LAWRENCE BERKELEY LABORATORY — UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
LH 1001	M 7800	1 OF 30

AUTHOR	DEPARTMENT	LOCATION	DATE
EGON HOYER			10/8/99

PROGRAM — PROJECT — JOB: US - LHC COLLABORATION

1.1.4 — ABSORBERS — TAS

MAG

TITLE: AMBIENT COOLING OF TAS IN THE CMS SHIELDING

SUMMARY

AMBIENT COOLING IS CONSIDERED HERE FOR THE TAS INSTALLED IN THE CMS SHIELD ROTATING SYSTEM WITH A DESIGN HEAT LOAD OF 400 WATTS (ULTIMATE LUMINOSITY). CALCULATIONS SHOW THAT THE TAS WILL REACH THE 75° TEMPERATURE LIMIT IN 2½ MONTHS & 94°C IN SIX MONTHS. IF A BAKEOUT SHIELD IS ADDED TO THE TAS, THE 75°C LIMIT WILL BE REACHED IN < 1 MONTH. WITH 160 WATTS (DESIGN LUMINOSITY) THE TAS WITH A BAKEOUT SHIELD REACHES THE 75°C LIMIT IN 6 MONTHS.

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7600-54250

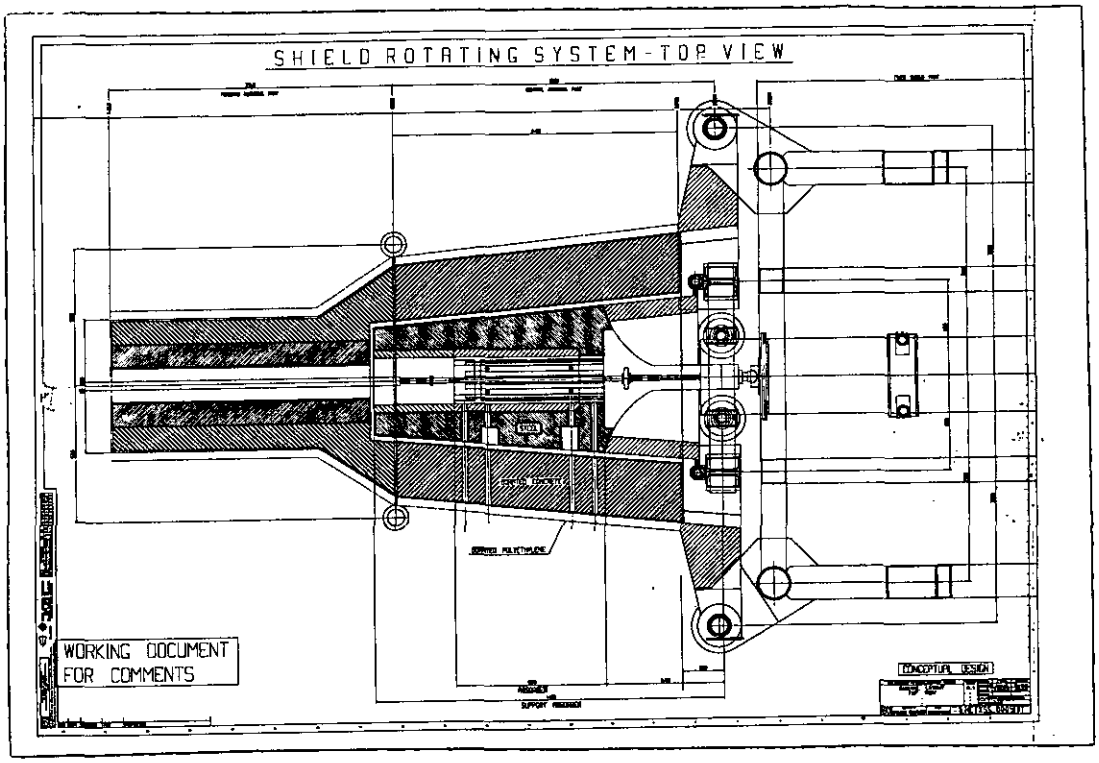
RL-3220 (Rev. 5/75)

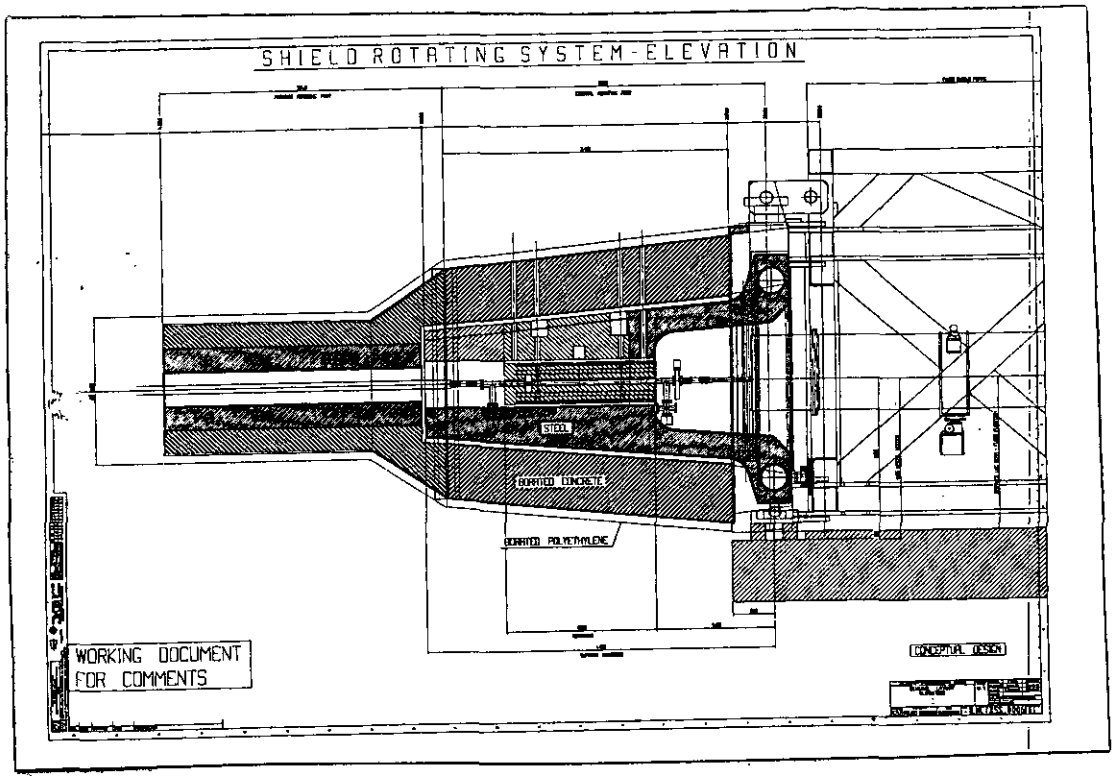
TAS INPUT POWER:

- ABSORBED COLLISION POWER AT INJECTION 219 W
- 24 HR AVERAGE ABSORBED COLLISION POWER
  (219 W)(0.6) 131 W
- 24 HR AVERAGE ABSORBED COLLISION POWER @ ULTIMATE LUMINOSITY
  (219 W)(0.6)(2.5) 329 W

BASE CALCULATIONS ON 400 W ABSORBED IN THE TAS

TAS SHIELDING CONFIGURATION (CMS):





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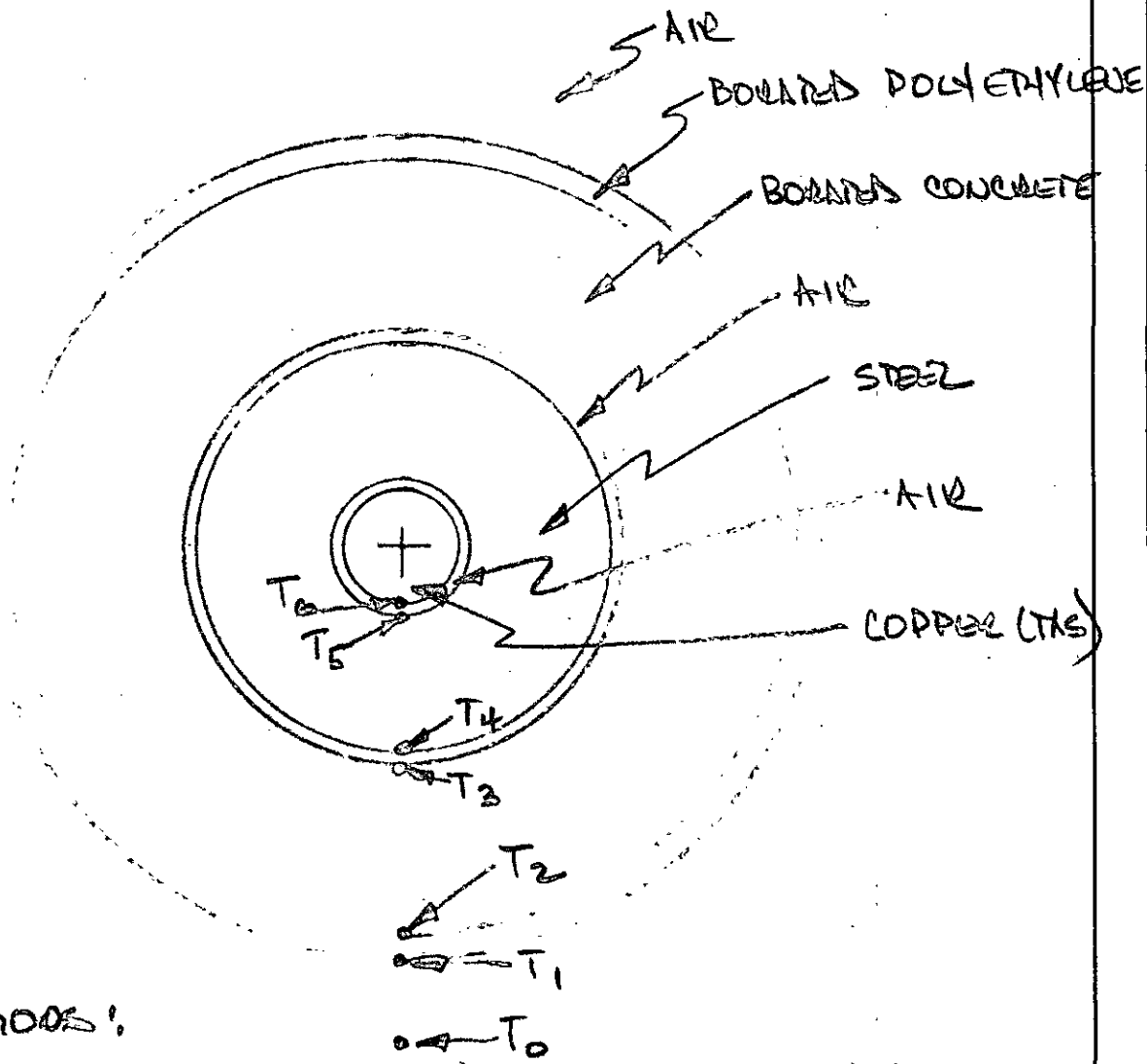
THERMAL MODEL (CENTRAL SECTION):



ASSUMPTIONS:

- NO HEAT FLOW DOWN THE VACUUM PIPE.
- NO HEAT FLOW OUT THE ROTATING SHIELDING FRONT END.
- NO HEAT FLOWS INTO THE FIXED SHIELD REGION
- START BY ASSUMING 3/4 OF THE TAS ENERGY FLOWS RADIALLY OUTWARD IN THE CENTRAL SECTION & 1/4 FLOWS FORWARD TO THE FRONT SECTION, ADJUST LATER SO THAT THE FRONT & CENTRAL AIR - STEEL SHIELDING DT'S ARE THE SAME.

TEMPERATURE DIFFERENTIALS (CENTRAL SECTION):

(BASED ON 300W FLOWING RADIALLY IN THE CENTRAL SECTION)

- BORATED POLYETHYLENE - AIR TEMPERATURE DIFFERENTIAL $(T_1 - T_0)$:

$$Q = h_{1-2} A_{1-2} (T_1 - T_0) + \sigma \epsilon A_{1-2} F (T_1^4 - T_0^4)$$

- GRASHOF NUMBER

$$Gr = \frac{g\beta}{\nu^2} \Delta T L^3$$

$$= \left(\frac{1.36 \times 10^{+8}}{°K\ m^3}\right)(3.2\ m)^3 \Delta T \quad \text{(AIR @ 20°C)}$$

$$= \underline{4.46 \times 10^9\ \Delta T}$$

$$Pr = \underline{0.71} \quad \text{(AIR)}$$

FOR A SINGLE LONG CYLINDER

$$\overline{Nu}_D = 0.53 (Gr_D Pr)^{0.25}$$

(VALID FOR $10^3 < Gr < 10^9$ - USE ANYWAY)

$$\bar{h}_D = \frac{k}{D} 0.53 (Gr_D Pr)^{0.25}$$

ASSUME $\Delta T = 3°C$

$$\bar{h}_D = \left(\frac{.0251\ \frac{W}{m\ °K}}{3.2\ m}\right)(0.53)\left[(4.46 \times 10^9)(3)(.71)\right]^{.25}$$

$$= 1.30 \ \frac{W}{m^2\ °K}$$

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$$f(Q) = \left(1.30\frac{W}{m^2\,{}^\circ K}\right)(3.2\,m)\overbrace{(\pi)(3.5\,m)}^{35.19}(T_1 - T_0)$$

$$+\left(\frac{5.67\times10^{-8}\,W}{m^2\,{}^\circ K^4}\right)(.9)\overbrace{(3.2\,m)\,\pi\,(3.5\,m)}^{35.19}(1)(T_1^4 - T_0^4) - 300\,W$$

$$f(Q) = 45.74\,(T_1 - T_0) + 1.796\times10^{-6}(T_1^4 - T_0^4) - 300\,W$$

FOR $T_0 = 293\,{}^\circ K$

T_1 (°K)	296	295	294	294.3
$f(Q)$	358	157	-72.6	-4.1

CLOSE ENOUGH – CORRECT ASSUMED ΔT

TRY $\Delta T = 1.3\,{}^\circ C$

$$\bar{h}_D = \left(1.30\,\frac{W}{m^2\,{}^\circ K}\right)\left[\frac{1.3}{3}\right]^{.25}$$

$$= \underline{1.05}\ W/m^2\,{}^\circ K$$

$$\therefore\ f(Q) = \left(\frac{1.05}{1.30}\right)45.74(T_1 - T_0) + 1.796\times10^{-6}(T_1^4 - T_0^4) - 300$$

T_1 °K	294.3
$f(Q)$	-15.4

$$T_1 - T_0 = 294.3 - 293.0$$

$$= \underline{1.3\,{}^\circ C}$$

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– BORATED POLYETHYLENE TEMPERATURE DROP $(T_2 - T_1)$:

$$Q = k A \frac{T_2 - T_1}{\Delta X}$$

$$T_2 - T_1 = \frac{Q \Delta X}{k A}$$

$$= \frac{(300\,W)(.1\,m)}{\left(0.17 \frac{W}{m\,°K}\right)(35.19\,m^2)}$$

$$= \underline{5.0}\ °C$$

– BORATED CONCRETE TEMPERATURE DROP $(T_3 - T_2)$:

$$Q = 2\pi L k \frac{(T_3 - T_2)}{\ln \frac{r_2}{r_3}}$$

$$T_3 - T_2 = \frac{Q \ln \frac{r_2}{r_3}}{2\pi L k}$$

$$= \frac{(300\,W) \ln \frac{319}{178}}{(2)(\pi)(3.45\,m)\ 0.128 \frac{W}{m\,°K}}$$

$$= \underline{63.1}\ °C$$

– BORATED CONCRETE – STEEL SHIELDING AIR GAP $(T_4 - T_3)$:

$$T_3 = T_0 + (T_1 - T_0) + (T_2 - T_1) + (T_3 - T_2)$$

$$= 20°C + 1.3°C + 5.0°C + 63.1°C$$

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$T_3 = 89.4°C$

$$Q = h_{4-3} A_{4-3} \frac{(T_4 - T_3)}{\nu} + \Delta\epsilon A_{4-3} F (T_4^4 - T_3^4)$$

FOR AIR @ 100°C

$Ra_\nu = Gr_\nu Pr$

$$Gr_\nu = \frac{g\beta}{\nu^2} \Delta T \, \nu^3$$

$$= \left(\frac{.472 \times 10^8}{°K\, m^3}\right)(\Delta T)(.05\, m)^3$$

$$= 5900\, \Delta T$$

$D_i = 1.64\, m$

$D_o = 1.74\, m$

ASSUME $\Delta T = 2°C$

$Gr_\nu = (5900)(2) = 1.18 \times 10^4$

$Pr = 0.71$

$Ra_\nu = (1.18 \times 10^4)(.71)$

$= \underline{8.378 \times 10^3}$

FOR CONCENTRIC CYLINDERS, KREITH, pg 265

$$\frac{h_{eff}}{k} = .386 \underbrace{\left[\frac{\ln (D_o/D_i)}{\nu^{3/4}\left(\left(\frac{1}{D_i}\right)^{3/5} + \left(\frac{1}{D_o}\right)^{3/5}\right)^{5/4}}\right]}_{I} \left(\frac{Pr}{0.861 + Pr}\right)^{1/4} Ra^{1/4}$$

$$I = \frac{\ln \frac{1.74}{1.64}}{(.05)^{3/4}\left(\frac{1}{1.74}^{3/5} + \frac{1}{1.64}^{3/5}\right)^{5/4}}$$

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$I = 0.1956$

EQUATION VALID FOR

$0.70 \le Pr \le 600$

$10 \le [I]^4 Ra_L \le 10^7$

$[I]^4 Ra_L = (.1956)^4 (18.378 \times 10^3)$

$= 12.3$ OK

$$\frac{k_{eff}}{k} = (.386)(.1956)\left(\frac{.71}{.86+.71}\right)^{1/4}(18.378 \times 10^3)^{1/4}$$

$= 0.592$

FOR AIR @ 100°C

$$k_{eff} = \left(.0307 \frac{W}{m\,°K}\right)(0.592)$$

$= \underline{0.0182} \frac{W}{m\,°K}$

$$\epsilon_{4\text{-}3} = \frac{\epsilon_4 \epsilon_3}{\epsilon_3 + (1-\epsilon_3)\epsilon_4}$$

$$\epsilon_{4\text{-}3} = \frac{(0.78)(0.93)}{(0.93) + (1-0.93)(0.78)}$$

$= \underline{0.74}$

$$f(Q) = \left(.0182 \frac{W}{m\,°K}\right)\left(\pi(1.69m)(3.45m)\frac{(T_4 - T_3)}{.05m}\right)$$

$$+ \left(5.67 \times 10^{-8} \frac{W}{m^2\,°K^4}\right)(.74)(\pi)(1.69m)(3.45m)(1)(T_4^4 - T_3^4) - 300W$$

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$$f(Q) = 6.62\,(T_4 - T_3) + 7.6855\times10^{-7}\,(T_4^4 - T_3^4) - 300$$

FOR $T_3 = 273 + 89.4 = 362.4°C$

T_4	364.4	364.3		
$f(Q)$	8.3	-7.2		

CLOSE ENOUGH $\quad T_4 - T_3 = \underline{2.0°C}$

- STEEL SHIELDING TEMPERATURE DROP $(T_5 - T_4)$:

$$Q = 2\pi L k \frac{(T_5 - T_4)}{\ln \frac{r_4}{r_5}}$$

$$T_5 - T_4 = \frac{Q \ln \frac{r_4}{r_5}}{2\pi L k}$$

$$= \frac{(300\ W)\left(\ln \frac{1.64\,m}{0.56\,m}\right)}{(2\pi)(2.8\ m)\left(43\ \frac{W}{m\,°K}\right)}$$

$$= \underline{0.4°C}$$

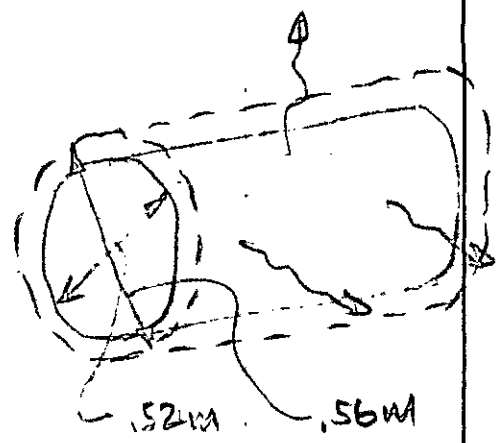
- TAS - STEEL SHIELDING AIR GAP $(T_6 - T_5)$:

$$Q = h_{6-5} A_{6-5}(T_6 - T_5) + \sigma \epsilon A_{6-5} F (T_6^4 - T_5^4)$$

$$T_5 = T_3 + (T_4 - T_3) + (T_5 - T_4)$$

$$= 89.4 + 2.0 + 0.4 = \underline{91.8\ °C}$$

FOR AIR @ 100°C



$$Ra_{\ell} = Gr_{\ell}\, Pr_{\ell}$$

$$Gr_{\ell} = \frac{g\beta}{\nu^2}\Delta T\, \ell^3$$

$$= \left(\frac{.472\times10^{8}}{\text{or } m^3}\right)\Delta T\,(.02m)^3$$

$$= 3.78\times10^{2}\,\Delta T$$

ASSUME $\Delta T = 10°C$

$$Gr_{\ell} = 3.78\times10^{2}\times10$$

$$= 3780$$

$$Pr = 0.71$$

$$Ra_{\ell} = (3780)(.71)$$

$$= \underline{2.684\times10^{3}}$$

FOR CONCENTRIC CYLINDERS –

$$\frac{k_{eff}}{k} = .386\underbrace{\left[\frac{\ln(D_o/D_i)}{\ell^{3/4}\left(\frac{1}{D_i}^{3/5}+\frac{1}{D_o}^{3/5}\right)^{5/4}}\right]}_{I}\left(\frac{Pr}{.861+Pr}\right)^{1/4} Ra^{1/4}$$

$$I = \left[\frac{\ln .56/.52}{(.02)^{3/4}\left(\frac{1}{.52}^{3/5}+\frac{1}{.56}^{3/5}\right)^{5/4}}\right]$$

$$= 0.369$$

$$[I^4]\, Ra_{\ell} = (.369)^4\,(2.684\times10^{3})$$

$= 49.8$ OK

$$\frac{h_{eff}}{h_s} = (.386)(.369)\left(\frac{.71}{.861 + .71}\right)^{1/4}\left(2.664\times10^{3}\right)^{1/4}$$

$$= \underline{0.841}$$

FOR AIR @ 100°C

$$h_{eff} = \left(\frac{.0307\ W}{m\,°K}\right)(.841)$$

$$= \underline{0.0258\ \frac{W}{m\,°K}}$$

$$\epsilon_{65} = \frac{\epsilon_5\,\epsilon_6}{\epsilon_6 + (1-\epsilon_6)(\epsilon_5)}$$

$$= \frac{(0.7)(0.78)}{0.78 + (1-.78)(.70)}$$

$$= \underline{0.585}$$

$$f(Q) = \left(\frac{.0258\ W}{m\,°K}\right)(\pi)(.52\,m)(1.6\,m)\frac{(T_6 - T_5)}{.02\,m}$$
$$+ \left(\frac{5.67\times10^{-8}\ W}{m^2\,°K}\right)(.585)\,\pi(.52\,m)(1.6\,m)(1)\left(T_6^4 - T_5^4\right) - 300$$

$$= 3.793\,(T_6 - T_5) + 9.747\times10^{-8}\left(T_6^4 - T_5^4\right) - 300$$

FOR $T_5 = 91.8°C = 364.8°K$

$\Delta T = 16.5°C$

T_6	374.8	376.8	377.0	377.5	380.8	381.3
$f(Q)$	-64.8	-15.9	-11.0	1.4	84.0	96.7

$T_6 - T_5 = 12.7°C$

SUMMARY:

WITH 300 WATTS FLOWING RADIAL OUT OF THE CENTRAL SECTION

DESCRIPTION	TEMPERATURE
CAVERN AIR TEMP. (T_0)	20°C
BORATED POLY ETHYLENE – OUTER SURFACE TEMP (T_1)	21°C
BORATED CONCRETE – OUTER SURFACE TEMP (T_2)	26°C
BORATED CONCRETE – INNER SURFACE TEMP (T_3)	89°C
STEEL SHIELDING – OUTER SURFACE TEMP (T_4)	91°C
STEEL SHIELDING – INNER SURFACE TEMP (T_5)	92°C
TAS (T_6)	104°C

$T_6 - T_0 = \underline{84°C}$

$T_4 - T_0 = \underline{71°C}$

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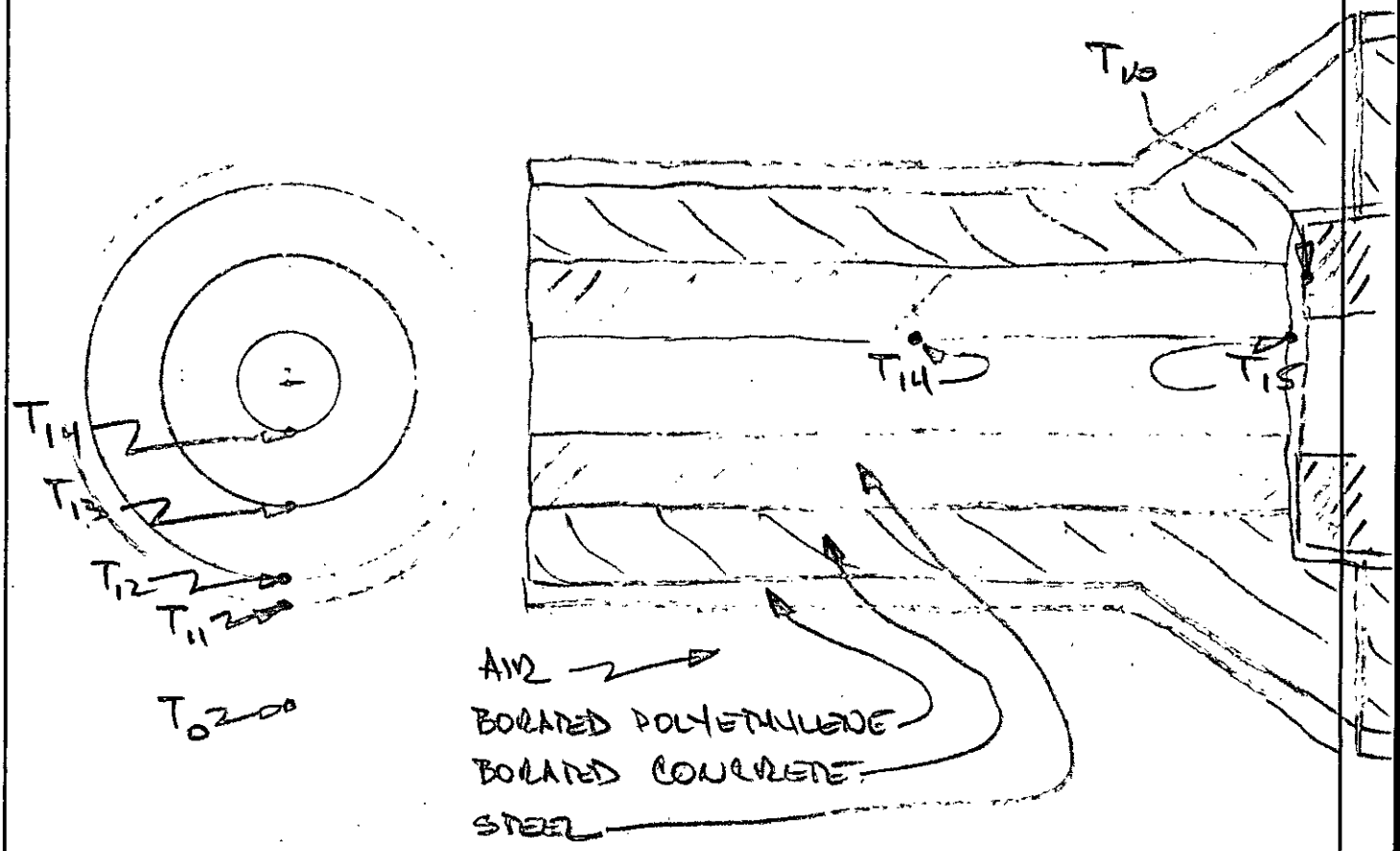
THERMAL MODEL (FORWARD SECTION):



ASSUMPTION:

- SOME 1/4 OF THE TAS ENERGY (100W) ENTERS THE FRONT SECTION.

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TEMPERATURE DIFFERENTIALS (FORWARD SECTION):

ASSUME 1/4 OF THE POWER (100 W) GOES INTO THE FORWARD SECTION.

- AIR - BORATED POLYETHELENE TEMPERATURE DIFFERENTIAL $(T_{11} - T_0)$

$$Q_{FS} = h_{11} A_{11} (T_{11} - T_0) + \Delta\epsilon A_{11} F (T_{11}^4 - T_0^4)$$

FOR AIR @ 20°C & $\Delta T = 1°C$

$$Gr = \left(\frac{1.36 \times 10^8}{°K\ m^3}\right)(1.8m)^3 (1°C)$$

$$= 7.93 \times 10^8$$

$$Pr = 0.71$$

$$h_{11} = \left(\frac{\frac{.0251\ W}{m\,°K}}{1.8m}\right)(.53)\left[(7.93 \times 10^8)(.71)\right]^{.25}$$

$$= \underline{1.14}\ \frac{W}{m^2\,°K}$$

$$\Delta(Q_{FS}) = \left(\frac{1.14\ W}{m^2\,°K}\right)\underbrace{(\pi)(1.8m)(3.35m)}_{18.94}(T_{11} - T_0)$$

$$+ \frac{5.67 \times 10^{-8}\ W}{m^2\,°K^4}(.9)(\pi)(1.8m)(3.35m)(T_{11}^4 - T_0^4) - 100$$

$$= 21.6(T_{11} - T_0) + 9.665 \times 10^{-7}(T_{11}^4 - T_0^4) - 100$$

FOR $T_0 = 293°K$

T_{11}	294	293.8
$\Delta(Q)$	19.3	-5.4

CLOSE ENOUGH $T_{11} - T_0 = \underline{0.8°C}$

- BORATED POLYETHYLENE TEMPERATURE DROP $(T_{12}-T_{11})$

$$Q_{FS} = k A_{11} \frac{(T_{12}-T_{11})}{\Delta x}$$

$$T_{12}-T_{11} = \frac{(100\,W)(0.1\,m)}{\left(0.17\,\frac{W}{m\,^\circ K}\right)(18.9\,m^2)}$$

$$= \underline{3.1}\ ^\circ C$$

- BORATED CONCRETE TEMPERATURE DROP $(T_{13}-T_{12})$:

$$Q_{FS} = 2\pi L \frac{(T_{13}-T_{12})}{\ln \frac{r_{12}}{r_{13}}}$$

$$T_{13}-T_{12} = \frac{100\,W \ln \frac{1.6\,m}{1.0\,m}}{2\pi\ 3.35\,m\ \frac{0.128\,W}{m\,^\circ K}}$$

$$= \underline{17.4}\ ^\circ C$$

- STEEL SHIELDING RADIAL TEMPERATURE DROP $(T_{14}-T_{13})$

$$T_{14}-T_{13} = \frac{100\,W \ln \frac{1.0}{0.4\,m}}{(2\pi)(3.05\,m)\left(43\,\frac{W}{m\,^\circ K}\right)}$$

$$= \underline{0.1}\ ^\circ C$$

- STEEL SHIELDING LONGITUDINAL TEMPERATURE DROP $(T_{15}-T_{14})$:

$$Q_{FS} = k A_{14} \frac{(T_{15}-T_{14})}{L/2}$$

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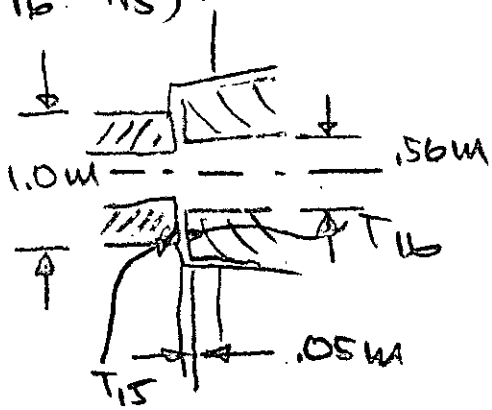
$$T_{15}-T_{14} = \frac{(100\,W)\left(\frac{3.05\,m}{2}\right)}{\left(\frac{43\,W}{m\,°K}\right)\left(\frac{\pi}{4}\left(1.0\,m^2 - .4\,m^2\right)\right)}$$

$$= \underline{5.4°C}$$

– AIR GAP BETWEEN STEEL FORWARD SHIELDING & STEEL CENTRAL SHIELDING $(T_{16}-T_{15})$:

$$Q_{FS} = h_{15} A_{15} (T_{16}-T_{15}) + \Delta \epsilon_{15} A_{15} F (T_{16}^4 - T_{15}^4)$$



$$T_{15} = T_0 + (T_{11}-T_0) + (T_{12}-T_{11}) + (T_{13}-T_{12}) + (T_{14}-T_{13}) + (T_{15}-T_{14})$$

$$= 20°C + 0.8°C + 3.1°C + 17.4°C + 0.1°C + 5.4°C$$

$$= 46.8°C$$

FOR AIR @ 40°C + $\Delta T = 20°C$

$$Gr_\delta = \left(\frac{1.01\times10^{+8}}{m^3\,°K}\right)(20°C)(.05\,m)^3$$

$$= 2.53\times10^5$$

$$Pr = 0.71$$

$$Ra_\delta = (2.53\times10^5)(0.71)$$

$$= \underline{1.80\times10^5}$$

$$\frac{L}{\delta} = \frac{\frac{1.0\,m - .56\,m}{2}}{.05\,m}$$

$$= \underline{4.4}$$

$$\overline{Nu}_\delta = 0.22\left(\frac{L}{\delta}\right)^{-1/4}\left[\left(\frac{Pr}{.2+Pr}\right)(Ra_\delta)\right]^{0.28}$$

VALID FOR
$2 < \frac{L}{\delta} < 10$
$Pr < 10$
$Ra_\delta < 10^{10}$

$$\overline{Nu}_\delta = \frac{h_\delta \delta}{k}$$

$$h_\delta = \left(\frac{0.0265\ \frac{W}{m\,°K}}{.05\,m}\right)(.22)(4.4)^{-1/4}\left[\left(\frac{0.71}{.2+.71}\right)(1.8\times10^5)\right]^{0.28}$$

$$h_{15} = 2.224\ \frac{W}{m^2\,°K}$$

$$f(Q_{FS}) = \left(2.224\ \frac{W}{m^2\,°K}\right)\overbrace{\left(\frac{\pi}{4}\left(1.0\,m^2 - .56\,m^2\right)\right)}^{0.539\,m^2}(T_{16}-T_{15})$$
$$+ \frac{5.67\times10^{-8}\,W}{m^2\,°K^4}\left(\frac{.64}{.78}\right)\left(.539\,m^2\right)(1.0)\left(T_{16}^4 - T_{15}^4\right) - 100$$

FOR $T_{15} = 46.8°C = 319.8°K$

T_{16}	339.8°K	340.8°K	344.8°K
$f(Q_{FS})$	-19.8	-15.6	1.8

← CLOSE ENOUGH

$T_{16} - T_{15} = \underline{25°C}$

SUMMARY:

WITH 100 W FLOWING INTO THE FORWARD SECTION

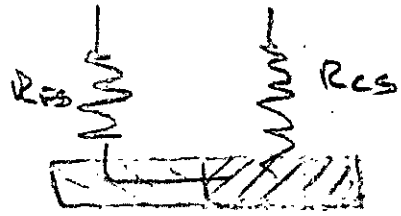
DESCRIPTION	TEMPERATURE
CAVERN AIR TEMP (T_0)	20°C
BORATED POLYETHYLENE – OUTER SURFACE TEMP (T_{11})	21°C
BORATED CONCRETE – OUTER SURFACE TEMP (T_{12})	24°C
STEEL SHIELDING – OUTER SURFACE TEMP (T_{13})	41°C
STEEL SHIELDING – INNER SURFACE TEMP (T_{14})	41°C
STEEL SHIELDING – INNER SURFACE TEMP @ FORWARD-CENTRAL SECTIONS INTERFACE (T_{15})	49°C
STEEL SHIELDING – CENTRAL SECTION TEMP (T_{16}) (T_4)	72°C

$$T_{16} - T_0 = 52°C$$

ADJUSTMENT:

IN THE CENTRAL SECTION $T_4 - T_0 = 71°C$, IN THE FORWARD SECTION $T_{16} - T_0$ or $T_4 - T_0 = 52°C$, THEREFORE IN REALITY MORE ENERGY FLOWS INTO THE FORWARD SECTION + LESS RADIALLY OUTWARD IN THE CENTRAL SECTION

$$\frac{1}{R_T} = \frac{1}{R_{FS}} + \frac{1}{R_{CS}}$$



$$Q = \frac{\Delta T}{R_i}$$

$$R_{FS} = \frac{52°C}{100W} = 0.52\ °C/W$$

$$R_{CS} = \frac{71°C}{300W} = 0.2367\ °C/W$$

$$R_T = \frac{R_{FS} R_{CS}}{R_{FS} + R_{CS}}$$

$$= \frac{(0.52)(0.2367)}{0.52 + 0.2367}$$

$$= \underline{0.1626\ °C/W}$$

$$Q_T = \frac{\Delta T_T}{R_T}$$

$$\Delta T_T = Q R_T$$

$$= (400W)\left(.1626\frac{°C}{W}\right)$$

$$= \underline{65.1\ °C}$$

$$Q_{FS} = \frac{65°C}{0.52\ °C/W}$$

$$= \underline{125\ W}$$

$$Q_{CS} = 400 - 125 = \underline{275W}$$

TEMPERATURE SUMMARY : (ULTIMATE LUMINOSITY)

CENTRAL SECTION :

275 W FLOWS RADIALLY OUTWARD

T_0	20°C
T_1	21°C
T_2	26°C
T_3	84°C
T_4	85°C
T_5	86°C
T_6	102°C

FRONT SECTION :

125 W FLOWS INTO THE FRONT SECTION

CHECKS

T_{11}	21°C
T_{12}	25°C
T_{13}	47°C
T_{14}	47°C
T_{15}	54°C
T_{16} (T_4)	85°C

APPROXIMATE TAS TEMPERATURES AT DESIGN LUMINOSITY

$$T_{6_{DL}} = 20°C + \frac{98-20}{25}$$

$$= \underline{51}\ °C$$

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HEATING RATES:

$$P\,dt = W C_p\,dT$$

$$\frac{dT}{dt} = \frac{P}{W C_p}$$

– FOR THE TAS: (400 W INPUT)
TAS WEIGHT = 3167 kg (MA 7749)

$$\left.\frac{dT}{dt}\right)_{TAS} = \frac{400\,W}{\underbrace{(3167\,kg)\left(\frac{10^3\,g}{kg}\right)\left(.098\,\frac{cal}{g\,°C}\right)\left(4.185\,\frac{W\text{-}sec}{cal}\right)}_{1.22\times10^8\,\frac{W\text{-}sec}{°C}}\left(\frac{hr}{3600\,sec}\right)}$$

$$= 1.181\ \frac{°C}{hr}$$

– FOR THE NEUTRAL STEEL SHIELDING: (275 W INPUT)

STEEL CONE WEIGHT:

$$W_{Fe} = \frac{7.87\,g}{cm^3}\left\{\left[156\,cm^2 - 56\,cm^2\right]\frac{\pi}{4}(276\,cm) + \frac{\pi}{4}\left[190\,cm^2 - 147\,cm^2\right]\ 113\,cm\right\}\frac{kg}{10^3\,g}$$

$$= 46'288\ kg$$

$$\left.\frac{dT}{dt}\right)_{Fe} = \frac{275\,W}{\underbrace{(46'288\,kg)\left(\frac{10^3\,g}{kg}\right)\left(0.108\,\frac{cal}{g\,°C}\right)\left(4.185\,\frac{W\text{-}sec}{cal}\right)}_{20.9\times10^6\,\frac{W\text{-}sec}{°C}}\left(\frac{hr}{3600\,sec}\right)}$$

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$$\left.\frac{dT}{dt}\right)_{Fe} = \underline{0.0473}\ {}^{\circ}C/HR$$

– FOR THE CENTRAL CONCRETE SHIELDING: (275 W INPUT

CONCRETE WEIGHT (LIGHT WEIGHT)

$$W_{conc} = \frac{1.4g}{cm^3}\left[319cm^2 - 179cm^2\right]\frac{\pi}{4}\ 345cm\left(\frac{kg}{10^3g}\right)$$

$$= \underline{26'583}\ kg$$

$$\left.\frac{dT}{dt}\right)_{conc} = \frac{275\ W}{\underbrace{(26'583kg)\left(\frac{.23\ cal}{g\ {}^{\circ}C}\right)\left(\frac{4.185\ W\text{-}SEC}{CAL}\right)\left(\frac{10^3g}{kg}\right)}_{25.6\times10^6\ W\text{-}SEC/{}^{\circ}C}\left(\frac{HR}{3600sec}\right)}$$

$$= \underline{0.0387}\ {}^{\circ}C/HR$$

– FOR THE FORWARD SECTION STEEL SHIELDING:
(125 W INPUT)

$$W_{\substack{Fe\\FS}} = \frac{7.87g}{cm^3}\left\{\left[100cm^2 - 40cm^2\right]\pi/4\right\}305cm\ \frac{kg}{10^3g}$$

$$= \underline{15'840\ kg}$$

$$\left.\frac{dT}{dt}\right)_{\substack{Fe\\FS}} = \frac{125\ W}{\underbrace{(15\,840kg)\left(\frac{10^3g}{kg}\right)\left(\frac{0.108\ cal}{g\ {}^{\circ}C}\right)\left(4.185\ \frac{W\text{-}SEC}{CAL}\right)}_{7.15\times10^6\ \frac{W\text{-}SEC}{{}^{\circ}C}}\ \frac{HR}{3600}}$$

$$= \underline{0.0629\ \frac{{}^{\circ}C}{HR}}$$

- FOR THE FORMED SECTION BOLTED CONCRETE: (125 W INPUT):

CONCRETE WEIGHT (LIGHT WEIGHT)

$$W_{\substack{CONC\\FS}} = \frac{1.4\,g}{cm^3}\left[160\,cm^2 - 100\,cm^2\right]\frac{\pi}{4}\;335\,cm\;\frac{kg}{10^3\,g}$$

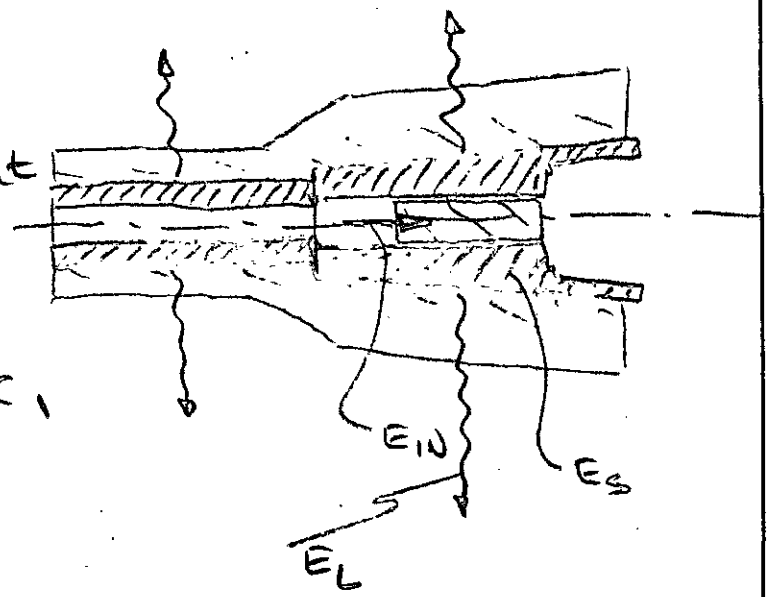
$$= \underline{5746\ kg}$$

$$\left.\frac{dT}{dt}\right)_{\substack{CONC\\FS}} = \frac{125\,W}{\underbrace{(5746\,kg)\left(1.23\,\frac{cal}{g\,^\circ C}\right)\left(4.185\,\frac{W\text{-}s}{cal}\right)\left(\frac{10^3}{kg}\right)}_{5.528\times10^5\ W\text{-}sec/^\circ C}\left(\frac{HR}{3600}\right)}$$

$$= \underline{0.0814\ ^\circ C/HR}$$

APPROXIMATE TAS TIME-TEMPERATURE RELATION!

MODEL: T = STEEL TEMPERATURE



$$E_{IN} = E_S + E_L$$

$$P_{IN}\,dt = W_S C_{PS}\,dT + KT\,dt$$

$$\frac{dT}{P_{IN} - KT} = \frac{dt}{W_S C_{PS}}$$

$$-\frac{1}{K}\ln(P_{IN} - KT) = \frac{t}{W_S C_{PS}} + C_1$$

FOR $t = 0$ $T = 0$

$$C_1 = -\frac{1}{K}\ln P_{IN}$$

$$-\frac{1}{K}\ln(P_{IN} - KT) = \frac{t}{W_S C_{PS}} - \frac{1}{K}\ln P_{IN}$$

$$\ln(P_{IN} - KT) - \ln P_{IN} = \frac{-Kt}{W_S C_{PS}}$$

$$\ln\left(\frac{P_{IN} - KT}{P_{IN}}\right) = \frac{-Kt}{W_S C_{PS}}$$

$$\frac{P_{IN} - KT}{P_{IN}} = e^{-\frac{Kt}{W_S C_{PS}}}$$

$$-KT = P_{IN} e^{-\frac{Kt}{W_S C_{PS}}} - P_{IN}$$

$$T = \frac{P_{IN}}{K}\left(1 - e^{-\frac{Kt}{W_S C_{PS}}}\right)$$

$$K = \frac{1}{R_T}$$

$$\tau = W_s C_{ps} R_T$$

$$T = P_{IN} R_T \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$P_{IN} R_T = (400W)(.1626\,°C/W)$$

$$= 65.1°C$$

BASE THE INTERNAL ENERGY ON HEATING THE TAS, STEEL SHIELDING & 1/2 THE CONCRETE

$$W_s C_{ps} = \left[1.22\times10^6 + 2.09\times10^8 + \frac{2.56\times10^7}{2} + 7.15\times10^6 + \frac{5.53\times10^6}{2}\right] \frac{W\text{-sec}}{°C}$$

$$= 44.8\times10^6 \ \frac{W\text{-sec}}{°C}$$

$$\tau = \left(44.8\times10^6 \ \frac{W\text{-sec}}{°C}\right)(.1626\,°C/W)$$

$$= 7.29\times10^6 \text{ sec} \ \frac{\text{month}}{2.635\times10^6 \text{ sec}}$$

$$= 2.77 \text{ months}$$

$$T_{STEEL} = 65.1\left(1 - e^{-\frac{t}{2.77 \text{ months}}}\right) + 20°C$$

$$T_{TAS} = T_{STEEL} + 16°C$$

t (months)	1	2	3	4	5	6	7	8
T_{STEEL} (°C)	39.7	53.5	63.1	69.7	74.4	77.7	79.9	81.5
T_{TAS} (°C)	55.7	69.5	79.1	85.7	90.4	93.7		

TAS - STEEL TEMPERATURE DIFFERENTIAL WITH A BAKE OUT SHIELD (ALUMINUM FOIL WRAPPED AROUND THE TAS):

FROM PAGE 10 & 12

$$Q = h_{6-5} A_{6-5} (T_6' - T_5) + \Delta \epsilon A_{6-5} F (T_6'^4 - T_5^4)$$

$$\epsilon F = \frac{1}{\frac{1}{\epsilon_6} + \frac{1}{\epsilon_5} - 1}$$

$$= \frac{1}{\frac{1}{0.78} + \frac{1}{.05} - 1}$$

$$= \underline{0.049}$$

$$f(Q) = 3.793 (T_6' - T_5) + \overbrace{(9.747 \times 10^{-8})\left(\frac{.049}{.58}\right)}^{8.235 \times 10^{-9}} (T_6'^4 - T_5^4) - 400$$

FOR $T_5 = 91.8°C = 364.8°K$

T_6' (°K)	394.8	404.8	424.8	434.8	432.8
f(Q	-232	.173	-50.1	+14.0	1.01

$T_6' - T_5 = 68°C$

- INCREASED ΔT WITH THE BAKEOUT SHIELD:

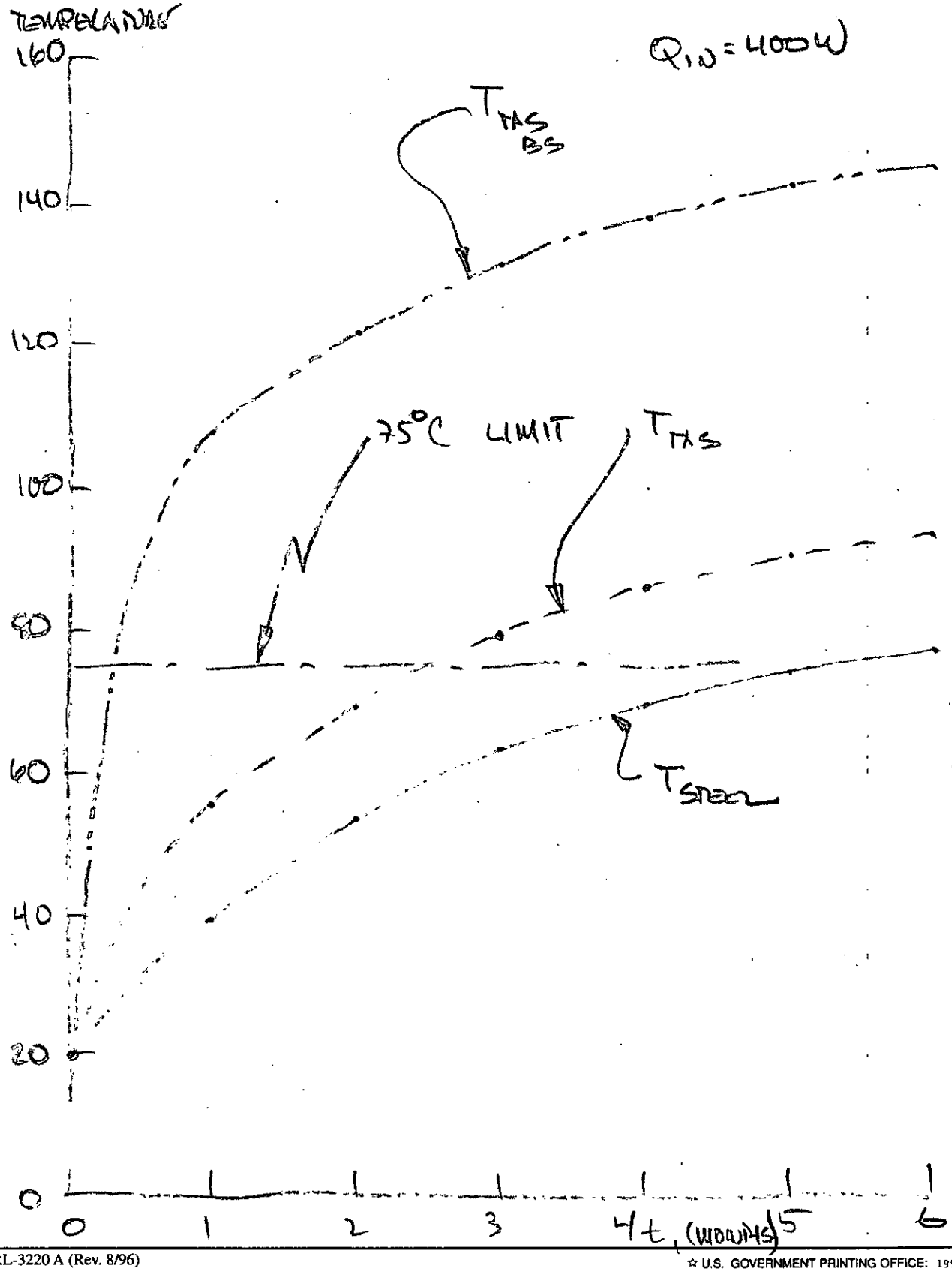
$$\Delta T_{INCREASE} = (T_6' - T_5) - (T_6 - T_5)$$

$$= 68°C - 16.5°C$$

$$= \underline{51.5°C}$$

$$T_{TAS_{B/O}} = T_{STEEL} + 68°C$$

TAS – TEMPERATURE VERSUS TIME FOR ULTIMATE LUMINOSITY (2.5×10^{29} cm^{-2} sec^{-1})



TAS TIME-TEMPERATURE FOR DESIGN LUMINOSITY:

$$P_{IN}\,RT = \left(\frac{400W}{2.5}\right)(.1626\,°C/W)$$

(160W)

$$= 26.0°C$$

$$T''_{STEEL} = 26.0\left(1 - e^{-\frac{t}{2.72\ \text{MONTHS}}}\right) + 20°C$$

$$T''_{TAS} = T_{STEEL} + 7°C$$

t (MONTHS)	1	2	3	4	5	6	7	8
T STEEL (°C)	27.9	33.4	37.2	39.9	41.7	43.0	43.9	44.6
T TAS (°C)	34.9	40.4	44.2	46.9	48.7	50.0	50.9	51.6

TAS - STEEL TEMPERATURE WITH A BAKEOUT SHIELD:

FROM PG 27:

$$f(Q) = 3.793\,(T''_6 - T''_5) + 8.235\times10^{-9}\,(T''^4_6 - T''^4_5) - 160W$$

FOR $T_{STEEL} = 46°C = 319°K$

T''_6 (°K)	349	300	351
f(Q)	-9.31	-4.11	1.09

$T''_6 - T''_5 = 32°C$

$$T''_{TAS\,BS} = T''_{STEEL} + 32°C$$

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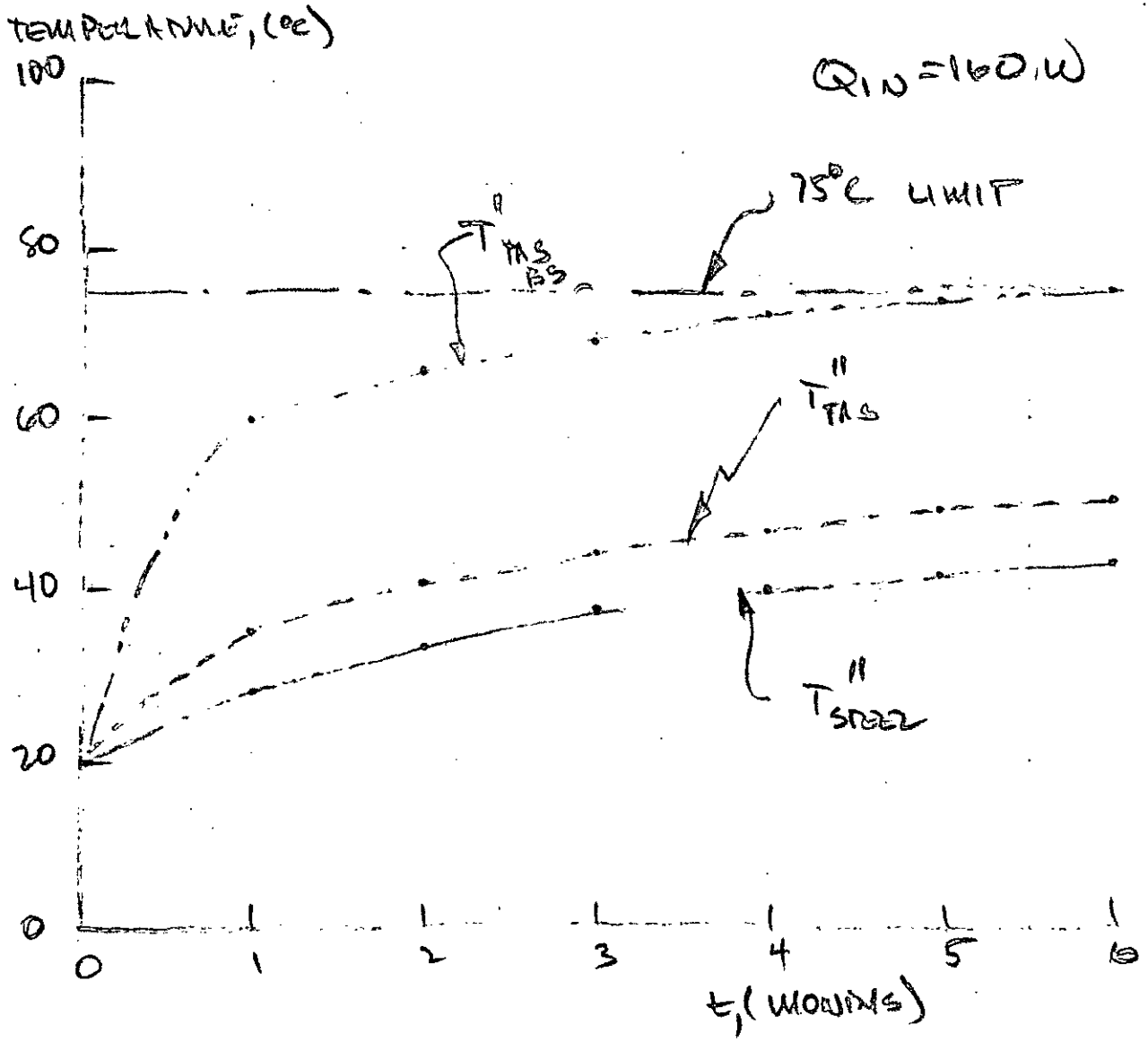
AUTHOR HOYER	DEPARTMENT	LOCATION	DATE 10/8/99

TAS – TEMPERATURE VERSUS TIME FOR DESIGN LUMINOSITY (1.0×10^{34} $cm^{-2}sec^{-1}$)



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