Title
HEAT TRANSFER CALCULATIONS FOIL WIGGLER MASKS

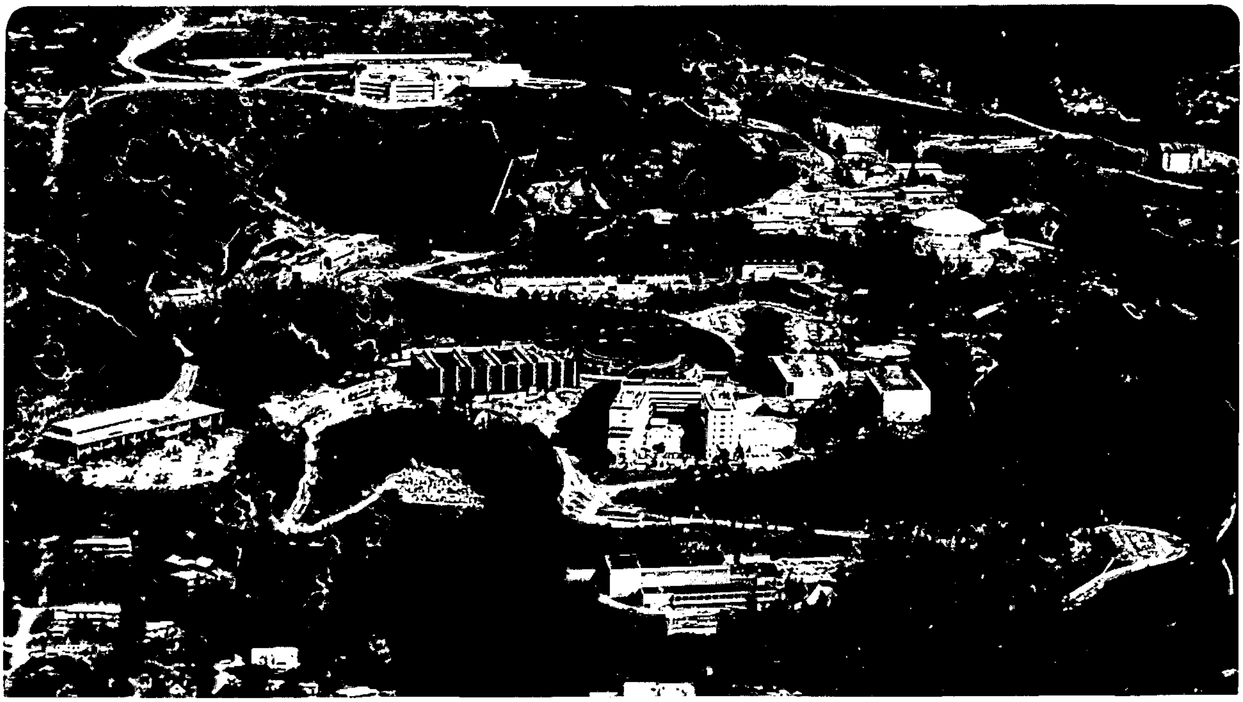
Author
Bayer, Egon.

Publication Date
1982-06-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Engineering & Technical Services Division



LBID 570

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
SL 0606	M 5946	1 of 10

AUTHOR	DEPARTMENT	LOCATION	DATE
EGON HOYER			6/25/82

PROGRAM — PROJECT — JOB

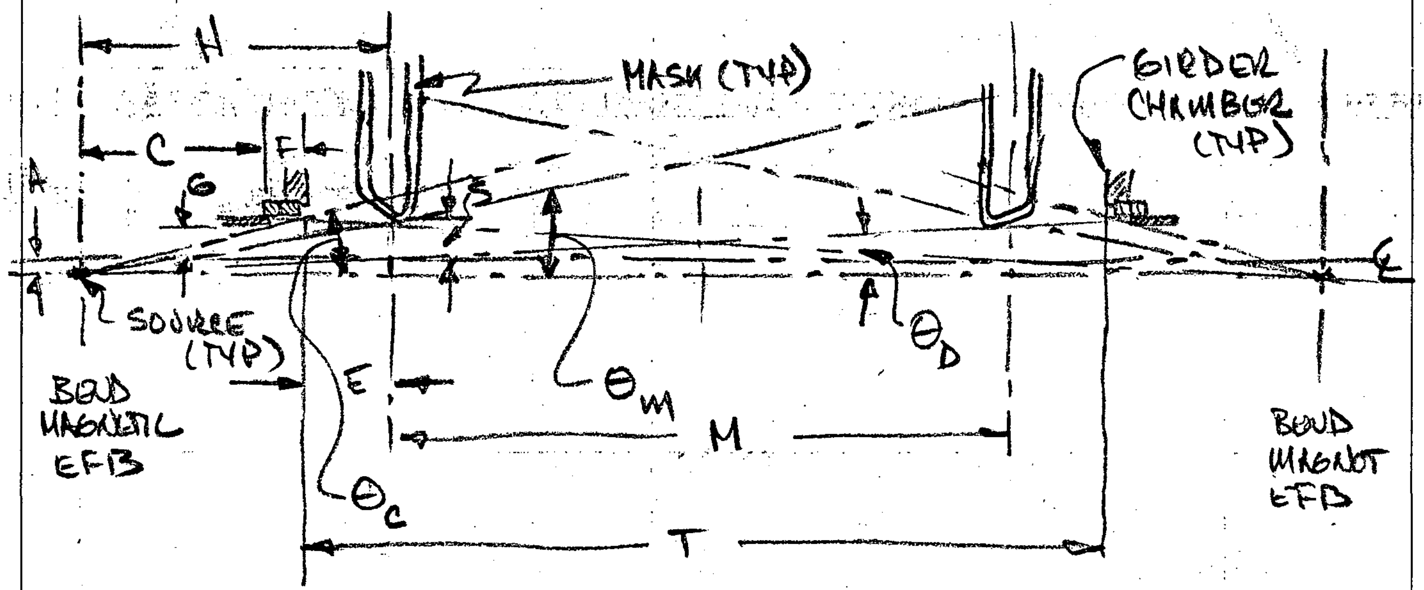
SLF - WIGGLER / BEAM LINE VI

MASKS — TWO MASK SYSTEM — DESIGN NO. 1

TITLE

HEAT TRANSFER CALCULATIONS FOR WIGGLER MASKS

LAYOUT:



MASK DESIGN PARAMETERS:

BEAM POWER (DESIGN) = 200 KW / BEAM
(130KW @ 3.7GEV, 100ma)

MAXIMUM TEMPERATURES = 250°C (SURFACE); 100°C (H_2O)

VERTICAL MASKING $= 2(9mm)[\sigma_y, \theta_v, \sigma_y'] + 2(6m)[\sigma_y'] = 30\ mm$

BEAM DIVERGENCE $(\pm\frac{1}{\gamma})$ = ±.14 mRAD (3.7GEV)

BEAM SPOT SIZE $(\pm\sigma_y)$ = ±.15 mm → USE $2\sigma_y = (2)(.15m$

DIMENSIONS:

$$C = \underset{(DRIFT)}{.625m} + \underset{(1/2\ QUAD)}{\frac{.50m}{2}} + \underset{(℄ QUAD-END)}{.432m} - \underset{(F)}{.051\ m} = \underline{1.256m}$$

$G = \underline{7.5cm}$ $\quad \underline{A = 1.0cm}$ (1cm OFFSET FROM ℄)

$$\theta_C = \tan^{-1}\frac{G+A}{C} = \tan^{-1}\frac{7.5+1.0cm}{126\ cm} = \underline{3.87^\circ}$$

E = 2.5cm (FLANGE) + 4.5cm (POSITION MONITOR) +
12.5cm (BELLOWS) + 0.2cm (CLEARANCE) + $\frac{6.0}{2}$ cm (1/2 MASK WIDTH)

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
560606	M5946	2 OF 10

AUTHOR	DEPARTMENT	LOCATION	DATE
EGON HOYER			6/25/82

$E = \underline{0.227\,m}$

$F = \underline{.051\,m}$

$H = C+F+E = 1.256 + .051 + .227 = \underline{1.534\ m}$

$M = \overset{1.89\,m}{(.07\,m)(27)}\ [27\ \text{PERIODS}] + \overset{.07\,m}{(.035\,m)(2)}\ [2\text{-}\tfrac{1}{2}\ \text{PERIODS}]$
$+ \overset{.164}{(.082\,m)(2)}\ [\text{WIGGLER ENDS}] + \overset{.06}{\left(\frac{.060}{2}\right)(2)}\ [2 - \tfrac{1}{2}\ \text{MASKS}]$
$= \underline{2.184\,m}$

$T = 2E + M$
$= (2)(.227) + 2.184 = \underline{2.638\ m}$

$T_{AVAIL} = 103.795'' = \underline{2.636}\ m$ OK ✓

$\theta_D = \tan^{-1}\frac{G+A}{C+2F+T} = \tan^{-1}\frac{7.5\,cm + 1.0\,cm}{125.6\,cm + 2(5.1\,cm) + 263.8\,cm} = \underline{1.22^\circ}$

$S = \tan\theta_D\,(H+M) - A$
$= (\overset{.021}{\tan 1.22^\circ})(1.534\,m + 2.184\,m) - .01\,m = \underline{.069}\ m$ ⊛

$\theta_M = \tan^{-1}\frac{S+A}{H} = \frac{6.9\,cm + 1.0\,cm}{153.4\,cm} = \underline{2.95^\circ}$

⊛ WIGGLER WILL HAVE A HORIZONTAL MOVEMENT CAPABILITY OF ± 6 MM. THEREFORE MASK WILL BE DESIGNED SUCH THAT $S_{MAX} = \underline{6.3\ cm}$.

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA **ENGINEERING NOTE**	CODE 560606	SERIAL M5946	PAGE 3 OF 10
AUTHOR EGON HOYER	DEPARTMENT	LOCATION	DATE 2/25/82

MASK HEATING:

$0 \leq \varphi \leq \Theta_D$:

SYNCHROTRON RADIATION IS ABSORBED BY OPPOSITE GIRDER CHAMBER

$\Theta_D \leq \varphi \leq \Theta_M$

SYNCHROTRON RADIATION IS ABSORBED BY FAR MASK -

POWER:

$$P_{D-M} = \left(\frac{200 KW}{360^0}\right)\left(2.95^0 - 1.22^0\right)\frac{10^3 W}{KW}$$

$$= \underline{961 W}$$

HEAT FLUX

$$W_{D-M} = \frac{P_{D-M}}{A}$$

$$A_F = (H+M)(\Theta_M - \Theta_D)\left[\left(\frac{1}{\gamma}\right)(H+M) + \Delta\right]2$$

$$= \left(153.4 \overset{371.8}{cm} + 218.4 cm\right)\left(\frac{2.95 - 1.22^0}{\frac{180^0}{\pi} RAD}\right) \overset{.030}{}$$

$$\left[(.14 \times 10^{-3} RAD)(371.8 cm) + .015 cm\right]2$$

$$=$$

$$= \underline{1.502} \ cm^2 \quad (11.2 \ cm \times .134 \ cm)$$

$$W_{D-M} = \frac{961 W}{1.502} = \underline{640 W/cm^2}$$

$\Theta_M \leq \varphi \leq \Theta_C$

SYNCHROTRON RADIATION IS ABSORBED BY NEAR MASK -

POWER:

$$P_{M-C} = \frac{200 KW}{360^0}\left(3.87 - 2.95^0\right)\frac{10^3 W}{KW}$$

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE	SERIAL	PAGE
560606	M5946	4 OF 10

AUTHOR	DEPARTMENT	LOCATION	DATE
EGON HOYER			6/25/82

$= \underline{511 \text{ WATTS}}$

HEAT FLUX

$$w_{m-c} = \frac{P_{m-c}}{A_N}$$

$$A_N = H\,(\theta_c - \theta_m)\left[\left(\frac{1}{\gamma}\right)H + \delta\right]2$$

$$= (153.4\text{ cm})\left(\frac{3.87^\circ - 2.95^\circ}{\frac{180^\circ}{\pi}}\right)\left[153.4\,(.14\times10^{-3}\text{ RAD}) + .015\right]2$$

$$= \underline{0.179}\ \text{cm}^2 \qquad (2.46\text{ cm} \times \overset{(28\text{ mils})}{.072\text{ cm}})$$

$$w_{m-c_\perp} = \frac{511\text{ WATTS}}{0.179\text{ cm}^2} = \underline{2847\ \text{W/cm}^2}\,!$$

- REQUIRES TAKING THE HEAT LOAD ON A SLOPING SURFACE

CONSIDER AN OFHC COPPER MASK

ABSORPTION COEFFICIENTS & LENGTHS:

FROM UCRL 50174 (MC MASTER, ET. AL. ...

E (KeV)	μ/ρ (cm²/gm)	l_0 (mm)
1.17	11000	.0001
2	2345	.0005
3	778	.001
4.09	319	.004
5	192.5	.006
5.92	120.1	.009
7	73.6	.015
8	52.2	.021

$$l_0 = \frac{1}{\mu/\rho\ \rho}$$

$$\rho = 8.94\ \text{gm/cm}^3$$

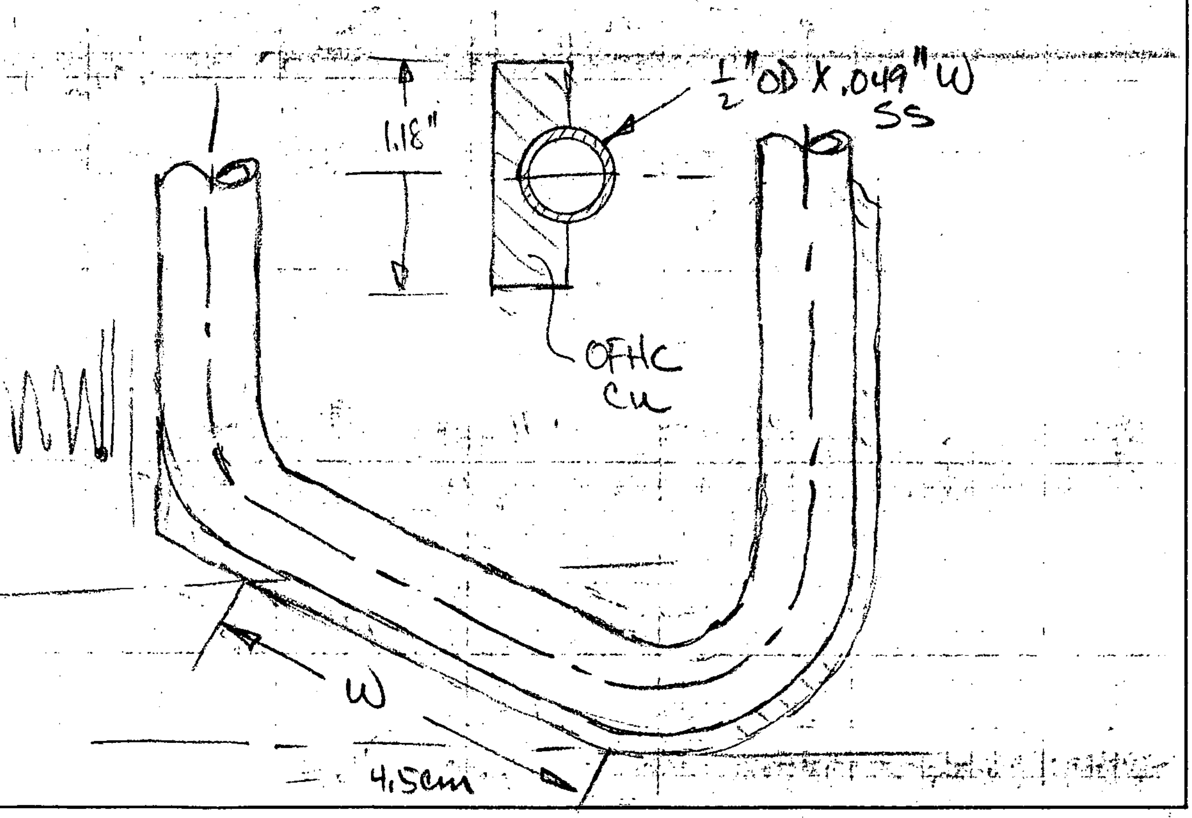
$$l_0(\text{mm}) = \frac{1.119}{\mu/\rho\ (\text{cm}^2/\text{gm})}$$

E (keV)	μ/ρ (cm²/gm)	l_0 (mm)
8.9	37.8	.030
9	290	.004
10	220	.005
15	74.4	.015
20	33.7	.033
25	18.3	.061
30	10.8	.104
40	4.86	.230
50	2.53	.442

@ 3 GEV $\epsilon_c = 4.7$ KEV FOR BENDING MAGNET RADIATION

CONCLUSION — FOR PRACTICAL PURPOSES X RAY DEPOSITION IS $\lesssim$ .1mm (.004")

CONSIDER THE FOLLOWING CONFIGURATION:



HEAT FLUX ON SLOPED SURFACE:

$$W_{M-C} = \left(2847\ \text{W/cm}^2\right)\left(\frac{2.46\text{cm}}{4.50\text{cm}}\right)$$

$$= \underline{1556\ \text{W/cm}^2}$$

TEMPERATURE DROP ACROSS COPPER

SEE PAGE 7 FOR COPPER MASK TEMPERATURE PROFILE AND SPACE FACTOR COMPUTATION

$$q = k A \frac{\Delta T_{cu}}{\Delta x} = k\, W\, \Delta y \cdot M \frac{\Delta T_{cu}}{\Delta x \cdot N}$$

$$q = k W S\, \Delta T_{cu}\ ; \quad \Delta T_{cu} = T_M - T_S \qquad S = \frac{\Delta y}{\Delta x} \cdot \frac{M}{N} \quad \Delta y = \Delta x$$

$$S\ (\text{SPACE FACTOR}) = \frac{M}{N}$$

$$\Delta T_{cu} = \frac{q}{k W S}$$

@200°C $k = 9.32$ W/IN°C FOR COPPER

$$= \frac{511\ \text{W}}{\left(\frac{9.32\text{W}}{\text{IN}^\circ\text{C}}\right)\left(\frac{4.5\text{cm}}{\frac{2.54\text{cm}}{\text{IN}}}\right)(0.8)}$$

$$= \underline{39.}\ ^\circ\text{C}$$

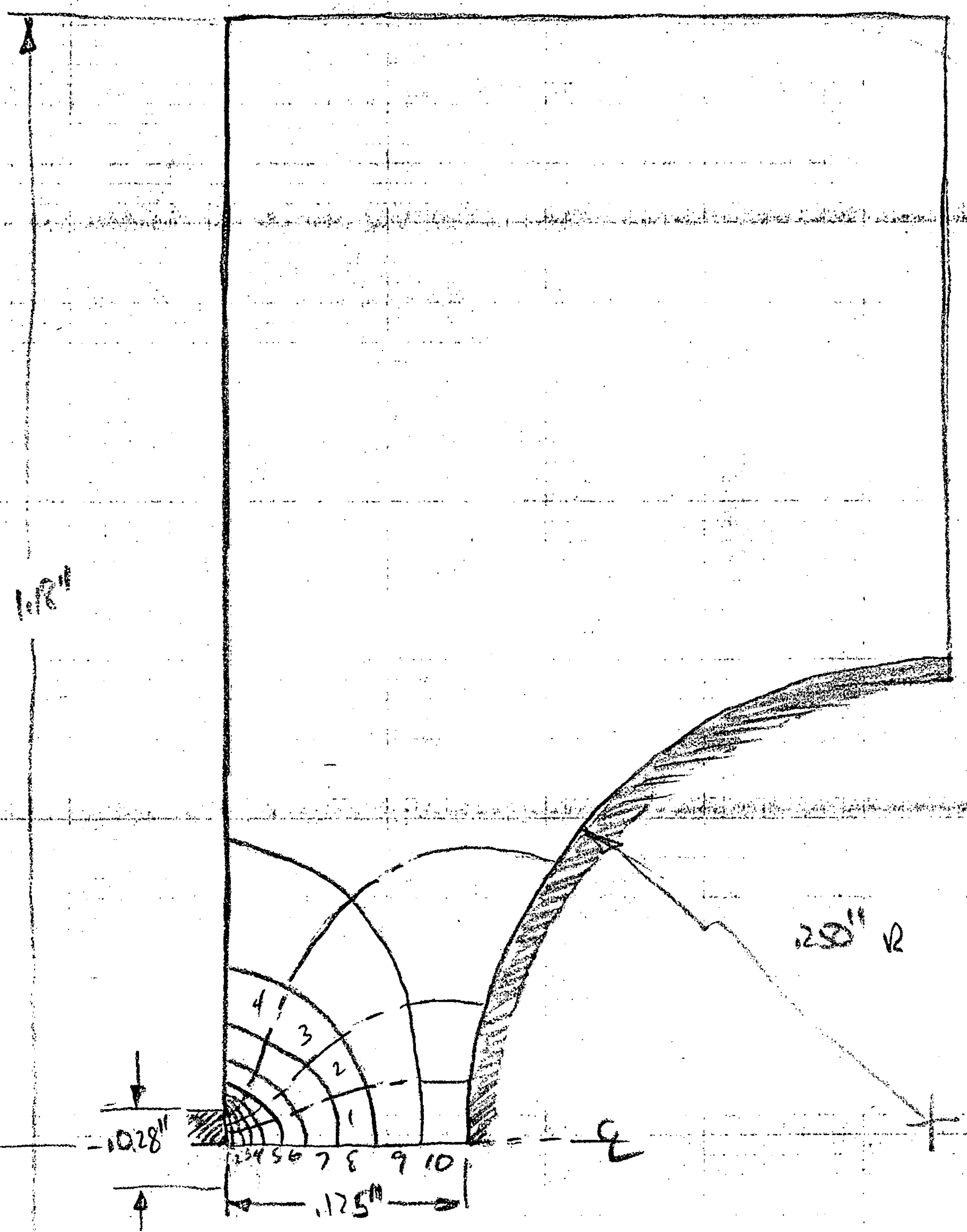
LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA

ENGINEERING NOTE

CODE SL0600
SERIAL M5946
PAGE 7 OF 10

AUTHOR EGON HOYER
DEPARTMENT
LOCATION
DATE 6/25/82

TEMPERATURE PROFILE ACROSS MASK (COPPER):



$$S = \frac{M}{N} = \frac{2 \times 4}{10} = 0.80$$

7600-54246 RL-3220A (Rev. 6/76)

TEMPERATURE DROP ACROSS SS:

$$q = KA \frac{\Delta T}{\Delta x}$$

$$\Delta T_{ss} = \left(\frac{q}{A_{ss}}\right) \frac{\Delta x_{ss}}{k_{ss}}$$

$$\Delta T_{ss} = M_{ss} \frac{\Delta x_{ss}}{k_{ss}}$$

$$M_{ss} = \frac{511 \text{ WATTS}}{(2)(.125'' + .014'')(4.5 \text{ cm} + (.125'')(2)(2.54 \frac{\text{cm}}{''}))(2.54 \frac{\text{cm}}{\text{IN}})}$$

$$= \underline{141} \text{ WATTS/cm}^2$$

FOR .049'' WALL SS TUBING:

$$\Delta T_{ss} = \frac{\left(141 \frac{\text{W}}{\text{cm}^2}\right)\left(\frac{2.54 \text{ cm}}{\text{IN}}\right)^2 (.049'')}{\left(\frac{9.4 \text{ BTU}}{\text{HR FT} \cancel{°F}}\right)\left(\frac{\cancel{\text{WATT-HR}}}{3.413 \text{ BTU}}\right)\left(\frac{\text{FT}}{12\cancel{''}}\right)\left(\frac{1.8\cancel{°F}}{°C}\right)}$$

$$.413 \frac{\text{W}}{\text{IN} °\text{C}}$$

$$= \underline{108} \ °C$$

FILM TEMPERATURE RISE:

$$\Delta T_f = \frac{M_{ss}}{h}$$

$$\frac{hd}{k_b} = (Nu)_b = .023 (Re)^{.8} (Pr)_b^{.4}$$

$$d = 4R$$

CONSIDER 20'/SEC WATER VELOCITY, BULK WATER TEMPERATURE ~ 65°C (150°F)

$$N_R = \frac{V(4R)}{\nu}$$

$$R_{CIR} = \frac{\pi r^2}{2\pi r} = \frac{r}{2}$$

$$R_{REC} = \frac{(6r)(2r)}{\substack{\cancel{2(2r+6r)} \\ 16r}} = \frac{3}{4} r$$

FOR 1/2" OD X .049" WALL

$$N_R = \frac{(20'/\text{SEC})(4)\left(\frac{.25" - .049"}{2}\right)\frac{\text{FT}}{12"}}{.477\ \text{FT}^2/\text{SEC} \times 10^{-5}} = \underline{1.40 \times 10^5}$$

$$P_r = \underline{2.74}$$

$$k = \underline{.394 \frac{\text{BTU}}{\text{HR FT °F}}}$$

$$h = \frac{.023\,(N_R)^{.8}(P_r)^{.4}\,k}{4R}$$

$$= \frac{(.023)\overset{1.31 \times 10^4}{(1.40 \times 10^5)^{.8}}\ \overset{1.497}{(2.74)^{.4}}}{(4)\left(\frac{.201"}{2}\right)(} \left(\frac{.394\ \text{BTU}}{\cancel{\text{HR}}\ \text{FT}\ \cancel{°F}}\right)\left(\frac{\text{W-H}}{3.413}\right) \leftarrow \left(\frac{1.8°\cancel{R}}{°C}\right)\left(\frac{\text{FT}}{12\text{IN}}\right)$$

$$= \underline{19.4}\ \frac{\text{W}}{\text{IN}^2\ °C}$$

$$3\ \text{W/cm}^2\ °C$$

$$M_{ss} = \left(141 \frac{W}{cm^2}\right)\left(\frac{6.45\,cm^2}{in^2}\right)$$

$$\underline{909}\ W/in^2$$

$$\Delta T_f = \frac{909\ W/in^2}{19.4\ W/in^2\ {}^\circ C} = \underline{47}\ {}^\circ C$$

BULK H_2O FLOWRATE + ΔT :

$$Q = VA = V\pi r^2$$

$$= (20'/sec)(\pi)(.201)^2 in^2 \left(\frac{ft^2}{144\,in^2}\right)\left(7.48 \frac{gal}{ft^3}\right)\frac{60\ se}{mi}$$

$$= \underline{7.9}\ GPM$$

$$\Delta T_w = \left(3.80 \frac{GPM\ {}^\circ C}{kW}\right)\left(\frac{(.511 + .961)\,kW}{7.9\,GPM}\right)$$

$$= \underline{0.7}\ {}^\circ C$$

MAX. WATER TEMPERATURE : (2 MASKS IN SERIES)

$$T_{\substack{max\\H_2O}} = T_{in} + \Delta T_w + \Delta T_f$$

$$= 40^\circ C + (0.7)(2) + 47^\circ C = \underline{89^\circ C}$$

MAX. SURFACE TEMP. OF MASK:

$$T_s = T_{\substack{max\\H_2O}} + \Delta T_{ss} + \Delta T_{cu}$$

$$= 89^\circ C + 108^\circ C + 39.^\circ C = \underline{236}\ {}^\circ C$$

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720