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SEPTEMBER 29, 1977

LOFT SHIELD TANK STEADY STATE TEMPERATURES WITH ADDITION OF GAMMA AND NEUTRON SHIELDING

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EG&G Idaho, Inc.

ENERGY SAFETY ENVIRONMENT

~~IDAHO NATIONAL ENGINEERING LABORATORY~~

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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REMARKS: Calculation shows that shield design is compatible with shield tank water and reactor vessel nozzle design temperatures. Recommended spacer is incorporated in shield design under Task 521712 (SWR 51024 and 50842).

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RESEARCH, ENGINEERING AND CONSTRUCTION REPORT
ENGINEERING ANALYSIS DIVISION

THERMAL ANALYSIS

LOFT SHIELD TANK STEADY STATE TEMPERATURES WITH ADDITION OF GAMMA AND NEUTRON SHIELDING

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IDAHO NATIONAL ENGINEERING LABORATORY
LOFT TECHNICAL REPORT
LOFT PROGRAM

TITLE LOFT Shield Tank Steady State Temperatures with Addition of Gamma and Neutron Shielding	REPORT NO. LTR No. 129-11
AUTHOR G. Kyllingstad G. Kyllingstad	GWA NO. 52171-203-000
PERFORMING ORGANIZATION Thermal Analysis Branch	DATE Published by CDCS 1-18-78 September 29, 1977
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SUMMARY

The effect of introducing a neutron and gamma shield into the annulus between the reactor vessel and the shield tank is analyzed. This addition has been proposed in order to intercept neutron streaming up the annulus during nuclear operations. Its installation will require the removal of approximately 20-1/2 inches of stainless steel foil insulation at the top of the annulus. The resulting conduction path is believed to result in increased water temperatures within the shield tank, possibly beyond the 150°F limit, and/or cooling of the reactor vessel nozzles such that adverse thermal stresses would be generated.

A two dimensional thermal analysis using the finite element code COUPLE/MOD2 was done for the shield tank system illustrated in Figure (1). The reactor was assumed to be at full power, 55 MW (th), with a loop flow rate of 2.15×10^6 lbm/hr (268.4 kg/s) at 2250 psi (15.51 MPa). Calculations indicate a steady state shield tank water temperature of 140°F (60°C). This is below the 150°F (65.56°C) limit. Also, no significant changes in thermal gradients within the nozzle or reactor vessel wall are generated. A spacer between the gamma shield and the shield tank is recommended, however, in order to ensure free air circulation through the annulus.

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1.0 INTRODUCTION

A modification to the radiation shielding for the LOFT reactor has been proposed. This modification is to include the removal of approximately 20-1/2 inches of stainless steel foil insulation at the top of the annulus between the reactor vessel and the shield tank for the installation of a neutron and gamma shield. Figures (1) and (2) present a detailed sketch of the proposed modification.

The neutron shield is to consist of two rows of steel canisters each filled with a mechanical mixture of 90% $TiH_{1.6}$ and 10% B_4C by weight. This is to be compacted to about 60% theoretical density. A 3/8" portion of each container is to be at a 95% theoretical density as shown in Figure (2).

The gamma shield, a 4-1/2" square steel block and 1/2" welded steel support plate, is to be bolted to the shield tank top and is also to provide support to the neutron shield canisters. A gap is to be provided between the gamma shield and the shield tank for free air circulation.

Since this new configuration constitutes an additional conduction path between the reactor vessel and the shield tank, the possibility of exceeding the 150°F (65.56°C) water temperature limit in the shield tank during full power operation (55 MW) needed to be investigated. Adverse temperature gradients within the reactor vessel nozzle were also considered. Thus a thermal analysis was made to determine the water temperature within the shield tank and the temperature profile of the nozzle with the proposed neutron and gamma shield configuration.

2.0 ANALYSIS

In determining the water temperature an energy balance of the shield tank was considered. A one-dimensional system was assumed and the electrical analogy for a multilayered system was applied. With the appropriate assumptions one equation with one unknown, the water temperature, can be written. The equation

$$Q_{in} + \dot{Q} = Q_{out} \quad \text{can be written as}$$

$$\frac{T_{RV} - T_W}{\sum R_{i_{in}}} + \dot{Q} = \frac{T_W - T_\infty}{\sum R_{i_{out}}}$$

where $T_{RV.}$ = 574°F (301°C) maximum temperature of the reactor vessel at full power, 55 MW (th)

T_∞ = 100°F (37.78°C) temperature of the atmosphere in the containment building

$\sum R_i$ = sum of the thermal resistances

$\dot{Q}$ = gamma and neutron heating of the shield tank water. Previously calculated in Reference (3).

Thermal conductivities and heat transfer coefficients have been calculated in past studies, Reference (3) and (4), and can be easily estimated considering they vary little for the temperature ranges considered. Thermal properties for the neutron shield were estimated from the literature review of $TiH_{1.6}$ and B_4C Reference (6) and (7). See Appendix C.

Hand calculations were made for the unmodified shield tank for comparison with the results of Reference (3) where the two-dimensional heat conduction code SIMIR was used. Hand calculation results were about 8% higher than SIMIR predictions. Therefore, hand calculations for the modified shield tank were also factored down by 8%. Detailed calculations are given in Appendix A.

The nozzle temperature profile was determined by COUPLE/MOD2, a two-dimensional finite element steady-state and transient heat conduction code. The finite element model is presented in Figure (3). Two axes of symmetry are possible, the center line of the reactor vessel or the center line of the nozzle. Use of either one will generate a distorted representation of the nozzle and shield tank. Choosing the proper axis, however, may minimize the distortion or at least give conservative answers. Choosing the center line of the nozzle will result in excess shielding being generated about the base of the nozzle, i.e., the gamma shield does not encircle the base of the nozzle, but encircles the reactor vessel. This simulation of excess material increases the conduction path between the base of the nozzle and the shield tank which in turn increases the thermal stress placed upon the nozzle. This was assumed to be the most conservative approach. Should no adverse thermal gradients result with this model a more detailed three-dimensional analysis would not be necessary.

The reactor was assumed to be at full power, 55 MW (th), with an intact loop flow of 2.15×10^6 lbm/hr (268.4 kg/s) at 2250 psi (15.51 MPa). Calculations of the various thermal properties used in the computer analysis and a listing of both the input and output data are presented in Appendix B. Thermal properties of the powdered mixture of $TiH_{1.6}$ and B_4C are presented in Appendix C. For simplicity only the powder material at 60% theoretical density was considered in the 20-1/2" annular space. Also the thermal effect of the steel can and supporting structure was considered negligible and hence was ignored.

3.0 RESULTS AND RECOMMENDATIONS

The maximum steady state shield tank water temperature calculated is 140°F (60°C) which is below the 150°F (65.56°C) limit. The temperature profile of the reactor vessel nozzle is given in Figure (4). No significant changes in thermal gradients are induced in the nozzle or reactor vessel wall, therefore, no adverse thermal stresses should be expected. In order to ensure free air circulation within the annulus between the reactor vessel and the shield tank it is important that a spacer be provided under the gamma shield. This would also reduce the conduction path from the gamma shield to the shield tank. This was assumed in the shield tank water temperature calculations where heat from the gamma shield was assumed to be conducted to the shield tank only through the 1/2 inch bolts.

4.0 REFERENCES

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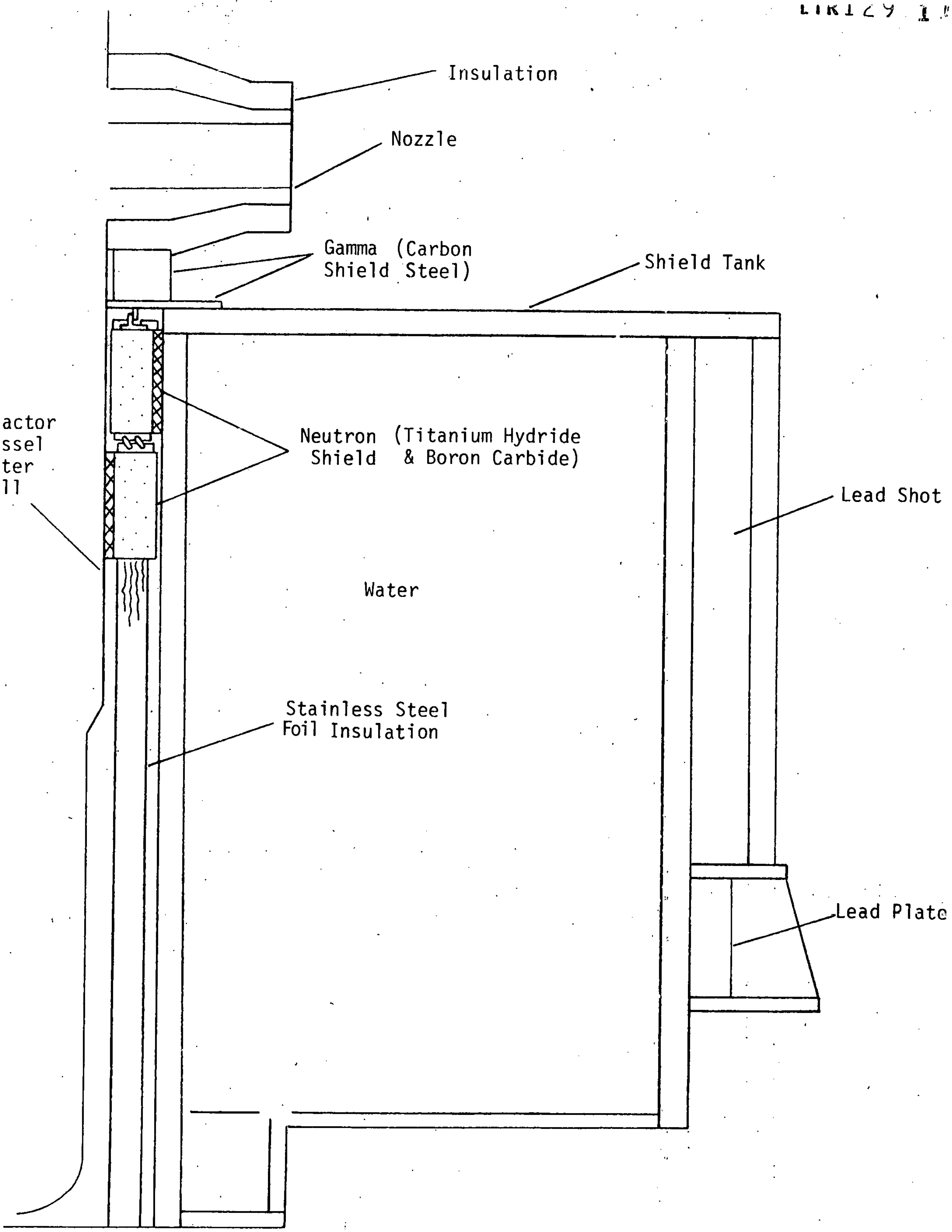


Figure 1. Cross Section of Shield Tank (not to scale)

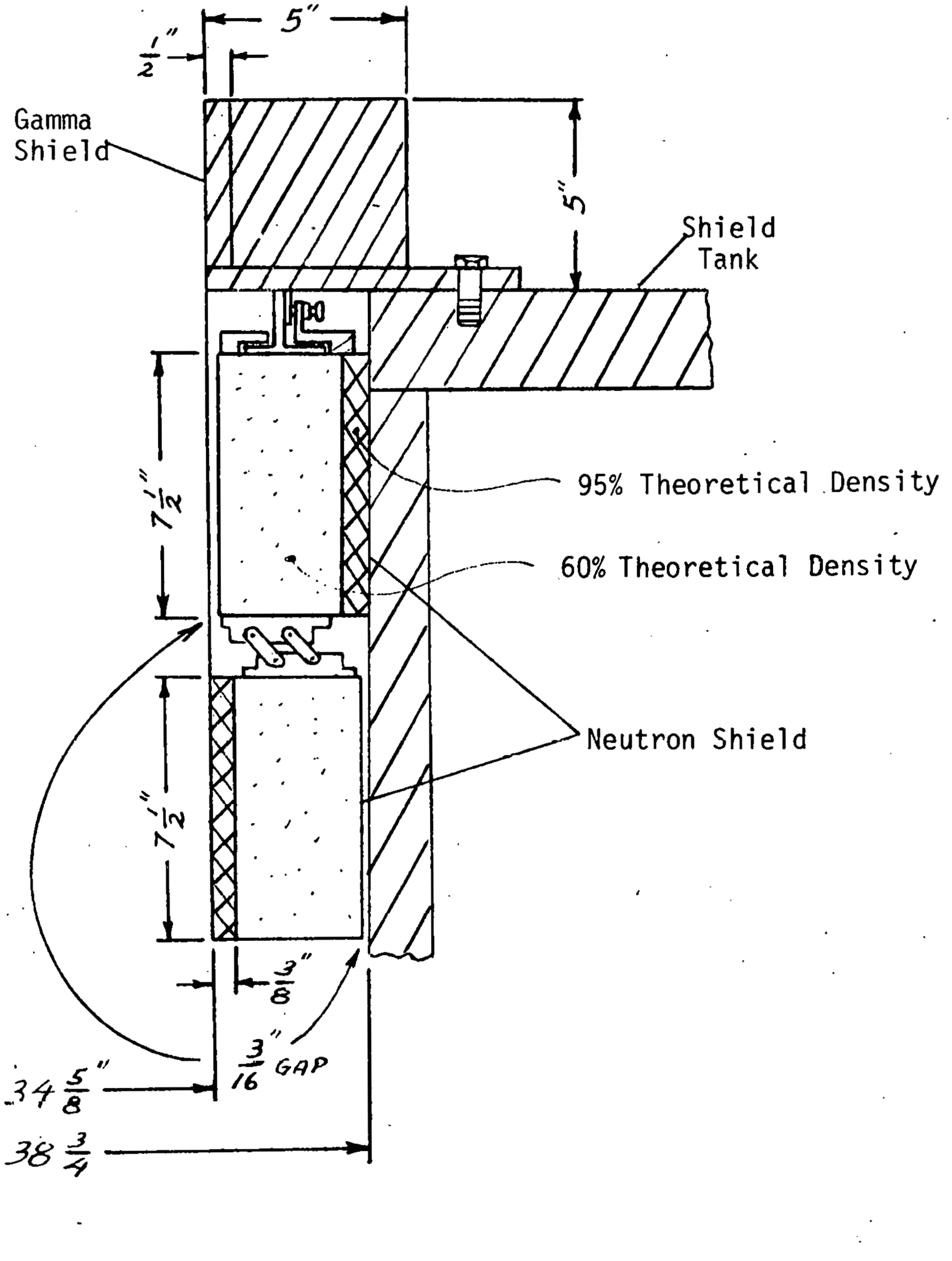


Figure 2. Detail of Gamma and Neutron Shield

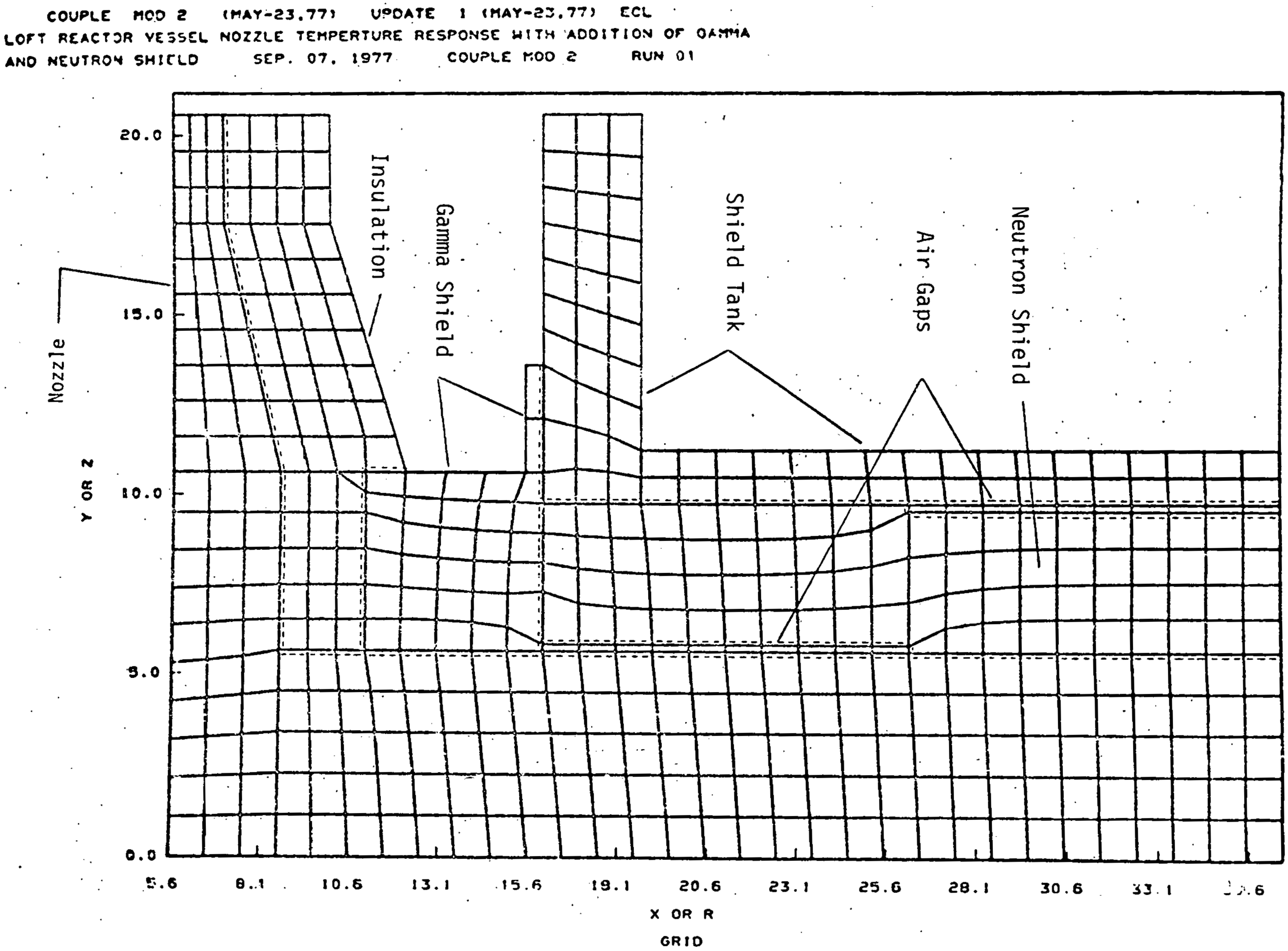


Figure 3. COUPLE/MOD2 Update 1 LOFT Reactor Vessel Nozzle Temperature Response with Addition of Gamma and Neutron Shield - Grid

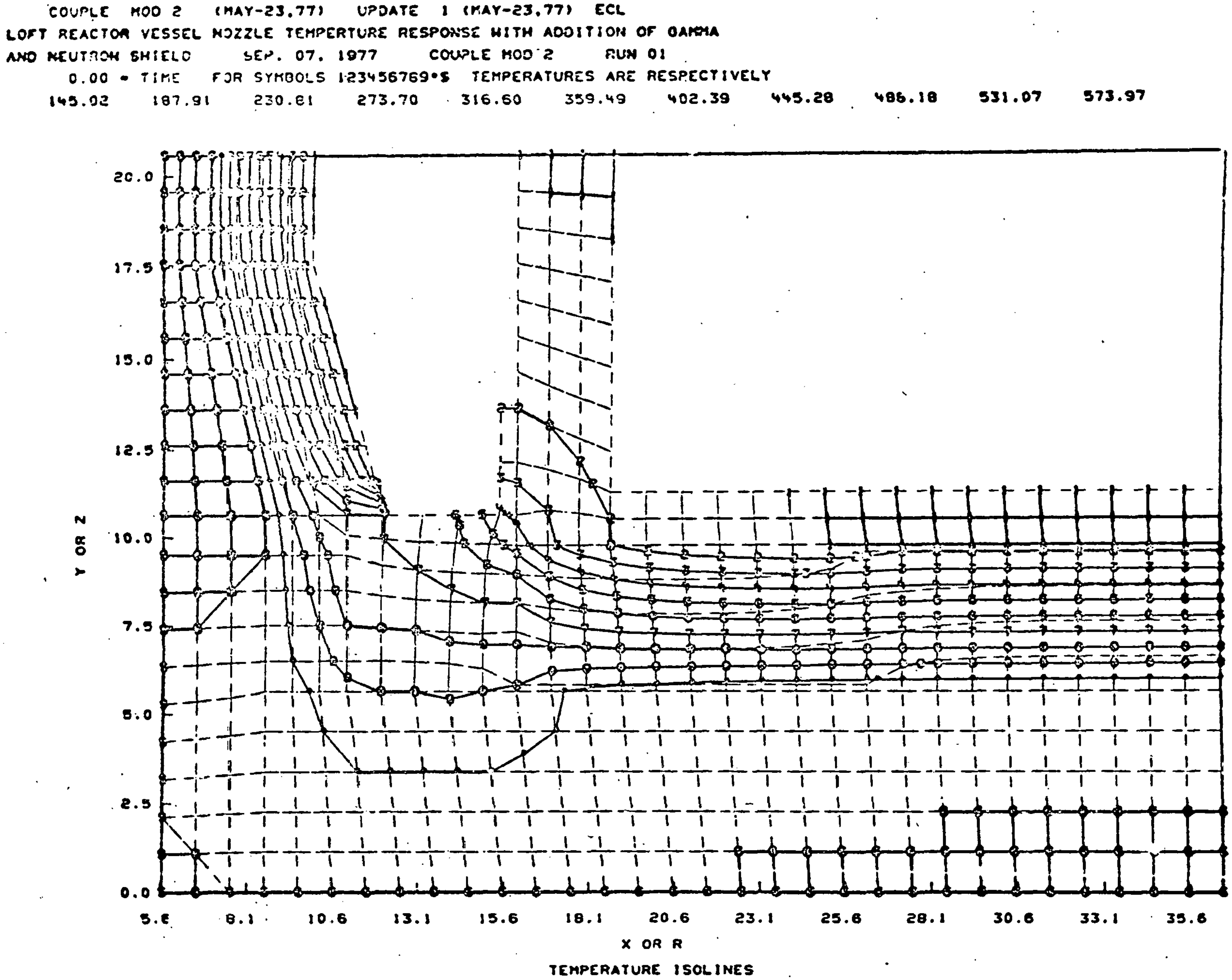


Figure 4. COUPLE/MOD2 Update 1 LOFT Reactor Vessel Nozzle Temperature Response with Addition of Gamman and Neutron Shield - Temperature Isolines

APPENDIX A

SHIELD TANK WATER TEMPERATURE CALCULATIONS

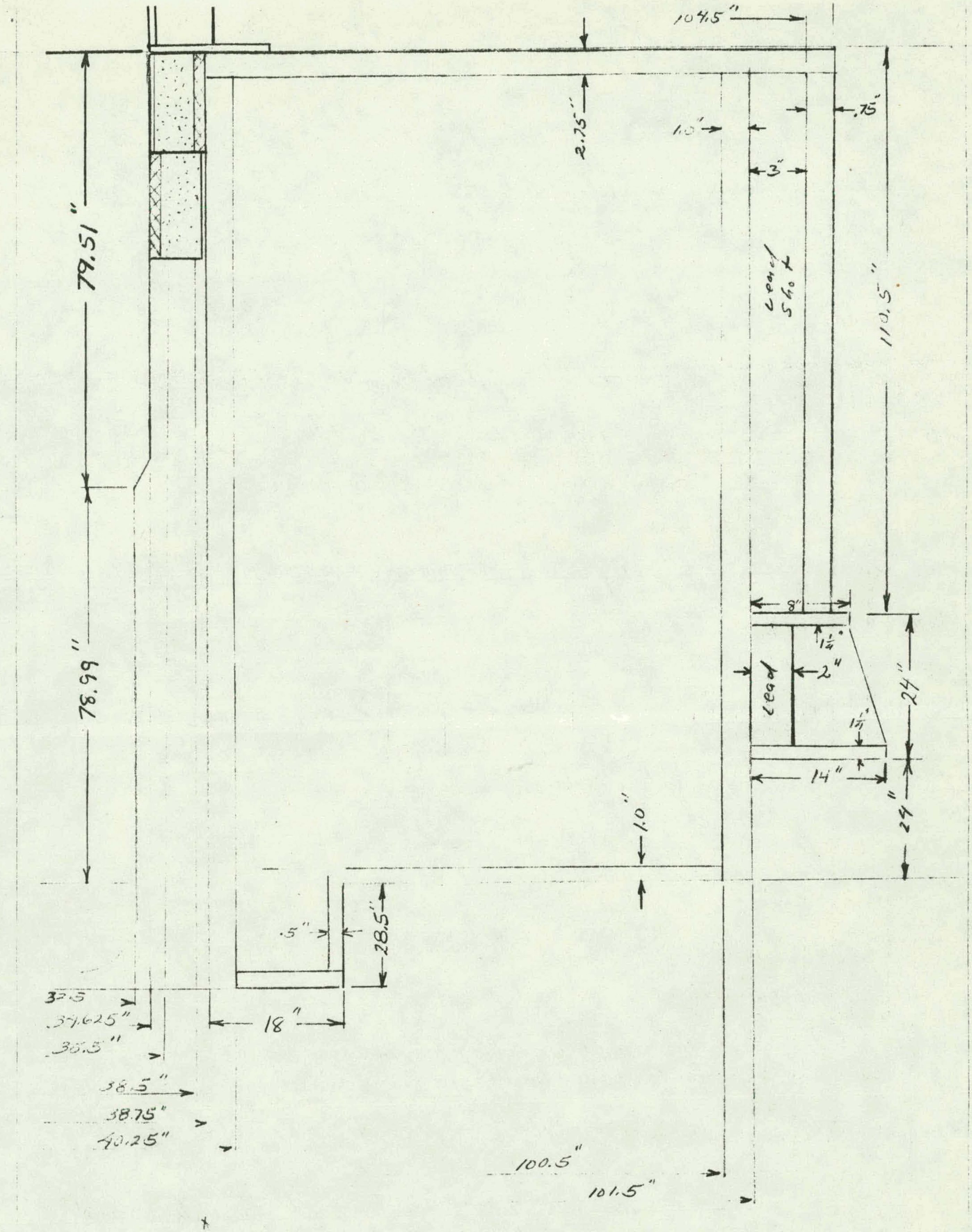
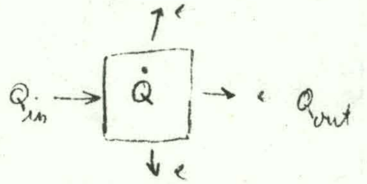


FIGURE A-1 DETAIL OF SHIELD TANK CROSS SECTION

In order to determine the water temperature an energy balance of the shield tank is considered.

$$Q_{in} + \dot{Q} = Q_{out}$$



Assuming a one dimensional system and applying the electrical analogy for a multilayered system.

$$Q = \frac{\Delta T}{\sum_i R_{th}}$$

We can write one equation with one unknown, the water temperature T_w.

$$Q_{out} = \frac{T_w - T_\infty}{\sum_i R_{out}} \qquad \text{where } \sum_i R = \sum \frac{1}{A_i h_i} + \frac{\ln R/r}{2\pi k L_j}$$

$\dot{Q}$ = gamma & neutron heating

$$Q_{in} = \frac{T_{R.V.} - T_w}{\sum_i R_i}$$

Additional assumptions

(1) $T_\infty = 100°F$ the most probable maximum ambient temp. of the containment building.

(2) $T_{RV} = 574°F$ The exterior temperature of the reactor vessel.

(3) The film coefficients do not vary greatly with temperature and can be estimated for the temperature ranges involved.

(4) Hinges & attaching clips for the neutron shield are ignored

Detail of gamma & neutron shield is given on page A-3 in Fig. A-2

3

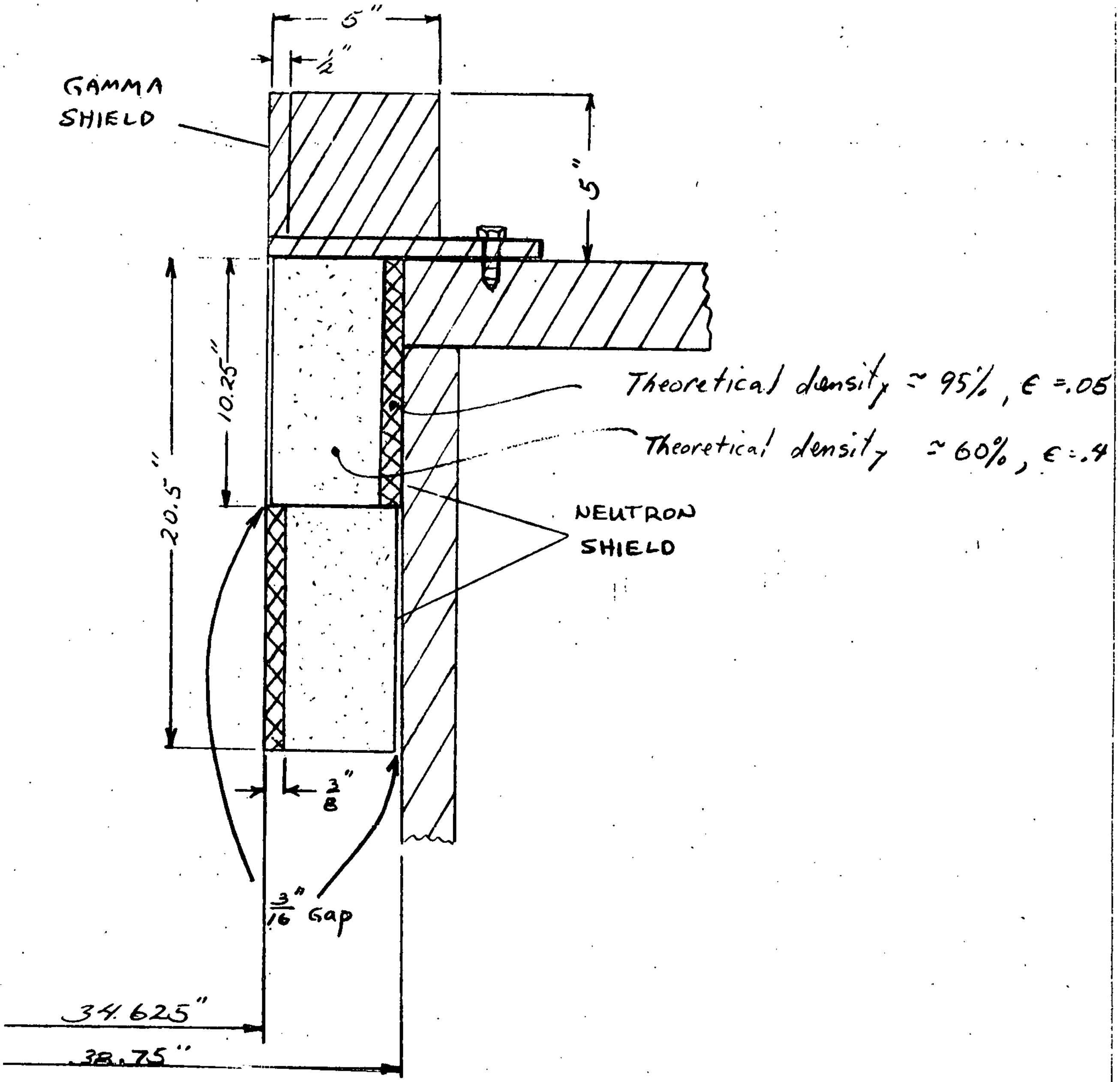


FIGURE A-2 DETAIL OF GAMMA & NEUTRON SHIELD.

Applying hand calculation method to original shield tank configuration for comparison to SIMIR run as an accuracy check Ref. (3)

$$\dot{Q}_{in} + \dot{Q} = \dot{Q}_{out}$$

$T_{RV} = 560°F$ used in SIMIR program

$$\frac{560 - T_W}{\dfrac{1}{2\pi\left(\frac{35}{12}ft\right)\left(\frac{79.51}{12}ft\right) \underset{\overset{\nearrow}{3.9\,\frac{Btu}{hr\,ft^2\,°F}}}{h_{air}}} + \dfrac{\ln\frac{38.50}{35.50}}{\underset{\overset{\uparrow}{.05\,\frac{Btu}{hr\,ft\,°F}}}{k_I}\, 2\pi\left(\frac{79.51}{12}ft\right)} + \dfrac{\ln\frac{38.75}{38.50}}{\underset{\overset{\nearrow}{.142\,\frac{Btu}{hr\,ft\,°F}}}{k_{air}}\, 2\pi\left(\frac{79.51}{12}ft\right)} + \dfrac{\ln\frac{40.25}{38.75}}{\underset{\overset{\nearrow}{30.96\,\frac{Btu}{hr\,ft\,°F}}}{k_{steel}}\, 2\pi\left(\frac{79.51}{12}ft\right)} + \dfrac{1}{2\pi\left(\frac{40.25}{12}ft\right)\left(\frac{79.51}{12}ft\right) \underset{\overset{\nearrow}{45.8\,\frac{Btu}{hr\,ft\,°F}}}{h_{water}}}}$$

$$+ \frac{560 - T_W}{\dfrac{1}{2\pi\left(\frac{34}{12}\right)\left(\frac{78.99}{12}\right) 4} + \dfrac{\ln\frac{38.5}{39.5}}{.05(2\pi)\left(\frac{78.99}{12}\right)} + \dfrac{\ln\frac{38.75}{38.5}}{.142(2\pi)\left(\frac{78.99}{12}\right)} + \dfrac{\ln\frac{40.25}{38.75}}{30.96(2\pi)\left(\frac{78.99}{12}\right)} + \dfrac{1}{2\pi\left(\frac{40.25}{12}\right)\left(\frac{78.99}{12}\right)(45.8)}}$$

$$+ \frac{560 - T_W}{\dfrac{1}{2\pi\left(\frac{35}{12}\right)\left(\frac{28.5}{12}\right)3.9} + \dfrac{\ln\frac{38.5}{35.5}}{.05(2\pi)\left(\frac{28.5}{12}\right)} + \dfrac{\ln\frac{38.75}{38.5}}{.142(2\pi)\left(\frac{28.5}{12}\right)} + \dfrac{\ln\frac{40.25}{38.75}}{30.96(2\pi)\left(\frac{28.5}{12}\right)}}$$

$$+ 9000\,\frac{Btu}{hr} + 21{,}000\,\frac{Btu}{hr} = Q_{out}$$

or

$$\frac{560 - T_W}{4.229 \times 10^{-2}} + \frac{560 - T_W}{4.265 \times 10^{-2}} + \frac{560 - T_W}{.1178} + 30{,}000 = Q_{out}$$

In calculating Q_{out} =

$$\frac{T_W - 100}{\dfrac{1}{2\pi\left(\frac{100.5}{12}\right)\left(\frac{107.75}{12}\right)\underset{\underset{36.4}{\uparrow}}{h_{water}}} + \dfrac{\ln\frac{101.5}{100.5}}{\underset{\underset{30.45}{\uparrow}}{h_{steel}}(2\pi)\left(\frac{107.75}{12}\right)} + \dfrac{\ln\frac{104.5}{101.5}}{\underset{\underset{.29}{\uparrow}}{k_{lead\ shot}}(2\pi)\left(\frac{107.75}{12}\right)} + \dfrac{\ln\frac{105.25}{104.5}}{\underset{\underset{30.45}{\uparrow}}{k_{steel}}\, 2\pi\left(\frac{107.75}{12}\right)} + \dfrac{1}{2\pi\left(\frac{107.75}{12}\right)\left(\frac{105.25}{12}\right)\underset{\underset{1.57}{\uparrow}}{h_{air}}}}$$

$$+ \frac{T_W - 100}{\dfrac{1}{2\pi\left(\frac{100.5}{12}\right)(2)(36.4)} + \dfrac{\ln\frac{101.5}{100.5}}{30.45(2\pi)(2)} + \dfrac{\ln\frac{103.5}{101.5}}{\underset{\underset{20}{\uparrow}}{k_{lead}}(2\pi)\,2'} + \dfrac{1}{2\pi\left(\frac{103.5}{12}\right)(2)(1.57)}}$$

$$+ \frac{T_W - 100}{\dfrac{1}{2\pi\left(\frac{100.5}{12}\right)\left(\frac{23}{12}\right)(36.4)} + \dfrac{\ln\frac{101.5}{100.5}}{30.45(2\pi)\frac{23}{12}} + \dfrac{1}{2\pi\left(\frac{101.5}{12}\right)\left(\frac{23}{12}\right)(1.57)}}$$

+ Q_{out} Top & bottom of shield tank + Q_{out} flange below lead shot compartment.

For Q_{out} top & bottom of shield tank, an effective area must be determined. $A_H = \frac{.2\pi}{144}(100.5^2 - 40.25^2) + \frac{2/3\,\pi}{144}(100.5^2 - 40.25^2) = 160\ ft^2$

$\therefore$ Q_{out} Top & bottom of shield tank $= \dfrac{T_W - 100}{\dfrac{1}{160\ ft^2 \times 1.57}} = \dfrac{T_W - 100}{3.981\times10^{-3}}$

The 20% effective heat transfer for the top and the 2/3 effective for the bottom assumption is from Ref. (4)

For the flange, only the bottom one and the 16 vertical webs are considered, and are treated as cooling fins.

From pp 540 - 542 of Kern Ref.(9)

$$(r_e - r_b)\sqrt{h_f/k y_b} \simeq 1\sqrt{\frac{1.3}{30.45\times\frac{1.25}{24}}} \simeq 1$$

$$\frac{r_e}{r_b} = \frac{115.5}{103.5} = 1.5 \longrightarrow \Omega \simeq .74$$

$$h_b = h_f\,\Omega = 1.3\times.74 = .962$$

$$Q_b = h_b\,\Theta_b\,A_f$$

$$A_f = \frac{2\pi\,(115.5^2 - 103.5^2)}{144} + \frac{2\pi\,(115.5)(1.25)}{144} = 121\ ft^2$$

$$Q = \frac{T_w - 100}{\frac{1}{(121)(.962)}} = \frac{T_w - 100}{8.591\times10^{-3}}$$

For the 16 vertical webs again from Kern

$$Q_b = h_b\,\Theta_b\,b\,P\times16 \qquad \text{P 576 of Kern}$$

$$h_b = h_f\,\Omega \qquad \Omega = \frac{\tanh(mb)}{mb}$$

$$m = \left[\frac{h_f P}{k a_x}\right]^{1/2}$$

$h_f = 1.3\ \frac{Btu}{hr\,ft^2\,°F}$

P = Perimeter of fin $2/12 + .75 + .75 = 1.67$ ft

$k = 30.45\ \frac{Btu}{hr\,ft\,°F}$

a_x = cross section area of fin $= \frac{1}{12}\times1.79 = .15\ ft^2$

b = height of fin $\simeq \frac{9}{12} = .75$ ft

$$\therefore\ m = \left(\frac{1.3\times1.67}{30.45\times.15}\right)^{1/2} = .60894\ ft$$

$$mb = .517\ ; \quad \Omega = \frac{\tanh(.517)}{.517} = .91\ , \quad h_b = .91\times1.3 = 1.18$$

$$Q = \frac{T_w - 100}{\frac{1}{16\,h_b\,b\,P}} = \frac{T_w - 100}{\frac{1}{16(1.18)(.75)(1.67)}} = \frac{T_w - 100}{4.2288\times10^{-2}}$$

and finally across annular portion below shield tank

$$\frac{T_W - 100}{\dfrac{1}{2\pi\left(\frac{56.25}{12}\right)\left(\frac{28.5}{12}\right)(36.4)} + \dfrac{\ln\frac{56.75}{56.25}}{30.45(2\pi)\left(\frac{28.5}{12}\right)} + \dfrac{1}{2\pi\left(\frac{56.75}{12}\right)\left(\frac{28.5}{12}\right)1.57}} = \frac{T_W - 100}{9.438 \times 10^{-3}}$$

collecting terms

$$\frac{560 - T_W}{4.229 \times 10^{-2}} + \frac{560 - T_W}{4.265 \times 10^{-2}} + \frac{560 - T_W}{.1178} + 30,000 = \frac{T_W - 100}{3.135 \times 10^{-3}} + \frac{T_W - 100}{6.22 \times 10^{-3}} + \frac{T_W - 100}{6.552 \times 10^{-3}}$$

$$+ \frac{T_W - 100}{3.981 \times 10^{-3}} + \frac{T_W - 100}{8.591 \times 10^{-3}} + \frac{T_W - 100}{4.229 \times 10^{-2}} + \frac{T_W - 100}{9.438 \times 10^{-3}}$$

$$560(55.58) - (55.58)T_W + 30,000 = (1129.57)T_W - 100(1129.57)$$

$$T_W = \frac{174081.8}{1185.15} = 146.88 \qquad \text{SIMIR} \rightarrow 136$$

8% high

Let it then be assumed that hand calculations are 8% on the high side.

Equation to solve:

$$\frac{574°F - T_w}{\sum R_{in}} + \dot{Q} = \frac{T_w - 100°F}{\sum' R_{out}}$$

$Q_{in} =$

across top plug

$$\frac{574 - T_w}{\frac{\ln\frac{38.75}{38.375}}{3.033(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{38.375}{34.6875}}{.187(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{34.6875}{34.625}}{.142(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{40.25}{38.75}}{30.96(2\pi)\frac{10.25}{12}} + \frac{1}{2\pi(\frac{40.25}{12})(\frac{10.25}{12})(45.8)}}$$

$\epsilon = .05$ $\epsilon = .4$ air steel water film

across bottom plug

$$\frac{574 - T_w}{\frac{\ln\frac{38.75}{38.6815}}{.142(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{38.6875}{35.00}}{.187(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{35.0}{34.625}}{3.033(2\pi)\frac{10.25}{12}} + \frac{\ln\frac{40.25}{38.75}}{30.96(2\pi)\frac{10.25}{12}} + \frac{1}{2\pi(\frac{40.25}{12})(\frac{10.25}{12})(45.8)}}$$

across section from bottom of neutron shield to shoulder in reactor vessel.

$$\frac{574 - T_w}{\frac{1}{2\pi(\frac{35}{12})(\frac{59.01}{12})(3.9)} + \frac{\ln\frac{38.5}{35.5}}{.05(2\pi)(\frac{59.01}{12})} + \frac{\ln\frac{38.75}{38.5}}{.142(2\pi)(\frac{59.01}{12})} + \frac{\ln\frac{40.25}{38.75}}{30.96(2\pi)(\frac{59.01}{12})} + \frac{1}{2\pi(\frac{40.25}{12})(\frac{59.01}{12})(46.8)}}$$

air gap insulation

to bottom of shield tank

$$\frac{574 - T_w}{\frac{1}{\pi(\frac{34}{12})(\frac{78.99}{12})4} + \frac{\ln\frac{38.5}{35.5}}{.05(2\pi)(\frac{78.99}{12})} + \frac{\ln\frac{38.75}{38.5}}{.142(2\pi)(\frac{78.99}{12})} + \frac{\ln\frac{40.25}{38.75}}{.96(2\pi)(\frac{78.99}{12})} + \frac{1}{2\pi(\frac{40.25}{12})(\frac{78.99}{12})(45.8)}}$$

air gap

thru 28½" section @ bottom of
Shield Tank

$$\frac{574 - T_w}{\dfrac{1}{2\pi\left(\frac{35}{12}\right)\left(\frac{28.5}{12}\right)3.9} + \dfrac{\ln\frac{38.5}{35.5}}{.05(2\pi)\left(\frac{28.5}{12}\right)} + \dfrac{\ln\frac{38.75}{38.50}}{.142(2\pi)\left(\frac{28.5}{12}\right)} + \dfrac{\ln\frac{40.25}{38.75}}{30.96(2\pi)\left(\frac{28.5}{12}\right)}}$$

thru gamma shield & bolts in
shield tank

$$\frac{574 - T_w}{\dfrac{1}{\frac{\pi}{4}\frac{(.5)^2}{144}(45.8)(32)} + \dfrac{3.25/12}{(30.96)\frac{\pi}{4}\frac{(.5)^2}{144}(32)}}$$

$+ 9000 \frac{Btu}{hr} + 21,000 \frac{Btu}{hr}$

Reactor vessel support lugs

gamma & neutron heating of shield tank water

$= Q_{out}$

across lead shot compartment

$$\frac{T_w - 100}{\dfrac{1}{2\pi\left(\frac{100.5}{12}\right)\left(\frac{107.75}{12}\right)(36.4)} + \dfrac{\ln\frac{101.5}{100.5}}{30.45(2\pi)\left(\frac{107.75}{12}\right)} + \dfrac{\ln\frac{104.5}{101.5}}{.29(2\pi)\left(\frac{107.75}{12}\right)} + \dfrac{\ln\frac{105.25}{104.5}}{30.45(2\pi)\left(\frac{107.75}{12}\right)} + \dfrac{1}{2\pi\left(\frac{107.75}{12}\right)\left(\frac{105.25}{12}\right)1.57}}$$

10

across lead sheet

$$+\frac{T_w - 100}{\frac{1}{2\pi(\frac{100.5}{12})(2)(36.4)} + \frac{\ln\frac{101.5}{100.5}}{30.45(2\pi)(2)} + \frac{\ln\frac{103.5}{101.5}}{20(2\pi)(2)} + \frac{1}{2\pi(\frac{103.5}{12})(2)(1.57)}}$$

across Tank section below flange

$$+\frac{T_w - 100}{\frac{1}{2\pi(\frac{100.5}{12})(\frac{23}{12})(36.4)} + \frac{\ln\frac{101.5}{100.5}}{30.45(2\pi)\frac{23}{12}} + \frac{1}{2\pi(\frac{101.5}{12})(\frac{23}{12})(1.57)}}$$

across shield tank
top & bottom

$$+\frac{T_w - 100}{\frac{1}{(160\,ft^2)(1.57)}}$$

across small section below
shield tank

$$+\frac{T_w - 100}{\frac{1}{2\pi(\frac{56.25}{12})(\frac{28.5}{12})(36.4)} + \frac{\ln\frac{56.75}{56.25}}{30.45(2\pi)(\frac{28.5}{12})} + \frac{1}{2\pi(\frac{56.75}{12})(\frac{28.5}{12})(1.57)}}$$

thru flanges below lead
shot compartment

$$+\frac{T_w - 100}{\frac{1}{(.962)(121\,ft^2)}} + \frac{T_w - 100}{\frac{1}{16(.75')(1.67')(1.18)}}$$

$$\frac{574-T_w}{.105}+\frac{574-T_w}{.104}+\frac{574-T_w}{5.222\times10^{-2}}+\frac{574-T_w}{4.265\times10^{-2}}+\frac{574-T_w}{.1178}+$$

$$\frac{574-T_w}{.7009}+9000+21,000=\frac{T_w-100}{3.135\times10^{-3}}+\frac{T_w-100}{6.22\times10^{-3}}+\frac{T_w-100}{6.552\times10^{-3}}$$

$$+\frac{T_w-100}{3.981\times10^{-3}}+\frac{T_w-100}{9.438\times10^{-3}}+\frac{T_w-100}{8.591\times10^{-3}}+\frac{T_w-100}{4.229\times10^{-2}}$$

$$(574)(71.65)-(71.65)T_w+30,000=(1129.57)T_w-100(1129.57)$$

$$T_w=\frac{184084.1}{1201.22}$$

$$T_w=153.2\ F$$

assuming this 8% high

$$\underline{\underline{T_w=140°F}}$$

APPENDIX B

COMPUTER MODEL CALCULATIONS AND COUPLE/MOD2 INPUT AND OUTPUT LISTING

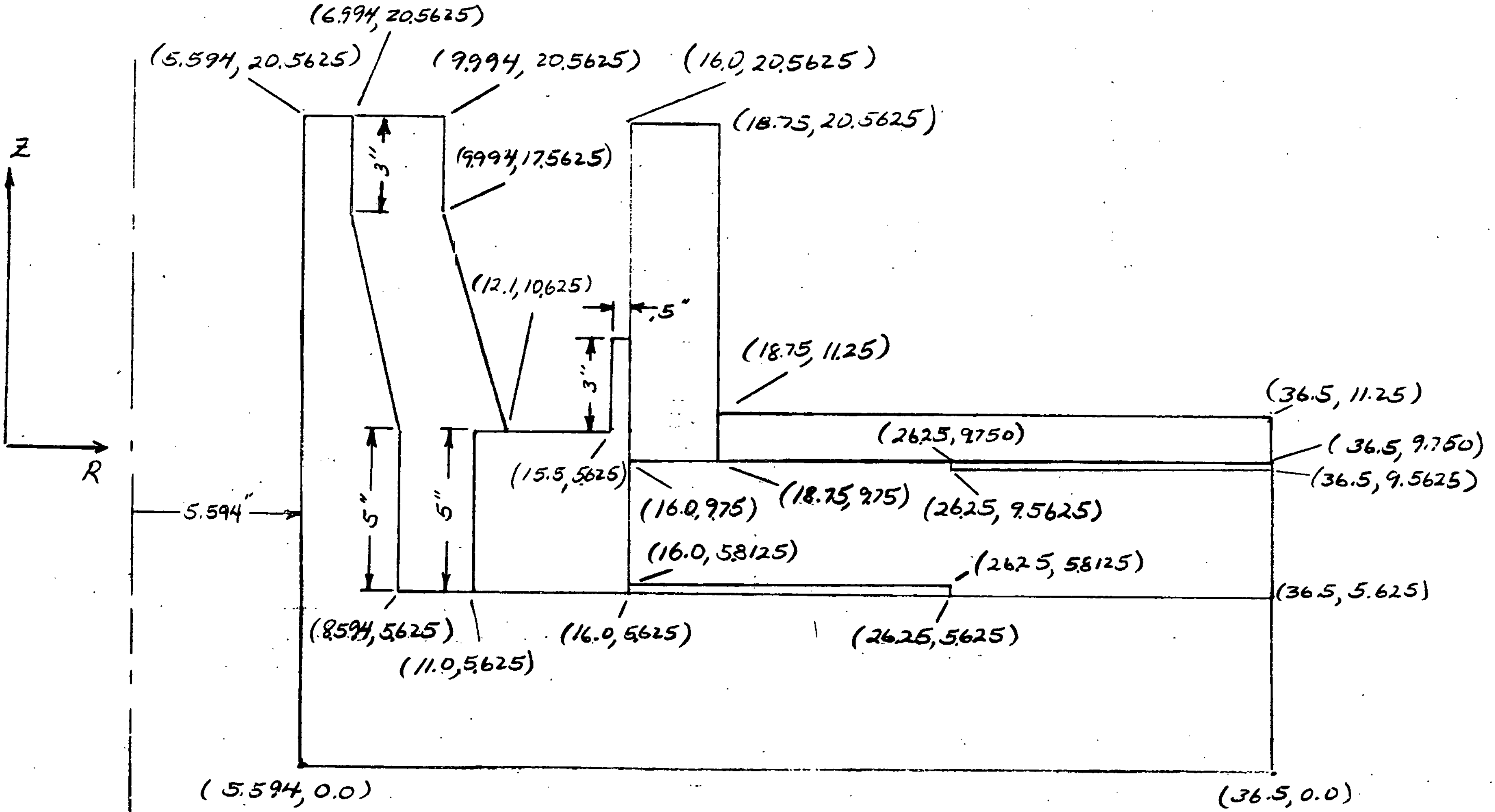


FIGURE B-1 Model Coordinates

8/1/77

For vertical surfaces

$$h_T = h_c + h_r$$

$$h_c = 0.19 (\Delta T_1)^{1/3}$$

$$h_r = \frac{0.122 [T_2^4 - T_1^4]}{10^8 [T_2 - T_1]}$$

For horizontal surfaces

$$h_c = 0.22 \Delta t_1^{1/3}$$

$t_2 = 574°F$
$t_1 = 400°F$ assumed

T in °R

$$h_r = \frac{0.122 [T_2^4 - T_1^4]}{10^8 [T_2 - T_1]}$$

$$h_c = 0.22 (174)^{1/3} = 1.23$$

$$h_r = \frac{0.122 [10.34^4 - 8.60^4]}{174} = 4.\text{[illegible]}$$

$$h_T = 5.41 \frac{Btu}{hr\ ft^2\ °F}$$

suppose $t_2 = 100°F = 560°R$

$$h_c = 0.22 (474)^{1/3} = 1.715$$

$$h_r = \frac{.122 [10.34^4 - 5.60^4]}{474} = 2.69$$

$$h_T = 4.41$$

suppose $t_2 = 200°F = 660°F$

$$h_c = 0.22 (374)^{1/3} = 1.585$$

$$h_r = \frac{.122 (10.34^4 - 6.6^4)}{374} = 3.11$$

$$h_T = 4.7$$

8/3/77

material properties for air gaps   COMPLE MOD 2 Input

∇f = Stefan-Boltzmann constant times emmissivity factor times geometric shape factor

$$F_r = \nabla f \left\{ (T_\infty + 460) + (T + 460) \right\} \left\{ (T_\infty + 460)^2 + (T + 460)^2 \right\}$$

T_∞ = driving temp °F

$$\nabla_f \simeq 1 \times .5 \times 0.1714 \times 10^{-8} \frac{Btu}{hr\,ft^2\,°R^4} = 8.57 \times 10^{-10} \frac{Btu}{hr\,ft^2\,R^4}$$; $K = (F_r + h)\Delta x$

$\Delta x = \frac{.875}{12}$, $h = 1.4$

$T_\infty = 574$

	T	T_m	F_r	K_e
	200	387	2.18	.261
	300	437	2.53	.287
inner air gap	400	487	2.94	.317
	500	537	3.40	.350
	574	574	3.79	.378

$T_\infty = 300$

	T	T_m	F_r	K_e
outer air gap	100	200	1.0082	.175
	200	250	1.233	.192
	300	300	1.5	.211

ρC

T °F	ρ @ 12.5 psia lbm/ft³	C Btu/lbm °F	ρC $\frac{Btu}{ft^3\,°F}$
80.6	.0624	.2402	.015
170.6	.0529	.2410	.013
260.6	.0468	.2422	.011
350.6	.0415	.2438	.010
440.6	.0373	.2459	.0092
530.6	.0340	.2482	.0084
620.6	.0311	.2520	.0078

Ambient air

$$h_T = 0.19(\Delta t)^{1/3} + .122\left[\frac{(560+\Delta t)^4 - 560^4}{10^8\,\Delta t}\right]$$

h_T	Δt °F
1.049	1
1.193	5
1.290	10
1.361	15
1.420	20
1.603	40
1.749	60
1.877	80
1.997	100
2.546	200
3.096	300

h_T	Δt °F
3.690	400

8/3/77

Film Coefficient for Water

$h = A(\Delta t_f)^{1/3}$ see figure A-2 of LOFT Report A-70 Note 10/24/69 LOFT Shield Tank Temperature Study For Steady-State Operating Conditions.

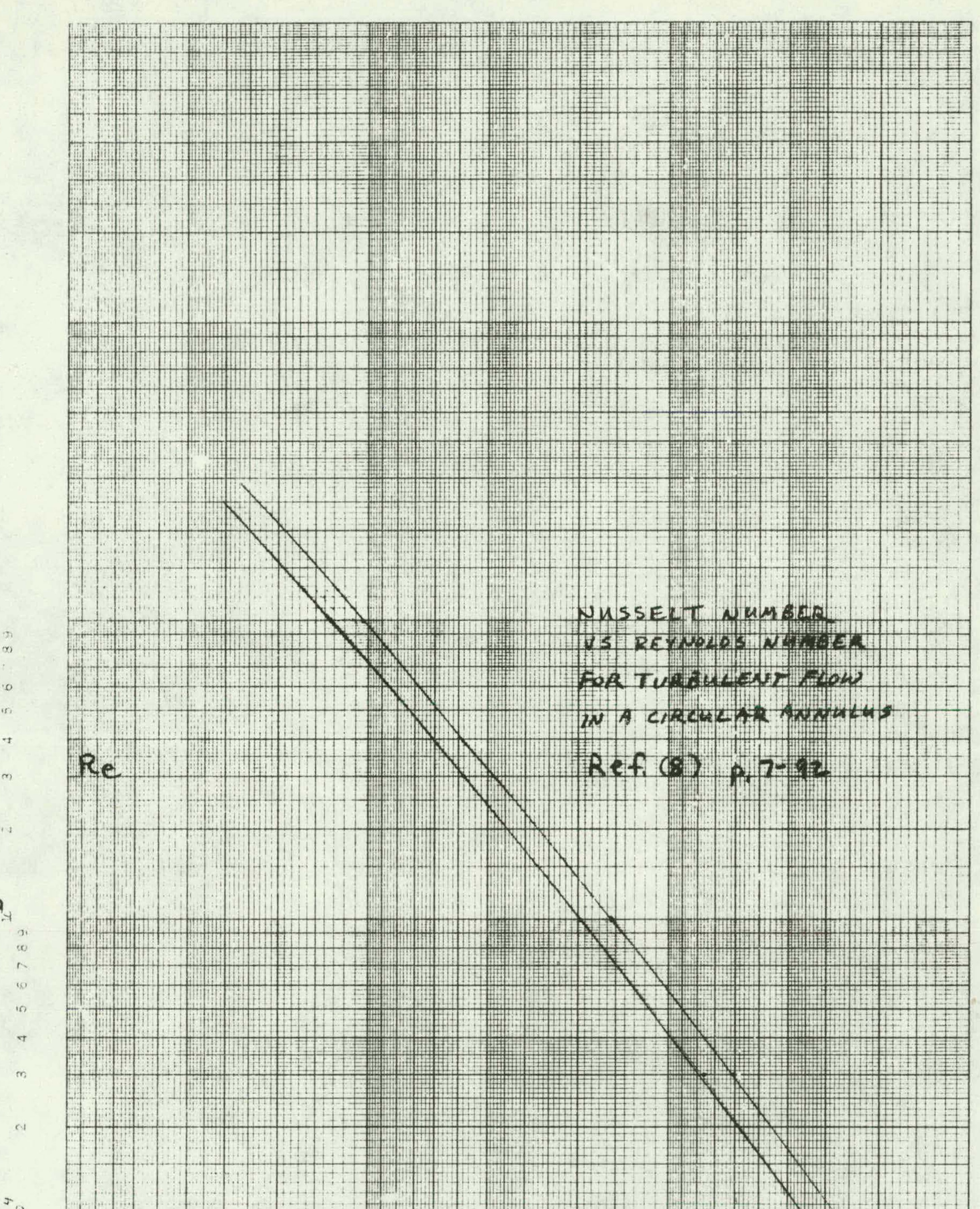
If the film temperature is assumed to be 140°F then:

$h_c / \Delta t^{1/3} = 50.4$

and $h_c = 50.5 \Delta t^{1/3}$

Δt	h_c
1	50.4
2	63.5
3	72.7
4	80.8
5	86.2
6	91.6
7	96.4
8	100.8
9	104.8
10	108.6
15	124.3
20	136.8

COUPLE MOD 2 Input



NUSSELT NUMBER
VS REYNOLDS NUMBER
FOR TURBULENT FLOW
IN A CIRCULAR ANNULUS

Ref. (8) p. 7-92

FIGURE B-2

9/6/77

In the 1/4" downcomer annulus

$Re = \frac{D_e G}{\mu}$ $\quad D_e = 2(r_o - r_i) = 2 \times \frac{1}{4} = .5'' = .0417 ft$

$G = \rho v$

From Steam tables

@ 574°F, 2250 psi = 155 bars

$v = 1/\rho = .02197$

$\rho = 45.5\ lb_m/ft^3$

$\mu = 918 \times .0672 \times 10^{-6} = 6.169 \times 10^{-5}\ \frac{lb_m}{ft\,sec}$

$\dot{m} = 2.13 \times 10^6\ lb_m/hr$

but thru 1/4" annulus

$\dot{m}$ is 1/10 of 2.13×10^6

$\therefore \dot{m}_{1/4} = 2.13 \times 10^5\ lb_m/hr$

$\dot{m} = \rho v A$

$\rho v = \dot{m}/A = G$ $\qquad A = \frac{\pi(29 in^2 - 28.75 in^2)}{144\ in^2/ft^2} = .315\ ft^2$

$\therefore G = 2.13 \times 10^5 \frac{lb_m}{hr} \Big/ (.315\ ft^2 \times 3600 \frac{sec}{hr})$

$G = 187.8\ \frac{lb_m}{ft^2 sec}$

$$Re = \frac{\frac{2}{12}(29 - 28.75)\,ft \times (187.8\ \frac{lb_m}{ft^2 sec})}{6.169 \times 10^{-5}\ \frac{lb_m}{ft\,sec}} = 1.268 \times 10^5$$

$P_r = \frac{\hat{C}_p \mu}{k}$ $\qquad \hat{C}_p^{-1} = .77$ From Steam Tables, ASME

$\hat{C}_p^{-1} \simeq 1.3\ \frac{Btu}{lb_m °F}$

$\mu = 6.169 \times 10^{-5}\ \frac{lb_m}{ft\,sec} \times 3600\ \frac{sec}{hr}$

$k = .322\ \frac{Btu}{hr\,ft\,°F}$

$P_r = .896$, From Chart $P_r = .893$; close

From Table 24 p. 7-92 Handbook of Heat Transfer (extrapolated)

$N_u \simeq 235 = \frac{h D_e}{k}$ $\quad \therefore h = \frac{235 \times .322}{.0417} \frac{Btu}{hr\,ft\,°F} = \boxed{1{,}815\ \frac{Btu}{hr\,ft^2\,°F}}$

COUPLE MODEL INPUT

In nozzle

$D = 11.2''$ $A = \frac{\pi}{4}\frac{11.2^2}{144} = .684\ ft^2$

$R_e = \frac{DG}{\mu}$ $G = \frac{\dot{m}}{A} = \frac{2.13 \times 10^6\ lbm/hr}{.684\ ft^2 \times 3600\frac{sec}{hr}} = 865\ \frac{lbm}{ft^2\,sec}$

$$R_e = \frac{\frac{11.2}{12}ft \times 865\ \frac{lb_m}{ft^2 sec}}{6.169 \times 10^{-5}} = 1.3087 \times 10^7$$ turbulent

$N_u = (.022)\,R_e^{0.8}\,P_r^{0.6}$ Ref(8) Handbook of Heat Transfer eq. 48 p 7-33

$R_e = 1.3087 \times 10^7$

$P_r \simeq .896$

$Nu \simeq (.022)(1.3087 \times 10^7)^{0.8}(.896)^{0.6}$

$Nu \simeq 10,169$

$$h = \frac{Nu\,k}{D} = \frac{10169 \times .322\ \frac{Btu}{hr\,ft\,^\circ F}}{11.2/12\ ft}$$

$h = 3,508\ \frac{Btu}{hr\,ft^2\,^\circ F}$ COUPLE MOD2 Input

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0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

TITLE
LOFT REACTOR VESSEL NOZZLE TEMPERTURE RESPONSE WITH ADDITION OF GAMMA
AND NEUTRON SHIELD      SEP. 07, 1977     COUPLE MOD 2      RUN 01

MATERIAL
   4    1
  01        1.0     CARBON STEEL
 2.3148E-5 2.3148E-5 578.70E-6    1    1    2
  02        1.0     NEUTRON SHIELD TIH1.6 & B4C
 2.3148E-5 2.3148E-5 578.70E-6    3    3    4
  03        1.0     REACTOR VESSEL INSULATION
 2.3148E-5 2.3148E-5 578.70E-6    5    5    6
  04        1.0     AIR GAP BETWEEN RV & SHIELD TK
 2.3148E-5 2.3148E-5 578.70E-6    7    7    8

MESHTAPE
  510       452    0              0    0

STEP
    0.0    3600.0               16    0 574.       -10    0


FUNCTIONS
   16
    1   12    2     THERMAL CONDUCTIVITY OF CARBON STEEL BTU/HR,FT,F
   70.       31.50   100.       31.00    150.        30.50
  200.       30.00   250.       29.50    300.        29.10
  350.       28.60   400.       28.10    450.        27.60
  500.       27.20   550.       26.70    600.        26.20
    2   12    2     DENSITY * SPECIFIC HEAT OF CARBON STEEL BTU/FT**3,F
   70.        .5692  100.        .5609   150.         .5421
  200.        .5246  250.        .5079   300.         .4928
  350.        .4770  400.        .4616   450.         .4467
  500.        .4358  550.        .4198   600.         .4061
    3    4    2     THERMAL CONDUCTIVITY OF NEUTRON SHIELD BTU/HR,FT,F
   80.6       .3889  260.6       .3860   440.6        .3816
  620.6       .3785
    4    4    2     DENSITY * SPECIFIC HEAT OF NEUTRON SHIELD BTU/FT**3,F
   80.6    219.7849  260.6    273.6123   440.6     324.1604
  620.6    377.9683
    5    2    2     THERMAL CONDUCTIVITY OF R. V. INSULATION BTU/HR,FT,F
  100.0       .0504  600.0       .0504
    6    2    2     DENSITY * SPECIFIC HEAT OF R. V. INSULATION BTU/FT**3,F
  100.0      9.8496  600.0      9.8496
    7    6    2     THERMAL COND. IN AIR GAPS BETWEEN R.V. & SHLD TK BTU/HR,FT,F
  100.0       .1750  200.0       .1920   300.0        .2110
  400.0       .3170  500.0       .3500   574.0        .3780
    8    7    2     DENSITY * SPECIFIC HEAT OF AIR GAPS     BTU/FT**3,F
   80.6       .0150  170.6       .0130   260.6        .0110
  350.6       .0100  440.6       .0092   530.6        .0084

0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
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0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  620.6          .0078
     9  11     3     CONVECTION COEFF. FOR WATER IN SHIELD TK BTU/HR,FT**2,F
   1.0       50.4         2.0      63.5     3.0      72.7
   4.0       80.0         5.0      85.2     6.0      91.6
   7.0       96.4         8.0     100.8     9.0     104.8
  10.0      108.6        20.0     136.8
    10  12     3     CONVECTION COEFF. FOR AMBIENT AIR BTU/HR,FT**2,F
   1.0      1.049         5.0     1.193    10.0     1.290
  15.0      1.361        20.0     1.420    40.0     1.603
  60.0      1.749        80.0     1.877   100.0     1.997
 200.0      2.546       300.0     3.096   400.0     3.690
    11   2     3     OVERALL HEAT TRANSFER COEFF. INSIDE R.V. BTU/HR,FT**2,F
   1.0   1815.           50.0  1815.
    12   2     3     CONVECTION COEFF. IN R.V. NOZZLE BTU/HR,FT**2,F
   1.0   3500.           50.0  3500.
    13   2     1     TEMP. OF WATER IN SHIELD TANK   DEGREES F
   0.0      140.0      3600.0   140.0
    14   2     1     TEMP. OF AMBIENT AIR DEGREES F
   0.0      100.0      3600.0   100.0
    15   2     1     TEMP. OF WATER IN REACTOR VESSEL DEGREES F
   0.0      574.0      3600.0   574.0
    16   6     1     VARIABLE TIME INCREMENT
   0.0        5.0        55.0       5.0    60.0      60.0
 240.0       60.0       300.0     300.0  3300.0     300.0

CONVECTSETS
  102
  384  -1   385    1 1.9290E-6         9     1.0          13
  385  -1   387    2 1.9290E-6         9     1.0          13
  387  -1   390    1 1.9290E-6         9     1.0          13
  390  -1   393    3 1.9290E-6         9     1.0          13
  393  -1   395    2 1.9290E-6         9     1.0          13
  395  -1   397    1 1.9290E-6         9     1.0          13
  397  -1   399    2 1.9290E-6         9     1.0          13
  399  -1   400    1 1.9290E-6         9     1.0          13
  400  -1   402    2 1.9290E-6         9     1.0          13
  402  -1   407    1 1.9290E-6         9     1.0          13
  384  -1   413   29 1.9290E-6         9     1.0          13
  413  -1   418    5 1.9290E-6         9     1.0          13
  418  -1   432    7 1.9290E-6         9     1.0          13
  432  -1   436    4 1.9290E-6         9     1.0          13
  436  -1   441    5 1.9290E-6         9     1.0          13
  441  -1   449    4 1.9290E-6         9     1.0          13
  367  -1   412   45 1.9290E-6        10     1.0          14
  412  -1   419    7 1.9290E-6        10     1.0          14
  419  -1   459   40 1.9290E-6        10     1.0          14
  459  -1   488   29 1.9290E-6        10     1.0          14
  488  -1   508   20 1.9290E-6        10     1.0          14
  508  -1   513    1 1.9290E-6        10     1.0          14
  349  -1   367   18 1.9290E-6        10     1.0          14

0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
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0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  349   -1  350    11.9290E-6          10     1.0           14
  350   -1  352    21.9290E-6          10     1.0           14
  352   -1  379   271.9290E-6          10     1.0           14
  379   -1  408   291.9290E-6          10     1.0           14
  408   -1  409    11.9290E-6          10     1.0           14
  409   -1  414    51.9290E-6          10     1.0           14
  414   -1  420    61.9290E-6          10     1.0           14
  420   -1  427    71.9290E-6          10     1.0           14
  427   -1  433    61.9290E-6          10     1.0           14
  433   -1  438    51.9290E-6          10     1.0           14
  433   -1  446    41.9290E-6          10     1.0           14
    1   -1   32    11.9290E-6          11     1.0           15
    1   -1   47   461.9290E-6          12     1.0           15
   47   -1   81   341.9290E-6          12     1.0           15
   81   -1  110   291.9290E-6          12     1.0           15
  110   -1  145   351.9290E-6          12     1.0           15
  145   -1  186   411.9290E-6          12     1.0           15
  186   -1  206   201.9290E-6          12     1.0           15
  206   -1  253   471.9290E-6          12     1.0           15
  253   -1  274   211.9290E-6          12     1.0           15
  274   -1  317   431.9290E-6          12     1.0           15
  317   -1  351   341.9290E-6          12     1.0           15
  351   -1  392   411.9290E-6          12     1.0           15
  392   -1  429   371.9290E-6          12     1.0           15
  429   -1  450   211.9290E-6          12     1.0           15
  450   -1  452    11.9290E-6          12     1.0           15
  452   -1  456    41.9290E-6          12     1.0           15
  456   -1  458    21.9290E-6          12     1.0           15
  458   -1  460    21.9290E-6          12     1.0           15
  460   -1  461    11.9290E-6          12     1.0           15
PLOTS
    1    7    2    1
     5.594    36.500     0.000   20.5625
     5.594     8.594     0.000   20.5625
     6.594    12.125    10.625   20.5625
     8.594    26.500     0.000    5.625
     8.594    16.000     5.625   13.625
    16.000    35.500     5.625     9.75
    16.000    36.000     9.750   20.5625
COUPLE
END OF DATA
0        1         2         3         4         5         6         7         8
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     COUPLE  MOD 2   (MAY-23,77)   UPDATE  1 (MAY-23,77)  ECL
LOFT REACTOR VESSEL NOZZLE TEMPERATURE RESPONSE WITH ADDITION OF GAMMA
AND NEUTRON SHIELD      SEP. 07, 1977     COUPLE MOD 2      RUN 01

 N O D E   D A T A

NODE     R          Z           NODE     R          Z           NODE     R          Z           NODE     R          Z           NODE     R          Z
   1  5.59E+00  0.                 2  6.59E+00  0.                 3  7.59E+00  0.                 4  8.59E+00  0.                 5  9.59E+00  0.
   6  1.06E+01  0.                 7  1.16E+01  0.                 8  1.26E+01  0.                 9  1.36E+01  0.                10  1.46E+01  0.
  11  1.56E+01  0.                12  1.66E+01  0.                13  1.76E+01  0.                14  1.86E+01  0                 15  1.96E+01  0.
  16  2.05E+01  0.                17  2.15E+01  0.                18  2.25E+01  0.                19  2.35E+01  0.                20  2.45E+01  0.
  21  2.55E+01  0.                22  2.65E+01  0.                23  2.75E+01  0.                24  2.85E+01  0.                25  2.95E+01  0.
  26  3.05E+01  0.                27  3.15E+01  0.                28  3.25E+01  0.                29  3.35E+01  0.                30  3.45E+01  0.
  31  3.55E+01  0.                32  3.65E+01  0.                33  1.45E+01  1.13E+00          34  1.55E+01  1.13E+00          35  1.65E+01  1.13E+00
  36  1.75E+01  1.13E+00          37  1.85E+01  1.13E+00          38  1.95E+01  1.13E+00          39  2.05E+01  1.13E+00          40  2.15E+01  1.13E+00
  41  2.25E+01  1.13E+00          42  7.59E+00  1.10E+00          43  9.56E+00  1.13E+00          44  2.35E+01  1.13E+00          45  2.45E+01  1.13E+00
  46  1.09E+01  1.13E+00          47  6.59E+00  1.06E+00          48  6.59E+00  1.08E+00          49  1.35E+01  1.13E+00          50  8.59E+00  1.13E+00
  51  1.25E+01  1.13E+00          52  1.15E+01  1.13E+00          53  2.55E+01  1.13E+00          54  2.65E+01  1.13E+00          55  2.75E+01  1.13E+00
  56  2.85E+01  1.13E+00          57  2.95E+01  1.13E+00          58  3.05E+01  1.13E+00          59  3.15E+01  1.13E+00          60  3.25E+01  1.13E+00
  61  3.35E+01  1.13E+00          62  3.45E+01  1.13E+00          63  3.55E+01  1.13E+00          64  3.65E+01  1.13E+00          65  1.54E+01  2.25E+00
  66  1.64E+01  2.25E+00          67  1.74E+01  2.25E+00          68  1.84E+01  2.25E+00          69  6.59E+00  2.16E+00          70  1.94E+01  2.25E+00
  71  7.59E+00  2.20E+00          72  1.44E+01  2.25E+00          73  2.04E+01  2.25E+00          74  8.59E+00  2.25E+00          75  1.24E+01  2.25E+00
  76  1.05E+01  2.25E+00          77  2.14E+01  2.25E+00          78  1.34E+01  2.25E+00          79  2.24E+01  2.25E+00          80  2.34E+01  2.25E+00
  81  5.59E+00  2.11E+00          82  2.44E+01  2.25E+00          83  2.54E+01  2.25E+00          84  2.64E+01  2.25E+00          85  9.53E+00  2.25E+00
  86  1.14E+01  2.25E+00          87  2.74E+01  2.25E+00          88  2.84E+01  2.25E+00          89  2.94E+01  2.25E+00          90  3.05E+01  2.25E+00
  91  3.15E+01  2.25E+00          92  3.25E+01  2.25E+00          93  3.35E+01  2.25E+00          94  3.45E+01  2.25E+00          95  3.55E+01  2.25E+00
  96  3.65E+01  2.25E+00          97  1.52E+01  3.38E+00          98  1.62E+01  3.38E+00          99  1.72E+01  3.38E+00         100  1.83E+01  3.38E+00
 101  1.93E+01  3.38E+00         102  2.03E+01  3.38E+00         103  2.13E+01  3.38E+00         104  2.23E+01  3.38E+00         105  2.33E+01  3.38E+00
 106  2.43E+01  3.38E+00         107  2.53E+01  3.38E+00         108  2.64E+01  3.38E+00         109  7.59E+00  3.30E+00         110  5.59E+00  3.17E+00
 111  2.74E+01  3.36E+00         112  6.59E+00  3.23E+00         113  9.49E+00  3.37E+00         114  1.04E+01  3.37E+00         115  8.59E+00  3.33E+00
 116  1.42E+01  3 38E+00         117  1.33E+01  3.37E+00         118  1.13E+01  3.37E+00         119  1.23E+01  3.37E+00         120  2.64E+01  3.38E+00
 121  2.94E+01  3.38E+00         122  3.04E+01  3.38E+00         123  3.14E+01  3.38E+00         124  3.24E+01  3.38E+00         125  3.35E+01  3.38E+00
 126  3.45E+01  3.38E+00         127  3.55E+01  3.38E+00         128  3.65E+01  3.38E+00         129  1.41E+01  4.50E+00         130  1.51E+01  4.50E+00
 131  1.61E+01  4.50E+00         132  1.71E+01  4.50E+00         133  1.82E+01  4.50E+00         134  1.31E+01  4.50E+00         135  1.92E+01  4.50E+00
 136  1.22E+01  4.50E+00         137  2.02E+01  4.50E+00         138  2.12E+01  4.50E+00         139  2.22E+01  4.50E+00         140  2.32E+01  4.50E+00
 141  2.43E+01  4.50E+00         142  2.53E+01  4.50E+00         143  2.63E+01  4.50E+00         144  2.73E+01  4.50E+00         145  5.59E+00  4.22E+00
 146  2.83E+01  4.50E+00         147  2.94E+01  4.50E+00         148  7.59E+00  4.39E+00         149  6.59E+00  4.30E+00         150  3.04E+01  4.50E+00
 151  3.14E+01  4.50E+00         152  3.24E+01  4.50E+00         153  3.34E+01  4.50E+00         154  3.45E+01  4.50E+00         155  3.55E+01  4.50E+00
 156  9.59E+00  4.50E+00         157  1.12E+01  4.50E+00         158  3.65E+01  4.50E+00         159  1.03E+01  4.50E+00         160  9.45E+00  4.50E+00
 161  1.70E+01  5.63E+00         162  1.61E+01  5.63E+00         163  1.91E+01  5.63E+00         164  2.01E+01  5.63E+00         165  2.11E+01  5.63E+00
 166  2.22E+01  5.63E+00         167  2.32E+01  5.63E+00         168  2.42E+01  5.63E+00         169  2.52E+01  5.63E+00         170  2.63E+01  5.63E+00
 171  2.73E+01  5.63E+00         172  2.83E+01  5,63E+00         173  1.30E+01  5.63E+00         174  2.93E+01  5.63E+00         175  1.40E+01  5.63E+00
 176  3.04E+01  5.63E+00         177  1.50E+01  5.63E+00         178  1.60E+01  5.63E+00         179  3.14E+01  5.63E+00         180  3.24E+01  5.63E+00
 181  3.34E+01  5.63E+00         182  3.45E+01  5.63E+00         183  1.20E+01  5.63E+00         184  1.10E+01  5.63E+00         185  3.55E+01  5.63E+00
 186  5.59E+00  5.28E+00         187  7.59E+00  5.46E+00         188  3.65E+01  5.63E+00         189  6.59E+00  5.36E+00         190  1.02E+01  5.63E+00
 191  8.59E+00  5.63E+00         192  9.40E+00  5.63E+00         193  1.60E+01  5.81E+00         194  1.70E+01  5.81E+00         195  1.50E+01  6.28E+00
 196  1.81E+01  5.81E+00         197  1.91E+01  5.81E+00         198  2.01E+01  5.81E+00         199  2.11E+01  5.81E+00         200  2.22E+01  5.81E+00
 201  2.32E+01  5.81E+00         202  2.42E+01  5.81E+00         203  2.52E+01  5.81E+00         204  1.02E+01  6.50E+00         205  1.20E+01  6.51E+00
 206  5.59E+00  6.33E+00         207  2.63E+01  5.81E+00         208  1.10E+01  6.50E+00         209  2.73E+01  6.31E+00         210  2.83E+01  6.49E+00
 211  2.93E+01  6.56E+00         212  3.03E+01  6.59E+00         213  3.14E+01  6.60E+00         214  8.59E+00  6.50E+00         215  3.24E+01  6.60E+00
 216  3.34E+01  6.61E+00         217  3.45E+01  6.61E+00         218  3.55E+01  6.61E+00         219  1.40E+01  6.42E+00         220  1.30E+01  6.48E+00
 221  3.65E+01  6.61E+00         222  6.59E+00  6.39E+00         223  1.60E+01  7.31E+00         224  7.59E+00  6.45E+00         225  1.70E+01  6.99E+00
 226  1.80E+01  6.88E+00         227  1.90E+01  6.83E+00         228  9.40E+00  6.50E+00         229  2.00E+01  6.82E+00         230  2.11E+01  6.81E+00
 231  2.21E+01  6.82E+00         232  2.31E+01  6.84E+00         233  1.40E+01  7.30E+00         234  2.42E+01  6.88E+00         235  2.52E+01  6.96E+00
 236  2.63E+01  7.06E+00         237  2.73E+01  7.31E+00         238  2.83E+01  7.45E+00         239  6.59E+00  7.43E+00         240  2.93E+01  7.53E+00
 241  1.10E+01  7.50E+00         242  3.03E+01  7.56E+00         243  1.50E+01  7.26E+00         244  3.14E+01  7.58E+00         245  8.59E+00  7.50E+00
 246  1.02E+01  7.50E+00         247  3.24E+01  7.59E+00         248  9.40E+00  7.50E+00         249  7.59E+00  7,47E+00         250  3.34E+01  7.59E+00
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251  3.45E+01  7.59E+00   252  3.55E+01  7.59E+00   253  5.59E+00  7.39E+00   254  1.20E+01  7.43E+00   255  1.30E+01  7.36E+00
256  3.65E+01  7.59E+00   257  1.60E+01  8.13E+00   258  1.70E+01  7.96E+00   259  1.80E+01  7.87E+00   260  1.90E+01  7.83E+00
261  1.55E+01  8.12E+00   262  2.00E+01  7.71E+00   263  1.41E+01  8.17E+00   264  2.10E+01  7.81E+00   265  1.31E+01  8.24E+00
266  2.21E+01  7.82E+00   267  2.31E+01  7.55E+00   268  2.42E+01  7.92E+00   269  2.52E+01  8.06E+00   270  2.63E+01  8.31E+00
271  2.73E+01  8.42E+00   272  2.83E+01  8.49E+00   273  6.59E+00  8.46E+00   274  5.59E+00  8.44E+00   275  2.93E+01  8.53E+00
276  1.10E+01  8.50E+00   277  3.04E+01  8.56E+00   278  3.14E+01  8.57E+00   279  3.24E+01  8.57E+00   280  3.34E+01  8.55E+00
281  8.59E+00  8.58E+00   282  3.49E+01  8.58E+00   283  7.59E+00  8.48E+00   284  9.40E+00  8.50E+00   285  1.02E+01  8.50E+00
286  3.55E+01  9.01E+00   287  3.65E+01  8.58E+00   288  1.01E+01  8.97E+00   289  1.60E+01  8.94E+00   290  1.20E+01  8.35E+00
291  1.41E+01  8.75E+00   292  1.70E+01  8.87E+00   293  1.79E+01  9.82E+00   294  1.69E+01  8.60E+00   295  1.31E+01  9.09E+00
296  1.99E+01  8.79E+00   297  1.21E+01  9.22E+00   298  2.10E+01  8.78E+00   299  2.20E+01  8.79E+00   300  2.31E+01  8.82E+00
301  2.41E+01  9.56E+00   302  2.52E+01  9.07E+00   303  2.63E+01  9.56E+00   304  2.73E+01  9.55E+00   305  2.83E+01  9.55E+00
306  2.93E+01  9.50E+00   307  3.04E+01  9.56E+00   308  3.14E+01  9.56E+00   309  3.24E+01  9.56E+00   310  6.59E+00  9.50E+00
311  7.59E+00  9.56E+00   312  3.34E+01  9.56E+00   313  3.45E+01  9.56E+00   314  3.55E+01  9.56E+00   315  6.59E+00  9.50E+00
316  3.65E+01  9.56E+00   317  5.59E+00  9.50E+00   318  9.40E+00  9.50E+00   319  1.02E+01  9.50E+00   320  1.42E+01  9.63E+00
321  1.52E+01  9.79E+00   322  1.60E+01  9.75E+00   323  1.69E+01  9.75E+00   324  1.32E+01  9.87E+00   325  1.78E+01  9.75E+00
326  1.83E+01  9.75E+00   327  1.10E+01  9.50E+00   328  1.98E+01  9.75E+00   329  1.21E+01  9.94E+00   330  2.09E+01  9.75E+00
331  2.20E+01  9.75E+00   332  1.10E+01  1.01E+01   333  2.30E+01  9.75E+00   334  2.41E+01  9.75E+00   335  2.52E+01  9.75E+00
336  2.53E+01  9.75E+00   337  2.73E+01  9.75E+00   338  2.83E+01  9.75E+00   339  2.93E+01  9.75E+00   340  3.04E+01  9.75E+00
341  3.14E+01  9.75E+00   342  3.24E+01  9.75E+00   343  3.34E+01  9.75E+00   344  3.45E+01  9.75E+00   345  3.55E+01  9.75E+00
346  3.65E+01  9.75E+00   347  [illegible]  1.06E+01   348  7.59E+00  1.06E+01   349  1.33E+01  1.06E+01   350  1.44E+01  1.06E+01
351  5.59E+00  1.05E+01   352  1.55E+01  1.06E+01   353  1.60E+01  1.06E+01   354  9.40E+00  1.06E+01   355  1.69E+01  1.07E+01
356  1.78E+01  1.07E+01   357  1.88E+01  1.05E+01   358  1.98E+01  1.05E+01   359  8.59E+00  1.05E+01   360  2.09E+01  1.05E+01
361  2.19E+01  1.05E+01   362  2.30E+01  1.05E+01   363  2.40E+01  1.05E+01   364  1.02E+01  1.06E+01   365  2.51E+01  1.05E+01
366  2.51E+01  1.05E+01   367  1.21E+01  1.06E+01   368  2.72E+01  1.05E+01   369  2.82E+01  1.05E+01   370  2.93E+01  1.05E+01
371  3.03E+01  1.05E+01   372  3.13E+01  1.05E+01   373  3.24E+01  1.05E+01   374  3.34E+01  1.05E+01   375  3.44E+01  1.05E+01
376  3.55E+01  1.05E+01   377  1.10E+01  1.06E+01   378  3.65E+01  1.05E+01   379  1.55E+01  1.21E+01   380  1.60E+01  1.21E+01
381  1.59E+01  1.19E+01   382  1.78E+01  1.16E+01   383  7.44E+00  1.16E+01   384  1.88E+01  1.13E+01   385  1.98E+01  1.13E+01
386  8.37E+00  1.16E+01   387  2.03E+01  1.13E+01   388  2.19E+01  1.13E+01   389  2.29E+01  1.13E+01   390  2.40E+01  1.13E+01
391  9.16E+00  1.16E+01   392  5.59E+00  1.16E+01   393  2.50E+01  1.13E+01   394  9.95E+00  1.16E+01   395  2.61E+01  1.13E+01
396  2.71E+01  1.13E+01   397  2.81E+01  1.13E+01   398  6.52E+00  1.16E+01   399  2.92E+01  1.13E+01   400  3.02E+01  1.13E+01
401  1.10E+01  1.16E+01   402  3.13E+01  1.13E+01   403  3.23E+01  1.13E+01   404  3.34E+01  1.13E+01   405  3.44E+01  1.13E+01
406  3.55E+01  1.13E+01   407  3.65E+01  1.13E+01   408  1.55E+01  1.36E+01   409  1.60E+01  1.36E+01   410  1.69E+01  1.31E+01
411  1.78E+01  1.28E+01   412  1.16E+01  1.16E+01   413  1.88E+01  1.24E+01   414  1.60E+01  1.46E+01   415  1.59E+01  1.42E+01
416  6.44E+00  1.25E+01   417  1.78E+01  1.39E+01   418  1.83E+01  1.36E+01   419  1.15E+01  1.26E+01   420  1.60E+01  1.56E+01
421  7.29E+00  1.26E+01   422  1.69E+01  1.53E+01   423  1.78E+01  1.50E+01   424  8.92E+00  1.26E+01   425  1.88E+01  1.47E+01
426  8.14E+00  1.25E+01   427  1.60E+01  1.66E+01   428  1.69E+01  1.64E+01   429  5.59E+00  1.26E+01   430  1.78E+01  1.61E+01
431 .9.71E+00  1.26E+01   432  1.88E+01  1.59E+01   433  1.50E+01  1.76E+01   434  1.69E+01  1.74E+01   435  1.78E+01  1.72E+01
436  1.88E+01  1.71E+01   437  1.07E+01  1.26E+01   438  1.60E+01  1.86E+01   439  1.69E+01  1.85E+01   440  1.78E+01  1.83E+01
441  1.86E+01  1.82E+01   442  1.50E+01  1.96E+01   443  1.69E+01  1.95E+01   444  1.76E+01  1.95E+01   445  1.88E+01  1.94E+01
446  1.60E+01  2.06E+01   447  1.89E+01  2.06E+01   448  1.76E+01  2.06E+01   449  1.88E+01  2.06E+01   450  5.59E+00  1.35E+01
451  5.59E+00  1.45E+01   452  5.50E+00  1.56E+01   453  7.14E+00  1.36E+01   454  1.04E+01  1.36E+01   455  9.47E+00  1.36E+01
456  5.59E+00  1.65E+01   457  5.59E+00  1.76E+01   458  5.59E+00  1.85E+01   459  1.12E+01  1.35E+01   460  5.59E+00  1.95E+01
461  5.59E+00  2.06E+01   462  7.91E+00  1.36E+01   463  6.37E+00  1.36E+01   464  6.29E+00  1.46E+01   465  6.21E+00  1.55E+01
466  8.69E+00  1.36E+01   467  6.14E+00  1.66E+01   468  6.06E+00  1.76E+01   469  6.06E+00  1.35E+01   470  6.06E+00  1.96E+01
471  6.06E+00  2.06E+01   472  6.98E+00  1.46E+01   473  6.83E+00  1.56E+01   474  6.68E+00  1.66E+01   475  6.53E+00  1.76E+01
476  6.53E+00  1.86E+01   477  6.53E+00  1.96E+01   478  6.53E+00  2.06E+01   479  7.68E+00  1.46E+01   480  7.45E+00  1.56E+01
481  7.22E+00  1.66E+01   482  6.99E+00  1.76E+01   483  6.99E+00  1.86E+01   484  6.99E+00  1.96E+01   485  6.99E+00  2.06E+01
486  8.45E+00  1.46E+01   487  8.22E+00  1.56E+01   488  1.09E+01  1.46E+01   489  7.96E+00  1.66E+01   490  7.74E+00  1.76E+01
491  7.74E+00  1.86E+01   492  7.74E+00  1.96E+01   493  7.74E+00  2.06E+01   494  9.22E+00  1.46E+01   495  8.98E+00  1.56E+01
496  8.74E+00  1.66E+01   497  8.49E+00  1.76E+01   498  8.49E+00  1.86E+01   499  8.49E+00  1.96E+01   500  8.49E+00  2.06E+01
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501  1.01E+01  1.46E+01   502  9.82E+00  1.56E+01   503  9.53E+00  1.66E+01   504  9.24E+00  1.76E+01   505  9.24E+00  1.86E+01
506  9.24E+00  1.96E+01   507  9.24E+00  2.06E+01   508  1.06E+01  1.56E+01   509  1.03E+01  1.66E+01   510  9.99E+00  1.76E+01
511  9.99E+00  1.86E+01   512  9.99E+00  1.96E+01   513  9.99E+00  2.06E+01
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     COUPLE  MOD 2    (MAY-23,77)    UPDATE  1 (MAY-23,77)  ECL
 LOFT REACTOR VESSEL NOZZLE TEMPERTURE RESPONSE WITH ADDITION OF GAMMA
 AND NEUTRON SHIELD       SEP. 07, 1977      COUPLE MOD 2      RUN 01

 E L E M E N T   D A T A

 ELEMENT NO(EL),CORNOR NODAL NOS(I,J,K,L),MATERIAL   NO(MAT),AND CONDUCTIVITY ANGLES(BETA)

  EL     I     J     K     L MAT BETA    EL     I     J     K     L MAT BETA    EL     I     J     K     L MAT BETA    EL     I     J     K     L MAT BET
   1     1     2    48    47   1   0.     2     2     3    42    48   1   0.     3     3     4    50    42   1   0.     4     4     5    43    50   1   0.
   5     5     6    46    43   1   0.     6     6     7    52    46   1   0.     7     7     8    51    52   1   0.     8     8     9    49    51   1   0.
   9     9    10    33    49   1   0.    10    10    11    34    33   1   0.    11    11    12    35    34   1   0.    12    12    13    36    35   1   0.
  13    13    14    37    36   1   0.    14    14    15    38    37   1   0.    15    15    16    39    38   1   0.    16    16    17    40    39   1   0.
  17    17    18    41    40   1   0.    18    18    19    44    41   1   0.    19    19    20    45    44   1   0.    20    20    21    53    45   1   0.
  21    21    22    54    53   1   0.    22    22    23    55    54   1   0.    23    23    24    56    55   1   0.    24    24    25    57    56   1   0.
  25    25    26    58    57   1   0.    26    26    27    59    58   1   0.    27    27    28    60    59   1   0.    28    28    29    61    60   1   0.
  29    29    30    62    61   1   0.    30    30    31    63    62   1   0.    31    31    32    64    63   1   0.    32    47    48    69    81   1   0.
  33    43    42    71    69   1   0.    34    42    50    74    71   1   0.    35    50    43    85    74   1   0.    36    43    46    76    85   1   0.
  37    46    52    86    75   1   0.    38    52    51    75    86   1   0.    39    51    49    78    75   1   0.    40    49    33    72    78   1   0.
  41    33    34    65    72   1   0.    42    34    35    66    65   1   0.    43    35    36    67    66   1   0.    44    36    37    68    67   1   0.
  45    37    38    70    68   1   0.    46    38    39    73    70   1   0.    47    39    40    77    73   1   0.    48    40    41    79    77   1   0.
  49    41    44    80    79   1   0.    50    44    45    82    80   1   0.    51    45    53    83    82   1   0.    52    53    54    84    83   1   0.
  53    54    55    87    84   1   0.    54    55    56    88    87   1   0.    55    56    57    89    88   1   0.    56    57    58    90    89   1   0.
  57    58    59    91    90   1   0.    58    59    60    92    91   1   0.    59    60    61    93    92   1   0.    60    61    62    94    93   1   0.
  61    62    63    95    94   1   0.    62    63    64    96    95   1   0.    63    81    69   112   110   1   0.    64    69    71   109   112   1   0.
  65    71    74   115   109   1   0.    66    74    85   113   115   1   0.    67    85    76   114   113   1   0.    68    76    86   118   114   1   0.
  69    86    75   119   118   1   0.    70    75    78   117   119   1   0.    71    76    72   116   117   1   0.    72    72    65    97   116   1   0.
  73    65    66    98    97   1   0.    74    66    67    99    98   1   0.    75    67    68   100    99   1   0.    76    63    70   101   100   1   0.
  77    70    73   102   101   1   0.    78    73    77   103   102   1   0.    79    77    79   104   103   1   0.    80    79    80   105   104   1   0.
  81    60    82   106   105   1   0.    82    82    83   107   106   1   0.    83    83    84   108   107   1   0.    84    84    87   111   108   1   0.
  85    87    88   120   111   1   0.    86    88    89   121   120   1   0.    87    89    90   122   121   1   0.    88    90    91   123   122   1   0.
  89    91    92   124   123   1   0.    90    92    93   125   124   1   0.    91    93    94   126   125   1   0.    92    94    95   127   126   1   0.
  93    95    96   128   127   1   0.    94   110   112   149   145   1   0.    95   112   109   148   149   1   0.    96   109   115   156   148   1   0.
  97   115   113   160   156   1   0.    98   113   114   159   160   1   0.    99   114   118   157   159   1   0.   100   118   119   136   157   1   0.
 101   119   117   134   135   1   0.   102   117   116   129   134   1   0.   103   116    97   130   129   1   0.   104    97    98   131   130   1   0.
 105    98    99   132   131   1   0.   106    99   100   133   132   1   0.   107   100   101   135   133   1   0.   108   101   102   137   135   1   0.
 109   102   103   138   137   1   0.   110   103   104   139   138   1   0.   111   104   105   140   139   1   0.   112   105   106   141   140   1   0.
 113   106   107   142   141   1   0.   114   107   108   143   142   1   0.   115   108   111   144   143   1   0.   116   111   120   146   144   1   0.
 117   120   121   147   146   1   0.   118   121   122   150   147   1   0.   119   122   123   151   150   1   0.   120   123   124   152   151   1   0.
 121   124   125   153   152   1   0.   122   125   126   154   153   1   0.   123   126   127   155   154   1   0.   124   127   128   158   155   1   0.
 125   145   149   189   186   1   0.   126   149   148   187   189   1   0.   127   143   156   191   187   1   0.   128   156   160   192   191   1   0.
 129   160   159   190   192   1   0.   130   159   157   184   190   1   0.   131   157   136   183   184   1   0.   132   136   134   173   183   1   0.
 133   134   129   175   173   1   0.   134   129   130   177   175   1   0.   135   130   131   178   177   1   0.   136   131   132   161   178   1   0.
 137   132   133   162   161   1   0.   138   133   135   163   162   1   0.   139   135   137   164   163   1   0.   140   137   138   165   164   1   0.
 141   138   139   166   165   1   0.   142   139   140   167   166   1   0.   143   140   141   168   167   1   0.   144   141   142   169   168   1   0.
 145   142   143   170   169   1   0.   146   143   144   171   170   1   0.   147   144   146   172   171   1   0.   148   146   147   174   172   1   0.
 149   147   150   175   174   1   0.   150   150   151   179   176   1   0.   151   151   152   180   179   1   0.   152   152   153   181   180   1   0.
 153   153   154   182   181   1   0.   154   154   155   185   182   1   0.   155   155   158   188   185   1   0.   156   186   189   222   208   1   0.
 157   189   187   224   222   1   0.   158   187   193   214   224   1   0.   159   191   192   228   214   3   0.   160   192   190   204   228   3   0.
 161   190   184   208   204   3   0.   162   184   183   205   208   1   0.   163   183   173   220   205   1   0.   164   173   175   219   220   1   0.
 165   175   177   195   219   1   0.   166   177   178   193   195   1   0.   167   178   161   194   193   4   0.   168   161   162   196   194   4   0.
 169   162   163   197   196   4   0.   170   163   164   198   197   4   0.   171   164   165   199   198   4   0.   172   165   166   200   199   4   0.
 173   166   167   201   200   4   0.   174   167   168   202   201   4   0.   175   168   169   203   202   4   0.   176   169   170   207   203   4   0.
 177   170   171   209   207   2   0.   178   171   172   210   209   2   0.   179   172   174   211   210   2   0.   180   174   176   212   211   2   0.
 181   176   179   213   212   2   0.   182   179   180   215   213   2   0.   183   180   181   216   215   2   0.   184   181   182   217   216   2   0.
 185   182   185   218   217   2   0.   186   185   188   221   218   2   0.   187   206   222   239   253   1   0.   188   222   224   249   239   1   0.
 189   224   214   245   249   1   0.   190   214   226   246   245   3   0.   191   228   204   246   248   3   0.   192   204   206   241   246   3   0.
 193   208   205   254   241   1   0.   194   205   220   255   254   1   0.   195   220   219   233   255   1   0.   196   219   195   243   233   1   0.
 197   195   193   223   243   1   0.   198   193   194   225   223   2   0.   199   194   196   226   225   2   0.   200   196   197   227   226   2   0.
 201   197   198   229   227   2   0.   202   198   199   230   229   2   0.   203   199   200   231   230   2   0.   204   200   201   232   231   2   0.
 205   201   202   234   232   2   0.   206   202   203   235   234   2   0.   207   203   207   236   235   2   0.   208   207   209   237   236   2   0.
 209   209   210   238   237   2   0.   210   210   211   240   238   2   0.   211   211   212   242   240   2   0.   212   212   213   244   242   2   0.
 213   213   215   247   244   2   0.   214   215   216   250   247   2   0.   215   216   217   251   250   2   0.   216   217   218   252   251   2   0.
 217   218   221   256   252   2   0.   218   253   239   273   274   1   0.   219   239   249   283   273   1   0.   220   249   245   281   233   1   0.
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        COUPLE  MOD 2   (MAY-23,77)    UPDATE  1 (MAY-23,77)  EDL
LOFT REACTOR VESSEL NOZZLE TEMPERTURE  RESPONSE WITH ADDITION OF GAMMA
AND NEUTRON SHIELD      SEP. 07, 1977     COUPLE MOD 2     RUN 01

H E A T   C O N D U C T I O N   S O L U T I O N


   TIME =      0.00000               DT =      0.00000               STEP =      1               PASS =     4

   NODE    TEMPERATURE         NODE    TEMPERATURE         NODE    TEMPERATURE         NODE    TEMPERATURE         NODE    TEMPERATURE
     1    5.7309E+02             2    5.7359E+02             3    5.7326E+02             4    5.7293E+02             5    5.7262E+02
     6    5.7234E+02             7    5.7213E+02             8    5.7200E+02             9    5.7196E+02            10    5.7203E+02
    11    5.7216E+02            12    5.7233E+02            13    5.7261E+02            14    5.7264E+02            15    5.7304E+02
    16    [illegible]           17    5.7134E+02            18    [illegible]           19    5.7352E+02            20    [illegible]
    21    5.7382E+02            22    5.7365E+02            23    5.7368E+02            24    5.7370E+02            25    5.7371E+02
    26    5.7372E+02            27    5.7378E+02            28    5.7370E+02            29    5.7374E+02            30    5.7374E+02
    31    5.7374E+02            32    5.7374E+02            33    5.5905E+02            34    5.6219E+02            35    5.6172E+02
    36    [illegible]           37    [illegible]           38    [illegible]           39    5.6605E+02            40    5.6906E+02
    41    5.6981E+02            42    5.6656E+02            43    [illegible]           44    5.7041E+02            45    5.7065E+02
    46    5.6176E+02            47    5.7372E+02            48    5.7135E+02            49    5.5803E+02            50    5.6613E+02
    51    [illegible]           52    5.6607E+02            53    5.7118E+02            54    5.7143E+02            55    5.7161E+02
    56    5.7175E+02            57    5.7185E+02            58    [illegible]           59    5.7199E+02            60    5.7203E+02
    61    5.7206E+02            62    5.7207E+02            63    5.7207E+02            64    5.7209E+02            65    5.4716E+02
    66    5.5035E+02            67    5.5401E+02            68    5.5753E+02            69    5.6896E+02            70    5.6058E+02
    71    5.6445E+02            72    5.4501E+02            73    5.6301E+02            74    5.5969E+02            75    5.4526E+02
    76    [illegible]           77    5.2491E+02            78    5.4433E+02            79    5.6634E+02            80    5.6741E+02
    81    5.7307E+02            82    5.6021E+02            83    5.6881E+02            84    5.6925E+02            85    5.5531E+02
    86    5.4765E+02            87    5.6959E+02            88    5.6964E+02            89    5.7002E+02            90    5.7016E+02
    91    5.7026E+02            92    5.7033E+02            93    5.7038E+02            94    5.7042E+02            95    5.7044E+02
    96    5.7044E+02            97    5.3217E+02            98    5.3789E+02            99    5.4406E+02           100    5.4996E+02
   101    5.5175E+02           102    [illegible]          103    5.6112E+02           104    5.5314E+02           105    5.6463E+02
   106    5.6574E+02           107    5.6657E+02           108    5.6718E+02           109    5.6115E+02           110    5.7343E+02
   111    5.6754E+02           112    5.5732E+02           113    5.5474E+02           114    5.4054E+02           115    5.5416E+02
   116    [illegible]          117    [illegible]          118    5.3443E+02           119    5.3001E+02           120    [illegible]
   121    [illegible]          122    [illegible]          123    5.6256E+02           124    5.6866E+02           125    5.6573E+02
   126    [illegible]          127    [illegible]          128    5.0386E+02           129    5.0664E+02           130    [illegible]
   131    5.2232E+02           132    [illegible]          133    5.4327E+02           134    5.0846E+02           135    5.4990E+02
   136    [illegible]          137    [illegible]          138    [illegible]          139    5.6042E+02           140    [illegible]
   141    [illegible]          142    [illegible]          143    5.6526E+02           144    5.5531E+02           145    5.7337E+02
   146    5.6622E+02           147    [illegible]          148    5.6971E+02           149    5.6664E+02           150    5.6675E+02
   151    5.5695E+02           152    5.6703E+02           153    5.6711E+02           154    5.6716E+02           155    5.6719E+02
   156    5.5092E+02           157    5.2007E+02           158    5.6720E+02           159    5.3033E+02           160    5.4153E+02
   161    5.2673E+02           162    5.3913E+02           163    5.4681E+02           164    5.5202E+02           165    5.5349E+02
   166    5.5433E+02           167    [illegible]          168    5.6166E+02           169    5.6274E+02           170    5.6393E+02
   171    5.6417E+02           172    [illegible]          173    4.8468E+02           174    5.6489E+02           175    [illegible]
   176    5.6513E+02           177    [illegible]          178    4.9951E+02           179    5.6531E+02           180    5.6543E+02
   181    5.6092E+02           182    5.6593E+02           183    4.0398E+02           184    5.0241E+02           185    5.6561E+02
   186    5.7240E+02           187    [illegible]          188    5.6562E+02           189    5.6717E+02           190    5.2549E+02
   191    5.5562E+02           192    5.4000E+02           193    4.8947E+02           194    5.1284E+02           195    4.6747E+02
   196    5.2333E+02           197    [illegible]          198    5.3417E+02           199    5.3721E+02           200    5.3945E+02
   201    5.4116E+02           202    5.4249E+02           203    5.4557E+02           204    5.0300E+02           205    4.6826E+02
   206    5.7331E+02           207    5.4465E+02           208    4.7150E+02           209    4.9663E+02           210    4.8010E+02
   211    4.7377E+02           212    4.7137E+02           213    4.7032E+02           214    5.6276E+02           215    4.6985E+02
   216    4.6970E+02           217    4.5961E+02           218    4.5992E+02           219    4.6285E+02           220    4.6429E+02
   221    4.6954E+02           222    5.6662E+02           223    4.3173E+02           224    5.6457E+02           225    4.3805E+02
   226    4.4169E+02           227    4.4260E+02           228    5.3209E+02           229    4.4256E+02           230    4.4215E+02
   231    4.4131E+02           232    4.3958E+02           233    4.3793E+02           234    4.3613E+02           235    4.3003E+02
   236    4.2097E+02           237    3.9823E+02           238    3.6573E+02           239    5.7026E+02           240    3.7954E+02
   241    4.4643E+02           242    3.7656E+02           243    4.3546E+02           244    3.7516E+02           245    5.6706E+02
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NODE     TEMPERATURE         NODE     TEMPERATURE         NODE     TEMPERATURE         NODE     TEMPERATURE         NODE     TEMPERATURE
246      4.3510E+02          247      3.7451E+02          248      5.2466E+02          249      5.6792E+02          250      3.7421E+02
251      3.7450E+02          252      3.7400E+02          253      5.7365E+02          254      4.4582E+02          255      4.4214E+02
256      3.7334E+02          257      4.0031E+02          258      3.7794E+02          259      3.6565E+02          260      3.5792E+02
261      4.0445E+02          262      3.5245E+02          263      4.1261E+02          264      3.4635E+02          265      4.2104E+02
266      3.4472E+02          267      3.4027E+02          268      3.3300E+02          269      3.1985E+02          270      2.9801E+02
271      2.9072E+02          272      2.8550E+02          273      5.7132E+02          274      5.7376E+02          275      2.8251E+02
276      4.2551E+02          277      2.8071E+02          278      2.7979E+02          279      2.7934E+02          280      2.7912E+02
281      5.0945E+02          282      2.7902E+02          283      5.7003E+02          284      5.1807E+02          285      4.7112E+02
286      2.7895E+02          287      2.7343E+02          288      3.7097E+02          289      3.6246E+02          290      4.2645E+02
291      3.8500E+02          292      3.1519E+02          293      2.8945E+02          294      2.7361E+02          295      4.0341E+02
296      2.6272E+02          297      4.1213E+02          298      2.5531E+02          299      2.4987E+02          300      2.4460E+02
301      2.3657E+02          302      2.1883E+02          303      1.7445E+02          304      1.6404E+02          305      1.8433E+02
306      1.8444E+02          307      1.9446E+02          308      1.8445E+02          309      1.8444E+02          310      5.7233E+02
311      5.7123E+02          312      1.8444E+02          313      1.8443E+02          314      1.8443E+02          315      5.7084E+02
316      1.8443E+02          317      5.7384E+02          318      5.0989E+02          319      4.5811E+02          320      3.6766E+02
321      3.3435E+02          322      2.9983E+02          323      2.3882E+02          324      3.9109E+02          325      2.0806E+02
326      1.8755E+02          327      4.1286E+02          328      1.7157E+02          329      4.0411E+02          330      1.6171E+02
331      1.5592E+02          332      4.0853E+02          333      1.5250E+02          334      1.5046E+02          335      1.4923E+02
336      1.4333E+02          337      1.4779E+02          338      1.4751E+02          339      1.4733E+02          340      1.4722E+02
341      1.4715E+02          342      1.4710E+02          343      1.4708E+02          344      1.4706E+02          345      1.4705E+02
346      1.4705E+02          347      5.7285E+02          348      5.7210E+02          349      3.8445E+02          350      3.5487E+02
351      5.7359E+02          352      2.8317E+02          353      2.0290E+02          354      4.8972E+02          355      2.2833E+02
356      2.0350E+02          357      1.6503E+02          358      1.6945E+02          359      5.7167E+02          360      1.6009E+02
361      1.9403E+02          362      1.5139E+02          363      1.4943E+02          364      4.2998E+02          365      1.4822E+02
366      1.4742E+02          367      4.0004E+02          368      1.4691E+02          369      1.4660E+02          370      1.4641E+02
371      1.4630E+02          372      1.4822E+02          373      1.4619E+02          374      1.4616E+02          375      1.4615E+02
376      1.4614E+02          377      4.0716E+02          378      1.4614E+02          379      2.0897E+02          380      2.0985E+02
381      2.0513E+02          382      1.9556E+02          383      5.7260E+02          384      1.7948E+02          385      1.6423E+02
386      5.7221E+02          387      1.5676E+02          388      1.5237E+02          389      1.4969E+02          390      1.4805E+02
391      4.7881E+02          392      5.7392E+02          393      1.4703E+02          394      3.9656E+02          395      1.4635E+02
396      1.4991E+02          397      1.4563E+02          398      5.7318E+02          399      1.4547E+02          400      1.4537E+02
401      2.9735E+02          402      1.4531E+02          403      1.4527E+02          404      1.4525E+02          405      1.4523E+02
406      1.4523E+02          407      1.4522E+02          408      1.8803E+02          409      1.8491E+02          410      1.6574E+02
411      1.6106E+02          412      1.7184E+02          413      1.7320E+02          414      1.7065E+02          415      1.7270E+02
416      5.7338E+02          417      1.7028E+02          418      1.6499E+02          419      1.5159E+02          420      1.6231E+02
421      5.7294E+02          422      1.5381E+02          423      1.6204E+02          424      4.6767E+02          425      1.5837E+02
426      5.7260E+02          427      1.5678E+02          428      1.5729E+02          429      5.7394E+02          430      1.5622E+02
431      5.7153E+02          432      1.5357E+02          433      1.5309E+02          434      1.5326E+02          435      1.5232E+02
436      1.5037E+02          437      2.5149E+02          438      1.5074E+02          439      1.5071E+02          440      1.4955E+02
441      1.4827E+02          442      1.4943E+02          443      1.4930E+02          444      1.4848E+02          445      1.4709E+02
446      1.4901E+02          447      1.4835E+02          448      1.4805E+02          449      1.4671E+02          450      5.7395E+02
451      5.7395E+02          452      5.7395E+02          453      5.7316E+02          454      2.4491E+02          455      3.5851E+02
456      5.7397E+02          457      5.7361E+02          458      5.7397E+02          459      1.4624E+02          460      5.7396E+02
461      5.7396E+02          462      5.7237E+02          463      5.7352E+02          464      5.7361E+02          465      5.7367E+02
466      4.6107E+02          467      5.7368E+02          468      5.7360E+02          469      5.7373E+02          470      5.7377E+02
471      5.7377E+02          472      5.7331E+02          473      5.7341E+02          474      5.7348E+02          475      5.7330E+02
476      5.7356E+02          477      5.7360E+02          478      5.7360E+02          479      5.7306E+02          480      5.7320E+02
481      5.7329E+02          482      5.7338E+02          483      5.7341E+02          484      5.7344E+02          485      5.7345E+02
486      4.5789E+02          487      4.5709E+02          488      1.4502E+02          489      4.5931E+02          490      4.6833E+02
491      4.5723E+02          492      4.5370E+02          493      4.5282E+02          494      3.5224E+02          495      3.4984E+02
496      3.5192E+02          497      3.8208E+02          498      3.4902E+02          499      3.4384E+02          500      3.4256E+02
501      2.4102E+02          502      2.4106E+02          503      2.4482E+02          504      2.5780E+02          505      2.4578E+02
506      2.4154E+02          507      2.4043E+02          508      1.4540E+02          509      1.4710E+02          510      1.5194E+02
511      1.4728E+02          512      1.4577E+02          513      1.4540E+02
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APPENDIX C

TITANIUM HYDRIDE AND BORON CARBIDE THERMODYNAMIC PROPERTIES

Material & Thermal Properties of Neutron shield

The neutron shield is to be a powder mixture of $TiH_{1.6}$ 90% by weight and B_4C 10% by weight. Thermal conductivity of each component is strongly dependent on theoretical density or void fraction. Thermal conductivities of TiH_x and B_4C are plotted as a function of void fraction on Figure(C-1). Calculation method is presented in W.H. McAdams, <u>Heat Transmission</u>, McGraw-Hill Book company, Inc. (1954) page 290.

Specific Heat of $TiH_{1.6}$ is estimated from Figure(8), page 18 of the literature review. Ref(6)

C_p of $TiH_{1.6}$

T (°K)	C_p (cal/g°K)	
300	1.51	
400	1.78 to 1.87	estimate by extrapolation.
500	2.01 to 2.22	" " "
600	2.29 to 2.59	" " "

The literature review for B_4C listed the following equation for specific heat see Ref(7)

$$C_p = 22.99 + 5.4 \times 10^{-3} (T) - 10.72 \times 10^{5} (T)^{-2}$$

where T is in °K and C_p in cal/mole°K

For a MW of 53.7 g/gmole the equation becomes

$$C_p = .4281 = 1.006 \times 10^{-4} (T) - 19.963 \times 10^{3} (T)^{-2} \quad ; \; C_p \text{ in } \frac{cal}{gm°K} \text{ or } \frac{cal}{gm°C}$$

C_p of B_4C

T °K	C_p (cal/g°K)
300	.236
400	.344
500	.399
600	.433

In order to determine properties of the mixture, must determine mole fraction (X_i) of each constituent

Given: $M_{TiH_{1.6}} = .9 M_{mix}$; $M_{B_4C} = .1 M_{mix}$

$MW_{TiH_{1.6}} = 47.9 + 1.6 = 49.5$ kg/kg mole

$\% H_2 = 100 \times \frac{1.6}{49.5} = 3.2\%$

$\therefore \rho_{TiH_{1.6}} \simeq 3.8 \times 10^3 \, kg/m^3$ from Fig(10) p. 20 of Lit. Review Ref(6)

If powder is evenly mixed throughout the volume (as if it were a gas), then:

$$\frac{m_{TiH_{1.6}}}{V_{mix}} = \rho_{TiH_{1.6}} \qquad \text{let } V_{mix} = 100 \, m^3$$

$$m_{TiH_{1.6}} = \rho_{TiH_{1.6}} V_{mix} = 3.8 \times 10^3 \times 100 = 3.8 \times 10^5 \, kg$$

$$m_{TiH_{1.6}} = .9 \, m_{mix} \quad \therefore M_{mix} = \frac{3.8 \times 10^5}{.9} = 4.22 \times 10^5 \, kg$$

Then $M_{B_4C} = .1 M_{mix} = 4.22 \times 10^5$ kg

Based on an average density of $B_4C = 2.44 \, gm/cm^3$ from Table 1 page 17 of Lit. Review Ref(7)

$MW_{B_4C} \simeq 53.7$ kg/kg mole

Number of moles per constituent (air is negligible)

$$n_{TiH_{1.6}} = \frac{3.8\times10^5}{49.5} = 7677$$

$$n_{B_4C} = \frac{4.22\times10^4}{53.7} = 785.86$$

$$n_{Total} = 8462.85$$

$$X_{TiH_{1.6}} = \frac{7677}{8462.85} = .907 \simeq .9$$

$$\therefore\ X_{B_4C} = .1 \text{ since } X_{Total} = 1.0$$

@ 60% TD or $\epsilon = .4$

$$k_{mix} = (.311 \tfrac{W}{m°C})(.9) + (.43 \tfrac{W}{m°C})(.1)$$

$$k = .323 \frac{W}{m°C} = .187 \frac{Btu}{hr\,ft\,°F}$$

@ 95% TD or $\epsilon = .05$

$$k = (3.5 \tfrac{W}{m°C})(.9) + (21 \tfrac{W}{m°C})(.1)$$

$$k = 5.25 \frac{W}{m°C} = 3.033 \frac{Btu}{hr\,ft\,°F}$$

$21 \frac{W}{m°C}$ is from Fig(9) page 25 of Lit. Review Ref(7)

$$C_{p_{mix}} = X_{TiH_{1.6}} \, C_{p_{TiH_{1.6}}} + X_{B_4C} \, C_{p_{B_4C}}$$

T = 300°K

$$C_p = (.907)(1.51 \frac{cal}{g°K}) + (.093)(.236 \frac{cal}{g°K}) = 1.39 \frac{cal}{g°K} \quad @ \; 300°K$$

T = 400°K

$$C_p = (.907)(1.87) + (.093)(.344) \quad = 1.728 \frac{cal}{g°K} \quad @ \; 400°K$$

T = 500°K

$$C_p = (.907)(2.22) + (.093)(.399) \quad = 2.05 \frac{cal}{g°K} \quad @ \; 500°K$$

T = 600°K

$$C_p = (.907)(2.59) + (.093)(.433) \quad = 2.387 \frac{cal}{g°K} \quad @ \; 600°K$$

$$\rho_{mix \; \epsilon = .4} = .6 \times 4222 \; kg/m^3 = 2533.33 \; kg/m^3$$

Density * Specific heat

T(°K / °F)	$\frac{kJ}{m^3 \, K}$	$\frac{Btu}{ft^3 \, °F}$
300 / 80.6	1.474×10^4	219.7849
400 / 260.6	1.835×10^4	273.6128
500 / 440.6	2.174×10^4	324.1604
600 / 620.6	2.535×10^4	377.9883

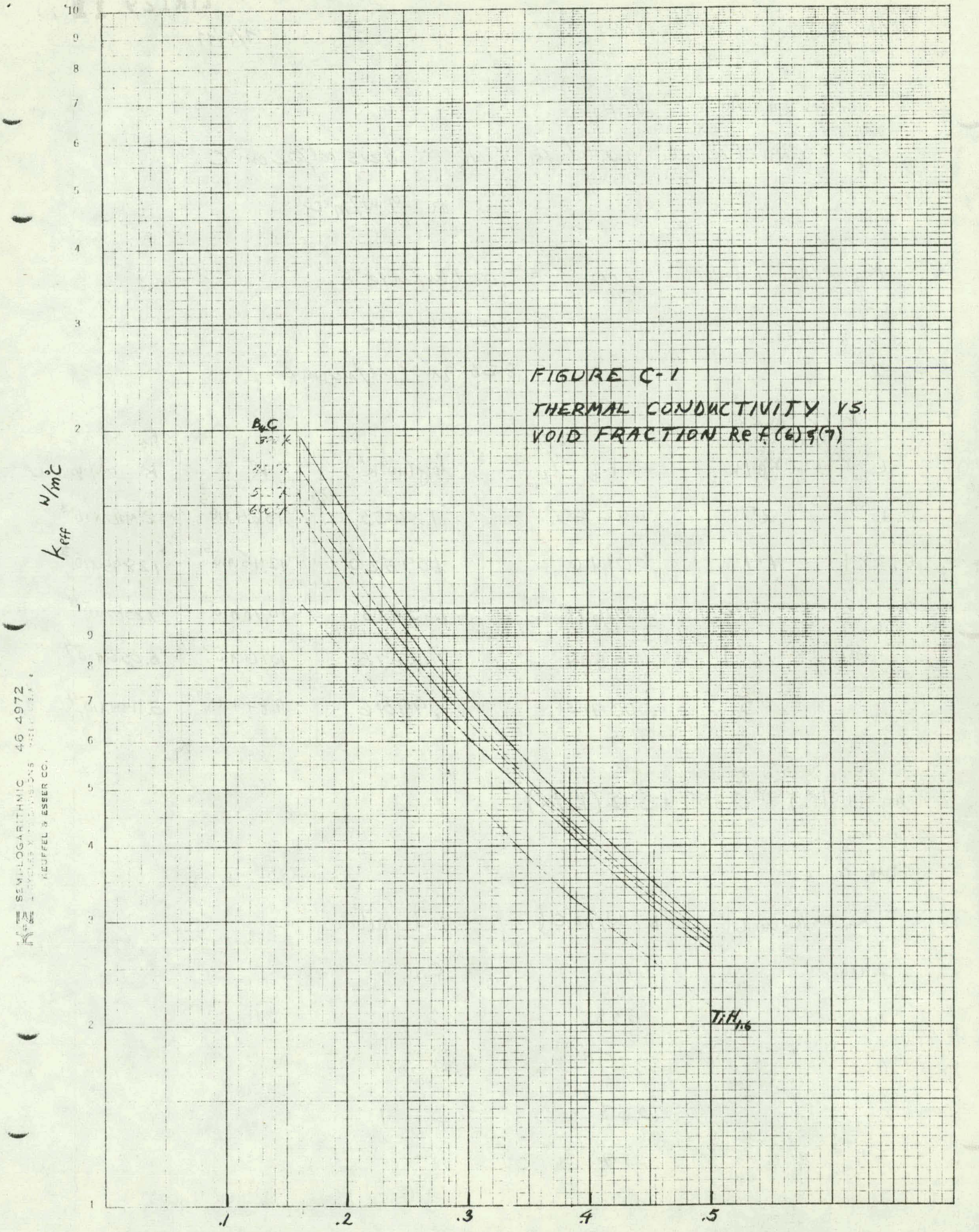

FIGURE C-1
THERMAL CONDUCTIVITY VS.
VOID FRACTION Ref. (6) & (7)

Kyllingplast

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thermal conductivity T_iH_2

k_s = thermal conductivity of solid for $T_iH_2 \simeq .0215$ cal/sec cm°C

or 9 W/m°C

K_g = thermal conductivity of air = .02 Btu/hr ft°F

= .0346 W/m°C

= 8.2689×10^{-5} cal/sec cm°C

$k_s/K_g = 260$

ϵ	K_B/K_g	K_B cal/sec cm	$\log_{10}(10^5K^*)$	K^*	K_B+K^* K cal/sec cm°C
0.163	27	.00223	1.27053	18.64×10^{-5}	2.416×10^{-3}
0.284	14	.00116	1.09520	12.45×10^{-5}	1.2845×10^{-3}
0.386	8.2	.000678	1.03278	10.78×10^{-5}	7.858×10^{-4}
0.494	6.1	.000504	1.00675	10.16×10^{-5}	6.056×10^{-4}
0.50	5	.000413	.99316	9.844×10^{-5}	5.1144×10^{-4}

$$\log_{10}(10^5K^*) = 0.859 + 3.12(k_s/a)$$

where $a = \epsilon$

K [cal/sec cm°C]	K [W/m°C]	Void fraction
2.416×10^{-3}	1.011	0.163
1.2845×10^{-3}	.538	0.284
7.858×10^{-4}	.329	0.386
6.056×10^{-4}	.253	0.494
5.1144×10^{-4}	.214	0.50

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Thermal conductivity B_4C

K_s (thermal conductivity of solid, B_4C)

T	K_s 99% TD
300°K (27°c, 80.6°F)	.0675 cal/sec cm°K or cal/sec cm°c
400°K (127°c, 260.6°F)	.061
500°K (227°c, 440.6°F)	.056
600°K (327°c, 620.6°F)	.051

$\log_{10}(10^5 K^*) = 0.859 + 3.12\,(K_s/a)$

$[\text{cal/sec cm °c}] \times 418.604 = [\text{W/m °c}]$

assume K_g (air) constant @ 8.2689×10^{-5} cal/sec cm°c, .0346 W/m°c

300°K K_s = .0675 cal/sec cm°K

$K_s/K_g = .0675/8.2689 \times 10^{-5} = 816$

ϵ	K_B/K_g	K_B cal/sec cm°c	$\log_{10}(10^5 K^*)$	K^* cal/sec cm°c	$K_B + K^*$ K cal/sec cm°c	K W/m °C
0.163	39	.00322	2.15102	141.6×10^{-5}	4.636×10^{-3}	1.941
0.284	18	.00149	1.60055	39.86×10^{-5}	1.8886×10^{-3}	.791
0.386	10.5	.000868	1.40460	25.39×10^{-5}	1.1219×10^{-3}	.470
0.454	7.5	.000620	1.32288	21.03×10^{-5}	8.303×10^{-4}	.348
0.50	6.	.000496	1.28020	19.06×10^{-5}	6.866×10^{-4}	.287

400°K K_s = .061 cal/sec cm°K

$K_s/K_g = .061/8.2689 \times 10^{-5} = 738$

ϵ	K_B/K_g	K_B cal/sec cm°c	$\log_{10}(10^5 K^*)$	K^* cal/sec cm°c	K cal/sec cm°c	K W/m °c
0.163	37	3.0595×10^{-3}	2.0266	106.3×10^{-5}	4.1225×10^{-3}	1.726
0.284	17.5	1.45×10^{-3}	1.52914	33.82×10^{-5}	1.7882×10^{-3}	.749
0.386	10.1	8.35×10^{-4}	1.35106	22.49×10^{-5}	1.0599×10^{-3}	.444
0.454	7.3	6.04×10^{-4}	1.27821	18.98×10^{-5}	7.938×10^{-4}	.332
0.50	5.99	4.95×10^{-4}	1.23964	17.36×10^{-5}	6.686×10^{-4}	.280

Kyllingstad

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Thermal conductivity B_4C

500°K

$k_s = .056$ cal/sec cm°C ; $k_g = 8.2689\times10^{-5}$ cal/sec cm°C

$K_s/K_g = 677$ $\log_{10}(10^5 K^*) = 0.859 + 3.12\,(K_s/\epsilon)$

[cal/sec cm°C] * 418.604 = [W/m°C]

ϵ	K_B/K_g	K_B cal/sec cm°C	$\log_{10}(10^5K^*)$	K^* cal/sec cm°C	K cal/sec cm°C	K W/m°C
0.163	35	2.8941×10^{-3}	1.93090	85.29×10^{-5}	3.747×10^{-3}	1.569
0.284	17	1.4057×10^{-3}	1.47421	29.80×10^{-5}	1.7037×10^{-3}	.713
0.386	10	8.2689×10^{-4}	1.31164	20.50×10^{-5}	1.0389×10^{-3}	.432
0.454	7.25	5.9950×10^{-4}	1.24385	17.53×10^{-5}	7.748×10^{-4}	.324
0.50	5.9	4.8786×10^{-4}	1.20844	16.16×10^{-5}	6.4946×10^{-4}	.272

600°K

$K_s = .051$ cal/sec cm°C ; $K_g = 8.2689\times10^{-5}$ cal/sec cm°C

$K_s/K_g = 617$

ϵ	K_B/K_g	K_B cal/sec cm°C	$\log_{10}(10^5K^*)$	K^* cal/sec cm°C	k cal/sec cm°C	k W/m°C
0.163	34	2.8114×10^{-3}	1.83520	68.41×10^{-5}	3.4955×10^{-3}	1.463
0.284	16	1.323×10^{-3}	1.41928	26.26×10^{-5}	1.5856×10^{-3}	.664
0.386	9.9	8.1862×10^{-4}	1.27123	18.67×10^{-5}	1.00532×10^{-3}	.421
0.454	7.1	5.8709×10^{-4}	1.20948	16.20×10^{-5}	7.4909×10^{-4}	.314
0.50	5.8	4.796×10^{-4}	1.17724	15.04×10^{-5}	6.3×10^{-4}	.264