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APPENDIX
FOR
FINAL REPORT

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THE DESIGN, DEVELOPMENT AND DELIVERY OF HIGH TEMPERATURE
VACUUM INSULATION SYSTEMS
FOR
SNAP-21 THERMOELECTRIC POWER SYSTEM

by

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Prepared for

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APPENDIX A

CALCULATION OF UNIT GETTER REQUIREMENTS

Calculation of Insulation Material Surface Area

Nickel Foil (Main Wrap):

Cylindrical Wrap: 46 turns, 12" wide
Mean diameter = 9"

$$\text{Cylindrical Insulation Area} = 46 \times \frac{12}{12} \times \pi \times \frac{9}{12} = 108.33 \text{ Ft.}^2$$

Bottom Head: 8" diameter x 46 discs

$$\text{Bottom Head Insulation Area} = 46 \times \frac{\pi}{4} \left(\frac{8}{12}\right)^2 = 16.04 \text{ Ft.}^2$$

Top Head is in the Form of a Collar:

$$\text{Top Head Insulation Area} = 46 \left[\frac{\pi}{4} \left\{ \left(\frac{7}{12}\right)^2 - \left(\frac{5}{12}\right)^2 \right\} \right] = 6.018 \text{ Ft.}^2$$

$$\text{Top insulation area} = 108.33 + 16.04 + 6.018 = 130.39 \text{ Ft.}^2$$

$$\text{Total surface area based on both sides of the foil} = 260.78 \text{ Ft.}^2$$

Nickel Foil (Last layers wrap):

Cylindrical Wrap: 5 layers, 12" wide
Mean diameter = 11.685"

$$\text{Cylindrical Insulation Area} = 5 \times \pi \times \frac{11.685 \times 12}{144} = 15.28 \text{ Ft.}^2$$

$$\therefore \text{Total surface area based on both sides of the foil} = 30.57 \text{ Ft.}^2$$

$$\therefore \text{Total Nickel Foil} = (260.78 + 30.57) = \underline{291.35 \text{ Ft.}^2}$$

Quartz Paper With Nickel Foil:

Cylindrical Wrap: 48 turns, 14" wide
Mean diameter = 9"

$$\text{Cylindrical Insulation Area} = 48 \times \pi \times \frac{9}{12} \times \frac{14}{12} = 131.88 \text{ Ft.}^2$$

Bottom Head: 9" diameter x 48 discs

$$\text{Bottom head insulation area} = 48 \times \frac{\pi}{4} \times \left(\frac{9}{12}\right)^2 = 21.19 \text{ Ft.}^2$$

$$\text{Top head insulation area} = 48 \times 0.785 \left[\left(\frac{7}{12}\right)^2 - \left(\frac{5}{12}\right)^2 \right] = 6.28 \text{ Ft.}^2$$

$$\text{Total insulation area} = (131.88 + 21.19 + 6.28) = 159.35 \text{ Ft.}^2$$

$$\text{Total Surface Area Based on both sides of the foil} = 318.7 \text{ Ft.}^2$$

Quartz Paper with Copper Foil:

Cylindrical Wrap: 55 turns, 20" wide
Mean diameter = 10.08"

$$\text{Cylindrical Insulation Area} = 55 \times \pi \times \frac{20}{12} \times \frac{10.08}{12} = 241.78 \text{ Ft.}^2$$

$$\text{Bottom head insulation area} = 55 \times \frac{\pi}{4} \times \left(\frac{6}{12}\right)^2 = 10.79 \text{ Ft.}^2$$

$$\text{Top head insulation area} = 55 \times \frac{\pi}{4} \left\{ \left(\frac{7}{12}\right)^2 - \left(\frac{5}{12}\right)^2 \right\} = 7.20 \text{ Ft.}^2$$

Quartz Paper with Last Layer of Nickel Foil:

Cylindrical Wrap: 3 turns, 12" wide
Mean diameter = 11.685"

$$\text{Cylindrical Insulation Area} = 3 \times \pi \times \frac{11.685}{12} \times \frac{12}{12} = 9.172 \text{ Ft.}^2$$

$$\text{Total insulation area} = (241.78 + 10.79 + 7.20) = 268.94 \text{ Ft.}^2$$

$$\text{Total Surface Area based on both sides of the foil} = 519.54 \text{ Ft.}^2$$

$$\text{Total Surface area of Quartz in Nickel Foil} = (318.70 + 7.2 \times 9.17) = 337.07 \text{ Ft.}^2$$

$$\text{Total Surface area of Quartz in Copper Foil} = 519.54 \text{ Ft.}^2$$

$$\therefore \text{Total Surface Area of Quartz} = (519.54 + 337.07) = 856.61 \text{ Ft.}^2$$

Copper Foil:

Cylindrical Wrap: 55 turns, 18" wide
mean diameter = 10.08"

$$\text{Cylindrical insulation area} = 55 \times \pi \times \frac{10.08}{12} \times \frac{18}{12} = 217.6 \text{ Ft.}^2$$

$$\text{Bottom head insulation area} = 55 \times \frac{\pi}{4} \left(\frac{5}{12} \right)^2 = 7.49 \text{ Ft.}^2$$

$$\text{Top head insulation area} = 55 \left[\frac{\pi}{4} \left\{ \left(\frac{7}{12} \right)^2 - \left(\frac{5}{12} \right)^2 \right\} \right] = 7.19 \text{ Ft.}^2$$

$$\text{Total insulation area} = (217.6 + 7.49 + 7.19) = 232.28 \text{ Ft.}^2$$

$$\text{Total Surface Area based on both sides of the foil} = 464.57 \text{ Ft.}^2$$

Aluminum Foil:

Cylindrical Wrap: 52 turns, 22" wide
Mean diameter = 11.16"

$$\text{Cylindrical Insulation Area} = 52 \times \pi \times \frac{11.16}{12} \times \frac{22}{12} = 276 \text{ Ft.}^2$$

Bottom Head Insulation area - None

$$\text{Top head insulation area} = 52 \left[\frac{\pi}{4} \left\{ \left(\frac{7}{12} \right)^2 - \left(\frac{5}{12} \right)^2 \right\} \right] = 6.80 \text{ Ft.}^2$$

$$\text{Total insulation area} = (276 + 6.8) = 282.8 \text{ Ft.}^2$$

$$\text{Total surface area based on both sides of the foil} = 565.6 \text{ Ft.}^2$$

106 Glass Paper

Cylindrical Wrap: 52 turns, 22" wide
Mean diameter = 11.16"

$$\text{Cylindrical insulation area} = 276 \text{ Ft.}^2$$

Bottom head insulation area = None

$$\text{Top head insulation area} = 6.8 \text{ Ft.}^2$$

$$\text{Total insulation area} = 282.8 \text{ Ft.}^2$$

$$\text{Total surface area based on both sides of the foil} = 565.6 \text{ Ft.}^2$$

Hastelloy-X:

The necktube is made of Hastelloy-X material. The offgassing area is estimated as follows:

$$\text{Area A} = \pi \times 5.065 \times 3.021 = 48.05 \text{ inch}^2$$

$$\text{Area B} = \pi \times 6.25 \times 0.135 = 2.65 \text{ inch}^2$$

$$\text{Area C} = \pi \times 3.735 \times 2.603 = 30.53 \text{ inch}^2$$

$$\text{Area D} = \left[\pi \times 3.24 \times 3.597 + \frac{\pi}{4} (3.243)^2 \right] = 44.88 \text{ inch}^2$$

$$\text{Total offgassing area} = 126.10 \text{ inch}^2 = 0.875 \text{ Ft.}^2$$

304 Stainless Steel:

The outer shell of the HIVIS unit is made of 304 Stainless Steel. The offgassing area is estimated as follows:

$$\text{Area "A"} = 1/2 (4 \pi r^2) = 1/2 \times 4 \times \pi \times (5.96)^2 = 223.07 \text{ inch}^2$$

Area "B" is estimated as of a cylinder 11.92" in diameter and 2" long

$$\therefore \text{Area "B"} = \pi \times 11.92 \times 2 = 74.85 \text{ inch}^2$$

Area "C" is estimated as of a cylinder 12.202" in diameter x 3-1/4 " long

$$\text{Area "C"} = \pi \times 12.202 \times 3.25 = 124.52 \text{ inch}^2$$

Area "D" is approximately equal to Area "B"

$$\text{Area "D"} = 74.85 \text{ inch}^2$$

Area "E" is calculated by Pappus Theorem

$$\text{Area "E"} = \left[(6.21 - 0.6332 \quad r) 2 \pi \right] \frac{\pi D}{4}$$

where: $r = 2.59"$

$$\therefore \text{Area "E"} = 116.70 \text{ inch}^2$$

Total offgassing area for 304 Stainless Steel enclosure = $\sum A+B+C+D+E$ (area) =

$$= 614 \text{ inch}^2 = 4.26 \text{ Ft.}^2$$

SUMMARY:

Offgassing Area of the Materials:

Nickel Foil	≈	291	Ft. ²
Quartz Paper	≈	857	Ft. ²
Copper Foil	≈	465	Ft. ²
Aluminum Foil	≈	566	Ft. ²
106 Glass Paper	≈	566	Ft. ²
Hastelloy-X	≈	0.875	Ft. ²
304 Stainless Steel	≈	4.26	Ft. ²

The offgassing rates of the following materials based on insulation area (one side area) are found as:

For Nickel foil = 0
 For Aluminum foil = $0.045 \mu - \text{liter/hr.} \cdot \text{Ft.}^2$ insulation area
 For Copper foil = 0
 For 106 Glass Paper = 0
 For Quartz Paper = 0
 For Nuclear Radiation Shield = 0
 For Hastelloy-X = $.0046 \mu - \text{liter/Hr.} \cdot \text{Ft.}^2$ insulation area
 For Stainless Steel = $.019 \mu - \text{liter/Hr.} \cdot \text{Ft.}^2$ insulation area

Total design offgassing period = 5 years = 43,800 hours

Offgassing From Aluminum Foil:

Offgassing rate based on surface area of Aluminum foil

$$= \frac{.045}{2} = .0225 \mu - \text{liter/Hr.} \cdot \text{Ft.}^2$$

Offgassing at 5 years = $0.0225 \times 43,800 \times 566 = 557,793 \mu - \text{liters}$

Offgassing From Hastelloy-X:

$$\text{Offgassing rate based on surface area} = \frac{.0046}{2} = .0023$$

Offgassing at 5 years = $.0023 \times 43,800 \times 0.875 = 88 \mu - \text{liters}$

Offgassing From 304 Stainless Steel:

$$\text{Offgassing rate based on surface area} = \frac{.019}{2} = .0095$$

Offgassing at 5 years = $.0095 \times 4.26 \times 43,800 = 1173 \mu - \text{liters}$

Offgassing Gas Composition is as follows:

For Aluminum Foil:

H_2 = 99.43%
 N_2 -CO = 0.15%
 Hydrocarbon = 0.42%

For Hastelloy-X:

H_2 = 95.46%
 N_2 -CO = 3.81%
 Hydrocarbon = .72%

For 304 Stainless Steel:

$$H_2 = 91.89\%$$

$$N_2-CO = 6.55\%$$

$$CO_2 = 1.56\%$$

Individual Gas Constituents From Offgassing Samples:

$$H_2 \text{ from Aluminum foil} = 557,793 \times 0.9943 = 554,614 \mu - \text{liters.}$$

$$N_2-CO \text{ from Aluminum foil} = 557,793 \times 0.0015 = 837 \mu - \text{liters.}$$

$$\text{Hydrocarbon from Aluminum foil} = 557,793 \times 0.0042 = 2343 \mu - \text{liters.}$$

Similarly,

$$H_2 \text{ from Hastelloy-X sheet} = 88 \times .9546 = 84 \mu - \text{liters}$$

$$N_2-CO \text{ from Hastelloy-X sheet} = 88 \times .0381 = 3 \mu - \text{liters}$$

$$\text{Hydrocarbon from Hastelloy-X sheet} = 88 \times .0072 = 1 \mu - \text{liters}$$

and

$$H_2 \text{ from 304 Stainless Steel sheet} = 1773 \times 0.9189 = 1629 \mu - \text{liters}$$

$$N_2-CO \text{ from 304 Stainless Steel} = 1773 \times 0.0655 = 116 \mu - \text{liters}$$

$$CO_2 \text{ from 304 Stainless Steel} = 1773 \times .0156 = 28 \mu - \text{liters}$$

SUMMARY OF OFFGASSING-IN MICRON-LITERS

<u>Gas Constituents</u>	<u>From Aluminum Foil</u>	<u>From Hastelloy-X</u>	<u>From 304 Stainless Steel</u>	<u>Total μ - liter</u>
H ₂	554,614	84	1629	556,327
CO ₂	-	-	28	28
N ₂ -CO	837	3	116	956
Hydrocarbon	2,343	1	-	2,344

Leakage Flow:

Assume at the end of a five year period, the allowable pressure rise of the system due to the presence of argon only is 10 μ.

System volume = $0.576 \text{ Ft.}^3 = 16.31 \text{ liters}$

@ 5 years $10 \times 16.31 = 163.1 \text{ } \mu\text{-liters}$ of Argon

at $\frac{1400 + 70}{2} = 750^\circ \text{F} = 1195^\circ \text{R.}$

Air is 100% of this argon

. . . Air = $16310 \text{ } \mu\text{-liters}$ @ 750°F

Temperature correction for air = $\frac{16310 \times 530}{1195} = 7,225 \text{ } \mu\text{-liters}$
at ambient conditions.

Allowable Leakage From the System @ 5 Years:

$$= 7225 \text{ } \mu\text{-liters} \times \frac{1 \text{ atm.}}{760,000 \mu} \times \frac{1,000 \text{ cc}}{\text{liters}} \times \frac{1}{43800 \text{ hrs.}} \times \frac{\text{Hr.}}{3600 \text{ sec.}}$$

$$= 6.03 \times 10^{-8} \text{ atm. cc air/sec.}$$

Leakage air of 7225 $\mu\text{-liters}$ contains

$$\text{N}_2 = 0.7809 \times 7225 = 5642 \text{ } \mu\text{-liters}$$

$$\text{O}_2 = 0.20955 \times 7225 = 1515 \text{ } \mu\text{-liters}$$

$$\text{CO}_2 = 0.0003 \times 7225 = 2.16 \text{ } \mu\text{-liters}$$

$$\text{Ar} = .0226 \times 7225 = 163 \text{ } \mu\text{-liters}$$

<u>Gas Constituents</u>	<u>Offgassing From Material $\mu\text{-liters}$</u>	<u>Leakage Air $\mu\text{-liters}$</u>	<u>Total Composition $\mu\text{-liters}$</u>	<u>% Composition</u>
H ₂	556,327	-	556,327	98.12
CO ₂	28	2	30	0.0053
N ₂ -CO	956	5,642	6,598	1.16
O ₂	-	1,515	1,515	0.267
Hydrocarbon	2,344	-	2,344	.413
Argon	-	163	163	0.0287

Based on the following getter capacity the total amount of getter required is calculated as follows.

Getter capacity for H_2 = 100,000 μ -liters/gm
 for CO = 8,000 μ -liters/gm
 for N_2 = 45,000 μ -liters/gm
 for O_2 = 40,000 μ -liters/gm
 for CO_2 = 5,000 μ -liters/gm
 for hydrocarbon = 23,000 μ -liters/gm

$$\text{Getter for } H_2 = \frac{556,327}{100,000} \frac{\mu\text{-liter} \times \text{gm}}{\mu\text{-liters}} = 5.56 \text{ gm}$$

$$\begin{aligned} N_2\text{-CO} &= \frac{6,598}{8,000} = .825 \text{ gm} \\ (\text{assuming all CO}) \end{aligned}$$

$$CO_2 = \frac{30}{5,000} = 0.006 \text{ gm}$$

$$O_2 = \frac{1515}{40,000} = 0.038 \text{ gm}$$

$$\text{Hydrocarbon} = \frac{2,344}{23,000} = 0.10 \text{ gm}$$

$$\therefore \text{Total hydrogen getter} = 6.43 \text{ gm}$$

$$\text{Total hydrocarbon getter} = 0.10 \text{ gm}$$

APPENDIX B

STATIC PROOF TEST CALCULATIONS

The structural components used for the static proof test were made from the following materials: Neck Tube - Inconel-X-750, Male Rod - Inconel-625 solution annealed, Female Rod - Inconel-625 solution annealed.

1. Derivation of Load Sharing Equation for Static Proof Test

The load sharing equation derived in Appendix F for the HTVIS support system is modified slightly for the static proof test to incorporate the stiffness of the top flange which is connecting the neck tube to the test fixture and the center plate (spider) which is connecting the tension rod to the shield.

The deflection of the flange,

$$\begin{aligned} t &= .375 \\ 2a &= 8.6 \text{ in.} \\ a &= 4.3 \text{ in.} \\ r_o &= 2.45 \text{ in.} \\ E &= 29.8 \cdot 10^6 \text{ psi} \end{aligned}$$

$$Q_{3F} = \frac{M}{\alpha_{Et}^3} = \frac{W(l_{1N} + l_2) - P(l_{1N} + l_2 + l_3)}{\alpha_{Et}^3}$$

$$\frac{r_o}{a} = \frac{2.45}{4.3} = .56$$

$$\alpha = 20.5$$

$$\alpha_{Et}^3 = 20.5 \times 29.8 \times 10^6 (.375)^3 = 32.2 \times 10^6$$

$$y_{31F} = \frac{W(l_{1N} + l_2) + P(l_{1N} + l_2 + l_3 + e \tan \alpha)}{32.2 \times 10^6} (l_{1N} + l_2 + l_3)$$

The reciprocal of the spring constants of the tension rod components were as follows:

a) Tension Rod,

$$\frac{1}{k} = \frac{l}{EA} = \frac{2.619}{29.8 \times 10^6 (.0585)} = 1.502 \times 10^{-6} \text{ in/lbs.}$$

$$E = 29.8 \times 10^6 \text{ psi (Inconel 625, at room temperature)}$$

$$A = .0585 \text{ in.}^2$$

$$l = 2.936 - 2(.16) = 2.619 \text{ in.}$$

b) Spherical Washer,

$$l = (.250 - .16) + .16/2 = .170$$

$$\frac{1}{k} = \frac{l}{EA} = \frac{.170}{29.8 \cdot 10^6 (.0875)} = .0651 \cdot 10^{-6} \text{ in/lb.}$$

$$E = 29.8 \cdot 10^6 \text{ psi (stainless steel at room temperature)}$$

$$A = (.515^2 - .392^2) \pi/4 = .0875 \text{ in.}^2$$

Calculation of tension rod displacement in the direction of the load due to the radial deflection of the spherical washer. The radius where the concentrated load is applied,

$$R = \frac{.515 - .392}{2} \cdot \frac{1}{3} + \frac{.392}{2} = .216 \text{ in.}$$

The radial component of the load P_r , at radius R ,

$$P_r = 1000 \tan 57^\circ 49' = 1550 \text{ lbs.}$$

The average pressure in the radial direction,

$$p_i = \frac{P_r}{\pi DL} = \frac{1550}{\pi (.216) 2 (.250)} = 4570 \text{ psi}$$

The maximum tangential stress due to the internal pressure p_i ,

$$\sigma_t = \frac{a^2 p_i}{b^2 - a^2} \left[1 + \frac{b^2}{r^2} \right] = \frac{(.216)^2 4570}{(.352)^2 - (.216)^2} \left[1 + \left(\frac{.352}{.216} \right)^2 \right] = 10,091 \text{ psi}$$

where,

$$a = R = .216 \text{ in.}$$

$$b = .352 \text{ in. (outside radius of washer)}$$

The deflection of the spherical washer in the radial direction at $r = a = R$

$$\begin{aligned} u_r \Big|_{r=a} &= \frac{ap_i}{E} \left[\frac{a^2 + b^2}{b^2 - a^2} + \mu \right] = \\ &= \frac{.216 (4570)}{29.8 \cdot 10^6} \left[\frac{.216^2 + .352^2}{.352^2 - .216^2} + .3 \right] = 82 \cdot 10^{-6} \text{ in.} \end{aligned}$$

The displacement of the rod in the direction of the load,

$$y_v = y_r \tan 60 = 82 (1.73) = 141 \cdot 10^{-6} \text{ in.}$$

$$\frac{1}{k} = \frac{141 \times 10^{-6}}{1000} = .141 \cdot 10^{-6} \text{ in./lbs.}$$

The sum of the reciprocal of spring constants for the spherical washer is,

$$\begin{aligned} \frac{1}{k \text{ (compression)}} + \frac{1}{k \text{ (radial deflection)}} &= .0651 (10^{-6}) + .141 \cdot 10^{-6} = \\ &= .206 \cdot 10^{-6} \text{ in./lbs.} \end{aligned}$$

c) Center Plate (Spider),

$$\frac{1}{k} = \frac{l}{EA} = \frac{3.125}{29.8 \cdot 10^6 (.75)} = .0139 \cdot 10^{-6} \text{ in./lbs.}$$

$$A = 1.5 \times .5 = .75 \text{ in.}^2$$

$$l = 3.125 \text{ in.}$$

$$\sum \frac{1}{k} = (1.502 + .206 + .0139) 10^{-6} = 1.721 10^{-6} \text{ in./lb.}$$

The Load Sharing Equation,

$$\begin{aligned}
 P \propto = & \frac{W}{\cos \alpha} \left\{ \frac{l_1^2 (2l_1 + 3l_2 + 3l_3) + 3l_1 l_2 (l_1 + 2l_2 + 2l_3)}{6EI} + \frac{2l_1 (2.58)}{EA} + \right. \\
 & + \frac{(l_{1N} + l_2) (l_{1N} + l_2 + l_3)}{32.2 (10^6)} \left| \frac{l_R}{E_R A_R} \frac{1}{\cos^2 \alpha} + \right. \\
 & + \frac{l_1^2 (2l_1 + 3l_2 + 3l_3) + 3l_1 (l_1 + 2l_2 + 2l_3) (l_2 + l_3 + e \tan \alpha)}{6EI} + \\
 & \left. + \frac{(l_{1N} + l_2 + l_3 + e \tan \alpha) (l_{1N} + l_2 + l_3)}{32.2 (10^6)} + \frac{2l_1 (2.58)}{EA} \right\}
 \end{aligned}$$

2.) Calculation of Predicted Load to Fail the Neck Tube in Shear Buckling

The neck tube is made from Inconel 750 X material. The modulus of elasticity of the neck tube is, $E = 31.0 \times 10^6$ psi at room temperature, 80°F.

$$I = (4.922^4 - 4.9^4) \pi / 64 = .5113 \text{ in.}^4$$

$$A = (4.922^2 - 4.9^2) \pi / 4 = .1696 \text{ in.}^2$$

Calculating each term in the load sharing equation.

$$\begin{aligned}
 l_1 &= 2.497 \text{ in.} & \sin \alpha &= .4666 \\
 l_{1N} &= 2.78 \text{ in.} & \cos \alpha &= .8844 \\
 l_2 &= 4.43 \text{ in.} & \tan \alpha &= .5276 \\
 l_3 &= 4.385 \text{ in.} \\
 e &= 3.125 \text{ in.} \\
 \alpha &= 27^\circ 49'
 \end{aligned}$$

$$\begin{aligned}
 x_1 &= \frac{l_1^2 (2l_1 + 3l_2 + 3l_3) + 3l_1 l_2 (l_1 + 2l_2 + 2l_3)}{6EI} = \\
 &= \frac{(2.497)^2 [2(2.497) + 3(4.43) + 3(4.385)] + 3(2.497)4.43(2.497 + 2(4.43) + (2) 4.385)}{6(31.0) 10^6 (.5113)} = \\
 &= 9.07 \cdot 10^{-6}
 \end{aligned}$$

$$x_2 = \frac{2l_1 (2.58)}{EA} = \frac{2(2.497)(2.58)}{(31.0) 10^6 .1696} = 2.44 \cdot 10^{-6}$$

$$G = \frac{E}{2(1 + \mu)} = \frac{31.0 \cdot 10^6}{2(1 + .29)} = 12.01$$

$$\frac{E}{G} = \frac{31.0}{12.0} = 2.58$$

$$\begin{aligned}
 x_3 &= \frac{2(l_{1N} + l_2)(l_{1N} + l_2 + l_3)}{32.2} = \frac{(2.78 + 4.43)(2.78 + 4.43 + 4.385)}{32.2} = \\
 &= 2.59 \cdot 10^{-6}
 \end{aligned}$$

$$\begin{aligned}
 x_4 &= \frac{l_1^2 (2l_1 + 3l_2 + 3l_3) + 3l_1 (l_1 + 2l_2 + 2l_3) (l_2 + l_3 + e \tan \alpha)}{6EI} = \\
 &= 2.497^2 [2(2.497) + 3(4.43) + 3(4.385)] + 3(2.497) [(2.497 + 2(4.43) + 2(4.385)] \\
 &\quad [4.43 + 4.385 + 3.125 (.5276)] / 6 (31.0) 10^6 (.5113) = 18.64 \cdot 10^{-6}
 \end{aligned}$$

$$X_5 = X_2 = 2.44 \cdot 10^{-6}$$

$$X_6 = \frac{(l_{1N} + l_2 + l_3 + e \tan \alpha) (l_{1N} + l_2 + l_3)}{32.2 \cdot 10^6} =$$

$$= \frac{[2.78 + 4.43 + 4.385 + 3.125 (.5276)] [2.78 + 4.43 + 4.385]}{32.2 \cdot 10^6} = 4.76 \cdot 10^{-6}$$

$$P_{\alpha} = \frac{W}{.8844} \frac{(9.07 + 2.44 + 2.59) \cdot 10^{-6}}{\frac{1.721 \cdot 10^{-6}}{(.8844)^2} + (18.64 + 2.44 + 4.76) \cdot 10^{-6}}$$

$$P_{\alpha} = \frac{W}{.8844} \frac{14.10 \cdot 10^{-6}}{2.20 \cdot 10^{-6} + 25.84} = .567 W$$

$$P = (.502) W$$

Calculate the critical shear load for the neck tube at failure in shear buckling.

$$\frac{R}{t} = \frac{2.450}{.011} = 222$$

$$\frac{\tau_{cr}}{E_r} \cdot 10^3 = .66$$

$$\tau_{cr} \text{ (shear)} = 1.2 (.66) E_r \cdot 10^{-3} = 1.2 (.66) (31.0) \cdot 10^6 = 24,552 \text{ psi}$$

The shear load,

$$V = \pi R t \tau_{cr} = \pi (2.450) (.011) 24,552 = 2077 \text{ lbs.}$$

$$V = W - P = (W - .502 W) = .498 W = 2077 \text{ lbs}$$

$$W = \frac{2077}{.498} = 4172 \text{ lbs.}$$

The load applied at the center of gravity of the support system to fail the neck tube in shear buckling is 4172 lbs. This load was calculated on the basis that the modulus of elasticity of the tension rod is constant.

Calculation of bending moments at neck tube ends and the ratio of critical shear stress to critical torsion stress

$$M_{(\text{Bottom End})} = Wl_2 - P(l_2 + l_3 + e \tan \alpha) =$$

$$= 4172(4.43) - (.502)(4172) [4.43 + 4.385 + 3.125 (.5276)]$$

$$= -3432 \text{ in-lbs.}$$

$$M_{(\text{Top End})} = W(l_1 + l_2) - P(l_1 + l_2 + l_3 + e \tan \alpha) =$$

$$= 4172 (2.497 + 4.43) - (.502)(4172) 2.497 + 4.43 + 4.385 + 3.125(.5276) =$$

$$= +1755 \text{ in-lbs}$$

$$\left(\frac{M}{RV}\right)_{(\text{Bottom End})} = \frac{-3432}{2.450(2094)} = .66$$

$$\left(\frac{M}{RV}\right)_{(\text{Top End})} = \frac{1755}{2.450 2094} = .34$$

$$\frac{fv}{s_s} = 1.2 \quad (\text{bottom end of neck tube})$$

$$\frac{fv}{s_s} = 1.2 \quad (\text{top end of neck tube})$$

The $f_v/S_S = 1.2$ ratio used in the calculation for determining the critical shear stress for the neck tube was correct.

Since the maximum stress in the tension rod exceeded the proportional limit (see Figure A-1) it is necessary to make correction in the load sharing equation to include the effect of changing modulus of elasticity. A stress-strain curve for the tension rod material is presented in Figure A-1.

In the load sharing equation, the variable modulus of elasticity of the tension rod only affects the first term in the denominator.

$$\frac{P}{W} = \frac{14.10 (10^{-6})}{\left[\frac{2.619}{E_R (.0585)} + .219 \cdot 10^{-6} \right] \frac{1}{(.88445)^2} + 25.84 (10^{-6})}$$

For small increments of strain, it is assumed that the modulus of elasticity is a constant, and therefore the load sharing equation and the deflection equations are applicable. The increments of strains used in the calculations are shown in Figure A-1.

<u>Increments</u>	<u>psi Stress in Rod</u>	<u>E_R</u>	<u>Calculated P/W from Load Sharing Equation</u>
1	0-30,000	29.8 10 ⁶	.502
2	30,000-35,000	23 10 ⁶	.492
3	35,000-37,500	16 10 ⁶	.474

The maximum radial force P and the corresponding load W is calculated for each increment of strain.

<u>Increments</u>	<u>σ Max (rod)</u>	<u>P = σ A cos α, lbs</u>	<u>W = P $\frac{1}{(P/W)}$ $\frac{1}{1.76}$</u>
1	30,000	1552	1756 psi
2	35,000	1810	2090
3	37,500	1940	2325

Calculations of radial deflection of the tension rods.

$$y_1 - y_0 = (P_1 - P_0) \frac{l}{EA} \frac{1}{\cos^2 \alpha} = (1552-0) \left[\frac{2.619}{29.8 \cdot 10^6 (.0585)} + .219 \cdot 10^{-6} \right] \times$$

$$\times \frac{1}{(.88445)^2} = .00341 \text{ in.}$$

$$y_2 - y_1 = (P_2 - P_1) \frac{l}{EA} \frac{1}{\cos^2 \alpha} = (1810-1552) \left[\frac{2.619}{23.0 \cdot 10^6 (.0585)} + .219 \cdot 10^{-6} \right] \times$$

$$\times \frac{1}{(.88445)^2} = .000714 \text{ in.}$$

$$y_3 - y_2 = (P_3 - P_2) \frac{l}{EA} \frac{1}{\cos^2 \alpha} = (1940-1810) \left[\frac{2.619}{16 \cdot 10^6 (.0585)} + .219 \cdot 10^{-6} \right] \times$$

$$\times \frac{1}{(.88445)^2} = .000501 \text{ in.}$$

The calculated radial deflections of the tension rod at different applied loads W are shown on Figure 45.

Calculation of neck tube deflection.

$$y_1 = \frac{(W-P) l_1^3}{3EI} =$$

$$y_2 = \frac{[W l_2 - P (l_2 + l_3 + e \tan \alpha)] l_1^2}{2EI}$$

$$y_3 = \frac{2(W-P) l_1^{2.58}}{EA}$$

$$y_F = \frac{[W(l_{1N} + l_2) - P(l_{1N} + l_2 + l_3 + e \tan \alpha)] l_{1N}}{C}$$

$$y_{\text{tot}} = y_1 + y_2 + y_3 + y_F$$

<u>Increments</u>	<u>E psi</u>	<u>P, lbs</u>	<u>ΔP, lbs</u>	<u>W, lbs</u>	<u>ΔW, lbs</u>
1	29.8	1552	1552	3090	3090
2	23.0	1810	258	3678	588
3	16.0	1940	130	4092	414

<u>Increments</u>	<u>$y_1 \times 10^{-6}$ in.</u>	<u>$y_2 \times 10^{-6}$ in.</u>	<u>$y_3 \times 10^{-6}$ in.</u>	<u>$y_F \times 10^{-6}$</u>	<u>y Total, in.</u>
1	503	-323	3769	149	.00392
2	108	-12	813	72	.00097
3	92	+60	695	109	.00095
					<u>.00584 Inch</u>

Calculated neck tube deflections for different applied loads W, were plotted on Figure 45. The calculated P/W ratios are shown on Figure 45. The P/W ratio at the load where the neck tube failed (W = 2250 psi) is calculated by a trial-error procedure.

Assume $W/P = .483$

$$W = 2250 = P \frac{1}{P/W} \frac{1}{1.76} = \frac{P}{(.486)(1.76)}$$

P = 1924 lbs.

The maximum stress in the rod,

$$\sigma = \frac{1924}{.0585 (.88445)} = 37,196 \text{ psi} \sim 37,200 \text{ psi}$$

The modulus of elasticity for the increment between 35,000 psi and 37,200 psi from Figure A-1 is $E = 18 \times 10^6$ psi. Recalculating the W/P ratio from the load sharing equation using $E = 18 \times 10^6$ modulus of elasticity gives $W/P = .481$. Using $W/P = .483$ ratio, the predicted load to fail the neck tube in shear buckling is,

$$V = 2077 = W - .483W = .517 W$$

$$W = \frac{2077}{.517} = 4017 \text{ lbs.}$$

The actual load applied on the support system at the failure of the neck tube was 4072 lbs. (The load applied by the hydraulic jack was 3960 lbs. and the weight of the stainless steel shield was 112 lbs.)

FIGURE B-1

STRESS STRAIN CURVE FOR INCONEL 625 SOLUTION ANNEALED
TENSION ROD AT ROOM TEMPERATURE
(STATIC PROOF TEST)

APPENDIX C

PHYSICAL PROPERTIES OF MATERIALS USED IN MODEL A INSULATION SYSTEM

This appendix is composed entirely of figures presenting the properties of the materials used in the Model A insulation system for the SNAP 21B thermoelectric generator system. The figures presented in this Appendix are as follows:

Figure C-1	Thermal Conductivity Versus Temperature for Hastelloy-X
Figure C-2	Mean Linear Thermal Expansion of Hastelloy-X
Figure C-3	Modulus of Elasticity Versus Temperature for Hastelloy-X
Figure C-4	Modulus of Elasticity Versus Stress for Hastelloy-X
Figure C-5	Proportional Limit Versus Temperature for Hastelloy-X
Figure C-6	Oxidation Rates of Hastelloy-X in Air
Figure C-7	Intergranular Oxidation for Hastelloy-X
Figure C-8	Stress Rupture Data for Hastelloy-X
Figure C-9	Thermal Conductivity Versus Temperature for Inconel-625
Figure C-10	Mean Linear Thermal Expansion of Inconel-625
Figure C-11	Modulus of Elasticity for Inconel-625
Figure C-12	Proportional Limit Versus Temperature for Inconel-625
Figure C-13	Stress Rupture Data for Inconel-625
Figure C-14	Thermal Conductivity Versus Temperature for Inconel-718
Figure C-15	Thermal Expansion Coefficient of Inconel-718
Figure C-16	Modulus of Elasticity Versus Temperature for Inconel-718
Figure C-17	Proportional Limit Versus Temperature for Inconel-718
Figure C-18	Minimum Creep Rate of Inconel-718
Figure C-19	} Thermal Expansion Coefficients of Candidate Materials for Hot End Connector
Figure C-20	
Figure C-21	Modulus of Elasticity Versus Stress for 304 Stainless
Figure C-22	Tensile Stress, Modulus of Elasticity and Elongation of Uranium-Molybdenum Alloys

FIGURE C-1

FIGURE C-2

FIGURE C-3

FIGURE C-4

PROPORTIONAL LIMIT VS. TEMPERATURE
FOR HASTELLOY-X SOLUTION ANNEALED

FIGURE C-5

FIGURE C-6

FIGURE 2-7

FIGURE C-8

THERMAL CONDUCTIVITY OF INCONEL 625

FIGURE C-9

FIGURE C-10

FIGURE C-11

PROPORTIONAL LIMIT VS. TEMPERATURE
FOR INCONEL 625
SOLUTION ANNEALED MATERIAL

REFERENCE:
INTERNATIONAL NICKEL CO.

FIGURE C-12

STRESS RUPTURE DATA FOR INCONEL 625
HEAT TREAT: ANNEALED 1600°F - 1800°F 1/HR.

FIGURE C-13

THERMAL CONDUCTIVITY VS. TEMPERATURE
FOR INCONEL 718

FIGURE C 14

THERMAL EXPANSION COEFFICIENT OF INCONEL 718

FIGURE C-15

MODULUS OF ELASTICITY VS. TEMPERATURE
FOR INCONEL 718

FIGURE C-16

PROPORTIONAL LIMIT VS. TEMPERATURE FOR INCONEL 718

FIGURE C 17

MINIMUM CREEP RATE OF INCONEL 718

FIGURE C-18

THERMAL EXPANSION COEFFICIENTS OF CANDIDATE MATERIALS FOR HOT END CONNECTOR

FIGURE C-19

THERMAL EXPANSION COEFFICIENT FOR CANDIDATE MATERIALS FOR HOT END CONNECTOR

FIGURE C-20

FIGURE C-21

X1000

TENSILE STRESS, MODULUS OF ELASTICITY AND ELONGATION OF URANIUM - MOLYBDENUM ALLOYS

FIGURE C-22

APPENDIX D

DERIVATION OF EQUATION FOR TEMPERATURE DISTRIBUTION IN A ROD

WITH ONE DIMENSIONAL HEAT CONDUCTION AND VARIABLE

THERMAL CONDUCTIVITY

If the thermal conductivity of the material varies significantly in the conduction region, the Laplace equation is not valid in such a case. The proper differential equation is determined from the general conduction equation. The equation* and the boundary conditions are:

$$\frac{d}{dX} \left(k \frac{dt}{dX} \right) = 0 \quad \text{at} \quad \begin{array}{l} X = 0 \\ X = L \end{array} \quad \begin{array}{l} t = t_1 \\ t = t_2 \end{array}$$

where k may be a function of X and t . The solution for this equation is presented below for the case when the thermal conductivity is a function of temperature, that is $k = f(t)$. Integrating and solving for the constants,

$$k \frac{dt}{dX} = C_1 \quad \text{from } t = t_1 \text{ at } X = 0$$

$$\int_{t_1}^t k dt = C_1 \int_0^X dX = C_1 X$$

from

$$t = t_2 \text{ at } X = L$$

$$\int_{t_1}^t k dt = C_1 L$$

$$C_1 = \frac{1}{L} \int_{t_1}^{t_2} k dt = -k_m \frac{t_1 - t_2}{L}$$

$$k_m = \frac{1}{t_1 - t_2} \int_{t_1}^{t_2} k dt$$

* See: "Heat Transfer", Benjamin Gebhart, McGraw-Hill, 1961.

where k_m is defined as the integrated value of k from t_1 to t_2 . For a linear variation of k with temperature this is equal to the average of k_1 and k_2 . The temperature distribution is given by

$$\int_{t_1}^t k dt = - k_m \frac{t_1 - t_2}{L} X$$

$$k = f(t) = a t + b$$

$$k_m = f(t_m) = a t_m + b$$

$$\text{where } t_m = (t_1 + t_2)/2$$

$$\int_{t_1}^t k dt = \int_{t_1}^t (a t + b) dt = \left[\frac{a t^2}{2} + b t \right]_{t_1}^t =$$

$$\frac{a t^2}{2} + b t - \frac{a t_1^2}{2} - b t_1 = - k_m (t_1 - t_2) \frac{X}{L}$$

$$\frac{a t^2}{2} + b t - \left[\frac{a t_1^2}{2} + b t_1 - k_m (t_1 - t_2) \frac{X}{L} \right] = 0$$

Solving the quadratic equation for t

$$t = \frac{-b \pm (b^2 + a^2 t_1^2 + 2 a b t_1 - 2 a k_m (t_1 - t_2) \frac{X}{L})^{1/2}}{a}$$

APPENDIX E

CALCULATION OF NECK TUBE TEMPERATURE PROFILE IN AN OPERATING UNIT

The temperature profile of the neck tube was determined by the relaxation method. The temperature grid used in the calculations is shown below.

Points 1 - 6 Insulation temperature profile

Points 7 - 12 Neck tube temperature profile

Points 16 - 20 Neck tube cold end temperature 150°F

Points 13 - 15 and 22 - 24 Neck tube hot end temperature 1285°F

Point 21 Temperature inside thermal electric generator (linear temperature drop was assumed through the thermal electric generator).

Write heat balance equations for points 8, 9, 10, and 11.

$$q_8 = K_{9-8} (t_9 - t_8) + K_{7-8} (t_7 - t_8) + K_{5-8} (t_5 - t_8) + K_{17-8} (t_{17} - t_8) + R_{5-8} (t_5^4 - t_3^4)$$

where:

$$K_{98} = \frac{k_{NT} A}{X} = (90 \frac{\text{Btu} \cdot \text{in.}}{\text{Ft.}^2 \text{ Hr. } ^\circ\text{F}}) (\frac{.011 \text{ in.} \times 1 \text{ in.}}{.5 \text{ in.}}) (\frac{\text{Ft.}^2}{144 \text{ in.}^2}) = .01375 \text{ Btu/Hr. } ^\circ\text{F.}$$

$$K_{78} = \frac{k_{NT} A}{X} = (70) (\frac{.011}{.5}) \frac{1}{144} = .0107$$

$$K_{58} = 0 \quad (\text{conduction heat transfer from the insulation to neck tube assumed negligible})$$

$$K_{17-8} = \frac{k_{(MINK)} A}{X} = (0.4 \frac{\text{Btu in.}}{\text{Ft.}^2 \text{ Hr. } ^\circ\text{F}}) (\frac{0.5 \text{ in.} \times 1 \text{ in.}}{0.5 \text{ in.}}) (\frac{\text{Ft.}^2}{144 \text{ in.}^2}) = .00278$$

$$R_{58} = \epsilon_{NT} \sigma A = (0.2) (0.1713 \times 10^{-8} \frac{\text{Btu}}{\text{Hr. Ft.}^2 ^\circ\text{F}}) (\frac{0.5 \text{ in.} \times 1 \text{ in.}}{144 \text{ in.}^2 / \text{Ft.}^2}) = 1.19 \times 10^{-12}$$

$$q_8 = .01375 (t_9 - t_8) + .0107 (610 - t_8) + .00278 (610 - t_8) + 1.19 \times 10^{-12}$$

$$[(930)^4 - t_8^4] =$$

$$q_8 = .01375 t_9 - .02723 t_8 - 1.19 \times 10^{-12} t_8^4 + 9.113 \quad (8)$$

$$q_9 = K_{10-9} (t_{10} - t_9) + K_{8-9} (t_8 - t_9) + K_{16-9} (t_{16} - t_9) + R_{4-9} (t_4^4 - t_9^4)$$

$$K_{10-9} = (110) \left(\frac{.011}{0.5} \right) \left(\frac{1}{144} \right) = 0.0168$$

$$K_{8-9} = K_{98} = 0.01375$$

$$K_{16-9} = \frac{(0.44)}{144} = 0.003056$$

$$R_{4-9} = R_{58} = 1.19 \times 10^{-12}$$

$$q_9 = 0.0168 (t_{10} - t_9) + 0.01375 (t_8 - t_9) + .003056 (1096 - t_9)$$

$$+ 1.19 \times 10^{-12} [(1310)^4 - t_9^4]$$

$$q_9 = 0.0168 t_{10} + 0.01375 t_8 - 0.0336 t_9 - 1.19 \times 10^{-12} t_9^4 + 6.855 \quad (9)$$

$$q_{10} = K_{11-10} (t_{11} - t_{10}) + K_{9-10} (t_9 - t_{10}) + K_{15-10} (t_{15} - t_{10}) +$$

$$+ R_{3-10} (t_3^4 - t_{10}^4)$$

$$K_{11-10} = (125) \left(\frac{0.011}{0.5} \right) \left(\frac{1}{144} \right) = 0.0191$$

$$K_{9-10} = K_{10-9} = 0.0168$$

$$K_{15-10} = \frac{kA}{X} = \frac{k_{\text{MINK}} (0.5 \text{ in.} \times 1 \text{ in.})}{0.25 \text{ in.}} = \frac{(0.46)(0.5)}{(0.25)(144)} = 0.00639$$

$$R_{3-10} = R_{58} = 1.19 \times 10^{-12}$$

$$q_{10} = 0.0191 (t_{11} - t_{10}) + 0.0168 (t_9 - t_{10}) + 0.00639 (1745 - t_{10}) + \\ + 1.19 \times 10^{-12} [(1560)^4 - t_{10}^4]$$

$$q_{10} = 0.0191 t_{11} + 0.0168 t_9 - 0.0423 t_{10} - 1.19 \times 10^{-12} t_{10}^4 + 18.20 \quad (10)$$

$$q_{11} = K_{12-11} (t_{12} - t_{11}) + K_{10-11} (t_{10} - t_{11}) + K_{14-11} (t_{14} - t_{11}) \\ + R_{2-11} (t_2^4 - t_{11}^4)$$

$$K_{12-11} = (135) \left(\frac{0.011}{0.5} \right) \left(\frac{1}{144} \right) = 0.02063$$

$$K_{10-11} = K_{11-10} = 0.0191$$

$$K_{14-11} = K_{15-10} = 0.00639$$

$$R_{2-11} = R_{58} = 1/19 \times 10^{-12}$$

$$q_{11} = 0.02063 (1745 - t_{11}) + 0.0191 (t_{10} - t_{11}) + 0.00639 (1745 - t_{11}) \\ + 1.19 \times 10^{-12} [(1680)^4 - t_{11}^4]$$

$$q_{11} = 0.0191 t_{10} - 0.04612 t_{11} - 1.19 \times 10^{-12} t_{11}^4 + 56.63 \quad (11)$$

From equations (8), (9), (10) and (11) the temperatures t_8 , t_9 , t_{10} and t_{11} were solved by trial and error procedure. The following temperatures were obtained: $t_8 = 465^\circ\text{F}$, $t_9 = 780^\circ\text{F}$, $t_{10} = 1,050^\circ\text{F}$ and $t_{11} = 1,192^\circ\text{F}$. The temperature profile of the neck tube determined from these temperatures is shown on Figure E-1 as "Calculated Neck Tube Profile". Figure E-1 also shows an approximate temperature profile of the neck tube, which was obtained by considering solid conduction heat transfer only. The insulation temperature profile shown on Figure E-1 was obtained from Linde test data and was used here in the calculations for the temperatures of points 1 to 6.

FIGURE E-1

DERIVATION OF LOAD SHARING EQUATION

DEFLECTION OF BEAM ON PLANE #1

a. DUE TO END LOADS (ROARK, PG. 104, CASE 1)

$$\delta_1 = \frac{(W-P)l_1^3}{3EI}$$

b. DUE TO END MOMENTS (ROARK, PG. 106, CASE 9)

$$\delta_2 = \frac{[Wl_2 - P(l_2 + l_3 + e \tan \alpha)]l_1^2}{2EI}$$

c. DUE TO SHEAR FOR SHORT DEEP BEAM
(ROARK, PG. 129-130)

$$\delta_3 = \frac{2(W-P)l_1}{AG}$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
		APPV'D	SHEET F-1	SHEETS
		APPENDIX F		
UNION CARBIDE CORPORATION LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, N.Y. 14150				

ROTATION OF BEAM AT PLANE #1

a. DUE TO END LOAD (ROARK, PG. 104, CASE 1)

$$\theta_1 = \frac{(w-p)l_1^2}{2EI}$$

b. DUE TO END MOMENT (ROARK, PG. 106, CASE 9)

$$\theta_2 = \frac{[wl_2 - p(l_2 + l_3 + e \tan \alpha)]l_1}{EI}$$

DEFLECTION ON PLANE #1 DUE TO END LOADS, MOMENTS, AND SHEAR

$$\begin{aligned} \delta_{1T} &= \delta_1 + \delta_2 + \delta_3 \\ &= \frac{(w-p)l_1^3}{3EI} + \frac{[wl_2 - p(l_2 + l_3 + e \tan \alpha)]l_1^2}{2EI} + \frac{2(w-p)l_1}{AG} \\ &= \frac{2(w-p)l_1^3 + 3[wl_2 - p(l_2 + l_3 + e \tan \alpha)]l_1^2}{6EI} + \frac{2(w-p)l_1}{AG} \end{aligned}$$

DEFLECTION OF PLANE #3 DUE TO ROTATION ON PLANE #1

$$\delta_{3\theta} = (l_2 + l_3)(\theta_1 + \theta_2)$$

$$\delta_{3\theta} = \left\{ \frac{(w-p)l_1^2}{2EI} + \frac{[wl_2 - p(l_2 + l_3 + e \tan \alpha)]l_1}{EI} \right\} (l_2 + l_3)$$

$$\delta_{3\theta} = \frac{(w-p)(l_1^2)(l_2 + l_3) + 2[wl_2 - p(l_2 + l_3 + e \tan \alpha)]l_1(l_2 + l_3)}{2EI}$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
		APPV'D	SHEET F-2	SHEETS
UNION CARBIDE CORPORATION LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, N.Y. 14150		APPENDIX F		

TOTAL DEFLECTION AT POINT *3

$$\delta_3 = \frac{2(W-P)l_1^3 + 3[Wl_2 - P(l_2 + l_3 + e \tan \alpha)]l_1^2}{6EI} + \frac{(W-P)(l_1^2)(l_2 + l_3) + 2[Wl_2 - P(l_2 + l_3 + e \tan \alpha)]l_1(l_2 + l_3)}{2EI} + \frac{2(W-P)l_1}{AG}$$

$$\delta_3 = \frac{2Wl_1^3 - 2Pl_1^3 + 3Wl_2l_1^2 - 3Pl_1^2(l_2 + l_3 + e \tan \alpha)}{6EI} + \frac{Wl_1^2(l_2 + l_3) - Pl_1^2(l_2 + l_3) + 2Wl_2l_1(l_2 + l_3) - 2P(l_2 + l_3 + e \tan \alpha)l_1(l_2 + l_3)}{2EI} + \frac{2Wl_1}{AG} - \frac{2Pl_1}{AG}$$

$$\delta_3 = \frac{2Wl_1^3 + 3Wl_2l_1^2 + 3Wl_1^2(l_2 + l_3) + 6Wl_2l_1(l_2 + l_3)}{6EI} - \frac{2Pl_1^3 + 3Pl_1^2(l_2 + l_3 + e \tan \alpha) + 3Pl_1^2(l_2 + l_3) + 6P(l_2 + l_3 + e \tan \alpha)l_1(l_2 + l_3)}{6EI} + \frac{2Wl_1}{AG} - \frac{2Pl_1}{AG}$$

$$\delta_3 = \frac{W[2l_1^3 + 3l_2l_1^2 + 3l_1^2(l_2 + l_3) + 6l_2l_1(l_2 + l_3)]}{6EI} - \frac{P[2l_1^3 + 3l_1^2(l_2 + l_3 + e \tan \alpha) + 3l_1^2(l_2 + l_3) + 6(l_2 + l_3 + e \tan \alpha)l_1(l_2 + l_3)]}{6EI} + \frac{2Wl_1}{AG} - \frac{2Pl_1}{AG}$$

$$\delta_3 = \frac{W[2l_1^3 + 3l_1^2l_2 + 3l_1^2l_2 + 3l_1^2l_3 + 6l_1l_2^2 + 6l_1l_2l_3]}{6EI} - \frac{P[2l_1^3 + 3l_1^2(l_2 + l_3) + 3l_1^2(l_2 + l_3 + e \tan \alpha) + 6(l_2 + l_3 + e \tan \alpha)l_1(l_2 + l_3)]}{6EI} + \frac{2Wl_1}{AG} - \frac{2Pl_1}{AG}$$

$$\delta_3 = \frac{W[l_1^2(2l_1 + 3l_2 + 3l_3) + 3l_1l_2(l_1 + 2l_2 + 2l_3)]}{6EI} - \frac{P[l_1^2(2l_1 + 3l_2 + 3l_3) + 3l_1(l_1 + 2l_2 + 2l_3)(l_2 + l_3 + e \tan \alpha)]}{6EI} + \frac{2Wl_1}{AG} - \frac{2Pl_1}{AG}$$

ROTATION OF NECK TUBE DUE TO UPPER HEAD DEFLECTION (ROARK, PG 219 & 242, CASE 10)

$$\theta_3 = \frac{M}{\alpha_c E t^3} = \frac{2W(l_1 + l_2) - 2P(l_1 + l_2 + l_3 + e \tan \alpha)}{\alpha_c E t^3}$$

ASSUME DEFLECTION DUE TO UPPER HEAD RADIUS IS SAME AS FOR UPPER HEAD FLAT FLANGE

$$\delta_{3F} = \left[\frac{2W(l_1 + l_2) - P(l_1 + l_2 + l_3 + e \tan \alpha)}{\alpha_c E t^3} \right] (l_1 + l_2 + l_3)$$

WHERE α_c IS FOUND AS FOLLOWS:

$$\frac{r_o}{a} = \frac{\text{Radius of Neck Tube}}{\text{Radius of Support Flange}} = \frac{2.520}{3.740} = 0.674$$

$$\alpha_c = 44 \quad (\text{ASSUME FIXED EDGE})$$

$$t = 0.375 \quad (\text{ROARK, PG 242})$$

$$E = 28 \times 10^6$$

$$\alpha_c E t^3 = 44(28 \times 10^6)(0.375)^3 = 64.9 \times 10^6$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT LETT
		APPV'D	SHEET F-3	SHEETS
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L-1744

$$e = \frac{Pl}{AE}$$

$$\delta_{RR} = \frac{\delta_R}{\cos \alpha} = \frac{P_R l_R}{A_R E_R \cos \alpha} = \frac{P l_R}{E_R A_R \cos^2 \alpha}$$

TOTAL DEFLECTION OF POINT 3

$$\delta_3 = W[m] - P[N]$$

$$\delta_3 = W \left[\frac{l_1^2(2l_1+3l_2+3l_3)+3l_1l_2(l_1+2l_2+2l_3)}{6EI} + \frac{2l_1}{AG} + \frac{2(l_{1N}+l_2)(l_{1N}+l_2+l_3)}{64.9 \times 10^6} \right] - P \left[\frac{2(l_{1N}+l_2+l_3+e \tan \alpha)(l_{1N}+l_2+l_3)}{64.9 \times 10^6} + \frac{2l_1}{AG} + \frac{l_1^2(2l_1+3l_2+3l_3)+3l_1(l_1+2l_2+2l_3)(l_2+l_3+e \tan \alpha)}{6EI} \right]$$

ALSO $\delta_{RR} = \delta_3$

SUBSTITUTING

$$\frac{Pl_R}{E_R A_R \cos^2 \alpha} = W[m] - P[N]$$

$$P = \frac{W[m]}{\frac{l_R}{E_R A_R \cos^2 \alpha} + [N]}$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT LETT
		APP'D	SHEET F-4	SHEETS
UNION CARBIDE CORPORATION LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, N.Y. 14150 L-174-4			APPENDIX F	

$$P_{\alpha} = \frac{W}{\cos \alpha} \left\{ \frac{[M]}{\frac{l_R}{E_R A_R \cos^2 \alpha} + [N]} \right\}$$

$$G = \frac{E}{2(1+\mu)} = \frac{E}{2.64}$$

FINAL EQUATION FORM FOR LOAD CARRIED BY TENSION ROD

$$P_{\alpha} = \frac{W}{\cos \alpha} \left\{ \frac{\frac{l_1^2(2l_1+3l_2+3l_3)+3l_1l_2(l_1+2l_2+2l_3)}{6E_{NT}I_{NT}} + \frac{2l_1}{AG} + \frac{2(l_{1N}+l_2)(l_1+l_2+l_3)}{64.9 \times 10^6}}{\frac{l_R}{E_R A_R \cos^2 \alpha} + \frac{2(l_{1N}+l_2+l_3+\epsilon \tan \alpha)(l_{1N}+l_2+l_3)}{64.9 \times 10^6} + \frac{2l_1}{AG} + \frac{l_1^2(2l_1+3l_2+3l_3)+3l_1(l_1+2l_2+2l_3)(l_2+l_3+\epsilon \tan \alpha)}{6E_{NT}I_{NT}}} \right\}$$

TITLE	REFERENCE	BY DATE	CHK'D	LATEST ALT. LETT.
		APPV'D	SHEET F-5	SHEETS
UNION CARBIDE CORPORATION LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, N. Y. 14150 I-174-4		APPENDIX F		

APPENDIX G

DERIVATION OF SPRING CONSTANT FOR THREE TENSION ROD SUPPORT SYSTEM

Case 1

$$0 < \alpha < 30^\circ$$

$$P_2 = P_3 = 0 \text{ (Compression)}$$

$$P_v = P_1 \cos \alpha_0$$

$$k_s^v = P_v / \delta_v = P_1 \cos \alpha_0 / \delta_v = P_1 \cos^2 \alpha_0 / \delta_1 = k \cos^2 \alpha_0$$

$$\alpha = 0$$

$$k_s = k_{rod}$$

$$\alpha = 30^\circ$$

$$k_s = 0.75 k_{rod}$$

Case 2

$$30^\circ < \alpha < 90^\circ$$

$$P_2 = 0 \text{ (Compression)}$$

LOADS IN TENSION RODS AND SPRING CONSTANT OF THE THREE
TENSION RODS FOR DIFFERENT ROD ORIENTATION

FIGURE G-1

$$P_v = P_1 \cos \alpha + P_3 \sin (\alpha - 30)$$

$$P_1 = k \delta_1 = k \delta_v \cos \alpha$$

$$P_3 = k \delta_3 = k \delta_v \sin (\alpha - 30)$$

Substituting P_1 and P_3 into P_v

$$P_v = k \delta_v \cos^2 \alpha + k \delta_v \sin^2 (\alpha - 30)$$

$$k_s = \frac{P_v}{\delta_v} = \frac{k \delta_v [\cos^2 \alpha + \sin^2 (\alpha - 30)]}{\delta_v}$$

$$k_s = k [\cos^2 \alpha + \sin^2 (\alpha - 30)]$$

α	$\cos \alpha$	$\cos^2 \alpha$	$\sin^2$	$(\alpha - 30)$	$[\cos^2 \alpha + \sin^2 (\alpha - 30)]$
30	.866	.750	0	0	.750
45	.7071	.500	.2588	.0669	.566
60	.500	.250	.5	.250	.5
75	.2588	.0669	.7071	.5	.566
90	0	0	.866	.750	.750

$$.5 k \quad k_s \quad .75 k$$

The spring constant of the three tension rods for different rod orientation is shown on Figure G-1.

The force in the tension rods

$$P \alpha = 1960 \frac{15.73 \cdot 10^{-6}}{\frac{1}{k_s} \left[\frac{.1933}{.0585} 10^{-6} + (.411) 10^{-6} \right] \frac{1}{(.88445)^2} + (28.74) 10^{-6}}$$

For various system spring constant, the resultant force $P \alpha$ in the direction of tension rods were calculated. Results are tabulated in Table G-1. The force in each tension rod can be obtained as follows

$$P = P_1 \cos \alpha_o + P_3 (\sin \alpha_o - 30) = P \alpha \cos \alpha$$

$$P_1 = k \delta_v \cos \alpha_o$$

$$P_3 = k \delta_v \sin (\alpha - 30)$$

$$P = P_v = k \delta_v \cos^2 \alpha_o + k \delta_v \sin^2 (\alpha - 30)$$

$$k \delta_v = \frac{P}{\cos^2 \alpha_o + \sin^2 (\alpha_o - 30)}$$

After solving for $k\delta_y$, the vertical components of the forces in the rods, P_1 and P_3 are calculated. The forces in the rods are

$$P_{1,} = P_1 / \cos \alpha$$

$$P_{3,} = P_3 / \cos \alpha$$

Results of the calculations are tabulated in Table G-1. The variation of the spring constant for three tension rods and loads in the tension rods for different rod orientations as show on Figure G-1.

TABLE G-1

Results of Load Calculations for Neck Tube, Tension Rod for Different Rod Orientations

α_o	k_s	$\frac{1}{k_s} \left[\frac{.1933}{.0585} 10^6 + (.411) 10^6 \right] \frac{1}{(.88445)^2}$	P_{α}	P	W-P	$k_{\sigma v}$	P_1	P_3	$P_1 \alpha$ ($\alpha = 27^\circ 49'$)	$P_3 \alpha$ ($\alpha = 27^\circ 49'$)
0	1 k_r	4.749 10^6	920	813	921	----	813	---	919	----
15	.933 k_r	5.09 10^6	911	805	929	----	833	---	941	----
30	.750 k_r	6.33 10^6	879	777	957	1036	897	0	1014	0
45	.566 k_r	8.39 10^6	830	734	1000	1296	916	335	1035	378
60	.5 k_r	9.498 10^6	806	712	1021	1424	712	712	805	805
75	.566 k_r	8.39 10^6	830	734	1000	1296	335	916	378	1035
90	.75 k_r	6.33 10^6	879	777	957	1036	0	897	0	1014

APPENDIX H

SNAP 21 PROTOTYPE UNIT THERMAL PERFORMANCE TEST--

CALCULATION OF UNIT HEAT LOSS

Measured Test Data: Data Book 12918, pp. 64-66

Hot end neck tube temperature	1285°F
Cold end neck tube temperature	135°F
Steady-state power input (W)	43.42 watts avg.
Steady-state voltage (E)	29.22 volts avg.
Steady-state current (I)	1.50 amps

Instrumentation Constants

Resistance of voltmeter (R_v)	3000 Ω
Resistance of wattmeter (R_w)	409.5 Ω /volt
Resistance of power lead to heaters (R_L)	.081 Ω

$$\text{Corrected input power} = W - \left[\frac{E^2}{R_w} + \frac{E^2}{R_v} \right] - I^2 R_L$$

$$= 43.42 - \left[\frac{853.8}{11966} + \frac{853.8}{3000} \right] - 2.25(.081)$$

$$= 42.88 \text{ watts}$$

To determine the heat loss of the unit, which includes the neck tube loss and insulation loss, the calculated loss through the following components must be subtracted from the corrected input power.

1. Neck tube insulation loss
2. Heater wire and insulation loss
3. Thermocouple wire and insulation loss

1. Neck Tube Insulation Loss

The neck tube was filled with block Min-K 2000 insulation. Powdered Min-K 2000 insulation was used to fill around the circumference of the neck tube and two 5/8-inch dia. holes in the block insulation for the passage of the heater and thermocouple wires.

Insulation thickness	2.65 inches
Insulation diameter	4.900 inches
Insulation area	18.75 sq. in.

Area of 2-5/8 in. dia. holes =	.59 sq. in.
Area of circumference gap 1/16 in. wide =	.96 sq. in.
Area of block insulation =	18.75 - .59 - .96 = 17.20 sq. in.
Area of powdered insulation =	1.55 sq. in.

$$\text{Mean temperature} = \frac{1285 + 135}{2} = 710^{\circ}\text{F}$$

$$\Delta T = 1285 - 135 = 1150^{\circ}\text{F}$$

$$\text{Conductivity of block insulation} = .26 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-}^{\circ}\text{F}}$$

$$\text{Conductivity of powdered insulation} = .51 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-}^{\circ}\text{F}}$$

$$\begin{aligned} \text{Heat loss} &= \frac{\text{Block } KA \Delta T}{L} + \frac{\text{Powder } KA \Delta T}{L} \\ &= .26 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-}^{\circ}\text{F}} \times \frac{17.20 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2} \times \frac{1150^{\circ}\text{F}}{2.65 \text{ in}} \\ &\quad + .51 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-}^{\circ}\text{F}} \times \frac{1.55 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2} \times \frac{1150^{\circ}\text{F}}{2.65 \text{ in}} \\ &= 13.49 \text{ Btu/hr} + 2.38 \text{ Btu/hr} = 15.87 \text{ Btu/hr.} \\ &= \frac{15.87 \text{ Btu}}{3.41 \text{ Hr}} \text{ Watt} \end{aligned}$$

$$\begin{aligned} \text{Neck tube} \\ \text{ins. loss} &= 4.66 \text{ watts} \end{aligned}$$

2. Heater Wire and Insulation Loss

Eight heater wires penetrated the neck tube insulation. Four wires had 42 strands and four wires had 7 strands each. Consider first the heat loss through the 42 strand wires.

Heater wires - 42 strands of 201 nickel - 30 ga. - .010 in. dia.
Covering the stranded wires was asbestos with an outside diameter of .140 in.

Stranded wire length = 2.31 in. as the stainless steel wire connector extended .34 in. above the heater block.

This connector was .156 in. O.D. and .090 in. I.D.

$$\text{Area of one stranded wire} = \frac{\pi}{4} (.010 \text{ in.})^2 (42) = .0033 \text{ in}^2$$

$$\text{Area of asbestos} = \frac{\pi}{4} (.140 \text{ in.})^2 - .0033 \text{ in}^2 = .0121 \text{ in}^2$$

$$\text{Area of solid heater wire} = \frac{\pi}{4} (.090 \text{ in.})^2 = .00631 \text{ in}^2$$

$$\text{Area of stainless connector} = \frac{\pi}{4} (.156 \text{ in})^2 - .00631 = .0119 \text{ in}^2$$

$$\text{Conductivity of 201 nickel (135°F - 1285°F)} = 432 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-°F}}$$

$$\text{Conductivity of 201 nickel @ 1285} = 428 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-°F}}$$

$$\text{Conductivity of asbestos} = .12 \frac{\text{Btu}}{\text{Hr-ft-°F}}$$

$$\text{Conductivity of stainless} = 10 \frac{\text{Btu}}{\text{Hr-ft-°F}}$$

First determine the temperature at the end of the stainless connector. The heat loss through the stranded wire and insulation is equal to the heat loss through the connector and heater pin wire.

$$\begin{array}{ccccc} \text{Stranded} & & \text{Asbestos} & & \text{Pin} \\ \text{Wire} & & & & \text{Wire} & \text{Connector} \\ \left(\frac{KA}{L} + \frac{KA}{L} \right) \Delta T_1 & = & \left(\frac{KA}{L} + \frac{KA}{L} \right) \Delta T_2 \end{array}$$

$$\left[432 \frac{\text{Btu-in}}{\text{Hr-ft}^2\text{-°F}} \times \frac{.0033 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2(2.31 \text{ in})} + .12 \frac{\text{Btu}}{\text{Hr-ft}^2\text{-°F}} \times \frac{.0121 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2} \times \frac{12 \text{ in}}{2.31 \text{ in}(\text{ft})} \right] \Delta T_1$$

$$= \left[\frac{428 \text{ Btu-in}}{\text{Hr-ft}^2\text{-°F}} \times \frac{.00631 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2(.34 \text{ in})} + \frac{10 \text{ Btu}}{\text{Hr-ft-°F}} \times \frac{.0119 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2} \times \frac{12 \text{ in}}{.344 \text{ in}(\text{ft})} \right] \Delta T_2$$

$$(.00428 + .0000525) \Delta T_1 = (.0545 + .0288) \Delta T_2$$

$$.00433 \Delta T_1 = .0833 \Delta T_2$$

$$\Delta T_1 = 19.3 \Delta T_2$$

$$\Delta T_1 + \Delta T_2 = 1150^\circ\text{F (test data)}$$

$$1150 - \Delta T_2 = 19.3 \Delta T_2$$

$$\Delta T_2 = 56.7^\circ\text{F}$$

$$\Delta T_1 = 1093.3^\circ\text{F}$$

The heat loss for one heater wire is

$$.00433 \times 1093.3 = 4.73 \text{ Btu/hr.}$$

The heat loss for four 42-strand wires is

$$\frac{4.73 \times 4}{3.41} = 5.55 \text{ watts}$$

Next consider the heat loss through the four 7-strand wires.

Heater wires - 7 strands of 201 nickel - 30 ga. - .010 in. dia.
 Covering the stranded wire was asbestos with an
 outside diameter of .0937 in. stranded wire.
 Length was 2.65 inches.

$$\text{Area of one stranded wire} = \frac{\pi}{4} (.010 \text{ in})^2 (7) = .00055 \text{ in}^2$$

$$\text{Area of asbestos} = \frac{\pi}{4} (.0937 \text{ in})^2 - .00055 \text{ in}^2 = .00603 \text{ in}^2$$

$$\begin{aligned} \text{Heat loss} &= \left(\frac{KA}{L} \right)_{\text{Stranded Wire}} + \left(\frac{KA}{L} \right)_{\text{Asbestos}} \Delta T \\ \text{one wire} &= \left(\frac{.432}{2.65} \times \frac{.00055}{144} + \frac{.12}{2.65} \times \frac{.00603}{144} \times 12 \right) 1150 \\ &= (.000623 + .0000228) 1150 \\ &= .744 \text{ Btu/hr.} \end{aligned}$$

$$\begin{aligned} \text{Heat loss} &= \frac{.744 \times 4}{3.41} = .87 \text{ watt} \\ 4 \text{ wires} & \end{aligned}$$

Total heat loss for the eight heater wires used is
 5.55 watts + .87 watt = 6.42 watts.

3. Thermocouple Wire and Insulation Loss

Two Chromel-Alumel thermocouples were used to measure the hot end neck tube temperature. The wires were each 20 ga. - .032 in. dia. and had a thermal length of 2.65 in. Each wire was insulated with ceramic beads .108 in. O.D. x .055 in. I.D.

$$\text{Area of thermocouple wire} = \frac{\pi}{4} (.032 \text{ in})^2 = .000804 \text{ in}^2$$

$$\text{Area of bead insulation} = \frac{\pi}{4} [(.108 \text{ in})^2 - (.055 \text{ in})^2] = .00677 \text{ in}^2$$

$$\text{Conductivity of Chromel} = 15.2 \text{ Btu/hr-ft-}^\circ\text{F}$$

$$\text{Conductivity of Alumel} = 19.8 \text{ Btu/hr-ft-}^\circ\text{F}$$

$$\text{Conductivity of ceramic} = 1.02 \text{ Btu/hr-ft-}^\circ\text{F}$$

$$\begin{aligned} \text{Heat loss} &= \frac{KA \Delta T}{L} = \frac{15.2 \text{ Btu}}{\text{Hr-ft-}^\circ\text{F}} \times \frac{.000804 \text{ in}^2 (\text{ft}^2)}{144 \text{ in}^2} \frac{1150^\circ\text{F}}{2.65 \text{ in}} \times \frac{12 \text{ in.}}{\text{ft.}} \\ 2 \text{ Chromel} & \\ \text{Wires} & \\ &= .884 \text{ Btu/hr.} \end{aligned}$$

$$\begin{aligned}
 \text{Heat loss} &= \frac{KA \Delta T}{L} = \frac{19.8 \text{ Btu}}{\text{Hr-ft-}^\circ\text{F}} \times \frac{.00804 \text{ in}^2(\text{ft}^2)}{144 \text{ in}^2} \times \frac{1150^\circ\text{F}}{2.65 \text{ in}} \times \frac{12 \text{ in.}}{\text{ft.}} \\
 \text{2 Alumel wires} &= 1.052 \text{ Btu/hr.}
 \end{aligned}$$

For the ceramic bead heat loss, the conductivity of the ceramic was divided by 2 because of the surface contact resistance.

$$\begin{aligned}
 \text{Heat loss} &= \frac{KA \Delta T}{L} = \frac{.60 \text{ Btu}}{\text{Hr-ft-}^\circ\text{F}} \times \frac{.00677 \text{ in}^2(\text{ft}^2)}{144 \text{ in.}} \times \frac{1150^\circ\text{F}}{2.65 \text{ in}} \times \frac{12 \text{ in}}{\text{ft}} \times 4 \\
 \text{4 ceramic beads} &= .59 \text{ Btu/hr.}
 \end{aligned}$$

Total heat loss through thermocouples is

$$\frac{.884 + 1.052 + .59}{3.41} = .74 \text{ watt}$$

The unit heat loss is therefore equal to corrected power input - calculated losses: 42.88 watts - 4.66 watts - 6.42 watts - .74 watt.

Unit heat loss is therefore 31.06 watts.

APPENDIX I

THERMAL PERFORMANCE TEST HEAT LOSS CALCULATIONS

The subtractible heat losses during a thermal performance test include the heat losses through elements of the test system which are not a part of the HTVIS unit and therefore not chargeable to the unit heat loss. These subtractible losses result from the inner liner Min-K insulation, the heater wire power leads, and the thermocouple wires. In addition to these losses, other subtractible heat losses can be present depending on the geometry of the Min-K system. For example, if the Min-K temperature adjacent to the neck tube is higher than the neck tube temperature, there will be a lateral heat flow from the Min-K to the inner liner which provides a non-chargeable heat flow to the HTVIS unit. Conversely, if the heat flow is from the neck tube to the Min-K this flow is an additive and must be added to HTVIS unit heat loss.

To determine the subtractible heat losses, a two dimensional computer analysis was performed on the system comprised of the Min-K insulation, heater wires, neck tube, and multi-layer insulation. The following paragraphs discuss the two dimensional analyses.

Due to heterogeneous nature of the volume above the heater block and the anisotropic nature of the multi-layer insulation, there is a considerable potential for lateral heat flow in the thermal tests. For this reasons, a one-dimensional heat flow analysis is useful only as a rough approximation. The object of this study was to produce a two dimensional numerical analysis that would more accurately account for the subtractible heat losses out the center plug during a thermal test.

Some of the types of test geometries investigated appear in Figures I-1, I-2 and I-3. Also, the case of no ring and no disk (emitter plate only) was investigated since this is the configuration planned for future tests. Due to the presence of the heater wires at discrete angular positions, this is really a three dimensional problem but can be approximated by considering two characteristic sectors: one containing a wire and one without a wire. The net heat loss is then the addition of the losses of each type of sector, weighted by the areas that occur in the test units. Figure I-4 shows the array of nodal points for a sector containing a wire. For the sector not containing a wire, the conductances to the nodal points at the wire position involve the conductivity of solid Min-K. There are, in general, 198 unknown temperatures. Of course, when the emitter plate and/or disk are present, some of the temperatures become known.

To solve the problem, heat balances were made around each grind in cylindrical coordinates. Only radiation transfer was considered from the multi-layer insulation to the neck tube. The extreme left row of temperatures in Figure I-4 was initially fixed at the undisturbed insulation profile. The system of 198 equations can be written as:

$$(A) (T) = (B) \quad (1)$$

where

$$\begin{aligned} (A) &= 198 \times 198 \text{ temperature coefficient matrix} \\ &\quad \text{(from conductances)} \\ (T) &= 198 \text{ column temperature vector} \\ (B) &= 198 \text{ column constant vector} \end{aligned}$$

The solution of (1) is:

$$(T) = (A^{-1}) (B) \quad (2)$$

where

$$(A^{-1}) = \text{inverse of } (A)$$

The solution was obtained on the IBM 360 computer. Iteration was used to include the effect of temperature dependent thermal conductivities.

After examination of initial results from the computer program, it was evident that the temperatures could not be fixed at the undisturbed profile in the multi-layer insulation. In fact, the profile is disturbed everywhere in the multi-layer insulation. However, this disturbed insulation profile can be determined by essentially using the above program twice. Note from the insert in Figure I-4 that the sections AA to BB and CC to BB are both mathematically similar since both sections have an adiabatic axis of symmetry on one side and common unknown temperatures on the other side (plane BB). Both sections also have fixed temperatures on the hot and cold boundaries. The conductances ($kA/\Delta x$) of these two sections include the geometrical and conductivity differences within these two sections. The solution then proceeds as follows. The temperatures at the left on Figure I-4 (denoted SI_i) are first assumed. The temperature field in the top of the unit (Figure I-4) is then determined by equation (2). The lateral heat flows at the left side of Figure I-4 are then computed. The temperature field in the multi-layer insulation is then determined and the lateral heat flows calculated. If the lateral flows at every position are not the same for the two solutions, then the SI temperatures (see Figure I-4) are adjusted. The preceding process is continued until the lateral flows are calculated the same from the two sections of the unit. If the SI profile distortion had been anticipated, then a more efficient solution could be obtained by calculating the temperature field for the entire unit at the start. Iteration for the SI temperatures would then have been unnecessary. However, with the solution to the top plug completed, it was more expedient to solve the complete problem with the method presented above.

The temperature distributions from the computer are presented in Figures I-5 to I-10. The arrangement of the temperatures (in degrees R) corresponds to the arrangement of the X's in Figure I-4.

In order to determine the subtractible heat loss from the total heat input, it is convenient to consider a plane level with the top of the disk (or emitter or heater block, depending on the case). At this level, the heat entering the Min-K and flowing in the wire can be determined. In addition, The heat that flows from the Min-K and wire to the neck tube below the level of the top of the disk (or emitter) must be included in the subtractibles since this is heat that originated in the plug and should not be counted as part of the vacuum insulation system heat loss. A summary of the subtractibles appears in Table I-1. The thermocouple loss was taken as 0.75 watts from the one dimensional analysis which is sufficient in light of the magnitude of the quantity.

It should be noted that the subtractibles are higher for units 10-D1 retest through 10-D4 than on 10-D1 because of the addition of a ring and a disk in the Min-K system to simulate the 3M thermoelectric generator and thus achieve a corresponding temperature profile in the neck tube during the dynamic testing.

The subtractibles were also calculated using a one dimensional analysis (vertical heat flow) to determine the heat loss through the Min-K, heater wires, and thermocouple wires. This analysis was performed in the same manner as presented in Appendix H. The subtractibles as calculated for the one dimensional analysis are also presented in Table I-1.

FIGURE I-1 - SCHEMATIC OF INNER LINER INSULATION
SYSTEM (B10-D1 THERMAL TEST)

FIGURE I-2 - SCHEMATIC OF INNER LINER INSULATION

SYSTEM (B10-D1 RETEST AND B10-D2 THERMAL TEST)

FIGURE I-3 - SCHEMATIC OF INNER LINER INSULATION SYSTEM
B10-D3 THERMAL TEST AND B10-D4 THERMAL TEST

FIGURE I-4
NODAL POINTS
FOR TWO-
DIMENSIONAL
HEAT LOSS
ANALYSIS

FIGURE I-5

CASE 1 UNIT 10 - D1

WIRE SECTOR

782.06	782.13	782.19	782.26	782.32	782.39	782.45	782.51	782.56	782.61	782.66	782.70	782.73	782.76	782.78	782.80	782.81	782.82
960.80	961.58	962.31	962.99	963.62	964.21	964.75	965.24	965.69	966.09	966.44	966.75	967.01	967.22	967.38	967.50	967.57	967.60
1103.31	1104.55	1105.71	1106.79	1107.78	1108.69	1109.52	1110.27	1110.95	1111.55	1112.08	1112.53	1112.92	1113.23	1113.47	1113.65	1113.75	1113.79
1213.85	1214.65	1215.41	1216.12	1216.78	1217.39	1217.95	1218.46	1218.92	1219.34	1219.70	1220.01	1220.28	1220.50	1220.67	1220.79	1220.86	1220.89
1296.43	1296.86	1297.27	1297.67	1298.04	1298.40	1298.73	1299.04	1299.33	1299.59	1299.82	1300.02	1300.19	1300.33	1300.44	1300.52	1300.57	1300.58
1379.92	1380.79	1381.61	1382.37	1383.08	1383.73	1384.33	1384.87	1385.37	1385.80	1386.19	1386.53	1386.81	1387.04	1387.22	1387.35	1387.43	1387.45
1467.93	1468.84	1469.72	1470.56	1471.36	1472.10	1472.80	1473.45	1474.04	1474.58	1475.05	1475.47	1475.83	1476.12	1476.35	1476.51	1476.61	1476.64
1548.89	1550.74	1552.50	1554.18	1555.76	1557.23	1558.59	1559.82	1560.95	1561.95	1562.83	1563.60	1564.24	1564.77	1565.18	1565.47	1565.65	1565.71
1590.49	1594.38	1597.76	1600.71	1603.28	1605.51	1607.45	1609.14	1610.59	1611.83	1612.89	1613.77	1614.50	1615.08	1615.53	1615.94	1616.03	1616.09
1646.25	1650.72	1654.52	1657.73	1660.43	1662.71	1664.61	1666.21	1667.55	1668.66	1669.58	1670.33	1670.94	1671.42	1671.77	1672.02	1672.17	1672.22
1710.40	1714.19	1716.91	1718.90	1720.38	1721.49	1722.35	1723.02	1723.54	1723.96	1724.29	1724.56	1724.76	1724.92	1725.04	1725.13	1725.17	1725.19
				NECK					WIRE								

NO WIRE SECTOR

791.92	791.85	791.80	791.76	783.55	779.41	774.54	770.48	764.52	758.15	753.68	750.26	747.51	745.25	743.65	742.60	742.02	741.17
974.86	974.71	974.54	974.36	939.23	935.55	928.47	922.25	912.80	902.13	894.40	888.38	883.47	879.40	876.53	874.62	873.55	873.17
1121.71	1121.40	1121.05	1120.68	1076.70	1073.33	1065.58	1058.57	1047.63	1034.66	1024.97	1017.28	1010.93	1005.61	1001.83	999.31	997.90	997.51
1232.71	1232.40	1232.06	1231.69	1185.18	1182.03	1174.18	1167.00	1155.71	1141.97	1131.51	1123.10	1116.08	1110.16	1105.92	1103.11	1101.52	1101.14
1305.78	1305.55	1305.29	1305.01	1273.03	1270.25	1262.75	1255.78	1244.67	1230.88	1220.25	1211.64	1204.39	1198.26	1193.86	1190.92	1189.26	1188.87
1388.74	1388.47	1388.16	1387.83	1356.56	1354.03	1346.85	1340.16	1329.47	1316.12	1305.77	1297.35	1290.24	1284.21	1279.87	1276.56	1275.32	1274.92
1471.65	1471.27	1470.85	1470.39	1434.03	1431.71	1424.94	1418.63	1408.51	1395.96	1386.27	1378.38	1371.73	1366.07	1361.99	1359.26	1357.72	1357.35
1561.20	1560.36	1559.47	1558.52	1498.24	1496.32	1490.36	1484.61	1474.90	1463.47	1454.70	1447.58	1441.59	1436.50	1432.81	1430.35	1428.96	1428.62
1589.62	1587.99	1586.08	1583.84	1561.47	1559.85	1555.00	1550.45	1543.36	1533.85	1526.39	1520.32	1515.23	1510.94	1507.77	1505.68	1504.51	1504.24
1660.08	1658.84	1657.26	1655.27	1635.16	1633.60	1628.99	1624.80	1618.31	1610.78	1605.27	1600.94	1597.38	1594.41	1592.28	1590.86	1590.06	1589.87
1708.81	1707.79	1706.54	1706.28	1702.77	1700.37	1694.88	1690.85	1685.54	1680.70	1677.57	1675.27	1673.44	1671.93	1670.87	1670.17	1669.77	1669.68
				NECK													

FIGURE I-6

CASE 2 UNIT 10 - D1 RETEST AFTER DYN.

WIRE SECTOR

																	RING	
781.91	781.84	781.77	781.72	766.73	733.03	732.93	732.93	700.33	609.34	609.30	609.70	642.26	676.08	702.06	719.83	730.67	737.50	
969.79	969.57	969.32	969.06	915.30	868.74	868.57	868.53	806.04	613.25	612.98	613.05	688.85	760.05	810.76	843.80	863.26	873.02	
1111.67	1111.32	1110.93	1110.50	1057.84	1013.47	1013.28	1013.20	928.36	616.72	616.15	616.21	762.87	875.04	945.55	988.55	1013.06	1024.66	
1237.65	1237.27	1236.86	1236.41	1180.49	1150.68	1150.55	1150.43	1063.14	619.47	618.07	618.50	891.04	1024.71	1097.84	1140.49	1164.59	1176.65	
1408.78	1408.55	1408.29	1408.01	1383.24	1358.14	1358.22	1358.21	1304.25	1336.32	1311.16	1314.96	1350.64	1394.72	1430.96	1453.86	1467.17	1472.41	
1491.80	1491.58	1491.34	1491.08	1471.42	1522.59	1520.71	1523.08	1559.82	1565.01	1561.13	1563.40	1575.00	1591.19	1602.82	1612.01	1617.69	1619.86	
1571.52	1571.02	1570.47	1569.88	1534.13	1563.94	1564.25	1564.91	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1614.68	1613.19	1611.51	1609.60	1591.81	1607.00	1607.28	1607.76	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1670.42	1669.60	1668.51	1667.17	1653.17	1656.17	1656.32	1656.62	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1709.40	1708.94	1708.62	1708.45	1708.50	1701.37	1701.36	1701.40	1735.56	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
NECK				WIRE				EMITTER PLATE										

NO WIRE SECTOR

																	RING	
781.94	781.89	781.85	781.83	777.85	765.29	743.46	720.82	680.29	608.76	608.75	609.11	641.73	675.58	701.60	719.40	730.27	737.09	
969.85	969.68	969.50	969.30	930.02	912.65	973.50	832.00	755.80	612.14	611.96	612.05	687.84	759.08	809.89	843.02	862.53	872.30	
1116.69	1116.36	1116.00	1115.60	1068.34	1049.19	999.61	945.35	841.36	615.17	614.76	614.88	761.33	873.60	944.32	987.49	1012.12	1023.75	
1227.73	1227.43	1227.11	1226.76	1181.53	1165.11	1118.58	1065.56	956.21	617.60	616.52	617.04	888.76	1022.84	1096.40	1139.34	1163.60	1175.72	
1310.76	1310.51	1310.23	1309.92	1275.74	1266.19	1237.93	1207.01	1147.79	1025.10	995.46	1011.77	1109.79	1196.05	1253.22	1288.45	1308.73	1318.91	
1398.73	1398.45	1398.13	1397.79	1366.44	1365.30	1342.30	1358.39	1348.16	1311.97	1298.53	1308.41	1347.20	1392.83	1429.77	1453.01	1466.49	1471.81	
1481.70	1481.37	1481.01	1480.61	1450.03	1458.24	1486.13	1513.97	1551.44	1556.15	1555.34	1560.06	1573.18	1590.20	1602.23	1611.60	1617.36	1619.57	
1571.20	1570.56	1569.78	1568.94	1517.47	1534.55	1590.97	1661.11	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1604.79	1603.37	1601.71	1599.78	1581.06	1596.13	1644.74	1696.65	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1670.13	1669.02	1667.64	1665.94	1649.31	1658.02	1686.40	1716.65	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
1709.39	1708.90	1708.57	1708.39	1708.44	1710.04	1716.90	1724.24	1738.30	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	
NECK				WIRE				EMITTER PLATE										

FIGURE I-7

CASE 3 UNIT 10 - D2

WIRE SECTOR

RING																	
816.89	816.80	816.72	816.64	799.00	766.78	766.68	766.68	735.77	646.18	646.14	646.52	677.79	710.28	735.26	752.34	762.75	769.04
994.78	994.55	994.30	994.02	943.24	898.92	898.75	898.71	839.06	649.95	649.69	649.75	722.58	791.08	839.91	871.74	890.46	899.65
1131.67	1131.31	1130.91	1130.48	1080.98	1039.68	1039.49	1039.42	957.83	653.29	652.73	652.79	793.80	901.89	969.93	1011.44	1035.08	1046.09
1242.73	1242.44	1242.12	1241.77	1198.62	1173.05	1172.95	1172.81	1087.89	655.93	654.58	654.98	917.35	1046.42	1117.14	1158.39	1181.67	1193.15
1330.77	1330.51	1330.23	1329.93	1297.87	1290.98	1290.96	1290.87	1249.46	1078.49	1031.81	1040.41	1132.24	1214.32	1269.05	1302.81	1322.24	1331.85
1418.78	1418.53	1418.27	1417.98	1392.86	1410.04	1410.12	1410.12	1405.93	1348.96	1324.13	1327.58	1362.07	1404.80	1440.09	1462.30	1475.16	1480.04
1501.75	1501.49	1501.19	1500.86	1477.37	1529.77	1527.96	1530.26	1565.69	1570.51	1566.58	1568.68	1579.87	1595.55	1606.73	1615.65	1621.15	1623.22
1581.42	1580.92	1580.17	1579.48	1538.23	1569.64	1569.95	1570.60	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1614.94	1613.69	1612.24	1610.54	1594.45	1611.23	1611.51	1611.98	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1675.19	1674.13	1672.79	1671.14	1655.03	1658.84	1658.99	1659.28	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1714.08	1713.30	1712.65	1712.15	1709.60	1702.68	1702.67	1702.71	1735.84	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				WIRE				EMITTER PLATE									

NO WIRE SECTOR

RING																	
911.93	811.88	811.84	811.81	808.05	796.19	775.21	753.42	714.41	645.60	645.58	645.93	677.26	709.78	734.80	751.91	762.34	768.63
994.83	994.65	994.46	994.24	955.19	938.77	900.87	860.75	787.18	648.84	648.66	648.75	721.56	790.11	839.03	870.95	889.73	898.92
1136.68	1136.34	1135.96	1135.55	1089.12	1070.84	1022.76	970.21	869.66	651.73	651.34	651.46	792.25	900.45	968.70	1010.38	1034.14	1045.18
1247.69	1247.36	1247.01	1246.61	1198.73	1182.95	1137.73	1086.30	980.42	654.05	653.03	653.53	915.05	1044.54	1115.69	1157.23	1180.68	1192.21
1330.71	1330.40	1330.06	1329.68	1289.84	1280.60	1253.07	1223.02	1165.54	1046.74	1018.06	1033.81	1128.60	1212.12	1267.57	1301.71	1321.33	1331.01
1418.64	1418.26	1417.84	1417.39	1377.29	1376.16	1373.22	1369.44	1359.53	1324.44	1311.41	1320.99	1358.61	1402.89	1438.89	1461.45	1474.48	1479.43
1501.55	1501.06	1500.53	1499.95	1457.55	1465.56	1492.88	1520.15	1556.77	1561.46	1560.71	1565.30	1578.03	1594.55	1606.13	1615.23	1620.82	1622.93
1576.30	1575.56	1574.77	1573.92	1521.90	1538.72	1594.14	1662.89	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1609.58	1607.95	1606.08	1603.91	1583.32	1598.22	1646.20	1697.37	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1670.20	1669.16	1667.84	1666.20	1650.00	1658.68	1686.90	1716.90	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1709.40	1708.94	1708.62	1708.46	1708.66	1710.26	1717.09	1724.39	1738.34	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				EMITTER PLATE													

FIGURE I-8

CASE 4 UNIT 10 - D3

WIRE SECTOR

										RING									
801.92	801.85	801.79	801.74	799.64	759.39	759.29	759.29	728.05	638.22	638.18	638.57	670.77	704.59	731.53	752.15	770.93	776.11		
984.80	984.58	984.35	984.29	935.37	892.23	892.07	892.03	831.83	642.02	641.76	641.82	716.46	787.34	839.51	877.12	908.37	915.27		
1121.70	1121.37	1121.02	1120.62	1074.42	1033.89	1033.71	1033.63	951.40	645.39	644.84	644.89	788.55	899.65	971.67	1020.02	1058.60	1065.95		
1237.73	1237.45	1237.14	1236.79	1194.02	1158.24	1158.13	1158.00	1082.58	648.06	646.70	647.11	913.09	1045.13	1119.64	1167.51	1206.01	1212.75		
1325.78	1325.55	1325.29	1325.01	1295.14	1287.51	1287.48	1287.40	1245.76	1073.94	1072.13	1036.10	129.47	1213.70	1271.50	1310.73	1342.84	1348.06		
1413.82	1413.62	1413.40	1413.16	1392.04	1407.80	1407.89	1407.88	1403.66	1346.41	1321.56	1325.29	1360.53	1404.58	1441.88	1467.55	1487.37	1490.14		
1501.75	1501.49	1501.20	1500.98	1478.18	1528.62	1526.79	1529.10	1544.65	1569.45	1565.54	1567.77	1579.26	1595.50	1607.55	1617.97	1626.46	1627.69		
1575.52	1576.00	1575.45	1574.86	1539.16	1568.78	1569.09	1569.73	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1614.89	1613.51	1612.16	1610.51	1595.14	1610.64	1610.91	1611.38	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1666.07	1665.86	1665.35	1664.51	1654.85	1658.47	1658.62	1658.92	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1713.89	1712.97	1712.25	1711.73	1709.41	1702.50	1702.49	1702.53	1735.80	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
NECK										WIRE									
										EMITTER PLATE									

NO WIRE SECTOR

										RING									
901.94	901.90	901.86	901.84	800.14	788.27	767.33	745.57	706.56	637.63	637.62	637.97	670.23	704.09	731.07	751.72	770.51	775.69		
984.85	984.68	984.51	984.31	947.64	931.15	893.32	853.21	779.59	640.90	640.73	640.81	715.44	786.36	838.63	876.34	907.65	914.56		
1126.71	1126.40	1126.06	1125.68	1082.29	1063.94	1015.89	963.31	862.59	643.82	643.44	643.55	786.99	898.20	970.45	1018.99	1057.71	1065.08		
1242.69	1242.35	1241.98	1241.58	1192.87	1177.03	1131.83	1080.35	974.25	646.17	645.14	645.64	910.77	1043.24	1118.20	1166.39	1205.11	1211.89		
1315.80	1315.57	1315.33	1315.05	1284.72	1275.54	1248.18	1218.24	1160.82	1041.76	1013.18	1029.41	1125.79	1211.49	1270.03	1309.66	1342.04	1347.30		
1408.70	1408.37	1408.02	1407.63	1373.50	1372.43	1369.69	1366.08	1356.42	1321.47	1308.63	1318.59	1357.03	1402.65	1440.68	1466.73	1486.79	1489.60		
1496.70	1486.37	1486.00	1485.60	1455.07	1463.19	1490.78	1518.31	1555.30	1560.18	1559.55	1564.32	1577.39	1594.49	1606.95	1617.57	1626.18	1627.43		
1571.35	1570.66	1569.92	1569.13	1520.91	1537.76	1593.36	1662.43	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1604.92	1603.64	1602.14	1600.37	1583.24	1598.11	1646.08	1697.30	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1670.20	1669.16	1667.86	1666.26	1650.44	1659.04	1687.09	1716.98	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
1709.41	1708.96	1708.66	1708.51	1708.84	1710.43	1717.21	1724.48	1738.37	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00		
NECK										EMITTER PLATE									

FIGURE I-9

CASE 5 UNIT 10 - D4

WIRE SECTOR

RING																	
801.92	801.84	801.78	801.73	790.66	761.13	761.03	761.03	730.13	641.19	641.15	641.54	673.63	707.34	734.18	754.73	773.42	778.57
969.86	969.71	969.54	969.36	932.94	892.65	892.50	892.46	832.87	644.96	644.71	644.77	719.15	789.80	841.81	879.29	910.43	917.28
1116.70	1116.38	1116.03	1115.65	1070.30	1032.98	1032.81	1032.74	951.29	648.31	647.76	647.82	790.99	901.74	973.56	1021.77	1060.22	1067.53
1222.79	1222.57	1222.33	1222.07	1188.08	1166.21	1166.12	1165.99	1081.47	650.96	649.61	650.02	915.11	1046.78	1121.11	1168.85	1207.23	1213.94
1300.92	1300.83	1300.73	1300.61	1287.64	1284.86	1284.85	1284.77	1243.89	1074.24	1028.27	1037.55	1130.79	1214.88	1272.57	1311.70	1343.72	1348.92
1388.95	1388.89	1388.83	1388.77	1383.35	1404.87	1404.98	1404.98	1401.57	1345.89	1321.83	1325.92	1361.26	1405.29	1442.54	1468.16	1487.91	1490.68
1457.12	1457.25	1457.39	1457.54	1468.29	1525.83	1524.03	1526.35	1563.05	1568.94	1565.51	1567.96	1579.53	1595.79	1607.83	1618.22	1626.70	1627.92
1525.05	1525.10	1525.16	1525.22	1529.37	1566.22	1566.55	1567.22	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1586.01	1586.03	1586.05	1586.08	1587.34	1608.45	1608.74	1609.23	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1650.99	1650.98	1650.97	1650.96	1650.13	1656.96	1657.12	1657.43	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1714.86	1714.71	1714.56	1714.39	1708.05	1701.75	1701.75	1701.79	1735.65	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				WIRE				EMITTER PLATE									

NO WIRE SECTOR

RING																	
796.95	796.90	796.88	796.84	796.24	784.86	764.88	744.06	706.71	640.57	640.55	640.90	673.05	706.79	733.68	754.26	772.96	778.10
974.85	974.70	974.53	974.34	939.43	922.52	886.29	847.83	777.20	643.77	643.61	643.70	718.05	788.74	840.85	878.44	909.64	916.51
1111.73	1111.44	1111.12	1110.77	1068.72	1051.01	1005.04	954.65	857.93	646.64	646.27	646.39	789.30	900.16	972.22	1020.64	1059.24	1066.58
1217.75	1217.49	1217.20	1216.89	1176.06	1160.95	1118.22	1069.27	967.75	648.95	647.95	648.46	912.58	1044.71	1110.52	1167.62	1206.24	1212.99
1290.84	1290.64	1290.47	1290.26	1265.76	1257.42	1232.78	1205.52	1152.58	1039.29	1013.00	1030.19	1126.74	1212.43	1270.94	1310.53	1342.84	1348.08
1368.87	1368.74	1368.60	1368.43	1352.83	1352.92	1353.55	1353.05	1348.19	1317.91	1307.38	1318.45	1357.36	1403.15	1441.21	1467.26	1487.28	1490.08
1441.94	1441.87	1441.80	1441.71	1434.21	1443.88	1475.82	1507.31	1549.68	1557.83	1558.61	1564.06	1577.45	1594.67	1607.16	1617.70	1626.30	1627.64
1514.84	1514.69	1514.50	1514.31	1501.56	1520.47	1581.99	1656.90	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1575.88	1575.75	1575.60	1575.45	1568.01	1584.52	1637.34	1693.25	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1650.83	1650.65	1650.46	1650.25	1641.03	1650.60	1681.57	1714.36	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1709.92	1709.84	1709.75	1709.65	1705.69	1707.38	1714.74	1722.64	1737.78	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				EMITTER PLATE													

FIGURE I-10

CASE 6 QUAL. AND DLVY. UNITS

WIRE SECTOR

786.94	786.89	786.85	786.82	780.51	754.35	754.27	754.30	763.72	769.55	773.47	776.35	778.62	780.45	781.74	782.59	783.07	783.19
959.83	959.64	959.44	959.22	913.78	877.53	877.41	877.44	888.83	898.95	905.63	910.58	914.52	917.78	920.11	921.67	922.55	922.77
1096.68	1096.33	1095.94	1095.52	1041.66	1006.70	1006.56	1006.59	1017.08	1028.00	1035.53	1041.40	1046.32	1050.53	1053.61	1055.71	1056.91	1057.20
1207.68	1207.33	1206.96	1206.55	1150.82	1125.94	1125.83	1125.85	1133.55	1141.80	1148.53	1154.45	1159.77	1164.52	1168.05	1170.50	1171.91	1172.25
1280.74	1280.50	1280.22	1279.91	1242.89	1233.05	1233.02	1233.01	1236.23	1240.91	1246.74	1252.74	1258.41	1263.53	1267.36	1270.08	1271.63	1272.00
1353.84	1353.66	1353.47	1353.25	1331.51	1340.01	1340.05	1340.05	1337.27	1338.84	1345.02	1351.85	1358.16	1363.62	1367.61	1370.64	1372.26	1372.64
1426.87	1426.73	1426.58	1426.41	1411.93	1447.19	1445.51	1447.40	1426.14	1430.34	1440.61	1449.69	1456.91	1462.47	1466.30	1469.92	1471.43	1471.77
1494.76	1494.51	1494.23	1493.93	1472.52	1493.70	1483.69	1483.73	1465.17	1506.41	1526.40	1538.13	1545.71	1550.74	1553.64	1554.09	1554.80	1554.99
1555.66	1555.30	1554.91	1554.49	1533.02	1524.30	1524.28	1524.29	1539.31	1595.58	1618.06	1628.94	1634.99	1638.53	1640.38	1641.07	1641.46	1641.55
1630.63	1630.22	1629.78	1629.29	1606.42	1574.48	1574.31	1574.26	1638.22	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1709.53	1709.02	1708.49	1707.89	1684.73	1623.66	1620.33	1618.61	1648.99	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				RING				DISC									

NO WIRE SECTOR

806.93	806.87	806.83	806.80	802.54	799.32	796.11	793.60	790.14	787.23	785.80	785.17	785.01	785.18	785.47	785.72	785.90	785.94
974.89	974.77	974.64	974.49	947.30	944.92	940.48	936.90	931.89	927.69	925.79	925.15	925.25	925.85	926.56	927.14	927.51	927.60
1106.81	1106.61	1106.39	1106.14	1076.24	1074.32	1070.20	1066.81	1062.06	1058.47	1057.41	1057.69	1058.70	1060.16	1061.50	1062.51	1063.11	1063.26
1217.76	1217.51	1217.24	1216.94	1179.02	1177.44	1173.92	1171.16	1167.52	1166.03	1166.99	1169.01	1171.47	1174.08	1176.15	1177.59	1178.41	1178.61
1280.99	1280.77	1280.64	1280.49	1262.65	1261.54	1258.97	1257.03	1254.81	1256.49	1260.29	1264.51	1268.60	1272.40	1275.14	1276.92	1277.90	1278.14
1358.88	1358.75	1358.61	1358.45	1342.09	1342.16	1340.12	1338.72	1337.64	1345.07	1353.36	1360.49	1366.40	1371.48	1374.76	1376.76	1377.81	1378.06
1431.88	1431.75	1431.61	1431.46	1418.55	1417.82	1415.78	1413.82	1411.22	1431.11	1445.86	1455.96	1463.22	1469.52	1472.89	1474.82	1475.80	1476.03
1494.88	1494.75	1494.61	1494.45	1482.92	1482.85	1481.76	1477.49	1458.83	1511.50	1532.16	1543.27	1550.01	1553.10	1555.48	1556.93	1557.69	1557.87
1560.84	1560.66	1560.47	1560.27	1550.12	1552.43	1560.74	1568.42	1584.43	1610.98	1625.00	1632.90	1637.60	1640.12	1641.61	1642.48	1642.93	1643.04
1640.81	1640.61	1640.39	1640.15	1629.23	1633.83	1640.53	1669.36	1713.91	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
1709.83	1709.66	1709.47	1709.27	1701.36	1701.79	1705.68	1711.64	1727.80	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00	1745.00
NECK				DISC													

TABLE I-1
HEAT LOSS ANALYSIS
TWO-DIMENSIONAL

ONE-DIMENSIONAL

<u>Case</u>	<u>Unit</u>	<u>Insulation System</u>	<u>Min-K Insulation System</u>	<u>Corrected* Total Power To Unit</u>	<u>Cover Plate Temperature, °F</u>	<u>Heater* Wire Flow At Plate Level</u>	<u>Heat* Entering Min-K At Plate Level</u>	<u>Loss To* Neck Tube Below Plate Level</u>	<u>Total** Subtractibles</u>	<u>Unit* Heat Loss</u>	<u>Subtractibles*</u>	<u>Unit Heat Loss*</u>
1	B10-D1	45 layers nickel 60 layers copper	Figure 1	61.1	143	7.36	3.57	0	11.69	49.4	14.8	46.3
2	B10-D1 Re-test after Dynamic	60 layers alum 12 cut de-sign	Figure 2	69.7	126	9.60	11.25	3.19	24.03	45.7	19.8	49.9
3	B10-D2	Same as 10-D1	Figure 2	71.8	182	9.27	10.94	3.19	24.15	47.7	19.0	52.8
4	B10-D3	45 layers nickel 60 layers copper 60 layers alum 9 cut de-sign	Figure 3	71.3	174	9.34	11.08	3.19	24.33	47.0	19.1	52.2
5	B10-D4	105 layers copper 60 layers alum 9 cut de-sign	Figure 3	67.8	177	9.38	11.19	2.91	24.90	42.9	19.1	48.7
6	Qual. and dlv. Units		Accept. test Plan		145	8.21	4.65	-.39	13.22		15.4	

*Heat Flow in Watts
**Includes thermocouple loss (0.75 watts)

APPENDIX J

FUNCTIONAL PERFORMANCE ACCEPTANCE TEST PLAN

APPENDIX J

UNION CARBIDE CORPORATION
Linde Division
Development and Equipment Design
Tonawanda, New York

HIGH TEMPERATURE VACUUM INSULATION SYSTEM

Subcontract Number
AT(30-1)-3691-5511
TASK I

FUNCTIONAL PERFORMANCE ACCEPTANCE TEST PLAN

For

3M Company
Electrical Products Division
St. Paul, Minnesota

Revised
November 18, 1968

Approved December 26, 1968
Per 3M Reference 3691-1474

1.0 GENERAL

1.1 Scope

This test plan governs the Model A High Temperature Vacuum Insulation System (HTVIS) performance acceptance testing. This system is for use in the SNAP-21 10 watt isotope fueled thermoelectric generator. The HTVIS units under the jurisdiction of this plan are designated as 10DL-1 through 10DL-5 inclusive.

This test program is designed to satisfy the requirements of Specification 3M-37-IPL-33, Technical Specification for a High Temperature Vacuum Insulation System, dated 23 February 1967; specifically paragraphs 3.1.1, 3.1.2, and 3.2.1.

1.2 Objective

The primary objective of this test is to demonstrate that the assembled insulation system satisfies the performance and operational requirements as identified in paragraph 1.1 of this document.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this test plan.

2.1 Applicable Drawings

The drawings listed below govern the assembly of the HTVIS units to be tested under this plan.

2.1.1 Linde Drawings

<u>Drawing No.</u>	<u>Title</u>
E-664034 - Rev. C	HTVIS Model A, 10 watt Assembly

2.1.2 3M Drawings

<u>Drawing No.</u>	<u>Title</u>
PD-37-1349 - Rev. D	Envelope and Interface Requirements for HTVIS Model A (10 watts)

2.2 Applicable Specifications

Listed below are pertinent specifications and standards.

2.2.1 Linde Division

<u>Number</u>	<u>Title</u>
E-664034C	HTVIS Model A, 10 watt Assembly, Leak Check (Step 48)

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2.2.2 3M Company

<u>Number</u>	<u>Title</u>
3M-37-IPL-33 23 February 1967	Technical Specification for a High Temperature Vacuum Insulation System Model A

2.2.3 Military Standards

<u>Number</u>	<u>Title</u>
MIL-STD-810A 23 June 1964	Military Standard, Environmental test methods for Aerospace and Ground Equipment
	<u>Shock Testing</u>
	Method 516-1 Procedure 1, except that peak value shall be 6 g's and the nominal durations shall be 6 milliseconds.
	<u>Vibration Testing</u>
	Method 514-1 except that maximum "g" level shall not exceed 3.

3.0 ACCEPTANCE REQUIREMENTS

Acceptable High Temperature Vacuum Insulation System requirements are defined as follows.

3.1 Thermal Requirements

With an insulation system cold wall temperature of 50°F and a heat source surface (biological shield) temperature at the neck tube end of 1285°F, the maximum thermal heat loss of the system at steady state thermal conditions shall not exceed 45 watts. This 45 watt heat loss is a summation of heat flow through the multi-layer insulation system and heat source support system.

This heat loss must be demonstrated after the unit has been permanently sealed, (i.e. after the unit is no longer attached to vacuum pumps) and the unit has thermally achieved steady state at temperatures as previously stated.

Acceptance will be determined by supplying constant power at a predetermined level and observing that the 1285°F temperature remains steady or rises over a four hour test period.

3.2 Leak Rate Requirements

The system leak rate will be determined with a helium leak detector prior to system heating and seal-off. The leak rate is determined to insure operating life of the vacuum maintenance system.

Acceptable system leak rate shall not exceed 6×10^{-8} std-cc air per second.

3.3 Envelope and Interface Requirements

Linde/3M interface unit dimensions and weight will be determined using certified measuring instruments.

Acceptable unit dimensions are as shown on 3M Drawing PD-37-1349-D. Acceptable unit weight shall not exceed 60 pounds excluding the weight of the biological shield, spider, and associated bolts and washers.

3.4 Dynamic Requirements

Dynamic testing of the HTVIS system will be conducted using acceptable test equipment. The HTVIS unit is to be evaluated at both ambient and operating temperatures.

Acceptable unit performance will be determined by visual inspection of the inner liner for the ambient test conditions, and observation of the enclosure temperatures for operating temperature conditions. For acceptable unit performance, the inner liner should suffer no visible distortion or skin failure indicating loss of vacuum, while the external enclosure temperatures should not exceed 125°F during the operating temperature test, which would indicate loss of vacuum.

4.0 TEST SUMMARY

The HTVIS acceptance tests will be conducted at the Linde-Tonawanda facilities using Linde test equipment. The criteria for acceptance will be demonstration of acceptable performance as defined in paragraph 3.0 and further defined in paragraph 7.0 as it relates to the test results.

4.1 Thermal Test

The thermal test shall be conducted by bringing the biological shield neck tube end temperature to 1285°F and then supplying the unit with a predetermined power input equal to specified unit heat loss and losses incurred due to testing requirements. With an acceptable unit the biological shield temperature shall not drop over a four hour time period.

4.2 Leak Rate Test

The leak rate test shall be conducted by evacuating the unit with a helium leak detector and then enclosing the unit in a helium filled bag to result in a detector scale reading. The scale reading will be compared to the scale reading produced by a standard leak to determine unit leak rate.

4.3 Envelope and Interface

The envelope and interface test shall be comprised of direct measurements on the completed unit to determine the interface dimensions and

a direct weight measurement performed on a scale to determine the unit weight.

4.4 Dynamic Test

The HTVIS unit shall be vibrated at ambient temperature, and at operating temperature per MIL STD 810A, method 514-1 except that max. "g" load shall not exceed 3. After completion of vibration tests, unit shall be shock test at operating temperatures per MIL STD 810A, method 516-1, procedure 1 except that peak value shall be 6 g's and the nominal duration shall be 6 milli-seconds.

5.0 TEST CONDITIONS, EQUIPMENT, AND FACILITIES

5.1 Test Conditions

The test conditions specified for the HTVIS functional performance acceptance test are as follows.

5.1.1 Thermal Test

5.1.1.1 Temperature

Heat source cool (neck tube) end temperature	1285 $\pm$ 3°F
Cold wall (at girth weld) temperature	100 $\pm$ 15°F
Cover plate temperature (Figure 1)	140 $\pm$ 10°F

The above temperature changes from those specified in Section 3.1 are required because only the insulation system portion of the total generator system is being tested.

5.1.1.2 Power Input

With the temperatures as stated in 5.1.1.1 the total power supplied to the unit shall be 56.7 watts.

5.1.1.3 Inner Liner Insulation System

The inner liner cavity above the heater block (neck tube zone) shall be filled with Min-K 2000 insulation, which is retained by a cover plate.

5.1.1.4 Unit Support and Test Position

The unit shall be supported in the unit manipulating fixture (E-664064) with the Min-K 2000 filled inner liner positioned downward.

5.1.2 Leak Rate Test

5.1.2.1 Temperature

The entire unit shall be at ambient temperature during the leak detection.

5.1.2.2 Vacuum

The unit insulation space shall be evacuated to 100 microns or less prior to measuring the leak rate.

5.1.3 Envelope and Interface

5.1.3.1 Temperature

All interface dimensions and unit weight shall be determined at ambient temperature.

5.1.4 Dynamic Tests

5.1.4.1 Temperature

Dynamic testing shall be performed at

- a. ambient temperature with entire HTVIS unit at $80 \pm 20^{\circ}\text{F}$
(vibration testing only)
- b. operating temperatures with heat source hot (neck tube) end temperature $1285 \pm 15^{\circ}\text{F}$
Cold wall (at girth weld) temperature $100 \pm 15^{\circ}\text{F}$
cover plate temperature $140 \pm 10^{\circ}\text{F}$
(vibration and shock testing)

5.1.4.2 Power Input

During dynamic testing at operating temperature power shall be supplied continuously at 215 watts ± 10 watts to maintain the heat source (neck tube) end temperatures at $1285 \pm 15^{\circ}\text{F}$. Steady state temperatures shall be maintained by adjustment of a water cooled copper rod.

5.1.4.3 Inner Liner Insulation System

The inner liner cavity above the heater block assembly (neck tube zone) shall be filled with Min-K insulation during dynamic tests of HTVIS unit at operating temperature as shown on Figure 6.

5.1.4.4 Unit Support and Test Position

The unit shall be mounted in fixtures designed and built by the dynamic testing contractor. The designs shall be approved by Linde prior to fabrication. Test positions shall be the three mutually perpendicular axis as specified in Section 6.4.

5.2 Test Equipment

The test equipment specified for use for the HTVIS functional performance acceptance test is as follows.

5.2.1 Thermal Test

5.2.1.1 Unit Power Input A.C.

- a. Supplied by 3M as per Drawing No. PD-37-4161

b. Electrical Heater (Supplied by 3M)

4 Required
3M Drawing 37-TL-1062
5/8" dia. x 5" long
115 volts + 500 watts
Rama Industrial Heater Company

c. Radiation Disk

3M Drawing PD-37-4160

d. Isolation Transformer

Stancor Isolation Transformer
Model No. P-6371
Primary 117 volts, 60 cycle
Secondary 117 volts, 175 V.A.

e. Constant Voltage Transformer

Sola Electrical Company, Chicago, Illinois
Serial No. 17, Model 301903
Range 115-125 V, Rated 250 VA

f. Electric Fuse

Little Fuse, Des Plains, Illinois
8AG-5A-SB

g. Variac Auto Transformer

General Radio Company
Cambridge, Massachusetts
115 volts, 5 amps

h. Calibrated Recording Ammeter

Esterline Angus, Indianapolis, Indiana
E. A. Graphic Ammeter
Serial No. 145116
Model AW
0-5.0 amps
Accuracy - $\pm$ 1% of full scale

i. Ammeter

Sensitive Research, New Rochelle, New York
Serial No. 701174-C
0-5 amps

j. Voltmeter

Sensitive Research, New Rochelle, New York
Serial No. 701174-D
0-30 volts

5.2.1.2 Unit Power Input D.C.

- a. Same as Section 5.2.1.1 (a).
- b. Same as Section 5.2.1.1 (b).
- c. Same as Section 5.2.1.1 (c).
- d. D.C. Power Supply

Electro Products Laboratories, Inc., Chicago, Illinois
"Electro" Model NFB Filtered
D.C. Supply
Output 0-32 volts
15 amps D.C. maximum

e. Diode

Model A-40C diode

f. Batteries

2 Required
Delco DC-12
61 amp-hour
12 volts

g. Shunt

100 amp = 250 M.V.

h. Ammeter

Sensitive Research, New Rochelle, New York
D. C. Polyrange
Serial No. 912112
0-5 amp scale

i. Voltmeter

Weston D.C. Voltmeter
Model 622
Serial No. 23211
0-30 volt range

j. Recording Ammeter

Moseley Strip Chart Recorder
Model 80, Serial No. 59
Part No. 8043
0-5 amps range

k. Electric Fuse

Little Fuse, Des Plains, Illinois
8AG-5A-SB

l. Knife Switch

Single pole - single throw

m. Variable Resistance

Cenco Rheostat
Catalog No. 82965-3

5.2.1.3 Temperature Measurementa. Calibrated Thermocouples

Minneapolis Honeywell Regulator Company
Chromel-Alumel, 20 gauge (.032" dia.) with ceramic beads
Two High Temperature Thermocouples calibrated for Temperature
of 1300°F - 1200°F
Five low Temperature Thermocouples Calibrated for Temperature
of 350°F - 100 °F.

b. Potentiometer for Thermocouples Reading

Minneapolis Honeywell, Instrument Division
Philadelphia, Brown Potentiometer
Serial No. 589677

c. Millivolt Potentiometer

Rubicon Instruments
Model 2745, Serial No. 104804
0-80 M.V. Range

d. Ice Bath for T. C. Reference Junction5.2.1.4 Inner Liner Insulation Systema. Insulation for Neck Tube Plug

Johns-Manville Insulation Company, New Jersey
Min-K 2000 Series, Insulation Board

b. Cover Plate - Figure 15.2.1.5 Unit Support

Manipulating Fixture (E-664064)

5.2.2 Leak Rate Test

J-9

Helium Leak Detector

Veeco MS-9

Required Sensitivity of 1×10^{-10} std. cc/sec. air
Complete with Standard Leak

5.2.3 Envelope and Interface

a. Outside Micrometers

b. Transfer Caliper

c. Depth Micrometers

d. Radius Gauges

e. Platform Weight Scale

Toledo Scale, Toledo, Ohio
0-400 Range
 $\frac{1}{2}$ pound increments

5.2.4 Dynamic Tests

5.2.4.1 Vibration Test

5.2.4.1.1 Test Equipment and Instruments

a. Vibration Testing Equipment

Capable of performing vibration test (3g) as specified
by MIL-STD-810A, Method 514-1 dated 23 June 1964.

Similar to

M. B. Electronics
Model C-200

b. Accelerometers - 7 required

Similar to

Columbia Research Labs
Model 902

c. Variac Auto Transformer

Similar to: General Radio Co.
Cambridge, Massachusetts
115 volts, 5 amp

d. Recording Ammeter

Similar to: Easterline Angus
Indianapolis, Indiana
Serial No. 145116, Model AW, 0-3 amps

e. Electrical Heater (Supplied by 3M)

3M Drawing 37-TL-1062
5/8" dia. x 5" long
115 volts + 500 watts
Rama Industrial Heater Co.

f. Heater Block Complete with Holding Bolts (Linde Supplied)

g. Atmospheric Insulation Plug (Linde Supplied)

h. Calibrated Thermocouples (Linde Supplied)

i. Potentiometer

Similar to: Millivolt Potentiometer
Rubicon Instruments
Model 2745

j. Vibration Test Fixture

k. Seal Off Flange (Linde Supplied)

See Figure 6

l. Isolation Transformer

Similar to: Stancor Isolation Transformer
Model No. P-6371
Primary 117 volts, 60 cycle
Secondary 117 volts, 175 VA

m. Wattmeter

Similar to: Vancos
Model EMA
OTL A73

n. Oscillograph Recorder

Consolidated Electronics Corp.
Model 5-119

5.2.4.2 Shock Test

5.2.4.2.1 Test Equipment & Instruments

a. Same as listed under Section 5.2.4.1.1

b. Waveform Synthesizer

Similar to: Exact Electronics
Model 200 G

c. Oscilloscope

Similar to: Tektronics
Model RM32

d. Scope Camera

Similar to: A. B. Dumont
Model 5B52

5.2.5 Calibration5.2.5.1 Linde

All meters are maintained and calibrated by the Instrument Group, using equipment that provides traceability to the National Bureau of Standards.

All thermocouples will be constructed and calibrated by Instrument Group. The calibration shall be traceable to the National Bureau of Standards.

All dimensional measuring instruments shall be calibrated and the calibration traceable to the National Bureau of Standards.

Weight scales shall be calibrated and the calibration traceable to the National Bureau of Standards.

5.2.5.2 Contractor

Contractor shall use accelerometers calibrated against a standard accelerometer which is traceable to National Bureau of Standards.

5.2.6 Test Set-Up5.2.6.1 Thermal Test

a. Weld two Chromel-Alumel 20 gauge (.032 inch dia.) thermocouples to the radiation disk top side to be 180° apart and adjacent to the outside edge of the radiation disk.

b. Install the assembled heater block, electric heaters, and radiation disk into the inner liner cavity and secure to the inner liner.

c. Install the Min-K 2000 block insulation as shown in Figure 2 with maximum gap around the circumference of 1/16 inch. Gap to be filled with powdered Min-K 2000. Maximum cut out for heater wires to be 1/2 x 3/8 inch and maximum cut out for thermocouples to be 3/8 x 5/16 inch. Voids left in the cut out are to be filled with powdered Min-K 2000 insulation.

d. Install the cover plate (Figure 1) over the Min-K 2000 insulation and secure it to the unit top head with silicone rubber. Also

seal with silicone rubber the area where the thermocouple wires and heater wires exit the cover plate.

e. Install with soft solder the five Chromel-Alumel thermocouples on the outside of the unit as shown in Figure 3.

f. Connect all the thermocouples to the thermocouple recorder.

g. Assemble the A.C. power supply wiring system as shown in Figure 4 and connect to the electric heaters wired in parallel.

h. Assemble the D.C. power supply wiring system as shown in Figure 5.

i. Rotate the unit in the Unit Manipulating Fixture so that the Min-K insulation cover plate faces down.

5.2.6.2 Leak Rate Test

Connect an evacuation line from the unit seal-off device (female end) to the helium leak detector.

5.2.6.3 Envelope and Interface

The unit dimensions are determined with the unit in the support fixture (E-664055).

5.2.6.4 Dynamic Test

5.2.6.4.1 Vibration Test

5.2.6.4.1.1 Ambient Temperature

a. Remove unit from shipping container and place in test fixture. Place unit in fixture so that Rod No. 1 will be vertical during testing on Y-Y axis (Unit axis perpendicular to direction of vibration). Tighten fixture bolts to 50 ft-lb torque.

b. Assemble sides of test fixture.

c. Place unit on vibration machine to test in Y-Y axis and attach to machine head using all bolts.

d. Mount calibrated accelerometers on unit as follows:

1. Control accelerometer on face of fixture adjacent to top of unit.

2. Tri-axial accelerometer on enclosure of unit near girth weld bead.
3. Tri-axial accelerometer in inner liner cavity adjacent to inner liner bolt circle. (Caution, do not touch thin wall portion of inner liner.)

5.2.6.4.1.2 Operating Temperature

- a. The HTVIS unit shall be rigidly attached to the vibration test fixture.
- b. Install heater block assembly and radiation disk with thermocouples into the inner cavity and secure to inner liner. Install copper disk on radiation disk (Figure 6).
- c. Install Min-K 2000 board insulation to within 1/16 inch of liner and fill remaining gaps at circumference and at heater and thermocouple leads with powdered Min-K insulation.
- d. Install cover plate with provision for copper rod to simulate thermal losses attributable to thermoelectric unit, and seal plate to upper head as well as heater and thermocouple leads with silicone rubber.
- e. Soft solder thermocouples to the unit and connect to the thermocouple recorder as shown in Figure 3.
- f. Assemble the power supply wiring system as shown in Figure 4.
- g. Mount tri-axial accelerometer on enclosure of unit near girth weld bead. Mount control accelerometer on fixture adjacent to unit at neck tube end.

5.2.6.4.2 Shock Test

- a. The HTVIS unit is prepared for the operating temperature shock tests in the same manner as discussed in Section 5.2.6.4.1.2.

5.3 Test Facilities

5.3.1 Linde

The test facilities used are located at the Union Carbide Corporation, Linde Division Engineering Development Laboratory, Tonawanda, New York.

5.3.2 Contractor

Dynamic testing of the HTVIS insulation system shall be performed at an approved contractors site, similar to: Odgen Technology Laboratories, Comac Road, Deer Park, Long Island, New York.

6.0 TEST PROCEDURES

The following delineates in detail the HTVIS functional acceptance test procedures which were summarized in paragraph 4.0. The acceptance tests (except dynamic) will be conducted at the Linde Laboratory Facility using Linde test equipment (see paragraph 5.2.). The criteria of acceptance will be the demonstration of acceptance performance as defined in paragraph 3.0 and further defined as it relates to the test results in paragraph 7.0.

6.1 Thermal Test

a. Following the conditioning and seal-off of the unit (D-664064), reheat the unit to 1285°F. (heat source neck tube) using the A.C. power supply system (Figure 4). The power input schedule shall be as follows: 50 watts for 8 hours minimum, 100 watts for 8 hours minimum, 150 watts as required to reach 1285°F.

b. After the biological shield cool (neck tube) end temperature reaches 1285°F., as measured by the Chromel-Alumel thermocouples set the power supply system to the predetermined power level. (Note): Either the A.C. power supply system or the D.C. power supply system may be used.

c. Maintain the predetermined power level for a period of four hours and record each hour the temperature of one Chromel-Alumel thermocouple (No. 6) as referenced to ice which has been disconnected from the thermocouple recorder and read on the millivolt potentiometer.

d. If the unit meets the requirements as specified in paragraph 7.1, turn-off all power and allow the unit to cool.

e. If the unit does not meet the requirements as specified in paragraph 7.1. Adjust the power input as required to maintain 1285°F. at the heat source neck tube end. This power level must be maintained for a four hour period without a unit temperature change.

6.2 Leak Rate Test

a. Evacuate the unit below 100 μ pressure with leak detector vacuum pump.

b. The leak detector scale is zeroed.

c. The standard leak unit mounted on the side of the Veeco unit is opened into the system, causing the leak detector scale to indicate the number of units proportional to the standard leak.

d. Record this value of scale reading for calculation of leak rate.

e. Valve off the standard leak unit from the system and note that the detector scale returned to zero.

f. Enclose the unit in a plastic envelope containing helium at atmospheric pressure.

g. Record the steady state value of the scale reading for calculation of leak rate.

6.3 Envelope and Interface

- a. The overall length of the unit is measured using outside micrometers.
- b. The top and bottom diameter of the unit is measured using outside micrometers.
- c. The top and bottom radius are measured with radius gauges.
- d. The distance between the flat on the top head and the bolt flat on the inner liner is measured using depth micrometers.
- e. The weight of the unit is measured by placing the unit on a platform type weight scale.

6.4 Dynamic Tests

6.4.1 Vibration Tests

6.4.1.1 Ambient Temperature

- a. Perform the following sweeps log cycling from 5 to 50 cps in 7-1/2 minutes and from 50 to 5 cps in 7-1/2 minutes.

Sweep No. 1

Run at 1/2 g input. (Do not allow inner liner cavity g level to exceed 2.0 g. If g level of accelerometer in inner liner cavity shows g levels in excess of 1.0 g, do not run Sweep No. 2.

Sweep No. 2

5-8 cps at .4 inch double amplitude
 8-26 cps at 1.3 g
 26-40.5 cps at .036 inch double amplitude
 40.5-50 cps at 3.0 g
 50-40.5 cps at 3.0 g
 40.5-26 cps at .036 inch double amplitude
 26-8 cps at 1.3 g
 8-5 cps at .4 inch double amplitude

- b. If erratic behavior is noted on the print out of any accelerometers, stop the test and visually inspect the thin wall portion of the neck tube. The recording oscillograph used to record the accelerometers shall have a chart speed of at least 4 inches per second.
- c. At the conclusion of the sweep, remove the accelerometers from the unit and remove unit from the vibration machine.

6.4.1.2 Operating Temperature

- a. Heat the unit to operating temperature ($1285 \pm 15^{\circ}\text{F.}$) using the following power input schedule: 50 watts for 8 hours minimum, 100 watts for 8 hours minimum, 150 watts as required to reach operating temperature.
- b. Set power at 215 watts and install water cooled copper rod to maintain steady state operating temperature.
- c. Install unit in the test fixture on vibration test machine and subject each mutually perpendicular unit axis to three sweeps log cycling from 5 to 50 cps in 7-1/2 minutes and from 50 to 5 cps in 7-1/2 minutes as per the following schedule:
 - 5-8 cps at .4 inch double amplitude
 - 8-26 cps at 1.3 g
 - 26-40.5 cps at .036 inch double amplitude
 - 40.5-50 cps at 3.0 g
 - 50-40.5 cps at 3.0 g
 - 40.5-26 cps at .036 inch double amplitude
 - 26-8 cps at 1.3 g
 - 8-5 cps at .4 inch double amplitude
- d. After each sweep record the thermocouple temperatures at the locations shown on Figure 3.
- e. The recording oscillograph used to record the accelerometers shall have a chart speed of at least 4 inches per second to be used in the range 40-50 cps. A speed of .4 inches per second shall be used in the range 5-40 cps.

6.4.2 Shock Test

- a. Directly after the unit has been subjected to the operating temperature vibration test, subject the unit to the shock test while at operating temperature.
- b. Three shocks in each direction shall be applied along the three mutually perpendicular axes of the test unit (18 shocks). The shock pulse shape shall be in accordance with Figure 516-1, MIL-STD-810A specification and shall have a peak value (A) of 6 g and a nominal duration of 6 milliseconds.
- c. After each three shocks, record the thermocouple temperatures at the locations as shown on Figure 3.
- d. Record each shock pulse on a recording oscillograph and on Polaroid film.

7.0 PERFORMANCE EVALUATION

7.1 Thermal Test

The total power to the unit to achieve a unit with a 45 watt

maximum heat loss at operating conditions is determined as follows:

a. Correct the 45 watt operating heat loss to account for the variation in test conditions; i.e., the outside shell of the unit is at 100°F. and not at the specified 50°F. and the hot end of the biological shield is at ~1285°F. and not at the specified 1435°F. This correction yields the unit heat loss at test conditions to be 42.6 watts to be equivalent to a 45 watt heat loss at operating conditions.

b. To the above allowable test heat loss of 42.6 watts add the calculated heat loss of the inner liner insulation system, the heater wire heat loss, the thermocouple wire heat loss, and power lead I²R loss. This heat loss (not chargeable to the unit heat loss) has been calculated to be 14.1 watts for the system previously described in this acceptance test plan. The sum of the allowable test heat loss of 42.6 watts plus the non-chargeable additions of 14.1 watts yields 56.7 watts which is the predetermined power level setting used in paragraph 6.1.

c. If while maintaining this pre-determined power level setting of 56.7 watts, and the temperature initially at 1285°F. rises during the four hour test period, the unit shall have an acceptable heat loss.

7.2 Leak Rate Test

a. Calculate the leak rate from the leak detector values determined during the performance of the test procedure, paragraph 6.2, using the following equation:

$$\text{Leak Rate } \frac{\text{std-cm}^3}{\text{sec}} = \frac{\text{steady state detector scale reading (unit)}}{\text{standard leak detector scale reading (unit)}} \times \text{Value of standard leak } \left(\frac{\text{std-cm}^3}{\text{sec}} \right)$$

Sample of Calculations

Given:

Steady state detector scale reading = 0.2 unit

Standard leak detector scale reading = 6 unit

Value of standard leak 2.8×10^{-8} std.cc./sec. air

$$\text{Leak Rate} = \frac{0.2 \times 2.8 \times 10^{-8}}{6} = 9.3 \times 10^{-10} \frac{\text{std-cm}^3 \text{ air}}{\text{sec.}}$$

b. The unit leak rate shall be acceptable if the calculated leak rate is equal to or less than

$$6 \times 10^{-8} \frac{\text{std-cm}^3 \text{ air}}{\text{sec.}}$$

7.3 Envelope and Interface

a. The unit interface dimensions as measured during the performance of the procedures of paragraph 6.3 shall be compared to the corresponding dimensions on 3M Drawing PD-37-1349.

b. Each dimension shall be acceptable if it is within the tolerance allowed on 3M Drawing PD-37-1349.

c. The acceptance unit weight is determined by adding the following to the specified 60 pounds maximum, weight of biological shield and bolt ~244.9 pounds, and the weight of the spider ~7.8 pounds.

d. The total unit weight shall be acceptable if it is equal to or less than 60 pounds plus the actual weight of the biological shield, bolts, and spider.

7.4 Dynamic Tests

Dynamic Performance of the HTVIS unit shall be acceptable provided that

a. no visible distortion of inner liner or obvious loss of vacuum occurs during or following the ambient test schedule,

b. unit enclosure temperatures at the girth weld do not exceed 125°F. during or after test while the unit is at the operating temperature of $1285 \pm 15^\circ\text{F}$.

8.0 Unit Cooldown Procedures

These procedures are to be followed whenever the unit is to be cooled from operating to ambient temperature. Use of this procedure will prevent phase change.

a. Turn power off.

b. Loosen copper rod in cover plate (do not remove).

c. Disconnect heater wires and thermocouple wires from terminal strip (straighten and clip off at cover plate).

d. Cut silicone rubber seals around wires and seal around outer edge of cover plate.

e. Remove cover plate.

f. Remove bulk Min-K insulation with pointed edge tool.
(Caution - Do not touch neck tube with tools.)

g. Loosen packed Min-K insulation around emitter plate and emitter plate bolts.

bolts. h. Vacuum clean loose Min-K insulation to expose emitter plate

i. Loosen emitter plate bolts with long handle allen wrench and remove with long tweezers.

j. Thread lifting eye bolt in heater block.

k. Insert 3/4 inch diameter bar through eye of lifting bolt and lift heater block out of unit. (Set hot heater block on concrete floor.)

l. Vacuum clean inner liner.

m. Install copper chill block with water circulating through chill block.

n. Install and tighten special long bolts to secure chill block to inner liner.

MATL: 304 S.S.

COVER PLATE
UNIT THERMAL TEST

FIGURE J-1

FIGURE J-2 - SCHEMATIC OF INNER LINER INSULATION

THERMOCOUPLE LOCATION SCHEMATIC
UNIT THERMAL TEST

- 1 - VACUUM CONTROL - OUTLET FOR AC TO HEATERS.
- 2 - FUSE
- 3 - ISOLATION TRANSFORMER
- 4 - CONSTANT VOLTAGE TRANSFORMER
- 5 - VARIAC AUTO TRANSFORMER
- 6 - RECORDING AMMETER
- 7-8 - AMMETER, VOLTMETER, CONTAINED IN ITEM 9
- 9 - TESTING METER, CONTAINING 7,8 AND WATTMETER
- 10 - LOAD

THERMAL TEST POWER SUPPLY SCHEMATIC - AC

FIGURE J-4

- 1 - ELECTRONIC DC SUPPLY
- 2 - DIODE
- 3 - 12 VOLT BATTERY
- 4 - SHUNT
- 5 - AMMETER
- 6 - VOLTMETER
- 7 - AMPS RECORDER
- 8 - FUSE
- 9 - KNIFE SWITCH
- 10 - RHEOSTAT
- 11 - LOAD

THERMAL TEST POWER SUPPLY SCHEMATIC - DC

FIGURE J-5

FIGURE J-6 - SCHEMATIC OF INNER LINER INSULATION SYSTEM

APPENDIX K

LIST OF DRAWINGS

<u>Drawing Number</u>	<u>Title</u>
*A-664000	Radius Gauge - Checks 2.575 Inch Radius
*A-664001	Radius Gauge - Checks 2.590 Inch Radius
C-664002	Radius Gauge - Checks 6.509 Inch Radius
D-664003	Gauge - Checks Outline Dimensions on 3M Drawing PD-37-1349
E-664004	SNAP 21B Prototype Assembly Drawing
*A-664005	Specification for 1/2 Mil Nickel Foil
*A-664006	Specification for .005 Inch Thick Quartz Fabric
E-664007	HTVIS Model A Insulation Application
*A-664008	Specification for 1 Mil Nickel Foil
*A-664009	Specification for Quartz Paper
*A-664010	Specification for 106 Paper
*A-664011	Specification for 1/2 Mil Copper Foil
*A-664012	Specification for 1/4 Mil Aluminum Foil
A-664013	Instructions - HTVIS Model A Insulation Application
*B-664014	Getter Seal-off Device Male End
B-664015	Getter Seal-off Device Female End
C-664016	Top Head Machining SNAP 21B Prototype
C-664017	Shell Machining SNAP 21B Prototype
C-664018	Bottom Head Machining SNAP 21B Prototype
A-664019	Plug - Bottom Head SNAP 21B Prototype
A-664020	Tube Assembly for Outgassing Tests
A-664021	Girth Weld Joint 45° Bevel - Development Testing
D-664022	Evacuation and Getter Assembly for SNAP 21B Prototype
A-664023	10 Gram Getter Capsule - HTVIS
A-664024	Getter Casing - 90° Elbow
A-664025	Plug - Open End
A-664026	Plug - Closed End
A-664027	Getter Retainer
B-664028	Fitting - Evacuation
A-664029	Tube Connecting
A-664030	Fitting Plug
A-664031	1/8 Inch Vacuum Valve - Brass
*A-664032	24 Karat Gold O-ring for Seal-off Device
C-664033	SNAP 21B Prototype - Shipping Container
*D-664034	HTVIS Model A 10 Watt Assembly
*C-664035	Top Head Enclosure
*D-664036	Bottom Head Enclosure
*D-664037	Support Rod Assembly
*A-664038	Enclosure Support Rod Receptacle
*C-664039	Support Rod - Male End
*C-664040	Support Rod - Female End
*C-664041	Spherical Washer
A-664042	Support Rod Anti-Rotate Device
A-664043	Seal-off Plug - Support Rod
B-664044	Getter Retainer Assembly
C-664045	Dimensions for C. G. Calculation of HTVIS Model A

<u>Drawing Number</u>	<u>Title</u>
C-664046	Dummy Shield - Stainless
D-664047	Shield - Wood Dummy and Accessories
*C-664048	Shipping Container Assembly
*C-664049	Frame - Shipping Container
*D-664050	Suspension - Shipping Container
*A-664051	Top Flange - Shipping Container
*A-664052	Support - Shipping Container
*A-664053	Bottom Flange - Shipping Container
*A-664054	Flange - Shipping Container
*J-664055	Support Fixture
J-664056	Static Proof Test Fixture
*D-664057	Insulation Assembly
*D-664058	Insulation Detail
*E-664059	Insulation Detail
*B-664060	Spreader Bar Assembly - Shipping Container
*E-664061	Tension Rod Alignment Fixture
*C-664062	Tension Rod Alignment Fixture - Detail Sheets
*C-664063	Receptacle Welding Fixture
*E-664064	Unit Manipulating Fixture
664065	Drawing Not Used
*A-664066	Adjusting Pin Rod Angle
*B-664067	Hydrocarbon Getter Enclosure Assembly
*B-664068	Radius Gauge - Checks 6.515 Inch Radius
*B-664069	Radius Gauge - Checks 6.480 Inch Radius
*B-664070	Unit Lifting Adaptor
*D-664071	Bottom Head Sub-Assembly
*A-664072	Vacuum Gauge Adaptor
*D-664073	Assembly Spdier - Shield - Inner Liner
*D-664074	Support Rod Holding Fixture
*A-664075	Support Rod Installation Graph
*D-664076	Getter Installation and Evacuation Device
*A-664077	Leak Detection Procedure
*A-664078	Support Rod Ball Joint Lapping
*D-664079	Manufacturing Flow Plan
*D-664080	Insulation Profile Gauge - Lines "A" and "X"
*D-664081	Insulation Profile Gauge - Lines "Y" and <u>C</u>
*D-664082	Insulation Profile Gauge - Receptacle Clearance
*A-664083	Inner Liner Inside Diameter Inspection Fixture

* Indicates use on Model A HTVIS delivery units (10 Watt)