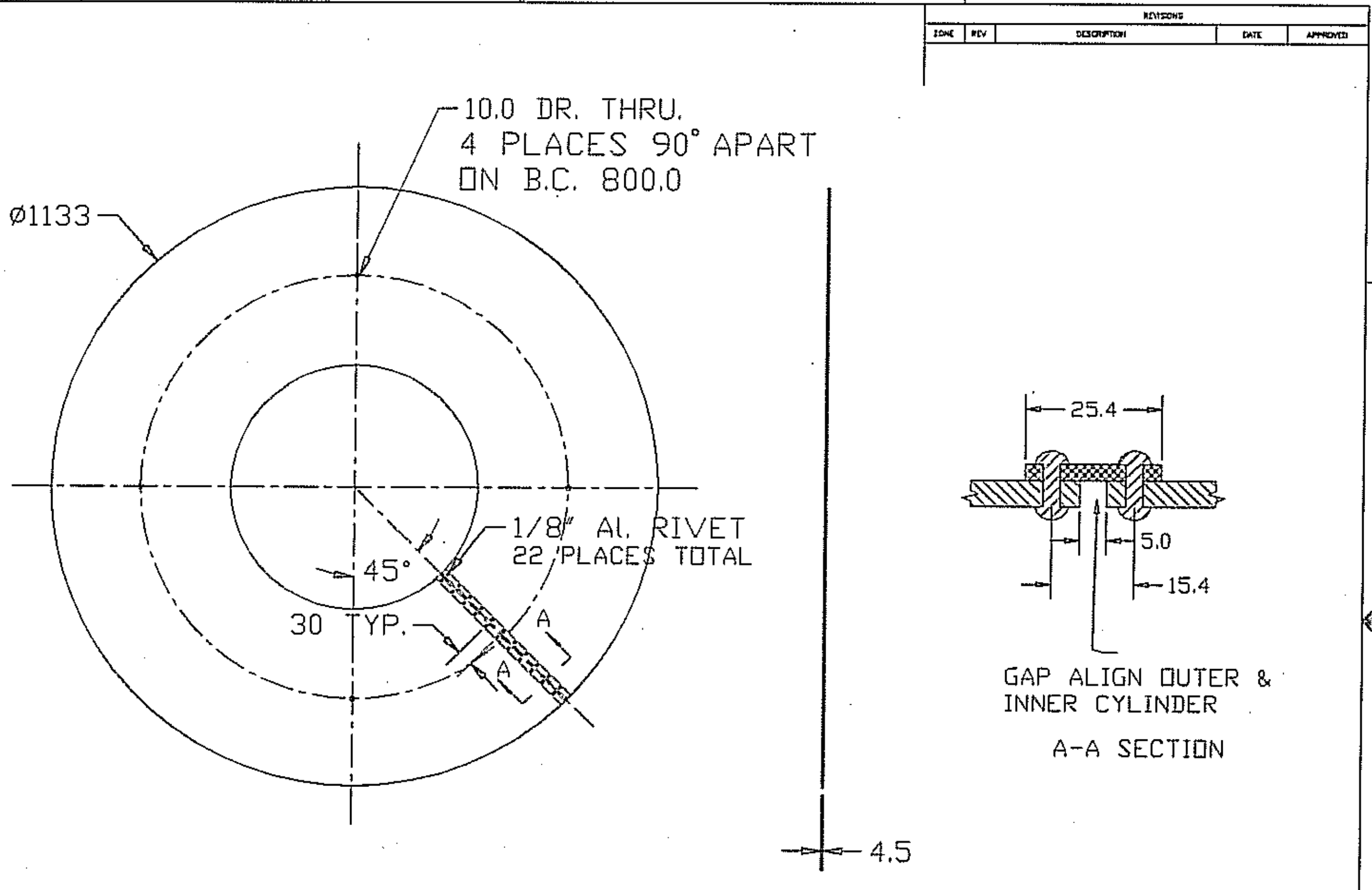
60K SHIELD

D MICE-6000



NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 3/16" THK. 6061T6 AL. SHEET
3) WORK: CUTTING MATERIAL, ROLLING, RIVETING, WELDING BI-METAL & CUTTING HOLES
4) QTY. 1

WANG NMR, INC.	
OUTER CYLINDER	
D	MICE-6100



NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 3/16" THK. 6061T6 AL. PLATE
3) QTY. 2

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

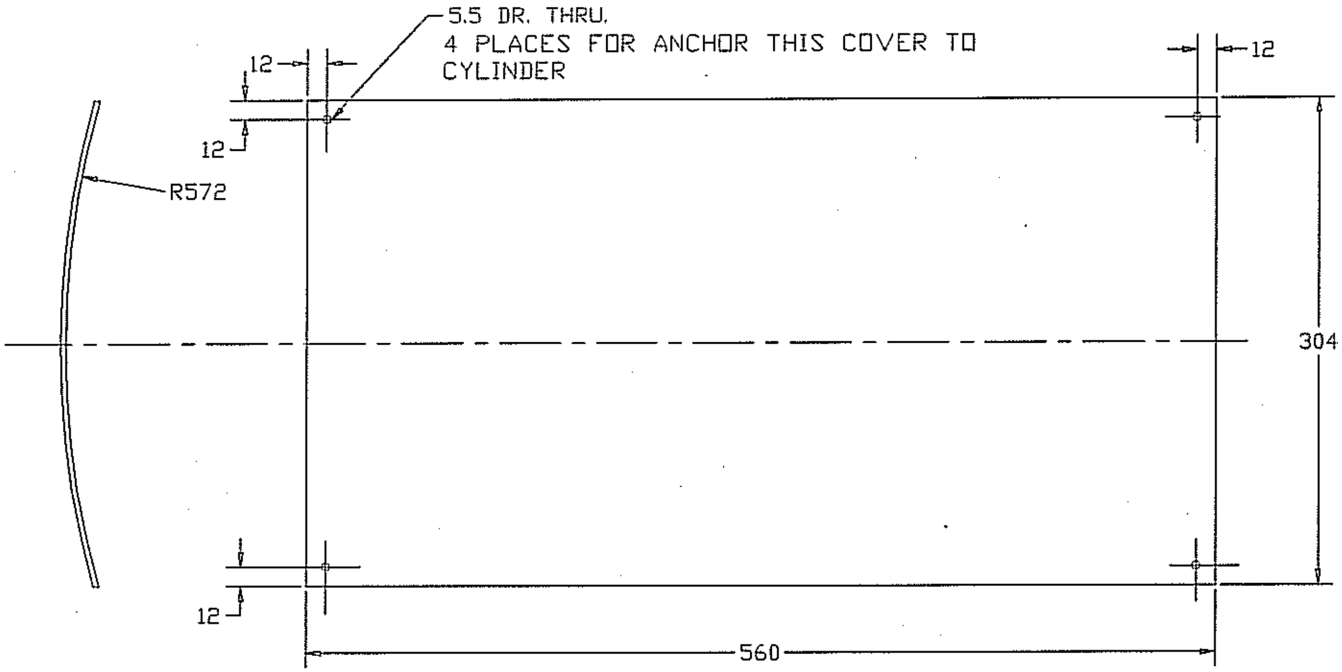
WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

TITLE: END PLATE

SIZE: C

DWG NO. MICE-6200

DO NOT SCALE



NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 3/16" THK. 6061T6 Al. PLATE
3) QTY.1

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

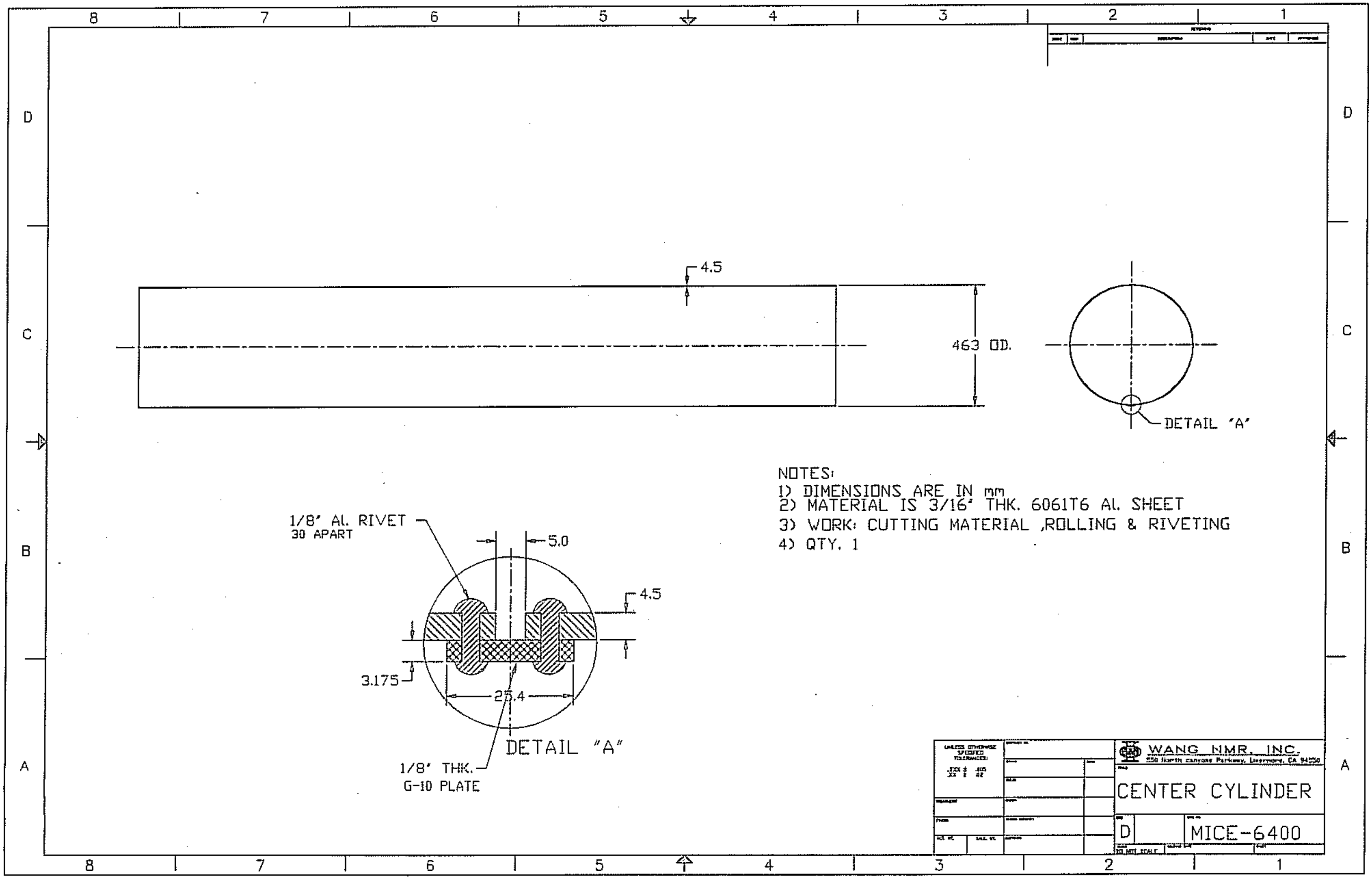
WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

REMOVABLE COVER

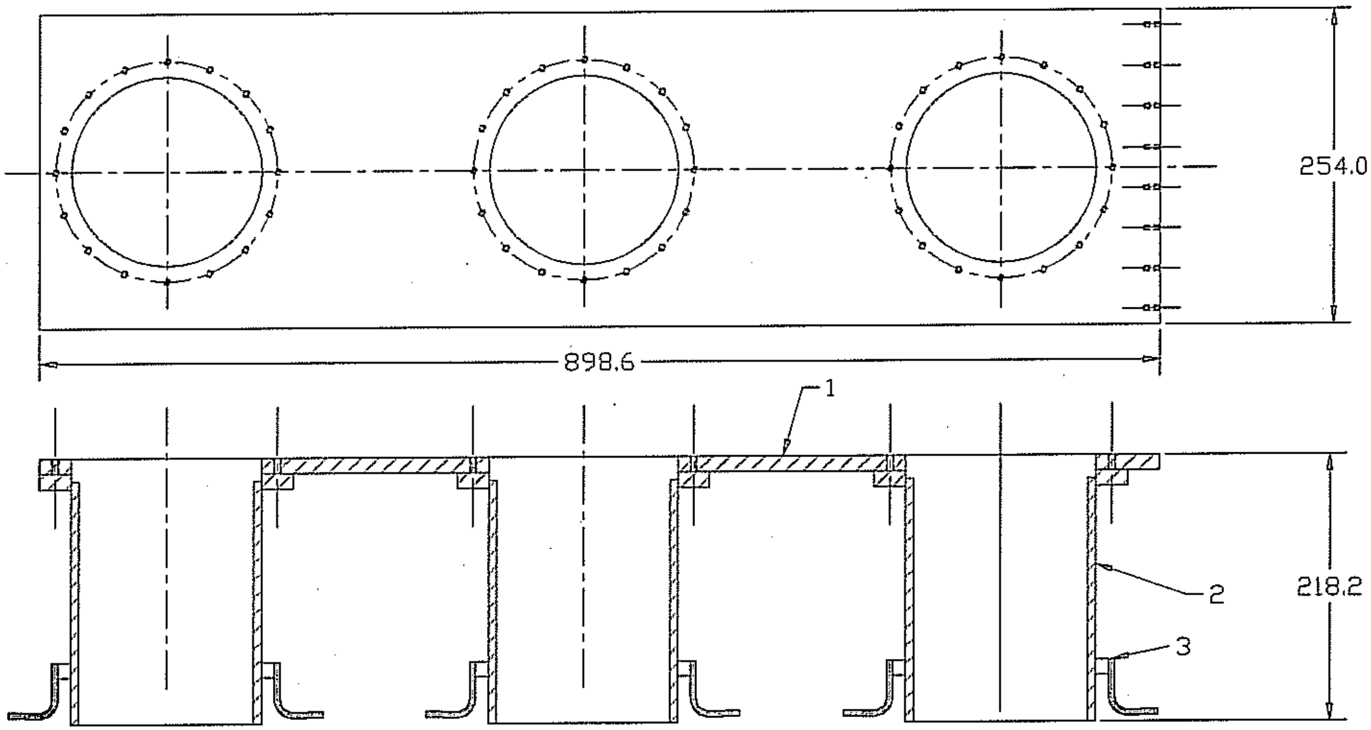
C

MICE-6300

DO NOT SCALE



4.5
463 OD.
DETAIL "A"
NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 3/16" THK. 6061T6 Al. SHEET
3) WORK: CUTTING MATERIAL ,ROLLING & RIVETING
4) QTY. 1
1/8" Al. RIVET
30 APART
5.0
4.5
3.175
25.4
DETAIL "A"
1/8" THK.
G-10 PLATE
WANG NMR, INC.
CENTER CYLINDER
D
MICE-6400



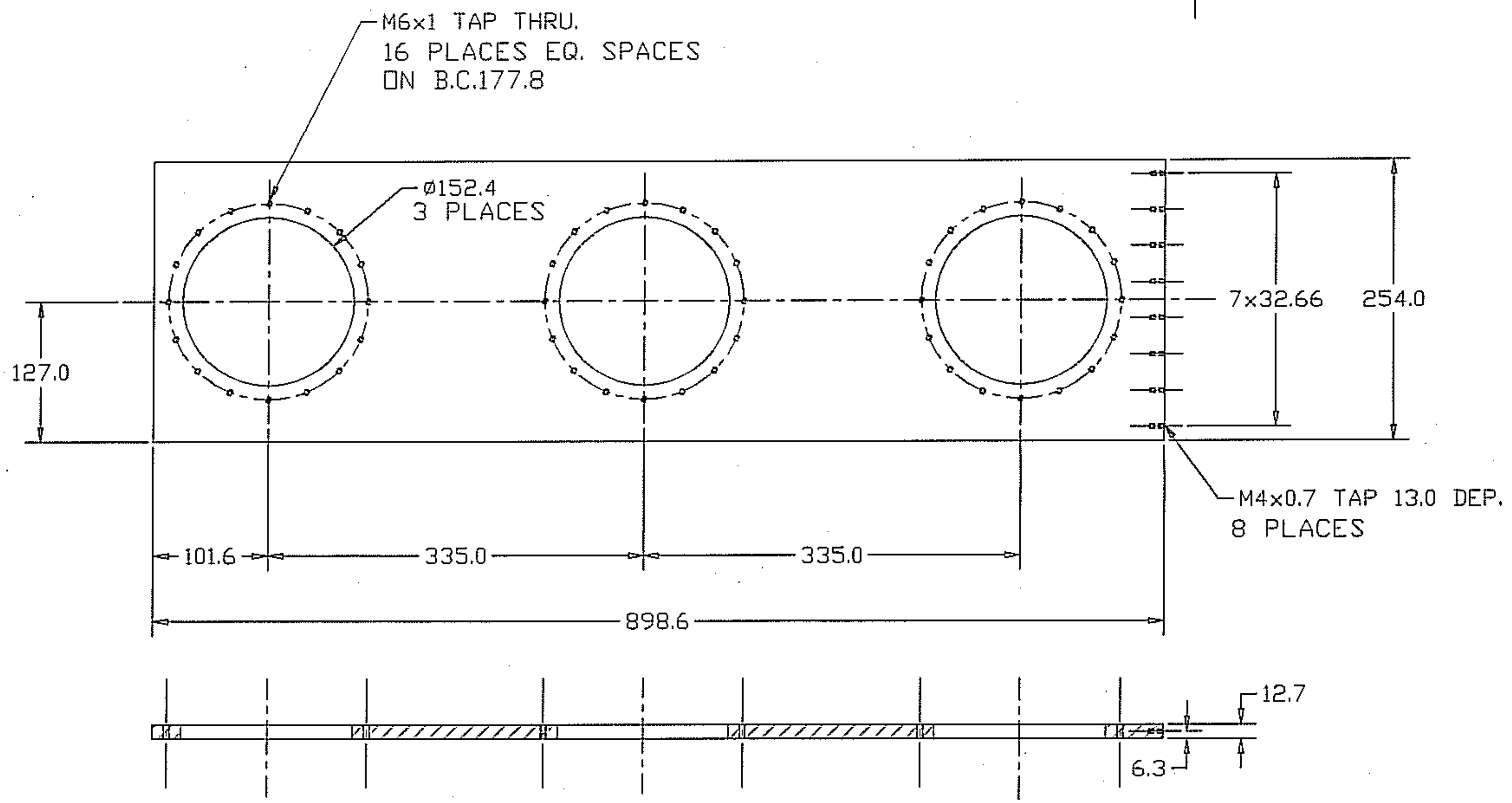
NOTES:
1) DIMENSIONS ARE IN mm

QTY.	ITEM	DWG. No.	DESCRIPTION	NOTE
12	3	MICE-6530	BI-METAL PART	Cu-Al
3	2	MICE-6520	EXTEND CYLINDER	6061T6
1	1	MICE-6510	MOUTING PLATE	OFHC

WANG NMR, INC.

CRYOCOOLER FIRST STAGE MOUNTING PORT

D MICE-6500

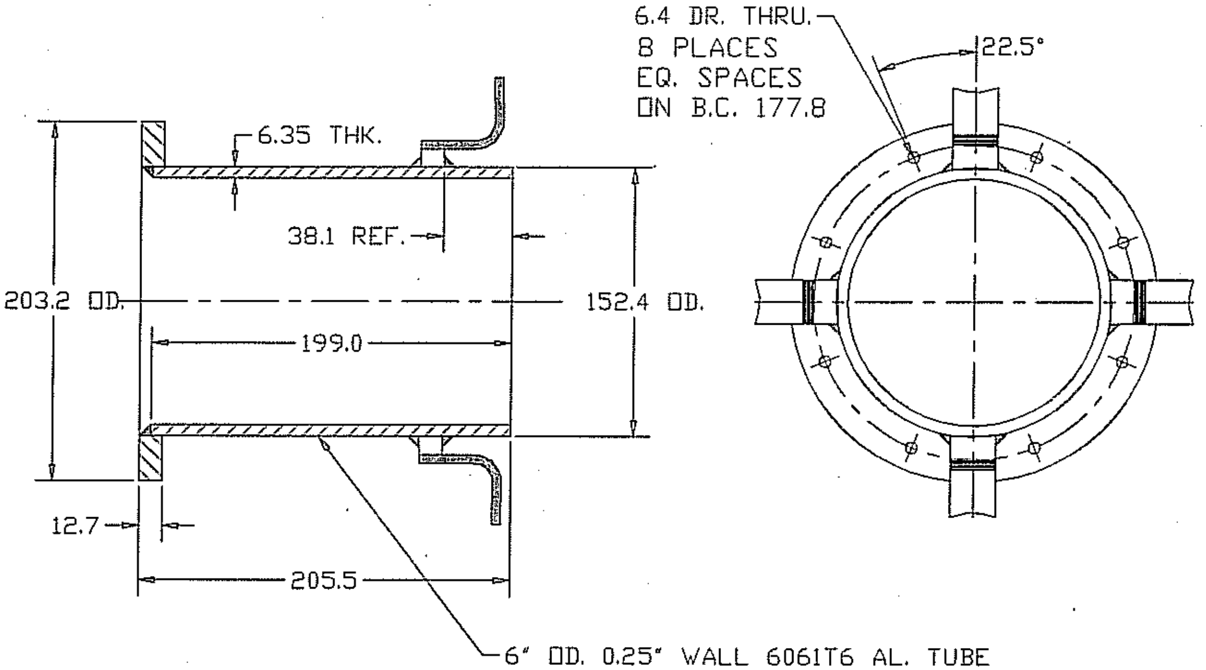


NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 1/2" THK. OFHC PLATE
3) QTY. 1

WANG NMR, INC.

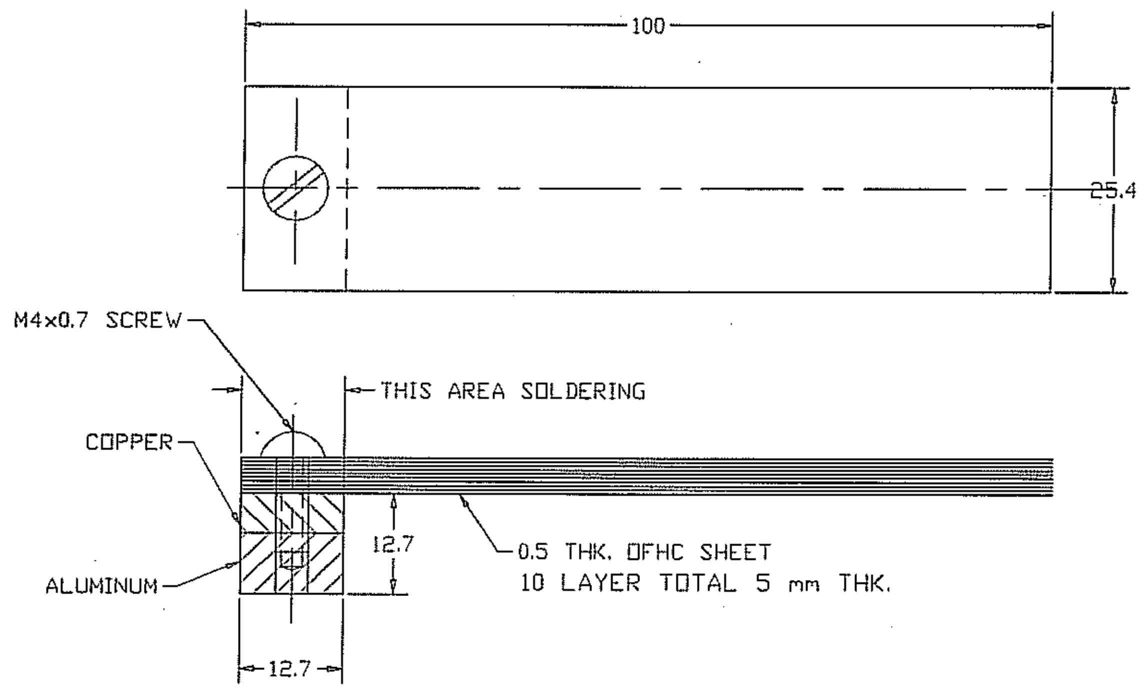
MOUTING PLATE

D MICE-6510



NOTES:
1) DIMENSIONS ARE IN mm
2) MATERIAL IS 6061T6 ALUMINUM
3) QTY. 3

UNLESS OTHERWISE SPECIFIED TOLERANCES: .XXX ± .005 .XX ± .02		WANG NMR, INC. 550 North canyons Parkway, Livermore, CA 94550
		EXTEND CYLINDER
		C — MICE-6520
		DO NOT SCALE



NOTES
1) DIMENSIONS ARE IN mm
2) MATERIAL IS Cu-Al BI-METAL
3) QTY. 12

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

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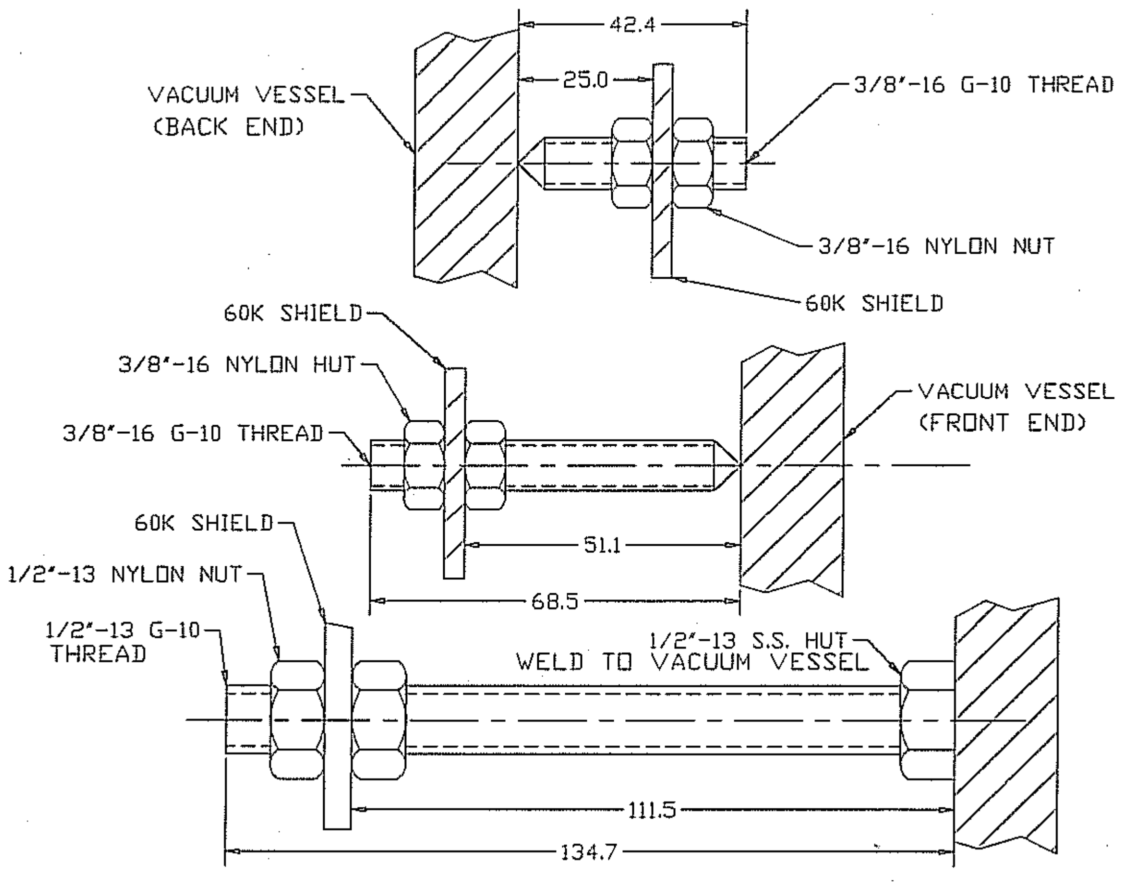
BI-METAL PART

C MICE-6530

DO NOT SCALE



NOTES:
1) DIMENSIONS ARE IN mm

UNLESS OTHERWISE SPECIFIED TOLERANCES:
.XXX ± .005
.XX ± .02

WANG NMR, INC.
550 North canyons Parkway, Livermore, CA 94550

THERMAL BUMPER

SIZE: C
DWG NO: MICE-6600
DO NOT SCALE