D-Zero Engineering Note
#3740.225-EN-318

End Calorimeter Warm Tube Heater

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8-6-91

Background

The Tevatron accelerator beam tube must pass through the End Calorimeter cryostats of the D-Zero Collider Detector. Furthermore, the End Calorimeter cryostats must be allowed to roll back forty inches without interruption of the vacuum system; hence, the Tev tube must slide through the End Calorimeter cryostat as it is rolled back. The Tev pass through the End Calorimeter can actually be thought of as a cluster of concentric tubes: Tev tube, warm (vacuum vessel) tube, 15 layers of superinsulation, cold tube (argon vessel), and Inner Hadronic center support tube. The vessel tubes are discussed in D-Zero Engineering Note #3740.225-EN-305.

Recognizing that 1/4" of insulating vacuum is marginal, it was desired to provide a heater (to be energized only as preparation for roll-back) in addition to a dry air purge (to prevent condensation or freezing) between the warm tube and Tev tubes. Specifically, nichrome wire will be wrapped around the OD of the tube (within the insulating vacuum). Two circuits will be provided for redundancy, with platinum resistors to measure temperature of the tube. An electrical feed-thru will be provided on the downstream (furthest from collision point) head, near the top of the vessel. Each circuit will be capable of 360 Watts, at 120 Volts; however, there is a danger of powering the nichrome beyond the critical temperature for Kapton (400° C). Although the tubes must be brought to at least the dew point (to drive out remaining moisture), and the dew point at D-Zero is intended to remain below room temperature, the design goal has been selected at 50° C. This is well below the continuous use temperature for Teflon. Furthermore, the superinsulation between the warm and cold tubes is aluminized Kapton which can safely be taken to 400° C as well. The instrument (dry) air purge is described in D-Zero Engineering Note #3740.225-EN-318.

Analysis

M. Foley generated an ANSYS model to study the heat load, to the cryostat, during collider physics studies; that is, without operation of the heater. A sketch of the model is included in the appendix. The vacuum space and superinsulation was modeled as a thermal solid, with conductivity derived from tests performed at Fermilab. An additional estimate was done, by this author, using data supplied by NR-2, a superinsulation manufacturer. The ANSYS result and hand calculation are in close agreement.

The ANSYS model was modified, by this author, to incorporate the effect of the heater. Whereas the earlier model studied steady state operation only, the revised model considers the heater-off steady state mode as the initial condition, then performs a transient analysis with a final load step for time tending towards infinity. Results show the thermal gradient as a function of time and applied voltage. It should be noted that M. Foley's model was generated for one half the warm tube, implying the tube to be symmetric. In reality, the downstream connection (relative to the collision point) attachment to the vacuum shell is via several convolutions of a 0.020" wall bellows; hence, a nearly adiabatic boundary condition. Accordingly, the results reported in the table reflect extrapolation of the curves to the downstream end of the tube.

Using results from the ANSYS analysis, that is, tube temperature and corresponding heat flux, temperature of the nichrome wire can be estimated.

Table 1: Results

Without heater operating

Steady state heat rate (ANSYS)	0.6 W
Steady state heat rate (mfg's data)	0.9 W
Minimum tube temperature	250 K

With heater operating	**40 Volts**	**50 Volts**	**75 Volts**
Current	1.00 A	1.25 A	1.87 A
Heat rate	40.0 W	62.5 W	140.6 W
Steady state max. tube temperature	360 K	425 K	625 K
Steady state nichrome temperature	673 K	912 K	1721 K
Time to reach 50° C, no ice	48 hr	24 hr	12 hr
Time to reach 50° C, with ice	460 hr	230 hr	115 hr

Note that all analysis described in this report is for the operation of a single nichrome wire. The resistance of the nichrome is slightly temperature dependent as shown in the accompanying plot.

Test

A 3' prototype warm tube with heater was constructed to test the design. Specifically, the warm tube, cold tube, vacuum, superinsulation, and liquid nitrogen were included. The heater successfully brought the tube from a steady state condition (surrounded by liquid nitrogen, with heater off) to 100° C (373 K) in approximately 40 minutes. Three cycles, each performed on different days were recorded. Afterwards, the prototype was disassembled and inspected. Despite a maximum current of 3.2 amps, there was no damage.

Conclusions

- The possibility of frost is of genuine concern, as evidenced by the 250 K minimum temperature for the warm tube while heaters are not operating.
- Noting that steady state operation at 1 Amp (40 volts) allows the nichrome wire to stay below the critical temperature for Kapton, a conservative plan is to allow several days of heater operation, at 1 Amp (40 volts), before roll-back.
- Warm-up can be accelerated by operating the heaters in excess of 1 Amp, as evidenced by the test where a maximum of 3.2 Amp was supplied. Operating the heaters in excess of 1 Amp must be done with care since a rapid rise in temperature will likely occur once any ice present has been melted.

Final Design

The warm tube heater is a layup of Kapton tape, nichrome wire, and Kapton tape, on the outside of the 2.375" diameter stainless steel tube. After a 3 layer wrap of Kapton was applied, the nichrome wire was laid in a helical pattern, 4.5 turns over the length of the tube. Recognizing that there will be a difference in thermal expansion between the tube and the nichrome, a helical pattern was deemed a safer than a straight line. The pattern is out-and-back with terminations at the downstream end of the tube. Two separate circuits are included for redundancy.

Four RTDs are evenly spaced along the "top" of the tube. It is intended that the tube be installed with the RTDs up, to best accommodate thermal motion. Recognizing that the entire calorimeter, including cold tube, will drop 0.190" during cool-down, it is intended that the warm tube be installed with a negative vertical deflection of 0.190" relative to the cold tube. Thermal motion in the horizontal direction occurs only during transient periods when thermal gradients in the cold vessel and calorimeter exist. Once everything is cold, horizontal deflection returns to zero. Note that the direction of horizontal motion is reversed for cool-down and warm-up.

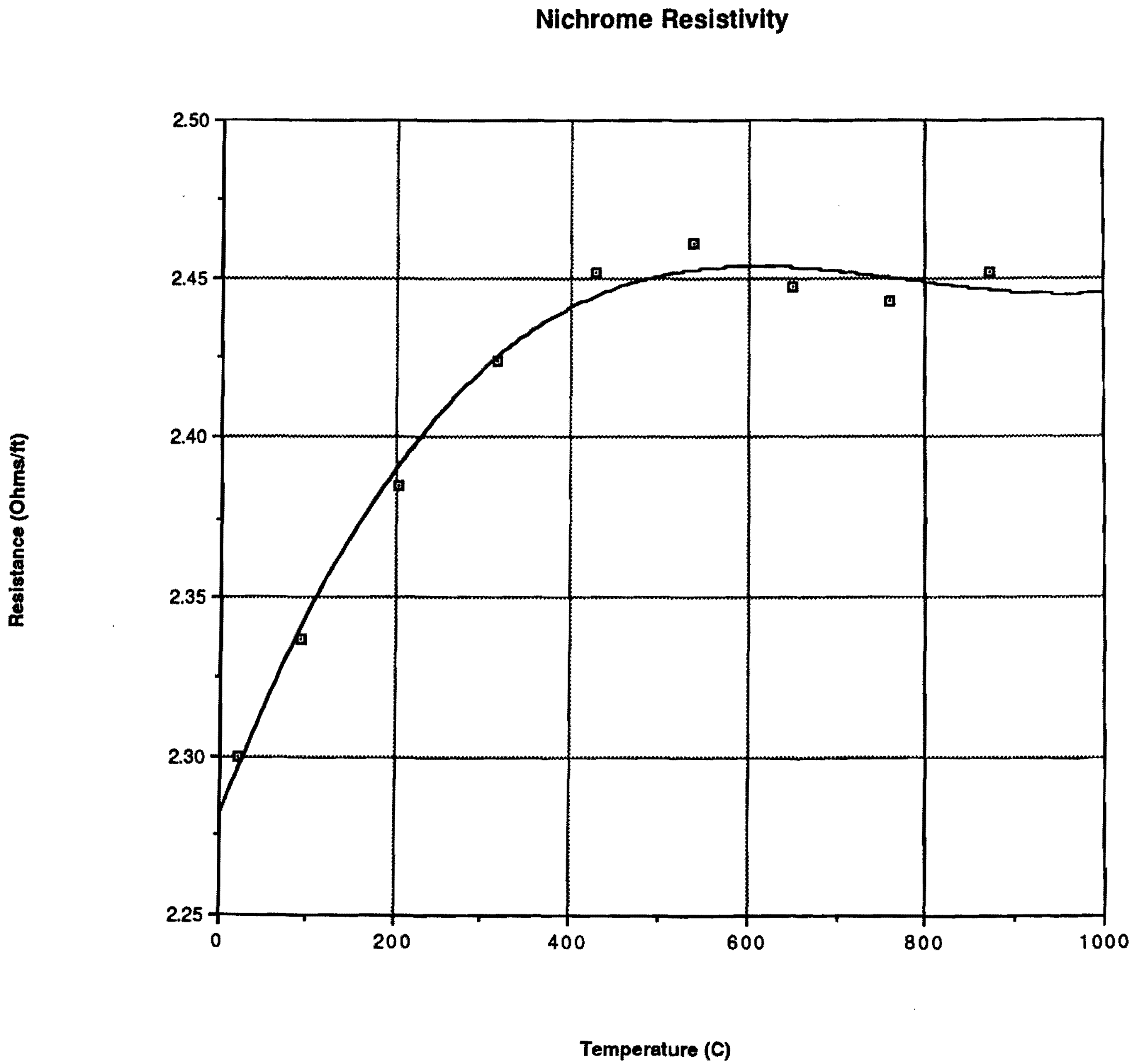
<u>**Table 2: Design Parameters**</u>

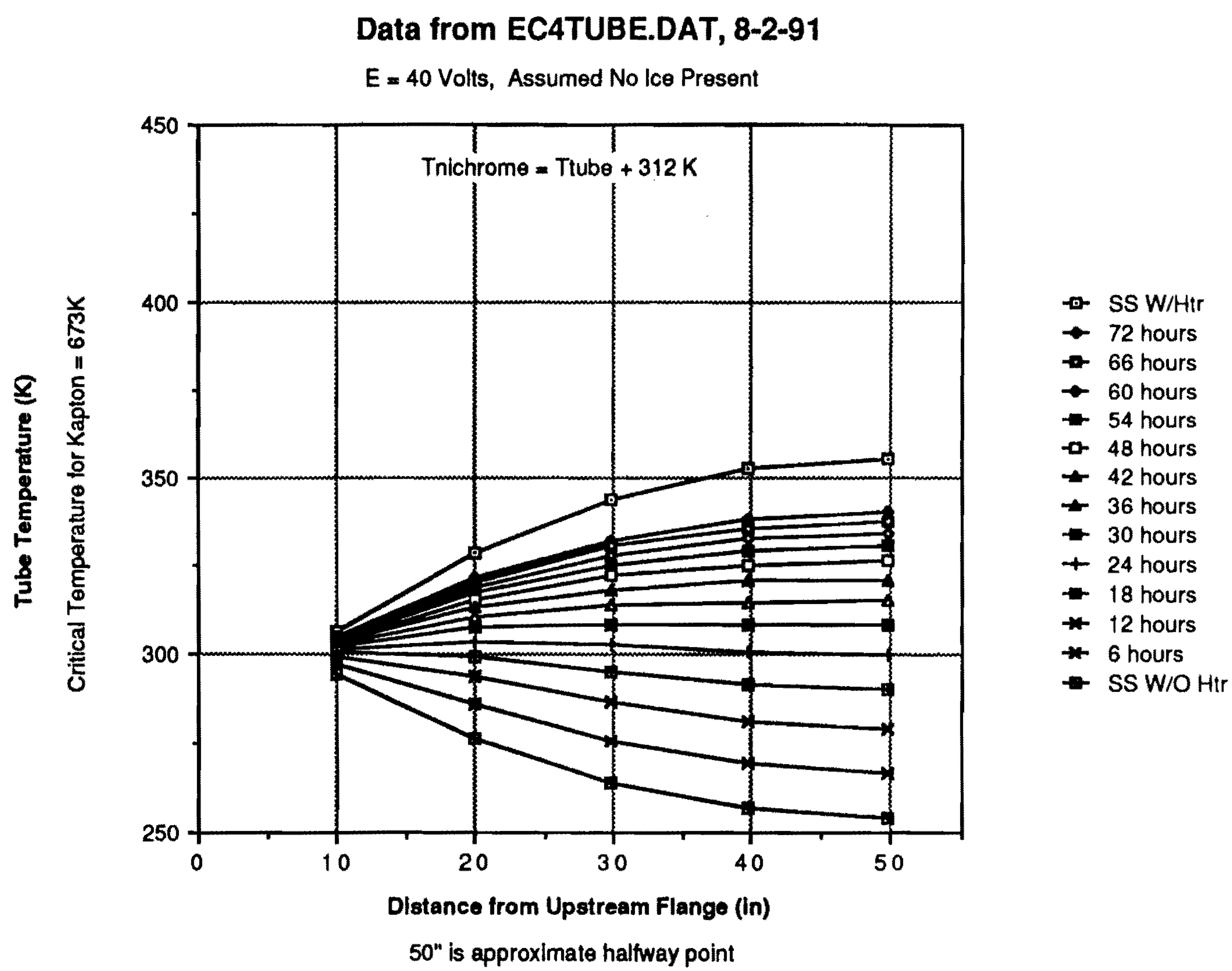
Nichrome wire	R/L = 2.301 Ω/ft @ 20° C w = .125" t = .0021" L = 202 in R = 38.7 Ω T_{melt} = 1350° C = 1623 K
Teflon	T_{melt} = 300° C = 573 K
Kapton	T_{crit} = 400° C = 673 K k = 50.8 x 10^{-6} W/in K
RTDs	100 Ω platium resistors
RTD wire	30 awg to end of tube twisted pair to feed-thru
RTD feed-throughs	ISI 9122001
AC power wire	12 awg Tefzel coated
AC power feed-throughs	ISI 9422028

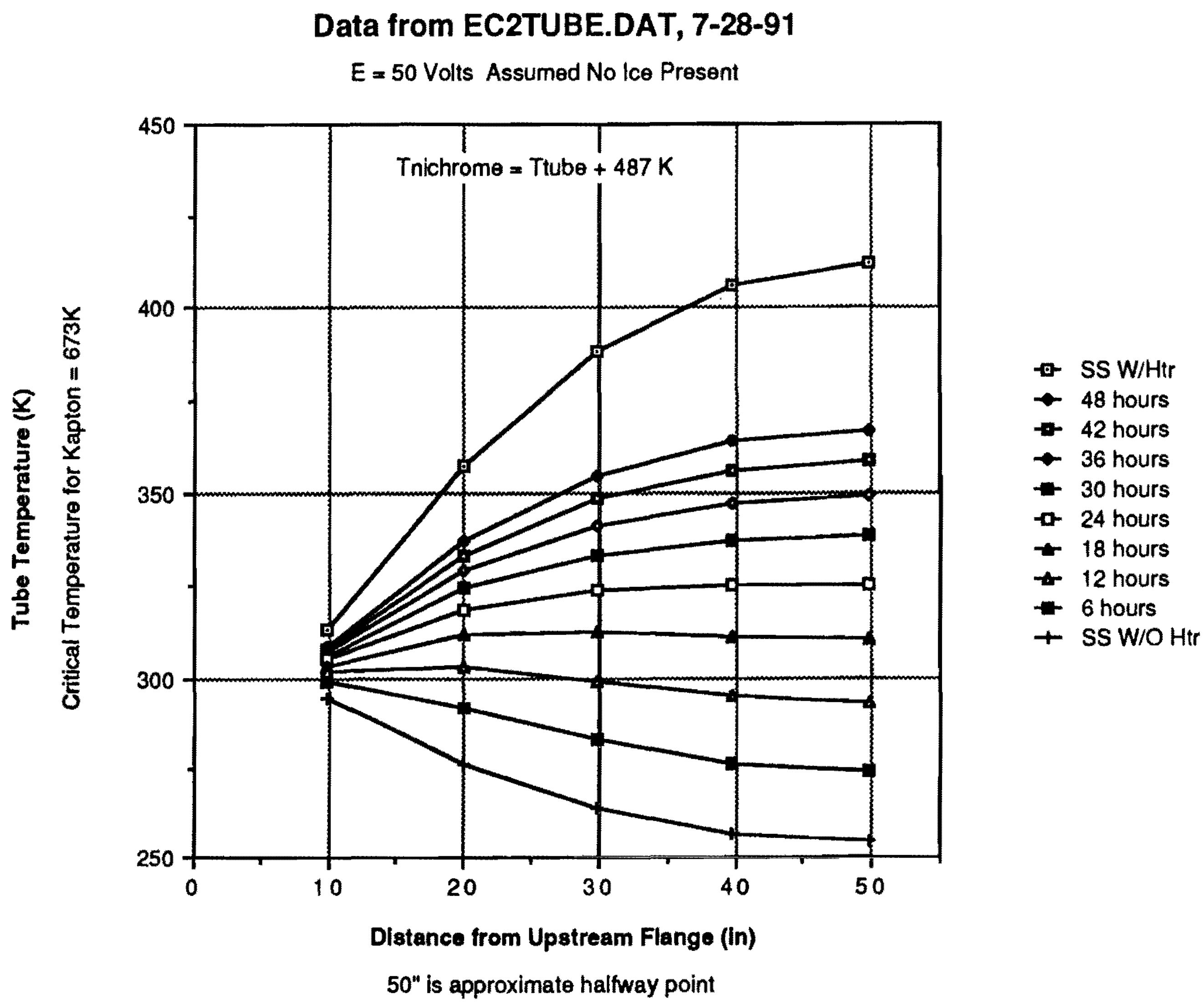
A two layer wrap of Kapton covers the heaters and RTDs. The Kapton is trimmed at both ends and secured with Kevlar string. All wires emerge from within the Kapton at the downstream end where, upon installation, they will be connected to wires previously installed between the vessel heads. Connections for RTD wires are simply soldered; however, connections to the nichrome wire are to be crimped. That is, the #12 awg wire and nichrome are both placed inside a metal sheath, which is crimped to hold the wires in contact.

Backup System

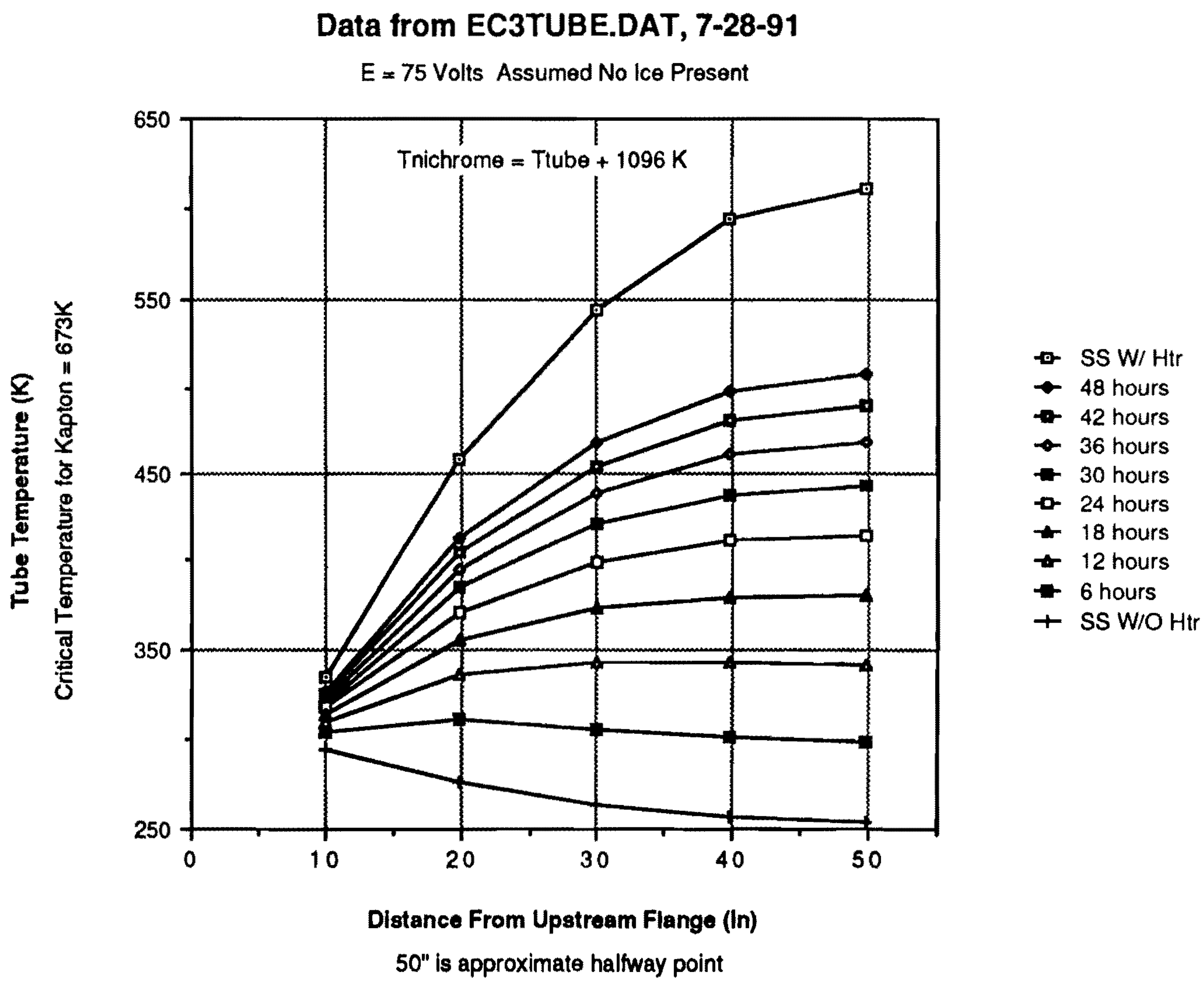
Should the dry air purge fail to prevent frost buildup, and both heating elements fail to melt an accumulation ice, the Tev tube can be warmed from within by a flow of heated dry nitrogen. The Accelerator Division/Cryogenics group uses such a nitrogen heater to warm magnet strings. Connections would be made to the Granville-Phillips valves at each SAMUS Collimator to flow heated dry nitrogen through the length of the detector.


Nichrome Resistivity
Resistance (Ohms/ft)
2.50
2.45
2.40
2.35
2.30
2.25
0
200
400
600
800
1000
Temperature (C)


Data from EC4TUBE.DAT, 8-2-91
E = 40 Volts, Assumed No Ice Present
Tnichrome = Ttube + 312 K
Tube Temperature (K)
Critical Temperature for Kapton = 673K
450
400
350
300
250
0
10
20
30
40
50
Distance from Upstream Flange (in)
50" is approximate halfway point
SS W/Htr
72 hours
66 hours
60 hours
54 hours
48 hours
42 hours
36 hours
30 hours
24 hours
18 hours
12 hours
6 hours
SS W/O Htr



Data from EC2TUBE.DAT, 7-28-91
E = 50 Volts Assumed No Ice Present
Tnichrome = Ttube + 487 K
Tube Temperature (K)
Critical Temperature for Kapton = 673K
450
400
350
300
250
0
10
20
30
40
50
Distance from Upstream Flange (in)
50" is approximate halfway point
SS W/Htr
48 hours
42 hours
36 hours
30 hours
24 hours
18 hours
12 hours
6 hours
SS W/O Htr



Data from EC3TUBE.DAT, 7-28-91
E = 75 Volts Assumed No Ice Present
Tnichrome = Ttube + 1096 K
Tube Temperature (K)
Critical Temperature for Kapton = 673K
650
550
450
350
250
0
10
20
30
40
50
Distance From Upstream Flange (In)
50" is approximate halfway point
SS W/ Htr
48 hours
42 hours
36 hours
30 hours
24 hours
18 hours
12 hours
6 hours
SS W/O Htr

Appendix A

ANSYS Model and Input File

BASIC ASSUMPTIONS — BOUNDARY CONDITIONS

* $T = 300°K$ on upstream region boundary due to prescence of heaters

* $Q \cong 0$ thru inner wall of beam pipe

* $Q \cong 0$ radially in Cryostat sufficient distance from axis of beam pipe (8" — 12")

* $Q \cong 0$ axially at mid-point of EC by symmetry

* Two cases
  - $h \cong 1.4 \cdot 10^{-3} \frac{W}{cm^2 \cdot K^\circ}$ (Tom Peterson TN DØ #3740 EN105) convection coefficient / inner wall of cryostat (varied by factor of 2 above and below
  - $T = 88°K$ maintained in interior of cryostat

NOTE: THE T = 88°K WAS DEEMED THE MORE LIKELY BOUNDARY CONDITION; HENCE, WAS MODIFIED AND DISCUSSED IN THIS WARM TUBE HEATER ENGINEERING NOTE

BASIC ASSUMPTIONS – MATERIAL PROPERTIES

* Annular region between beam tube and vacuum tube – nitrogen
  Pure conduction (Ref. Raithby & Hollands etc.)

* Region between cryostat walls
  NRC-2 insulation
  Equivalent $k_{axial} \triangleq \frac{Al}{.25\,in} \times k_{Al}$
  Equivalent $k_{radial} \triangleq \frac{\left(\frac{Q}{A}\right) L}{\Delta T}$

  $\frac{Q}{A}$ measured (Shu, Fast, et al) and manufacturers data

  ΔT assumed 200°K

* Bellows
  $k_{xx} = 6.5\,k$ (thickness)
  $k_{yy} = \frac{1}{4}\,k$ (convolutions)

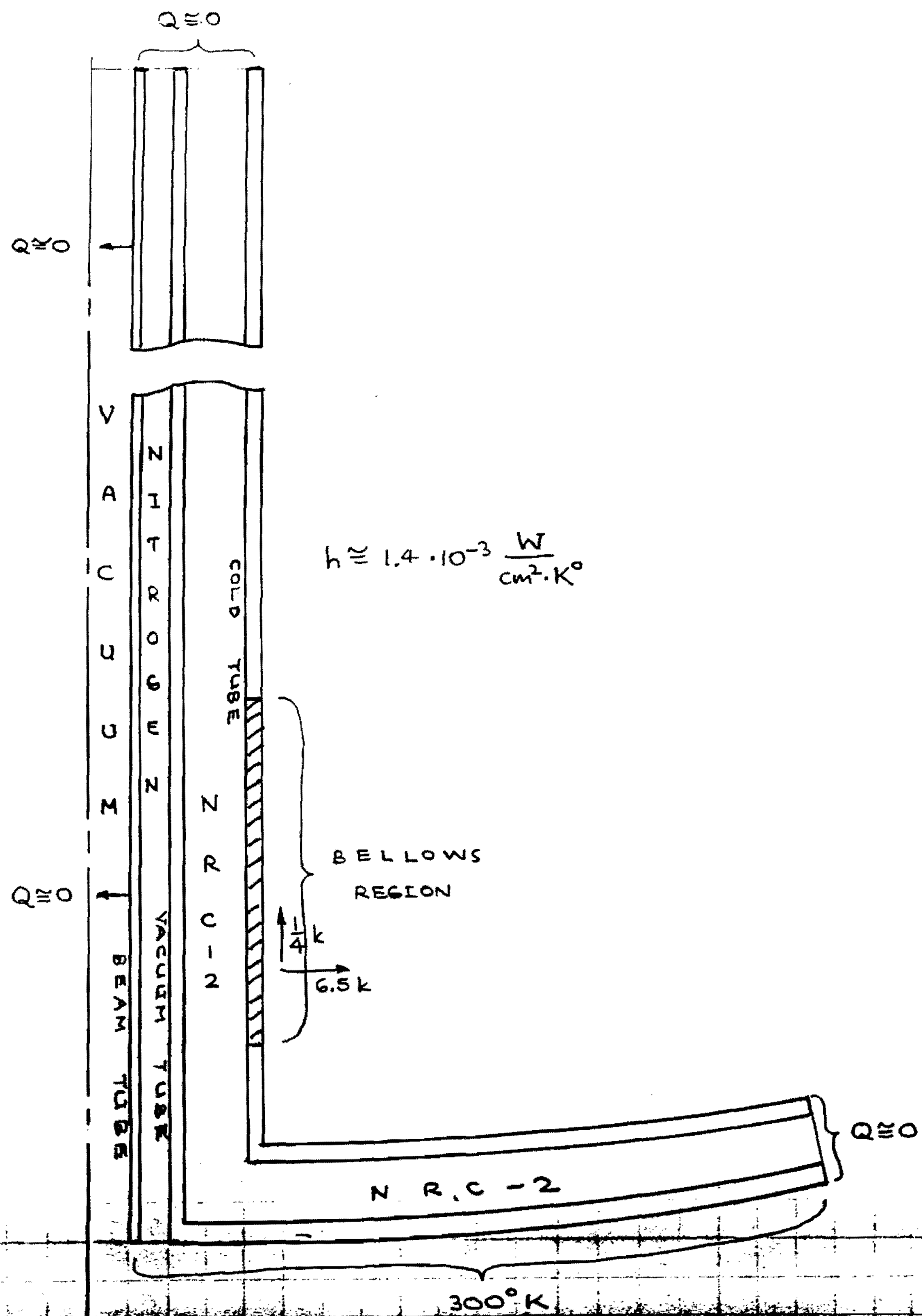
* $h \cong 1.4 \cdot 10^{-3}$

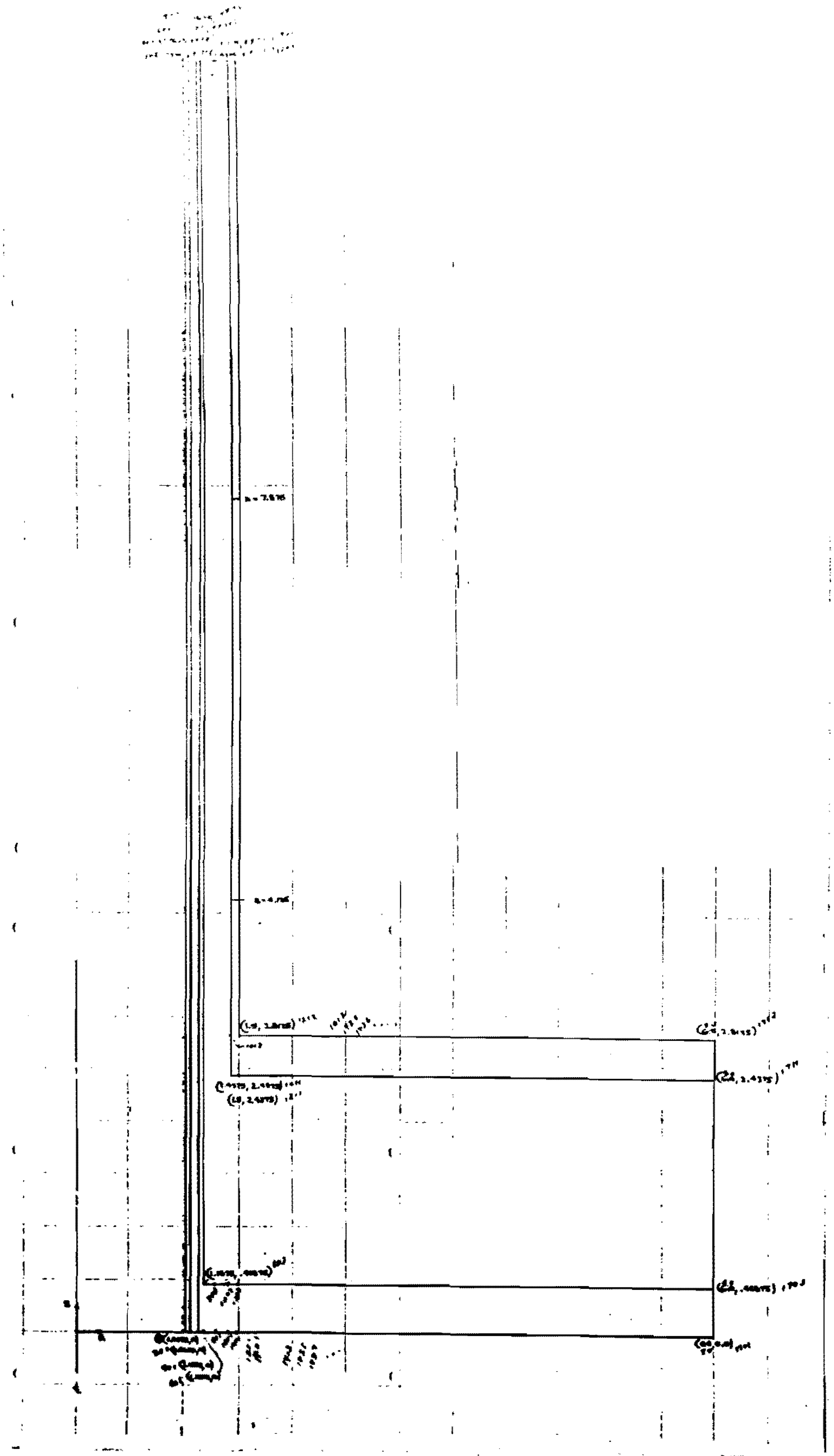
FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT

NAME	
DATE	REVISION DATE





```
/PREP7
/TITLE, EC BEAMPIPE INVESTIGATION

N,-1
kbc,1
ktemp,-1
ET,1,55,,,1

C***    MATERIAL 1 - 304 STAINLESS STEEL

KXX,1,.33
C,1,186.0
DENS,1,.285

C***    MATERIAL 2 - NITROGEN GAS

KXX,2,.000468
C,2,473.6
DENS,2,.000074

C***    MATERIAL 3 - NRC2 (AXIAL)

KXX,3,1.14E-06
KYY,3,4.754E-07
C,3,407.3
DENS,3,.0008

C***    MATERIAL 4 - NRC2 (RADIAL)

KXX,4,4.754E-07
KYY,4,9.12E-06
C,4,407.3
DENS,4,.0008

C***    MATERIAL 5 - BELLOWS REGION

KXX,5,2.15
KYY,5,.0825
C,5,186.0
DENS,5,.285

C***    DEFINE GEOMETRY OF SOLUTION REGION

N,1,1.0375,0.0
N,200,1.0375,49.75
FILL,1,200,198,2,1
NGEN,2,200,1,200,1,.025,0.0
NGEN,2,200,201,400,1,.076,0.0
N,601,1.1875,0.0
N,602,1.1875,.25
N,603,1.1875,.46875
N,604,1.1875,.75
N,800,1.1875,49.75
FILL,604,800,195,605,1
NGEN,2,200,601,800,1,.1125,0.0
NGEN,2,200,801,810,1,.1375,0.0
N,1011,1.4375,2.4375
N,1012,1.4375,2.8125
NGEN,2,200,813,1000,1,.1375,0.0
NGEN,2,200,1001,1200,1,.0625,0.0
```

```
NGEN,2,200,1201,1212,1,.25,0.0
NGEN,26,12,1401,1412,1,.25,0.0

MAT,1

E,1,201,202,2
EGEN,199,1,1
EGEN,2,400,1,199,1
EGEN,5,200,200,201,1
E,1011,1211,1212,1012
EGEN,7,1,407
E,1032,1232,1233,1033
EGEN,168,1,414
E,1211,1411,1412,1212
E,1401,1413,1414,1402
E,1402,1414,1415,1403
EGEN,25,12,583,584,1
E,1411,1423,1424,1412
EGEN,25,12,633

MAT,2

E,201,401,402,202
EGEN,199,1,658

MAT,3

E,610,810,811,611
EGEN,190,1,857
E,810,1010,1011,811
EGEN,190,1,1047

MAT,4

E,603,803,804,604
EGEN,7,1,1237
EGEN,3,200,1237,1243,1
E,1010,1210,1211,1011
EGEN,2,200,1251,1258,1
E,1403,1415,1416,1404
EGEN,8,1,1267
EGEN,25,12,1267,1274,1

MAT,5

E,1018,1218,1219,1019
EGEN,14,1,1475

C***    Load Step 1

tunif,273
nt,1701,temp,300.0
nt,1212,temp,88.0,,1400,1
nt,1412,temp,88.0,,1712,12
iter,1,0,1
time,2500000
lwrite

C***    Load Step 2
```

```
ktemp,-1
kbc,1
nsel,node,612,800
,all,.0339
.all
iter,24,0,1
time,2759200
lwrite

C***    Load Step 2

ktemp,-1
kbc,1
iter,1,0,1
time,2759200
lwrite

afwrite
finish

/input,27
finish

/post1

set,1,1
nsel,x,1.5
nrsel,y,2.82,100
nlis,all
rrfor
.sel,node,612
nasel,node,659
nasel,node,706
nasel,node,753
nasel,node,800
prtemp

*create,mac1
set,2,arg1
nsel,node,612
nasel,node,659
nasel,node,706
nasel,node,753
nasel,node,800
prtemp
*end
*use,mac1,1
rp24,,1

set,3,1
nsel,x,1.5
nrsel,y,2.82,100
nlis,all
nsel,node,612
asel,node,659
.asel,node,706
nasel,node,753
nasel,node,800
prtemp
```

finish

FROM EC4TUBE.LIS 8-2-91

LOAD STEP 1 ITERATION= 1 SECTION= 1
TIME= 0.25000E+07 LOAD CASE= 1

NODE	TEMP
612	294.46666
659	276.32963
706	263.94557
753	256.72441
800	254.35179

LOAD STEP 2 ITERATION= 1 SECTION= 1
TIME= 0.25108E+07 LOAD CASE= 1

NODE	TEMP
612	296.17184
659	281.60554
706	269.99707
753	262.92701
800	260.57493

LOAD STEP 2 ITERATION= 2 SECTION= 1
TIME= 0.25216E+07 LOAD CASE= 1

NODE	TEMP
612	297.41237
659	286.28694
706	275.90871
753	269.17430
800	266.88492

LOAD STEP 2 ITERATION= 3 SECTION= 1
TIME= 0.25324E+07 LOAD CASE= 1

NODE	TEMP
612	298.31952
659	290.22026
706	281.41027
753	275.25117
800	273.09353

LOAD STEP 2 ITERATION= 4 SECTION= 1
TIME= 0.25432E+07 LOAD CASE= 1

NODE	TEMP
612	299.03577
659	293.53538
706	286.40948
753	281.02342
800	279.07128

LOAD STEP 2 ITERATION= 5 SECTION= 1
TIME= 0.25540E+07 LOAD CASE= 1

NODE	TEMP
612	299.64165
659	296.40609
706	290.93592
753	286.43795
800	284.74906

LOAD STEP 2 ITERATION= 6 SECTION= 1
TIME= 0.25648E+07 LOAD CASE= 1

NODE	TEMP
612	300.17535
659	298.95585
706	295.05204
753	291.48067
800	290.08753

LOAD STEP 2 ITERATION= 7 SECTION= 1
TIME= 0.25756E+07 LOAD CASE= 1

NODE	TEMP
612	300.65536
659	301.25870
706	298.81516
753	296.15709
800	295.06900

LOAD STEP 2 ITERATION= 8 SECTION= 1
TIME= 0.25864E+07 LOAD CASE= 1

NODE	TEMP
612	301.09191
659	303.35885
706	302.26947
753	300.48322
800	299.69358

LOAD STEP 2 ITERATION= 9 SECTION= 1
TIME= 0.25972E+07 LOAD CASE= 1

NODE	TEMP
612	301.49149
659	305.28460
706	305.44819
753	304.47992
800	303.97363

LOAD STEP 2 ITERATION= 10 SECTION= 1
TIME= 0.26080E+07 LOAD CASE= 1

NODE	TEMP
612	301.85860
659	307.05576
706	308.37726
753	308.16966
800	307.92818

LOAD STEP 2 ITERATION= 11 SECTION= 1
TIME= 0.26188E+07 LOAD CASE= 1

NODE	TEMP
612	302.19660
659	308.68738
706	311.07811
753	311.57478
800	311.57893

LOAD STEP 2 ITERATION= 12 SECTION= 1
TIME= 0.26296E+07 LOAD CASE= 1

NODE	TEMP
612	302.50816
659	310.19171
706	313.56928
753	314.71665
800	314.94789

LOAD STEP 2 ITERATION= 13 SECTION= 1
TIME= 0.26404E+07 LOAD CASE= 1

NODE	TEMP
612	302.79549
659	311.57923
706	315.86738
753	317.61538
800	318.05627

LOAD STEP 2 ITERATION= 14 SECTION= 1
TIME= 0.26512E+07 LOAD CASE= 1

NODE	TEMP
612	303.06055
659	312.85922
706	317.98748
753	320.28969
800	320.92402

LOAD STEP 2 ITERATION= 15 SECTION= 1
TIME= 0.26620E+07 LOAD CASE= 1

NODE	TEMP
612	303.30508
659	314.04009
706	319.94342
753	322.75691
800	323.56971

LOAD STEP 2 ITERATION= 16 SECTION= 1
TIME= 0.26728E+07 LOAD CASE= 1

NODE	TEMP
612	303.53068
659	315.12954
706	321.74790
753	325.03307
800	326.01051

LOAD STEP 2 ITERATION= 17 SECTION= 1
TIME= 0.26836E+07 LOAD CASE= 1

NODE	TEMP
612	303.73882
659	316.13465
706	323.41267
753	327.13297
800	328.26228

LOAD STEP 2 ITERATION= 18 SECTION= 1
TIME= 0.26944E+07 LOAD CASE= 1

NODE	TEMP
612	303.93084
659	317.06194
706	324.94853
753	329.07025
800	330.33968

LOAD STEP 2 ITERATION= 19 SECTION= 1
TIME= 0.27052E+07 LOAD CASE= 1

NODE	TEMP
612	304.10800
659	317.91743
706	326.36547
753	330.85752
800	332.25621

LOAD STEP 2 ITERATION= 20 SECTION= 1
TIME= 0.27160E+07 LOAD CASE= 1

NODE	TEMP
612	304.27144
659	318.70668
706	327.67269
753	332.50639
800	334.02432

LOAD STEP 2 ITERATION= 21 SECTION= 1
TIME= 0.27268E+07 LOAD CASE= 1

NODE	TEMP
612	304.42222
659	319.43482
706	328.87869
753	334.02758
800	335.65552

LOAD STEP 2 ITERATION= 22 SECTION= 1
TIME= 0.27376E+07 LOAD CASE= 1

NODE	TEMP
612	304.56133
659	320.10658
706	329.99130
753	335.43097
800	337.16041

LOAD STEP 2 ITERATION= 23 SECTION= 1
TIME= 0.27484E+07 LOAD CASE= 1

NODE	TEMP
612	304.68967
659	320.72632
706	331.01775
753	336.72570
800	338.54876

```
LOAD STEP      2  ITERATION=     24  SECTION=  1
TIME=   0.27592E+07      LOAD CASE=  1

   NODE       TEMP
   612     304.80807
   659     321.29806
   706     331.96472
   753     337.92016
   800     339.82961

LOAD STEP      3  ITERATION=      1  SECTION=  1
TIME=   0.27592E+07      LOAD CASE=  1

   NODE       TEMP
   612     306.21868
   659     328.10989
   706     343.24696
   753     352.15103
   800     355.08962
```

Appendix B

Calculations & TEST RESULTS

ECI TUBE

NODE 1400 1212   49.75 - 2.8 [illegible] = 46.937"

$$L = \frac{46.937 in}{1400-1212} = .25 [illegible]$$

$$A = (3.000 in)\,\pi\,(.250 in) = 2.356 in^2$$

$$q_{MAX} = (.308 \times 10^{-3} w/RAD)(2\pi\ RAD) = 1.94 \times 10^{-3} w$$

← FROM ANSYS

$$q''_{MAX} = \frac{1.94 \times 10^{-3} w}{2.356 in^2} = .82 \times 10^{-3} w/in^2$$

$$= .13 \times 10^{-3} w/cm^2$$

$$Q = (.05\ w/RAD)(2\pi\ RAD) = .31\ WATTS$$ (HALF LENGTH TUBE)

← FROM ANSYS

QUICK ESTIMATE OF ΔT ALONG TUBE:

$$Q = \frac{KA}{L}\Delta T \quad \text{OR} \quad \Delta T = \frac{QL}{KA}$$

$$A = \pi\left[(1.1875)^2 - (1.1385)^2\right] = .358 in^2$$

$$k = .38\ w/in\,K$$

$$L = 100 in$$

$$\Delta T = \frac{(.31 w)(100 in)}{(.38 w/in\,k)(.358 in^2)} = 228 K = 228°C$$

$$T_{CRIT, KAPTON} = 400°C = 673 K = T_{MAX}$$

$$T_{MAX} - \Delta T = 400°C - 228°C = 172°C = 445 K$$

WHICH IS WELL ABOVE THE DEWPOINT!

[illegible] FOR [illegible]	6-8-90	KAP

FROM HR-2 SUMMARIZATION DATA:

[illegible]

[illegible] HEAT FLUX:

$q = .00163$ [illegible]

ASSUME:

$q = .001 \ W/in^2$

FOR 101" LONG EL

$Q = (101 in)(\pi)(2.875 in)(.001 W/in^2) = \underline{.9 \ WATTS}$

WORST CASE

$q = \varepsilon\sigma(T_1^4 - T_2^4)$

$\varepsilon = 1$

$\sigma = \left(5.67\times10^{-8} \frac{W}{m^2 K^4}\right)\left(\frac{1 m}{100 cm}\right)^2\left(\frac{2.54 cm}{1 in}\right)^2 = 3.66\times10^{-11} \ W/in^2 K^4$

$T_1 = 293K$

$T_2 = 87K$

$q = (1)(3.66\times10^{-11} W/in^2K^4)\left[(293K)^4 - (87K)^4\right] = .268 \ W/in^2$

$Q = (101 in)(\pi)(2.875 in)(.268 W/in^2) = 244 \ WATTS$

7-26-91 KAP

LOAD CASES FOR ANSYS RUNS

40 Ω 50 V

$$P = \frac{E^2}{R} = \frac{(50)^2}{40} = 62.5\ w$$

$$\frac{62.5\ w}{188\ \text{nodes}} = .332\ w/\text{node}$$

$$\frac{.332\ w/\text{node}}{2\pi\ \text{radian}} = .0529\ w/\text{node rad}$$

---

40 Ω 75 V

$$P = \frac{(75)^2}{40} = 140.6\ w$$

$$\frac{140.6\ w}{188\ \text{nodes}} = .748\ w/\text{node}$$

$$\frac{.748\ w/\text{node}}{2\pi\ \text{radian}} = .119\ w/\text{node rad}$$

---

40 Ω 40 V

$$P = \frac{(40)^2}{40} = 40\ w$$

$$\frac{40\ w}{188\ \text{nodes}} = .2128\ w/\text{node}$$

$$\frac{.2128\ w/\text{node}}{2\pi\ \text{radian}} = 33.9 \times 10^{-3}\ w/\text{node rad}$$

FIND $T_{NICHROME}$, USING ANSYS RESULTS FOR T_{TUBE}

$K_{KAPTON} = .12$ w/meter minute K

$$= \left(.12 \frac{w}{m\ min\ K}\right)\left(\frac{m}{100cm}\right)\left(\frac{2.54cm}{in}\right)\left(\frac{min}{60s}\right)$$

$$= 50.8 \times 10^{-6}\ w/in\ K$$

$A = (202\ in)(.125\ in) = 25.25\ in^2$

$L = (.003in)(3\ \text{LAYERS}) \cong .01\ in$

$Q = 62.5\ w$ (FOR 50 VOLTS)

$Q = 140.6\ w$ (FOR 75 VOLTS)

$\Delta T = T_{NICHROME} - T_{TUBE}$

$$Q = \frac{KA}{L}\Delta T \quad \text{OR} \quad \Delta T = \frac{L}{KA} Q$$

$$\Delta T = \frac{(.01 in)(62.5 w)}{(50.8 \times 10^{-6} w/in K)(25.25 in^2)} = 487 K$$

$$\Delta T = \frac{(.01 in)(140.6 w)}{(50.8 \times 10^{-6} w/in K)(25.25 in^2)} = 1096 K$$

$$\Delta T = \left(7.796 \frac{K}{w}\right) Q = \left(.195 \frac{K}{V^2}\right) E^2$$

CONSIDER ICE FILLED ANNULAR SPACE:

$$\frac{\pi}{4}\left[(2.277\text{in})^2-(2.000\text{in})^2\right](100\text{in}) = 83.6\,\text{in}^3$$

$$W = (83.6\,\text{in}^3)(.033\ \text{lb/in}^3) = 2.76\,\text{lb}$$

$h_{ice} = -151.2$ kJ/lb (0°C)

h_{water} 460.5 kJ/lb (50°C)

$$q_{ice} = (460.5\,\text{kJ/lb} + 151.2\,\text{kJ/lb})(2.76\,\text{lb}) = 1688.3\,\text{kJ}$$

CONSIDER STAINLESS:

$$W = (\pi)(.049\text{in})(2.375\text{in} + 2.000\text{in})(100\text{in})(.292\ \text{lb/in}^3) = 19.67\,\text{lb}$$

$$q = (19.67\,\text{lb})(.200\,\text{kJ/lb K})(50\,\text{K}) = 196.7\,\text{kJ}$$

$$\frac{q_{ice+stainless}}{q_{stainless}} = \frac{1688.3\,\text{kJ} + 196.7\,\text{kJ}}{196.7\,\text{kJ}} = 9.6$$

SO, APPROXIMATELY 10 TIMES AS LONG TO WARM UP IF PACKED W/ICE

Mock-up Drain Tube   Y. Orck

HEATER TEST

	time	Vac	Volts	T-12	T-24	
	1415	9	Ø	108.9	108.7	
-5-91	1420	8	5.3	108.9	108.9	
WARM	1425	8	10.8	109.5	109.4	
	1430	8	15.5	111.5	111.2	
	1435	9	20.2	113.9	113.8	
	1440	17	25.0	118.4	117.9	auto protect closed throttle valve
	1445	11	30.3	124.0	124.3	re-opened throttle valve
	1450	29	35.7	131.4	131.0	
	1455	34	40.1	139.2	139.4	OFF
	1600	6	Ø	134.3	132.6	
-6-91	1414	2	Ø	88.9	95.7	PRECOOLDOWN
-6-91	1430	88	Ø	80.6	86.9	
COLD	1435	106	5.6	76.8	83.3	
	1440	115	9.6	74.8	80.7	
	1445	122	15.1	73.3	79.1	
	1450	130	20.5	73.8	78.9	
	1455	131	25.5	75.9	80.3	
	1500	134	35.2	84.4	88.9	
	1505	134	35.1	90.9	94.1	
	1510	136	40.0	98.9	102.5	
	1515	136	40.0	107.4	109.1	
	1520	138	45.0	117.4	119.8	
	1525	138	45.0	129.5	129.9	
	1530	138	45.3	137.4	138.2	
	1535	240	43.4	144.8	144.1	
	1540	250	35.7	146.9	145.5	
	1545	250	36.1	148.3	146.1	turned off diff pump
	1550	244	32.9	148.5	145.6	
	1555	234	30.4	147.2	143.7	
	1600	232	30.0	146.4	142.8	
	1605	222	30.0	145.7	141.8	
	1610	210	30.0	144.6	140.8	
	1615	202	30.0	143.9	139.9	
	1620	188	29.7	143.1	139.4	
-91		MICRONS				

138 = 100°C

1-21 [illegible]

[illegible]

2:35 [illegible]

Volts	°C	2	3		
0	22	108.4	108.2	15:40	108Ω initial temp
10	22	108.6	108.5	15:45	
15	26	110.1	109.9	15:50	
20	32	112.6	112.4	15:55	
25	41	115.8	115.6	16:00	
30	53	120.6	120.4	16:05	
35	68	126.5	126.4	16:10	
40	85	132.8	132.9	16:15	
40	100	138.3	138.0	16:20	

$2.3\ \Omega/\text{FT} = .192\ \Omega/\text{in}$

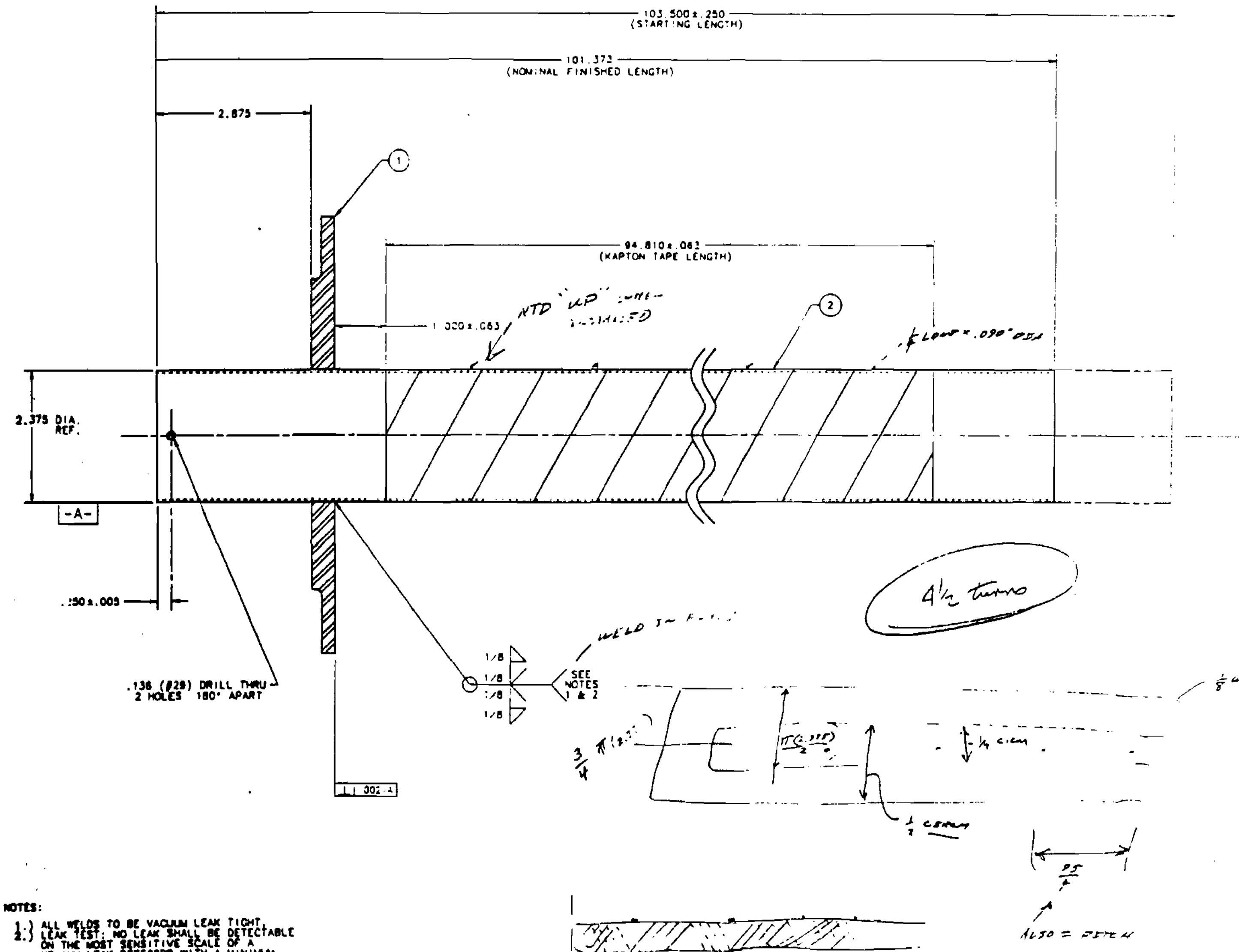
$(73'')(.192\ \Omega/\text{in}) = 14\ \Omega$

$P = \frac{E^2}{R} = \frac{(40)^2}{14} = 114$ WATTS

$I = \frac{E}{R} = \frac{40}{14} = 2.9$ AMPS

Appendix C

Drawings, Sketches, and Manufacturor's Data Sheets



NOTES:

1.) ALL WELDS TO BE VACUUM LEAK TIGHT.
2.) LEAK TEST: NO LEAK SHALL BE DETECTABLE ON THE MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10-9 ATM.CC/SEC.

2-6-91
IN PROGRESS

ITEM	PART NO.	DESCRIPTION OR SIZE
2		2.375 O.D. × .049 WALL TYPE 304 STAINLESS STEEL TUBE
1	MC-273056	VACUUM TUBE FLANGE

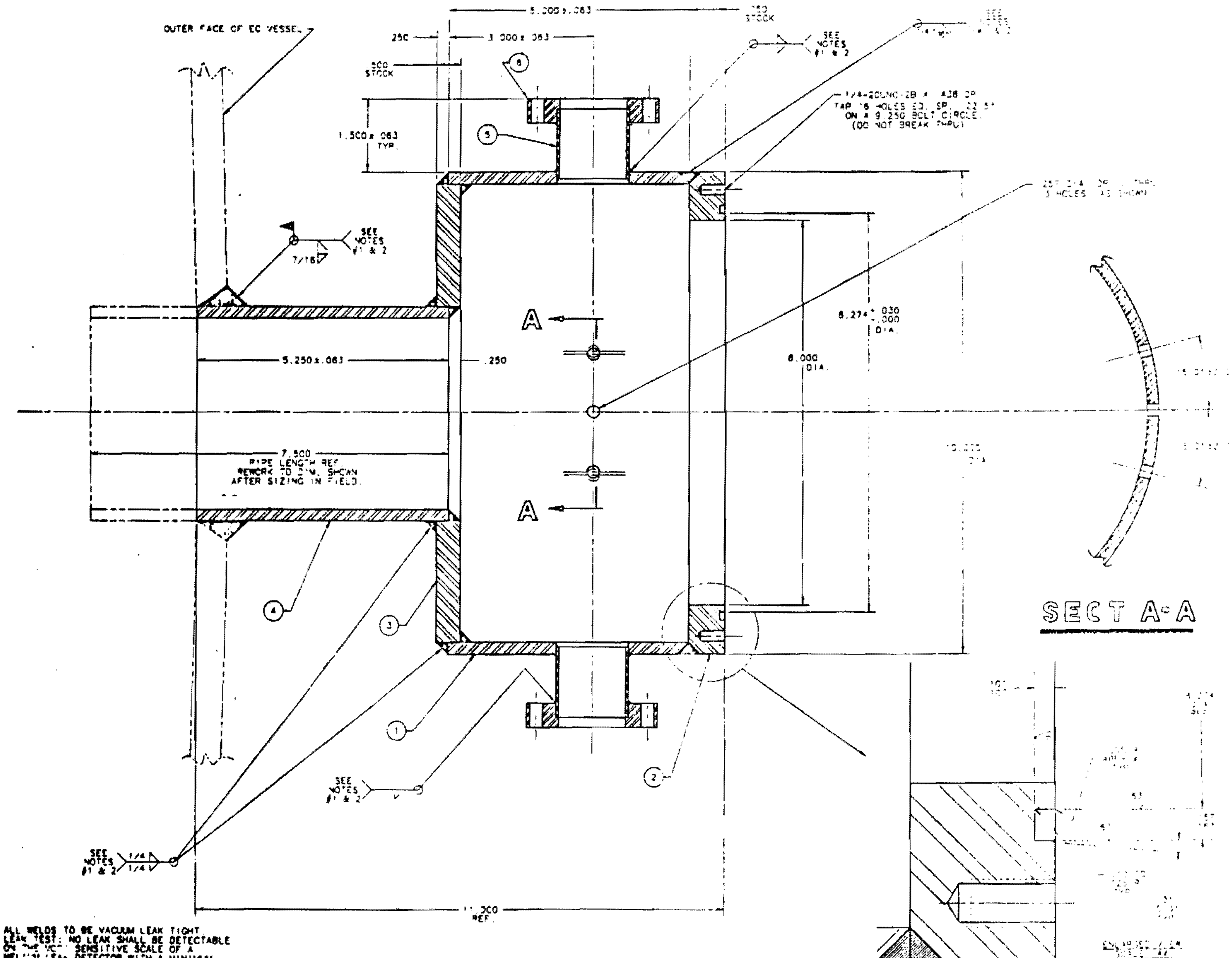
PARTS LIST

ORIGINATOR	M. MCAVOY
DRAWN	MATESA
CHECKED	
APPROVED	
USED ON	3740.220-ME-295181
MATERIAL	LISTED ABOVE

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D0 DETECTOR - END CALORIMETER
BELLOWS ASSEMBLY
WARM TUBE ASSEMBLY

DRAWING NUMBER 3740.220-MC-295355



NOTE:
1.) ALL WELDS TO BE VACUUM LEAK TIGHT.
2.) LEAK TEST: NO LEAK SHALL BE DETECTABLE ON THE MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10-9 ATM.CC/SEC.

ITEM	PART NO.	DESCRIPTION OR SIZE
6	3023-1220	[illegible]
5		1.500 O.D. × .065 WALL × 1.428 LG. TYPE 304 STAINLESS STL. TUBE
4		[illegible] TYPE 304 STAINLESS STEEL
3		1/2 THK. TYPE 304 STAINLESS STL.
2		3/4 THK. TYPE 304 STAINLESS STL.
1		10.000 O.D. × 1/4 WALL × 5.000 LG. TYPE 304 STAINLESS STL. TUBE

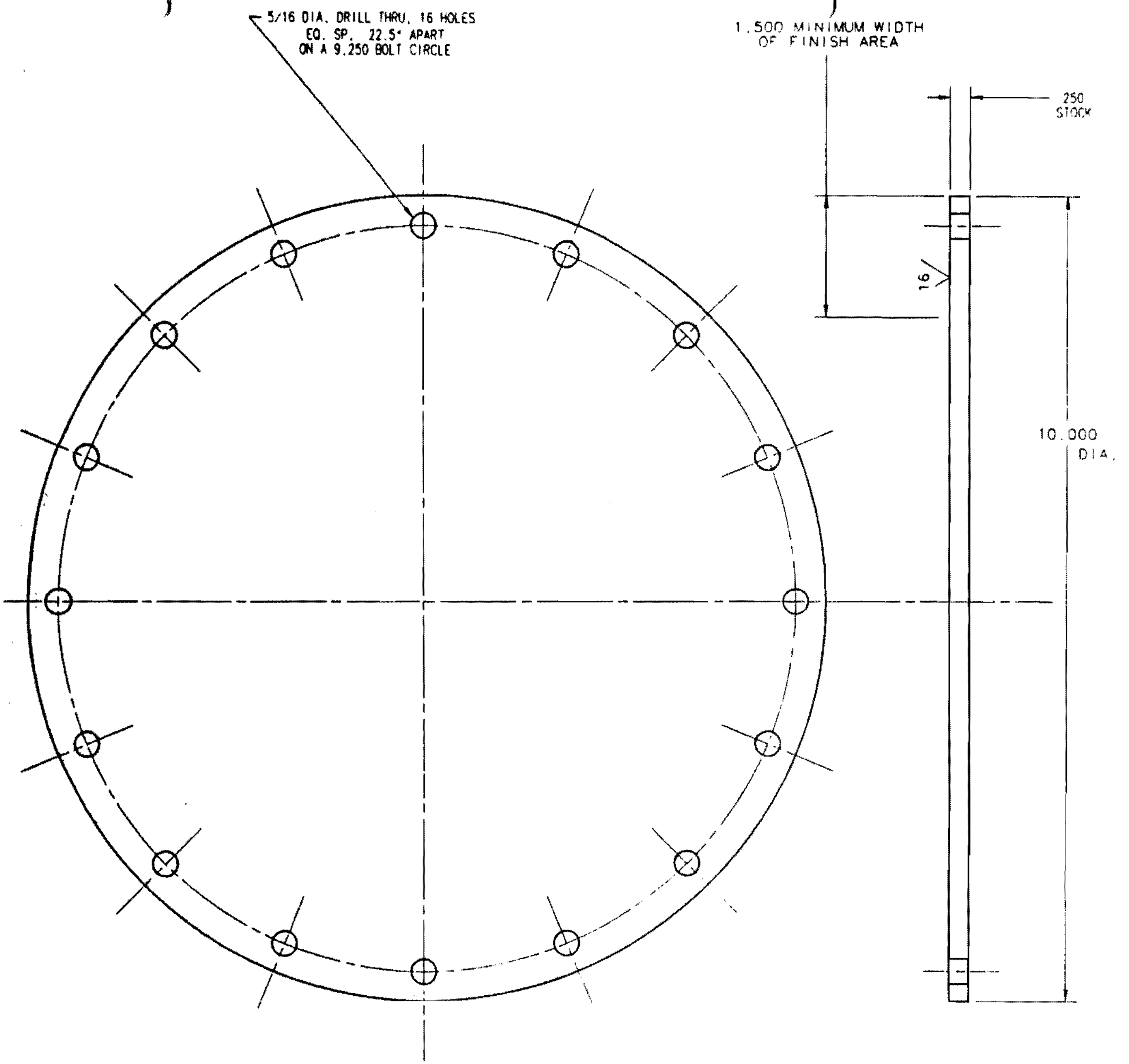
PARTS LIST

ORIGINATOR: [illegible]
DRAWN: MATESKI
USED ON: 3740.220-ME-295281
MATERIAL: LISTED ABOVE

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

D0 DETECTOR - END CALORIMETER DIFFUSION PUMP AND RTD/HV PORT LOCATIONS - BODY (RTD/HV PORT)

SCALE: FULL & NOTED
DRAWING NUMBER: 3740.220-MD-295295
CREATED WITH I-DEAS
USER NAME: MATESKI



ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTION	DECIMAL	ANGLES	ORIGINATOR	PRIMDAHL	6/21/91
± 1/32	± .031	± 1°	DRAWN	MATESKI	6/21/91
			CHECKED	[signature]	7-2-91
			APPROVED	[signature]	7-2-91

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ANSI Y14.5M-1982
4. MAX. ALL MACH. SURFACES 125√

USED ON: 3740.220-ME-295251

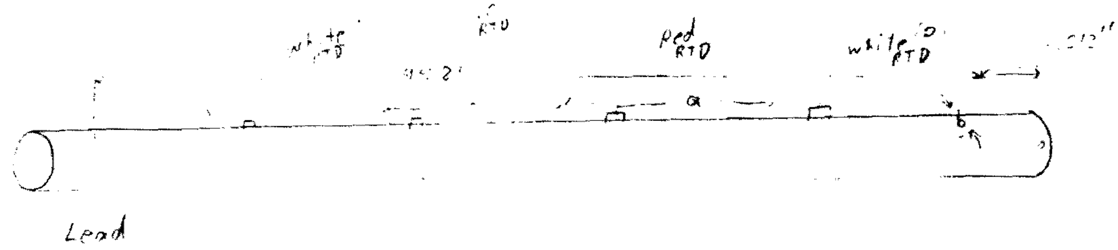
MATERIAL: TYPE 304 STAINLESS STEEL

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

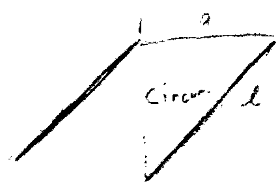
DO DETECTOR - END CALORIMETER
DIFFUSION PUMP AND RTD/HV PORT
COVER - RTD/HV PORT

SCALE	FILMED	DRAWING NUMBER	REV.
FULL		3740.220-MC-295296	

CADFILE: ECPIPING | CREATED WITH: IDEAS 7 | USER NAME: MATESKI



Nichrome Heater wire



$a = \frac{94.81'}{4.5} = 21''$

$b = 4''$

Circumference $= 2\pi\left(\frac{2.375}{2}\right) = 7.46'$

$l = \sqrt{a^2 + c^2} = \sqrt{21^2 + 7.46^2} = 22''$

Total length of each circuit $= 9(22'') + 4'' \approx$ **202'' + Leads at end of tube**

* This length was verified 7/26/91 with an actual measurement.

RTD wire lengths

white (1) $\approx 1.5(22'') =$ **33'' + Leads**

blue $\approx 2.5(22'') =$ **55'' + Leads**

red $\approx 3.5(22'') =$ **77'' + Leads**

white (2) $\approx 4.5(22'') =$ **99'' + Leads**

Multi-Pin Instrumentation Feedthroughs

- **Multi-Pin**
- **10 and 20 Conductors**
- **700 Volts - 10 Amps**

Please order by Part Number. Note that listed prices are for single unit sales. Contact factory for quantity discounts.

1.2 Description

Units are designed and rated for high and ultra high vacuum applications. They are constructed of vacuum grade materials including .032" diameter molybdenum conductor pins with high purity alumina insulation on type 304 stainless steel weldable mounts and flanges. Atmospheric side mating connectors are supplied. For additional connectors see page 141. Vacuum side connectors are detailed on page 145.

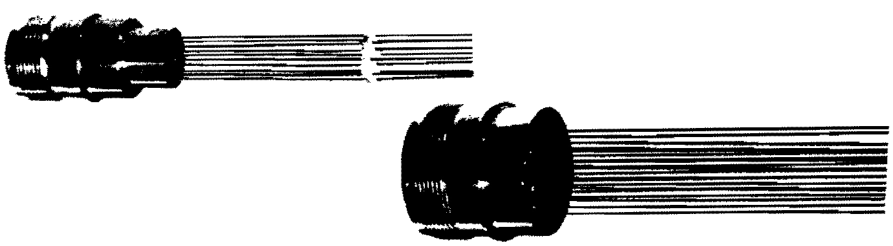
1.2 General Specifications

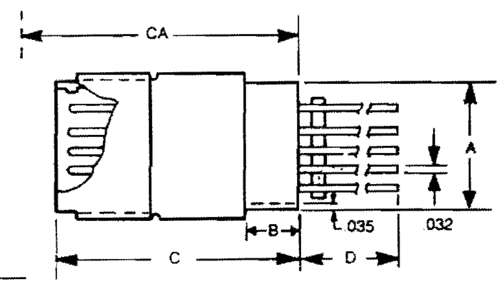
Voltage Rating	700V DC
Current Rating	10 Amps
Maximum Current, All Pins Loaded:	
10 Pins	50 Amps
20 Pins	75 Amps
Temperature Rating:	
Del-Weld & Del-Seal	to 450°C*
Kwik-Flange & Del-Thread	to 150°C**
Connectors	to 125°C

*Bakeable to 450°C without connector.
**Bakeable to 450°C without connector, O-ring, or Teflon tape.

Del•Weld • 10 and 20 Conductor Pins

Weldable Adapter

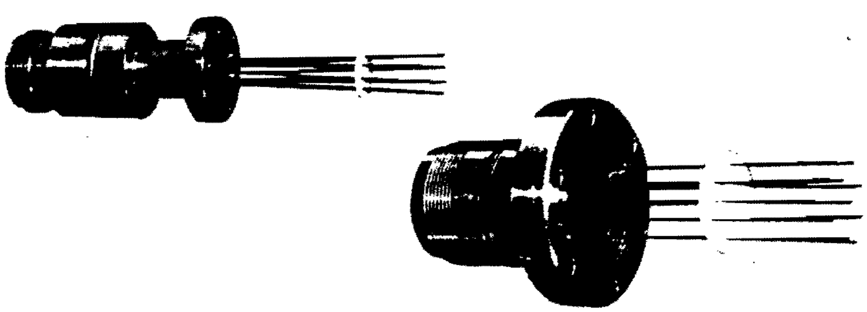


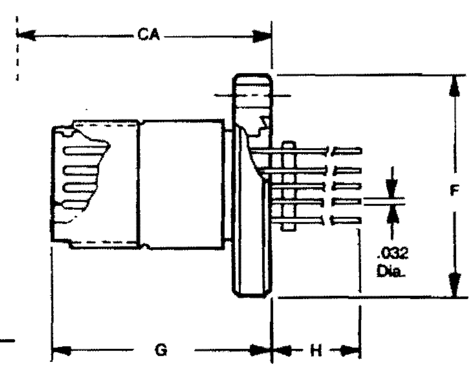


No. Pins	Part Number	Reference	A	B	C	D	CA	Unit Price
10	**9121000**	601B0875-1	.747	.60	2.11	3.79	3.95	$230.00
20	**9121001**	601B1142-2	1.372	.75	2.30	3.60	4.55	$370.00

Del•Seal • 10 and 20 Conductor Pins

Metal Seal Flange

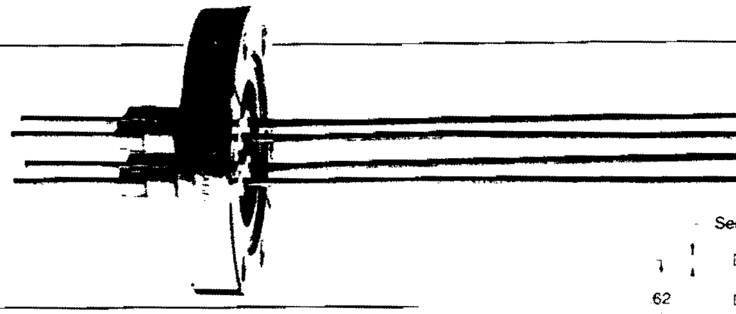


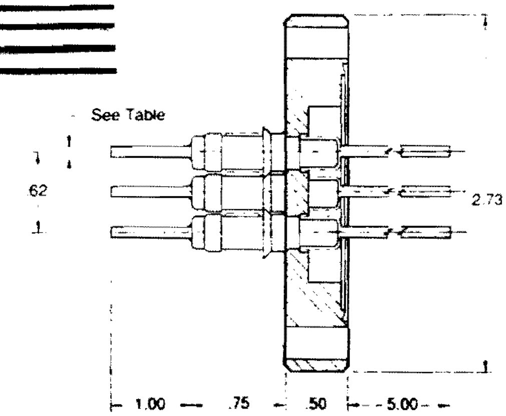


No. Pins	Part Number	Reference	Flange Nom	F	G	H	CA	Unit Price
10	**9122000**	601B0876-1	1⅓	1.33	2.61	3.29	4.45	$350.00
~~10~~	~~**9122001**~~	~~601B2225-1~~	~~2¾~~	~~2.73~~	~~2.16~~	~~3.74~~	~~4.00~~	~~$350.00~~
20	**9122002**	601B1142-1	2¾	2.73	2.35	3.55	4.60	$450.00

Del•Seal
Metal Seal Flange

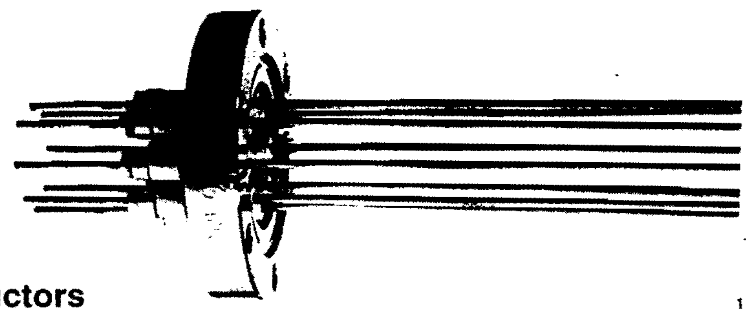
• 5000 Volts

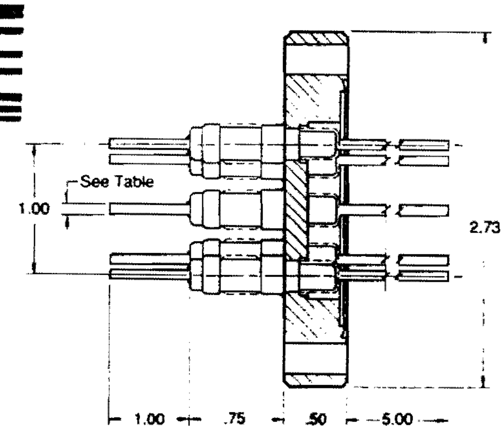




Four Conductors

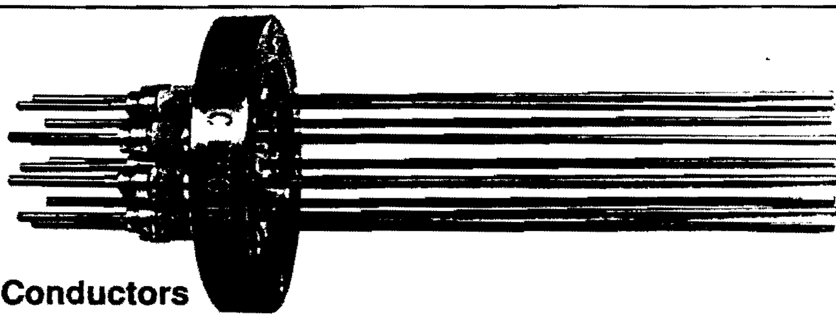
Part No.	Reference	Conductor	Amps	Flange	Price
9422028	601A0207-2	.094 Copper	30	2¾	$185.00
9422029	601A0207-1	.092 Nickel	15	2¾	$185.00
9422030	601A0207-5	.050 Copper	15	2¾	$185.00
9422031	601A0207-4	.050 Nickel	5	2¾	$185.00

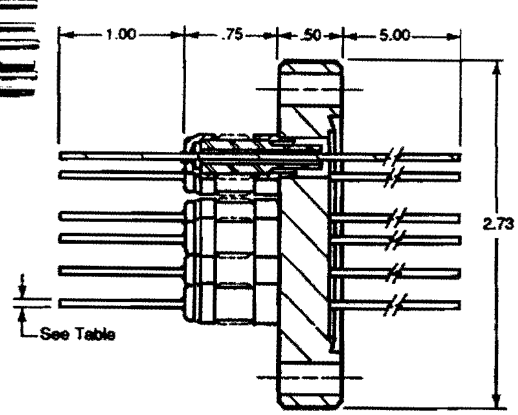




Eight Conductors

Part No.	Reference	Conductor	Amps	Flange	Price
9422032	601A0418-1	.094 Copper	30	2¾	$285.00
9422033	601A0418-2	.092 Nickel	15	2¾	$285.00
9422034	601A0418-3	.050 Copper	15	2¾	$285.00
9422035	601A0418-4	.050 Nickel	5	2¾	$285.00

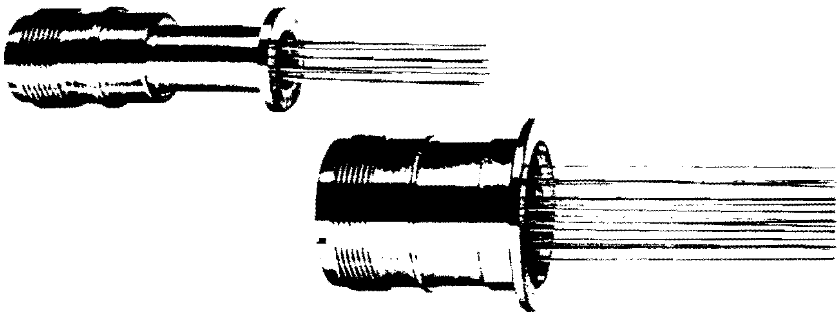


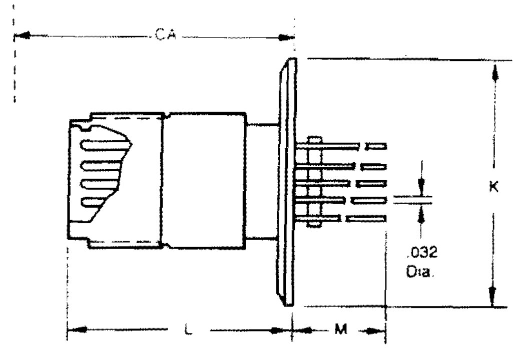


Twelve Conductors

Part No.	Reference	Conductor	Amps	Flange	Price
9422036	601B1977-2	.094 Copper	30	2¾	$350.00
9422037	601B1977-1	.092 Nickel	15	2¾	$350.00
9422038	601B1977-4	.050 Copper	15	2¾	$350.00
9422039	601B1977-3	.050 Nickel	5	2¾	$350.00

Kwik•Flange • 10 and 20 Conductor Pins
ISO O-Ring Flange

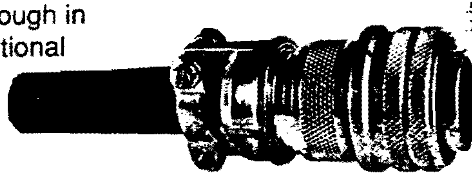


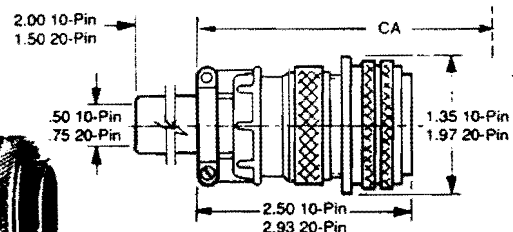


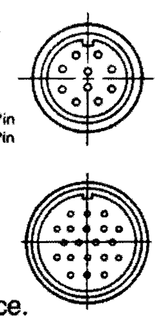
No. Pins	Part Number	Reference	Kwik-Flange	Ref ISO	K	L	M	CA	Unit Price
10	**9123000**	601B2481-1	K075	NW16	1.18	2.61	3.29	4.45	$350.00
10	**9123001**	601B2481-2	K100	NW25	1.57	2.11	3.79	3.95	$350.00
10	**9123002**	601B2481-3	K150	NW40	2.16	2.11	3.79	3.95	$355.00
10	**9123003**	601B2481-4	K200	NW50	2.95	2.11	3.79	3.95	$355.00
20	**9123004**	601B2482-1	K150	NW40	2.16	2.30	3.60	4.55	$450.00
20	**9123005**	601B2482-2	K200	NW50	2.95	2.30	3.60	4.55	$450.00

Multi-Pin Connectors

One mating air-side connector is supplied with each feedthrough in **Section 1•2.** To order additional connectors, see page 141.







Note: CA (Connector Attached) is the distance from end of connector to the vacuum sealing surface.