Attachment 2
Atmospheric Relief Valve Area
Heatup Calculations

Devonrue Calculation Cover Sheet

Project No. 8-9025.00

Subject: ARV Area Ambient Temperature Rise During SBO

Description This calculation evaluates the ambient temperature rise in the ARV area during a four hour station blackout. The calculation considers heat sources and heat sinks present in this area and provides a methodology for considering a concrete and metal ceiling as a heat sink surface area. The effects of opening a door to the mezzanine level of the Turbine Building is also evaluated.

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Number of Pages Cover + 24 + 5pp of attachments

Appendices —

Attachments 5

Subject: **Ginna Atmospheric Relief Valve (ARV) Area Ambient Temperature Rise - Revised Methodology**

Identification of Computer Calculations

No computer calculations have been utilized in this analysis. Excel spreadsheets have been utilized in the calculation of surface temperatures of insulated piping and in the calculation of total heat generated from hot surfaces. However, the formulas are provided in this calculation and a numerical check has been made of the accuracy of the spreadsheet calculations.

Identification Of Assumptions

1. The perimeter of the Intermediate Building is assumed to be as shown on Ginna Station Drawing 33013-2121, Rev. 0

2. The normal max. ambient temperature in the Intermediate Building is assumed to be 104°F, consistent with the NUMARC 87-00 Section 7 methodology and the maximum auxiliary building temperature listed in Ginna FSAR Table 3.11-1.

3. The normal maximum ambient temperature of the Containment Structure just adjacent to the South wall of the Intermediate Building is assumed to be 120°F as stated in Ginna FSAR Table 3.11-1.

4. The South wall of the ARV area is assumed to be poured concrete as shown on Ginna Station drawing 330103-2121, Rev. 0. The North, East, and West walls of the ARV area (the northern portion of the Intermediate Building) are solid concrete block as shown on Ginna Station drawing 330103-2121, Rev. 0. The walls are assumed to behave in a similar manner to poured concrete walls and will be treated similarly in this calculation.

5. The ceiling of the ARV area is 5" thick poured concrete, integrally bonded with 20 gauge fenestra holorib decking as shown on sketch D-523-22 and reproduced on Attachment 1. The calculation will treat this construction as 5" of concrete with an inside layer of 0.036" of steel and will use the thermal properties of steel and concrete reported in the ASHRAE handbook of fundamentals.

6. Thermal insulation on piping is assumed to be of the type and thickness defined in RG&E Specification ME-269, Revision 0.

7. Heating Steam piping and equipment is conservatively assumed to be normally operating at a temperature of 220°F.

8. Under SBO conditions, immediately following reactor trip and MSIV closure, only one Safety Relief Valve on each steam header will lift to remove decay heat as described in Ginna UFSAR Section 7.4.1.3. Once the operators are using the ARVs to remove decay heat, it is assumed that only one ARV will be operating. Ginna UFSAR section 7.4.1.3 states, "One atmospheric steam dump, which can be operated from the Control Room is sufficient for maintaining hot shutdown or to achieve cooldown of the reactor coolant system below hot shutdown conditions."

9. The ARVs are assumed to be actuated early enough to allow SRV tailpipe cooldown within the first hour of the event.

Any additional assumptions are noted in the body of the calculation.

Identification of Design Inputs and Verified Sources

1. NUMARC 87-00, "Guidelines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at Light Water Reactors," including Appendix E, Appendix F and the Appendix F Topical Report, November 1987.

2. RG&E Technical Specification, ME-269, "Pipe, Duct, and Equipment Insulation, Ginna Station," draft issue Revision 0, dated January 30, 1989.

3. Ginna Station Plant Arrangement Drawing No. 33013-2121, Rev. 0, Cont Structure & Intermediate Bldg Plan - Oper. Flr. El. 278'-4" & 274'-6".

4. Ginna Station Plant Arrangement Drawing No. 33013-2129, Rev. 0, Intermediate Bldg Plans Above Elev's.293'-0", 298'-4", & 315'-4".

5. Ginna Station P&ID Drawing No. 33013-1231, Rev. 13, Main Steam

6. Ginna Station P&ID Drawing No. 33013-1915, Rev.4, Heating Steam

7. Ginna UFSAR Table 3.11-1, "Environmental Service Conditions for Equipment Designed to Mitigate Design-Basis Events."

8. Ginna UFSAR Section 7.4.1.3, Revision 4, dated December, 1988

9. ASHRAE 1985 Handbook of Fundamentals, Chapter 39, Table 3, "Properties of Solids"

10. Kreith, Frank, and William Black, Basic Heat Transfer, 1980.

11. Incropera, Frank P, and David P. DeWitt, Introduction to Heat Transfer, 1979.

Methodology

The objective of this calculation is to determine the ambient temperature rise in the ARV area during a four (4) hour SBO-induced loss of ventilation. This calculation uses a modification of the NUMARC 87-00 section 7 methodology that accounts for the ARV area ceiling as a heat sink. The section 7 methodology is based on the assumption that pored concrete walls will act as heat sinks and that their surface temperatures remain essentially constant over the course of the 4 hour duration. However, the constant temperature assumption may not be valid for the ceiling because the ceiling is not as thick and has a different construction from the concrete walls. Therefore, the temperature rise in this surface must be considered if crediting it as a heat sink, the simplified methodology provided in NUMARC 87-00, section 7, cannot be applied directly.

In considering the surface temperature rise in the ceiling from heat generated within the ARV room, the heat input to this ceiling from the area above it is also accounted for.

The temperature of the ceiling after 4 hours is calculated by performing an energy balance:

$Q = rho\ c_p\ V\ dT/dt$, where

Q = heat generation rate

rho = density of the heat sink material

c_p is the specific heat at constant pressure of the heat sink material

dT/dt = the temperature change of the wall per unit time, or for this case;

(T_{final} - $T_{initial}$) / 4 hours

Once the surface temperature rise is computed for the ceiling, it will be considered in the simplified NUMARC 87-00 equation as follows:

$T_{air} = T_w + [Q/A]^{3/4}$ where

Tair = the resultant ambient air temperature in the ARV area;

Tw = the wall temperature after 4 hours computed as a weighted average of each wall or ceiling prorated on the basis of surface area;

Q = heat generation rate;

A = the total surface area of walls and ceilings acting as heat sinks.

The following steps shall be performed to accomplish the described method for determining the ARV area temperature:

1. Conservatively estimate the heat generation rate, Q, in the ARV area and in the room above. The heat generation rate will be calculated by considering heat rejected from hot piping and equipment and using the methodology supplied in NUMARC 87-00, Section 7.

2. Calculate the surface area of each wall and ceiling acting as a heat sink and determine the proportion represented by each.

3. Using flat plate heat transfer correlations, the amount of heat transferred into the ceiling from the area above the ARV area will be calculated. The amount of heat transferred from the ARV area will be calculated based on the proportion of total heat sink surface area in the ARV room represented by the ceiling

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4. Determine the ceiling temperature after four hours using the equation $Q = \text{rho}\ c_p\ V\ dT/dt$. The density and specific heat of the composite concrete/steel structure will be considered in this determination. The calculated ceiling temperature after four hours of heating will be conservatively assumed throughout the station blackout transient for the purposes of calculating ARV area temperature.

5. Determine the wall temperature Tw for use in the equation $T_{air} = T_w + [Q/A]^{3/4}$.

6. Determine the ARV room temperature after 4 hours using the above equation.

7. Consider the effects of opening doors using the relationship defined in Section 7 of NUMARC 87-00.

Step 1: Determine the heat generation rate, Q, in the ARV area and in the area above.

The major heat source in each of these areas is hot piping and equipment. A physical inspection of each area was performed to identify the relevant heat sources and define their characteristic dimensions such as diameter and length. In the case of insulated surfaces, the surface temperatures must be calculated. As stated in the assumptions section, the insulation type and thickness is assumed to be as specified in ME-269, Table 1, except in the case of the HHCC Tank where the insulation thickness was field measured. In accordance with ME-269, all insulation is treated as calcium silicate.

The surface temperature is calculated by considering the convective heat transfer between the insulated surface and the air:

$$q = h\ A\ dT = h\ (T_S - T_\infty)\ 2\ \pi\ r_S\ l$$

where h is the unit thermal surface conductance (Btu/hr. sq ft °F), r_S is the radius of the insulated surface, l is the pipe length, Ts is the insulated surface temperature, and T_∞ is the ambient air temperature

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and

the conductive heat transfer from the pipe surface through the insulation;

$$q = (T_i - T_\infty) * 1/ \{ [\ln (r_s/r_i)/2\pi kl] + 1/2\pi r_s l h\}$$

where T_i is the pipe surface temperature and r_i is the pipe radius. Combining the 2 equations yields;

$$T_s = \{ 1/h\ r_s * (T_i - T_\infty) \} / \{[\ln (r_s/r_i)/k] + 1/r_s h\} + T_\infty$$

In this evaluation, the following constant values are applied:

T_∞ = 104 °F (the initial room temperature. This is conservative since heat transfer from pipe surfaces will decrease as the room temperature rises.)
h = 1.6 Btu/hr sq ft °F (table 4.4.11 of Mark's handbook. Attachment 2 to this calculation)
k = 0.045 Btu/hr ft °F (Table 4.4.6 of Mark's handbook: Attachment 3 to this calculation)

For purposes of this evaluation, k is assumed to be constant over the range of temperatures in question. "h" has been selected from Attachment 2 on the basis of large horizontal pipes. This value is felt to produce reasonable results for this calculation.

The resultant surface temperatures calculated for the heat sources identified in the ARV area and the area above are provided in Tables 1 and 2, respectively, shown on the following pages.

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Description	Ti (°F)	Circ. (ft)	ri (ft)	Ins. thk. (ft)	rs (ft)	ln(rs/ri)	Ts (°F)
30" MS header	550		1.25	0.25	1.5	0.182322	148.31
6" SRV inlet	550		0.276	0.2083	0.4843	0.562304	148.47
6" stm to AFWTb	550		0.276	0.2083	0.4843	0.562304	148.47
6" ARV inlet	550		0.276	0.2083	0.4843	0.562304	148.47
14" MRW header	450		0.583	0.25	0.833	0.356846	136.65
HHCC Tank	220		1.625	0.25	1.875	0.143101	117.72
Heating Stm pipe	220	3	0.3945	0.083	0.4775	0.190961	133.64
"	220	1.25	0.1159	0.083	0.1989	0.539917	130.45
"	220	0.958	0.0695	0.083	0.1525	0.786069	128.48
"	220	1.29	0.1223	0.083	0.2053	0.517963	130.63

TABLE 1

SURFACE TEMPERATURE OF HEAT SOURCES IN THE ARV AREA[1]

1 Reviewer's note: a check of the Table 1 and Table 2 T_s values show that they are high by approximately 3°F. This is partially compensated for in Tables 3 and 4 by the apparent use of T_a and T_W values that are high by 2°F. The net effect is to slightly overestimate the heat generation rate in the room, which is conservative.

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Description	Ti (°F)	Circ. (ft)	ri (ft)	Ins. thk. (ft)	rs (ft)	ln (rs/ri)	Ts (°F)
30" MS header	550		1.25	0.25	1.5	0.182322	148.31
14" MFW hdr	450		0.583	0.25	0.833	0.356846	136.65
10" SRV tailppe	550		0.417	0.208	0.625	0.404665	151.33
12" ARV tailppe	550		0.5	0.25	0.75	0.405465	144.5
8" TB Exh. line	240		0.333	0.125	0.458	0.318727	128.49
heating stm line	220	1.083	0.0894	0.083	0.1724	0.656886	129.48
	220	1.667	0.1823	0.083	0.2653	0.375788	131.89
	220	3	0.3525	0.125	0.4775	0.30354	125.36

TABLE 2
SURFACE TEMPERATURE OF HEAT SOURCES LOCATED IN THE AREA ABOVE THE ARV AREA

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Note in the case of heating steam pipe where only the insulated circumference could be measured, the following has been applied:

Measured Circumference (ft) = $2 \pi r_s$
therefore, r_s = Measured circumference / 2π
and $r_i = r_s$ - insulation thickness

Using the results from Tables 1 and 2, the heat generation rate, Q, for each area can be calculated from the following equation found in Section 7 of NUMARC 87-00:

$$Q = \{ 0.1 [0.4 + 15.7(T_s - T_a)^{1/6} D^{1/2} + 170.3(T_s - T_a)^{1/3} D] (Ts - Ta) + 1.4E\text{-}7 D (T^4{}_s - T^4{}_w) \} L$$

Tables 3 and 4 present the resultant heat generation rates for the ARV area and the area above the ARV area, respectively.

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Description	Ts (°F)	Ts (°K)	L (ft)	L (m)	Do (ft)	Do (m)	Ts-Ta	Ts4-Tw4	Q (watts)
30" MS line	148.3	337.76	113	34.4	3	0.914	22.94	3.195E+09	51079.847
6" SRV inlet	148.5	337.87	16	4.88	0.968	0.295	23.05	3.212E+09	2420.91
10" SRV tailpipe	225	380.37	30	9.14	0.833	0.254	65.55	1.111E+10	15038.544
6" stm to AFWTb	148.5	337.87	28	8.53	0.97	0.296	23.05	3.212E+09	4245.0369
6" ARV inlet	148.5	337.87	10	3.05	0.97	0.296	23.05	3.212E+09	1516.0846
12" ARV tailpipe	500	533.15	5	1.52	1	0.305	218.3	7.098E+10	15736.817
14" MFW header	136.7	331.32	110	33.5	1.67	0.509	16.5	2.23E+09	18543.084
HHCC Tank	117.7	320.76	8.5	2.59	3.75	1.143	5.941	765876836	895.55073
Heating stm	133.6	329.59	19	5.79	0.995	0.303	14.77	1.981E+09	1690.7606
Heating stm	130.4	327.82	3	0.91	0.398	0.121	13	1.728E+09	95.00654
Heating stm	128.5	326.76	5	1.52	0.305	0.093	11.94	1.58E+09	111.09859
Heating stm	130.6	327.93	25	7.62	0.411	0.125	13.11	1.744E+09	824.72502

Total Q (watts)= 112197.5

SA (sqm)= 597.4

Tf(°C)= 92.4
TF(°F)= 198

TABLE 3
HEAT GENERATION RATE
ARV AREA

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Description	Ts(°F)	Ts(°K)	L(ft)	L(m)	Do(ft)	Do(m)	Ts-Ta	Ts4-Tw4	Q (watts)
30" MS hdr	148.31	337.767	133	40.5	3	0.914	22.95	3.196E+09	60138.9
14" MFW hdr	136.65	331.289	45	13.7	1.67	0.509	16.47	2.226E+09	7569.84
10 SRV (Ins)	151.33	339.444	13	3.96	1.25	0.381	24.62	3.456E+09	2737.52
10" SRV (unin)	225	380.372	21	6.4	0.083	0.253	65.55	1.111E+10	10490.3
12 ARV (ins)	144.5	335.65	6.5	1.98	1.5	0.457	20.83	2.872E+09	1322.69
12 ARV (unins)	550	560.928	10.5	3.2	1	0.305	246.1	8.918E+10	39540.7
8" TB ex line	128.5	326.761	17	5.18	0.916	0.279	11.94	1.58E+09	1072.6
heating stm	129.5	327.317	32	9.75	0.345	0.105	12.5	1.658E+09	844.035
heating stm	131.9	328.65	32	9.75	0.531	0.162	13.83	1.846E+09	1437.9
heating stm	125.4	325.039	32	9.75	0.955	0.291	10.22	1.342E+09	1733.95
							Total	Q(watts)=	126889

TABLE 4
HEAT GENERATION RATE
AREA ABOVE THE ARV AREA

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Tables 3 and 4 show that the SRV tail pipes were considered to have a surface temperature of 225 °F. This value is based upon the following justification:

> As previously stated in the Assumptions section, it is reasonable to assume that only 1 of 4 safety valves in each Main Steam header will be automatically cycled upon MSIV closure following reactor trip in response to the LOOP. In order to apply the NUMARC 87-00 correlations, the two affected tail pipes will be treated as 15 ft. each (30 ft. total) of uninsulated 10" diameter piping.
>
> The set pressure of the first safety valve is 1085 psig per Ginna UFSAR section 10.3.2.4. The steam saturation temperature at this pressure is 556 °F. The safety valve is treated as a throttling device which acts as a flow restrictor, leading to a pressure drop in the fluid. It is reasonable to assume that there is no change in enthalpy across the safety valve since the valve inlet and the tail pipe exit to atmospheric pressure are well separated and the exit is relatively far downstream from the valve itself. Therefore, considering the release of steam through the safety valve to be isenthalpic and reducing in pressure to essentially atmospheric conditions, the resultant temperature on the constant enthalpy curve of the Mollier diagram (Attachment 4 to this calculation) is approximately 300°F. The SRV tailpipes are expected to remain at this temperature for only a short period of time (less than 1 hour), since the ARVs will be used for cooldown and depressurization shortly after the onset of the event, precluding further SRV actuation.
>
> In order to use a steady state temperature calculation based on the NUMARC 87-00 methodology, a constant 4 hour heat source term must be used. The SRV tailpipe heat source contribution is approximated by selecting a constant 4 hour tailpipe temperature that will provide a heat source contribution that conservatively approximates the contribution from the actual brief period at high temperature. Since heat generation, Q, is directly proportional to the product of the temperature difference (between the hot surface and the ambient air) and time (dT*t), the following is reasonable:
>
> Since Q ~ (300°F - 104 °F) * 1 hour < Q' ~ (200 °F - 104°F) * 4 hours, a surface temperature of 225 °F is chosen for the tailpipes and will produce conservative results.

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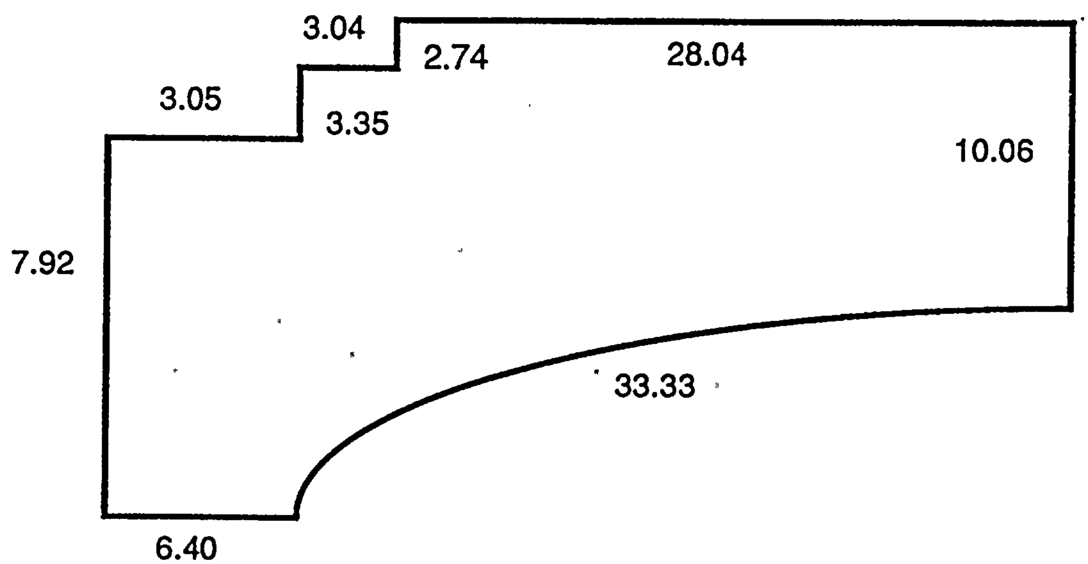
As indicated in Table 3, the surface temperature of the uninsulated 12" ARV tail pipe is assumed to be 500°F when calculating the heat generation rate in the ARV area. This is felt to be conservative since steam header temperature at the time when ARV operation begins will be somewhat less than the 550°F Main steam system design temperature. The ARVs will not be in operation until the operators take manual control of them. Therefore, the tail pipe is not expected to see steam conditions for the full four hours. In addition, the ARVs will be used to remove decay heat as well as cooldown the plant. Since the coping scenario involves plant cooldown, steam header temperatures will decrease below the hot standby operating temperature over the course of the four hours and the temperature of the steam seen by the ARV tailpipe will also decrease. On this basis, the use of a 500°F tailpipe operating temperature is judged to result in a conservative heat generation rate.

Step 2 Calculate the surface aréa of heat sinks

The straight wall lengths on the North, East and West sides of the room are scaled from the referenced arrangement drawings (see figure).



North Portion of Intermediate Building, El. 278'-4"

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Using the dimensions from the figure above, the perimeter of the room is calculated by summing these lengths.

Perimeter = 97.93 meters

The Surface Area of the walls, Awalls, is computed by multiplying the perimeter by the height of the walls. Review of the referenced drawings 33013-2121 and 2129 show that the height, h, is :

h = el 298'-4" - 278' -4" = 20' = 6.1 meters

therefore,

Awalls = 97.93 * 6.1 = 597.4 sq. meters

Since this wall will need to be treated separately later in this calculation, the area of the wall adjacent to the containment will now be calculated as :

Acont = 33.33 * 6.1 = 203.31 sq. meters

The remaining wall area is then:

Aremain = Awalls - Acont. = 597.4 - 203.31 = 394.09

The area of the ceiling is calculated conservatively as 3 rectangles using the values from the figure above:

Aceiling = (28.04 * 10.06) + (3*9) + (3*8)
Aceiling = 333.1 sq. meters[note 2]

2 Reviewer's note: a review of the drawing shows that the containment wall represented by the curved line in the figure actually extends upward farther than indicated. Thus, the 28.04x10.06 rectangle takes credit for some area that is actually in the containment rather than in the intermediate building. When this is accounted for, the ARV ceiling area is approximately 244 square meters.

Use of a larger ceiling area should not significantly affect the ceiling temperature determined later in this calculation. A corrected ceiling area of 244 square meters is used in the final room temperature where use of a larger area would be nonconservative.

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The total surface area acting as a heat sink is therefore,

$$\text{Atotal} = \text{Aceiling} + \text{Awalls} = 333.1 + 597.4 = 930.4\ m^2$$

Using this information, the following proportions are determined:

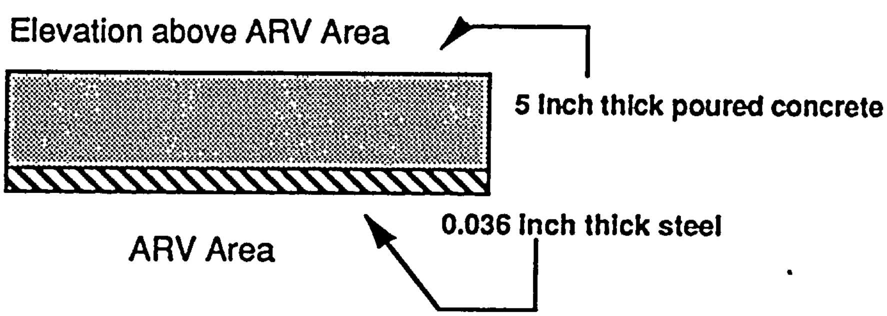
Proportion of the ceiling to total = 333.1 / 930.4 = 0.36

Proportion of the containment wall to total = 203.31 / 930.4 = 0.22

Proportion of the remaining walls to total = 394.09 / 930.4 = 0.42

Step 3 Determine the amount of heat transferred into the ceiling from the rooms above and below

As can be seen from Tables 3 and 4, the heat generation rate in the ARV room is 112,197.5 watts and the heat generation rate in the room above is 126,889 watts. As previously described, the ceiling of the ARV room is is 5" thick poured concrete, integrally bonded with 20 gauge fenestra holorib decking as shown on sketch D-523-22 and reproduced on Attachment 1. The concrete surface faces the elevation above the ARV room and the steel decking faces the ARV room. The calculation will treat this construction as 5" of concrete with an inside layer of 0.036" of steel as shown in the Figure below:



ARV Room Ceiling

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The heat transfer rate into the concrete surface from the area above will be calculated using flat plate convective heat transfer correlations for the upper surface of a cooled plate (i.e., the plate is cooler than the air). The following relationships will be applied from section 9.6 of Incropera and Dewitt using the dimensionless parameters of the Nusselt number, Nu, and the Rayleigh number, Ra:

$$Ra = [gB\ (T_S - T_\infty)\ L^3\ ] / \nu\ \alpha$$

$$Nu = 0.27Ra^{1/4}$$

$$Nu = h_c\ L / k\ ;\ \text{or}\ h_c = k\ Nu / L$$

$$Q = h_c\ A\ dT$$

where:

T_s = the surface temperature of the plate
T_∞ = the temperature of the air in the room
$B = 1/T_f$ where $T_f = (T_\infty + T_s)/2$
L = Surface area of the plate / Perimeter
g = the acceleration due to gravity, 9.8 m/sec^2

As can be seen from the above equations, the air temperature in this room must be calculated to obtain T_∞.

T_∞ will be calculated using the NUMARC 87-00 equation, $T_\infty = T_i + [Q/A]^{3/4}$ where
T_∞ = the resultant ambient air temperature in the room above the ARV area;
Ti = the initial temperature of the walls considered as heat sinks
Q = heat generation rate;
A = the total surface area of walls and ceilings acting as heat sinks.

From arrangement drawing 33013-2129, it can be seen that the perimeter of the room is virtually identical to that of the ARV room, i.e., 97.93 meters. and that the height of these walls is 17 feet, or 5.2 meters. The area of the ceiling in this room will be neglected to ensure conservative results.

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It should be noted that the construction of the ceiling in this room is identical to the ceiling of the ARV area.

Therefore , surface area of the walls = perimeter * height or:

$$A = 97.93 * 5.2 = 509.24 \text{ sq. meters}$$

Assuming that the initial air temperature is 104°F or 40°C, and that the surface is in equilibrium with the air, T_∞ is:

$$(126{,}889 \text{ watts.}/ 509.24 \text{ sq meters})\ 3/4 + 40\ °C$$
$$T_\infty = 62.7 + 40 = 102.7°C \text{ or } 217°F \text{ or } 375.85°K$$

Knowing T_∞ , T_f and B can be calculated based upon $B = 1/T_f$ where $T_f = (T_\infty + T_s)/2$

Assuming that the initial surface temperature of the plate is in equilibrium with the air, 40°C or 313.15°K:

$$T_f = (375.85°K + 313.15°K) / 2 = 344.5°K \text{ , } B = 0.0029°K^{-1}$$

Calculating L = Surface Area / perimeter, where the surface area was calculated in step 2,

$$L = 333 \text{ sq meters} / 97.93 \text{ meters} = 3.4 \text{ meters}$$

The constants ν and α are taken from Table A.4 from Incropera and Dewitt (provided as Attachment 5 to this calculation). The values for air at 350°F from the table will be used since the air temperature is 344.5 °K as calculated earlier in this step.

Therefore,

$$\alpha = 2.99E{-}5 \text{ and } \nu = 2.092E{-}5$$

Calculating the Rayleigh number, Ra , is the next step.

Knowing $Ra = [gB\ (T_S - T_\infty)\ L^3\ ] / \nu\ \alpha$, Ra is:

$$(9.8)\ (.0029)\ (62.7)\ (39.3)\ (1.6E9)$$

$$Ra = 1.12E11$$

Knowing that the Nusselt number, Nu, is $0.27\ Ra^{1/4}$,

$$Nu = 156.2$$

Using Nu and k, taken from Attachment 5, as 0.03, h_c can be calculated:

$$h_c = (0.03)\ (156.2)\ /\ (3.4) = 1.38\ W/m^2\ °K$$

The heat transfer rate into the plate from the room above is then calculated using the equation $Q = h_c\ A\ dT$ as follows;

$$Q = (1.38 W/m^2\ °K)\ (333\ m^2)\ (62.7\ °K)$$

Q= 28,813.2 W into the concrete surface from the area above

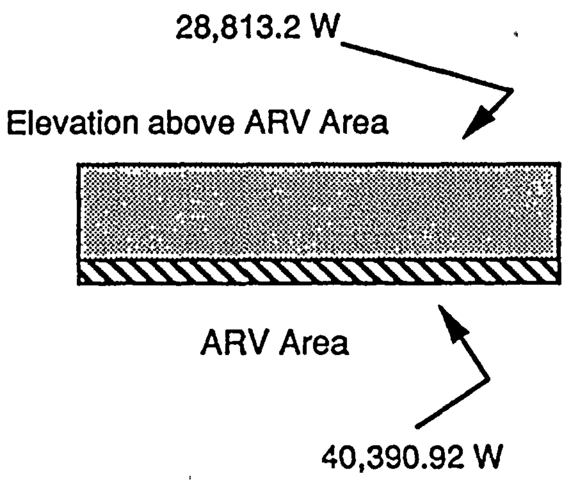
Having determined the heat transfer rate into the ceiling from the room above, the heat transfer rate into the ceiling from the ARV area itself must be calculated. A slightly different approach will be used to make this determination, since the surface area of the ceiling is to be treated as a heat sink.

As previously calculated in step 2, the surface area of the ceiling represents 36% of the total heat sink surface area. Therefore, 36% of the heat generated in the room will be transferred to this surface or:

$$Q = 0.36\ (\ 112,\ 197W) = 40,390.92\ W$$

This the total heat flux into this surface is shown on the following figure:

Subject: Ginna Atmospheric Relief Valve (ARV) Area Ambient Temperature Rise - Revised Methodology



The total heat flux into the ceiling is:

40, 390.92 W + 28,813.2 W = 69, 203.4 W

Step 4 Determine the ceiling surface temperature after 4 hours

The surface temperature of the ceiling after 4 hours will be calculated using the relationship:

Q = rho c_p V dT/dt, where

Q = heat generation rate into the ceiling

rho = density of the heat sink material

c_p = specific heat at constant pressure of the heat sink material

dT/dt = the temperature change of the wall per unit time, or for this case;

(T_{final} - $T_{initial}$) / 4 hours

As previously calculated in step 3, the total heat transfer rate, Q, into the ceiling volume is 69,203.4 W. The total volume of the plate which is the ceiling is computed as follows: (note the following calculations are made in English as opposed to SI units for the convenience of the preparer)

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Volume = Surface Area of plate* Thickness of plate

$$V = (333\ m^2 * 1\ ft^2 / 0.0929 m^2) * (5.036\ in./\ 12\ in/ft.)$$

$$V_{total} = 1504.3\ ft^3$$

Because the ceiling is constructed of two materials, a composite density and specific heat will be calculated based on the volumetric proportion of each material in the ceiling. As a first step, we must calculate the proportion of steel and proportion concrete to the total volume as follows:

Vconcrete / Vtotal = (thickness concrete * surface area) / (total thickness * surface area) or:

Vconcrete / Vtotal = thickness concrete / total thickness, and similarly
Vsteel / Vtotal = thickness steel / total thickness resulting in:

Vconcrete / Vtotal = 5 / 5.036 = 0.993
Vsteel / Vtotal = 0.036 / 5.036 = 0.007

Using these values the composite density and specific heat are calculated from the values for each individual material taken from the ASHRAE Handbook of Fundamentals:

$$rho_{concrete} = 145\ lb / ft^3 \qquad rho_{steel} = 487\ lbs / ft^3$$

$$c_{p(concrete)} = 0.156\ Btu/\ lb\ °F \qquad c_{p(steel)} = 0.113\ Btu/\ lb\ °F$$

Therefore, the composite density and specific heat of the ceiling is:

$$rho_{ceiling} = 0.993\ (145) + 0.007(487) = 147.4\ lbs / ft^3$$

$$c_{p(ceiling)} = 0.993(0.156) + 0.007(0.113) = 0.1557\ Btu/\ lb\ °F^{note\ 3}$$

The next step is to convert the heat transfer rate into units consistent with the english units used in this portion of the calculation as follows:

3 Reviewer's note: actually, the c_p of the ceiling should be mass weighted from the components rather than volume weighted. This results in a c_p of 0.1550 rather than 0.1557, which affects the dT of the ceiling by approximately 0.1°F. The effect on the final calculated room temperature will be negligible.

$$Q = 69,203.4 \text{ W} * (1 \text{ Btu/hr.} / 0.2931 \text{ W}) = 235,939.5 \text{ Btu/hr}$$

Inserting all values into the equation Q = rho c_p V dT/dt, yields:

235,939.5 Btu/hr = (147.4 lbs / ft^3) (0.1557 Btu/ lb °F) (1504.3 ft^3) (dT/4hrs)

which results in a **dT = 27.3°F.** If we assume, as stated earlier in this calculation, that the initial temperature of the ceiling is in equilibrium with the air at 104°F, then after four hours, the temperature will be:

Tceiling @ 4 hours = 104°F + 27.3°F = 131.3°F = 55.17°C

This temperature will conservatively be used as the ceiling temperature throughout the station blackout transient when calculating the ARV area temperature rise.

Step 5 Determine the representative wall temperature, T_W

In step 4, the surface temperature of the metal/concrete ceiling was calculated since it cannot be assumed to remain constant over the four hour heat-up scenario. In addition to considering the temperature of the ceiling surface, the temperature of the South wall which is adjacent to the containment structure must be considered. The South wall surface temperature inside the Intermediate Building will be calculated to be the average between the normal Containment maximum temperature and the Intermediate Building normal maximum temperature:

T(South wall) = (120°F + 104°F) / 2 = 112°F

The other walls in the Intermediate Building will be assumed to experience no temperature rise during the four hour loss of ventilation and are therefore assumed to be at 104°F.

The wall temperature to be used in the equation, $T_{air} = T_W + [Q/A]^{3/4}$ will be computed as a weighted average of each wall or ceiling prorated on the basis of surface area as follows:

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From step 2, the following proportions have been calculated:

Proportion of the ceiling to total = 333.1 / 930.4 = 0.36

Proportion of the containment wall to total = 203.31 / 930.4 = 0.22

Proportion of the remaining walls to total = 394.09 / 930.4 = 0.42

Therefore, Tw is calculated as follows:

$$Tw = 0.36(131.3°F) + 0.22(112°F) + 0.42(104°F)$$

$$Tw = 115.6°F = 46.4°C$$

Step 6 Determine the ARV Room Temperature

As previously stated, the ARV room temperature is calculated based on the simplified equation supplied in Section 7 of NUMARC 87-00:

$T_{air} = T_w + [Q/A]^{3/4}$ where

Tair = the resultant ambient air temperature in the ARV area;

Tw = the wall temperature after 4 hours computed as a weighted average of each wall or ceiling prorated on the basis of surface area;

Q = heat generation rate;

A = the total surface area of walls and ceilings acting as heat sinks.

Substituting the values determined throughout this calculation, the resultant air temperature is:[4]

$$T_{air} = 46.4°C + (112,197 / 841.3)^{3/4}$$

4 Reviewer's note: the corrected total wall areas are used for the remaining calculations, as discussed in footnote 2.

$$Tair = 39.2 + 46.4 = 85.6°C = 186°F$$

These results show that after four hours the temperature in the ARV area will rise to 186°F.

Step 7 Calculate the effects of openings doors

NUMARC 87-00, section 7 provides a methodology for calculating the effects of opening doors to allow the removal of heat from an area through natural circulation. However, Appendix E to this document clarifies that the methodology presented in Section 7 has been tested only within the following parameter ranges:

$24{,}000W < Q < 100{,}000W$
$0°C < dT < 50°C$

Examining these ranges we find that Q just slightly exceeds the limit at 112,197W, but that dT is within the range at (85.6 - 40)= 45.6°C.

Based on engineering judgement, the correlations presented in Section 7 will be applied in this case even though Q exceeds the parameter range. Since Q only exceeds the tested parameter range by 12%, the effect on the accuracy of the results is judged to be minimal.

The Section 7 methodology consists of the development of F, the door factor using the following equation:

$F = H^{3/2}$ W, where H is the door height (m) and W, the door width (m)

Once the door factor is calculated it is applied as follows:

$$T_f = 4 + T_W + [Q^{3/4} / A^{3/4} + 16.18 (F)^{0.8653}]$$

The F factor for the ARV room is based upon opening the door to the Turbine Building on the East side of the North wall. As shown on the arrangement drawing 33013-2121, this door opens to the

Turbine Building mezzanine, a large open area with roof ventilators without steam piping, which is not expected to experience any significant heatup during the loss of ventilation event. Therefore, it can be assumed that this area will have an ambient temperature of no higher than 104°F or 40 °C at the time the door is opened.

In addition, the door to the south portion of the Intermediate Building could be opened which leads to a stairwell. Due to the relatively small volume of the south portion of the Intermediate Building as compared to the ARv area (north portion), the effects of opening this door will not be calculated. However, it is expected that opening this door to the stairwell could have beneficial effects.

From the referenced arrangement drawings, the dimensions of this door are found to be 3 ft wide by 7 ft. high. Converting these dimensions to meters, the F factor is found to be:

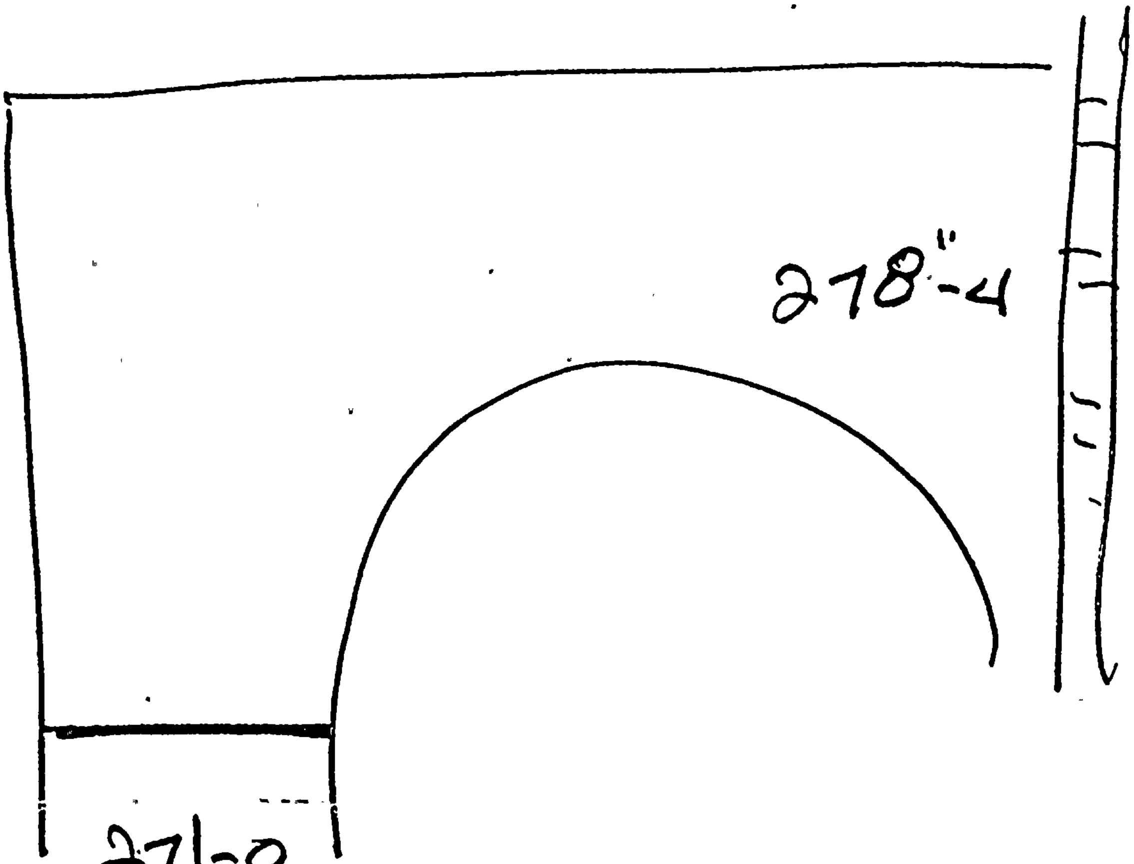
$$F = (2.13)^{3/2} \ (0.914) = 2.85$$

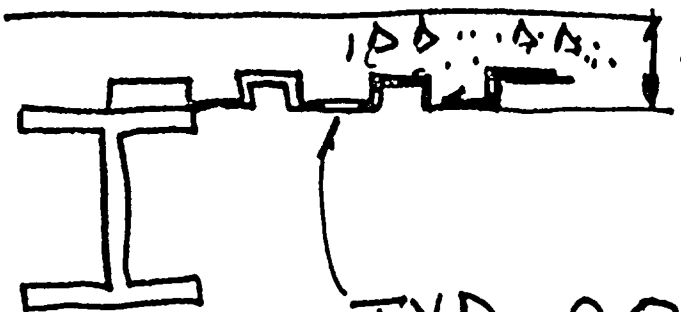
Applying this value in the above cited equation yields:

$$T_f = 4 + 46.4 + (112{,}197)^{3/4} \ / \ [(841.3)^{3/4} + 16.18 \ (2.85)^{0.8653}]$$

$$T_f = 4 + 46.4 + 31.2$$

$$T_f = 81.6°C = 178.9°F$$





TYP. 20GA.

FENESTRA HOLORIB DECK

integrally bonded to concrete

E278'-4

From: D-523-22
sketched by: Gene Pospisil

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appears to be the best available. Zuber also performed an analysis for subcooled liquids and proposed a modification which is also in excellent agreement with experiment:

$$(q/A)_{max} = K_1\rho_v[\lambda + C_{pl}(t_{sat} - t_l)]\left[\frac{\sigma g_L g_c(\rho_l - \rho_v)}{\rho_v^2}\right]^{0.25}\left(\frac{\rho_l}{\rho_l + \rho_v}\right)^{1/2}$$
$$\left\{1 + \frac{5.33(\rho_l C_{pl} k_l)^{1/2}(t_{sat} - t_l)}{\rho_v[\lambda + C_{pl}(t_{sat} - t_l)]}\left[\frac{g_L(\rho_l - \rho_v)\rho_v^2}{\sigma^3 g_c^2}\right]^{1/8}\right\} \quad (4.4.14c)$$

Zuber's hydrodynamic analysis of the Leidenfrost point yields

$$(q/A)_{min} = K_2\lambda\rho_v\left[\frac{\sigma g_L g_c(\rho_l - \rho_v)}{\rho_l^2}\right]^{1/4} \quad 0.144 < K_2 < 0.177 \quad (4.4.14d)$$

Berenson finds better agreement with the data if $K_2 = 0.09$. For very small wires, the heat flux will exceed that predicted by this flat-plate formula. A reliable prediction of the critical temperature is not available.

For nucleate boiling accompanied by forced convection, the heat flux may be approximated by the sum of the heat flux for pool boiling alone and the heat flux for forced convection alone. This procedure will not be satisfactory at high qualities, and no satisfactory correlation exists for the maximum heat flux.

For a given liquid and boiling pressure, the nature of the surface may substantially influence the flux at a given (Δt), Table 4.4.10. These data may be used as rough approximations for a bank of submerged tubes. Film coefficients for scale deposits are given in Table 4.4.8.

For forced-circulation evaporators, vapor binding is also encountered. Thus with liquid benzene entering a 4-pass steam-jacketed pipe at 0.9 fps, up to the point where 60 percent by weight was vaporized, the maximum flux of 60,000 Btu/h/ft² was obtained at an overall temperature difference of 60°F; beyond this point, the coefficient and flux decreased rapidly, approaching the values obtained in superheating vapor, see Eq. (4.4.8).

For comparison, in a natural convection evaporator, a maximum flux of 73,000 Btu/h/ft² was obtained at $(\Delta t)_o$ of 100°F.

Combined Convection and Radiation Coefficients In some cases of heat loss, such as that from bare and insulated pipes, where loss is by convection to the air and radiation to the walls of the enclosing space it is convenient to use a combined convection and radiation coefficient $(h_c + h_r)$. The rate of heat loss thus becomes

$$q = (h_c + h_r)A(\Delta t)_s \quad (4.4.15)$$

where $(\Delta t)_s$ is the temperature difference, deg F, between the surface of the hot body and the walls of the space. In evaluating $(h_c + h_r)$, h_c should be calculated by the appropriate convection formula [see Eqs. (4.4.11c) to (4.4.11g)] and h_r from the equation

$$h_r = 0.00685\epsilon(T_m/100)^3$$

Table 4.4.10 Maximum Flux and Corresponding Overall Temperature Difference for Liquids Boiled at 1 atm with a Submerged Horizontal Steam-Heated Tube

Liquid	Aluminum		Copper		Chromium-plated copper		Steel	
	$\frac{q/A}{1000}$	$(\Delta t)_o$	$\frac{q/A}{1000}$	$(\Delta t)_o$	$\frac{q/A}{1000}$	$(\Delta t)_o$	$\frac{q/A}{1000}$	$(\Delta t)_o$
Ethyl acetate........	41	70	61	55	77	55		
Benzene............	51	80	58	70	73	100	82	100
Ethyl alcohol........	55	80	85	65	124	65		
Methyl alcohol......	..	..	100	95	110	110	155	110
Distilled water......	..	..	230	85	350	75	410	150

Table 4.4.11 Values of $(h_c + h_r)$
For horizontal bare or insulated standard steel pipe of various sizes and for flat plates in a room at 80°F

Nominal pipe diam, in.	$(\Delta t)_s$, temperature difference, deg F, from surface to room														
	50	100	150	200	250	300	400	500	600	700	800	900	1000	1100	1200
½	2.12	2.48	2.76	3.10	3.41	3.75	4.47	5.30	6.21	7.25	8.40	9.73	11.20	12.81	14.65
1	2.03	2.38	2.65	2.98	3.29	3.62	4.33	5.16	6.07	7.11	8.25	9.57	11.04	12.65	14.48
2	1.93	2.27	2.52	2.85	3.14	3.47	4.18	4.99	5.89	6.92	8.07	9.38	10.85	12.46	14.28
4	1.84	2.16	2.41	2.72	3.01	3.33	4.02	4.83	5.72	6.75	7.89	9.21	10.66	12.27	14.09
8	1.76	2.06	2.29	2.60	2.89	3.20	3.88	4.68	5.57	6.60	7.73	9.05	10.50	12.10	13.93
12	1.71	2.01	2.24	2.54	2.82	3.13	3.83	4.61	5.50	6.52	7.65	8.96	10.42	12.03	13.84
24	1.64	1.93	2.15	2.45	2.72	3.03	3.70	4.48	5.37	6.39	7.52	8.83	10.28	11.90	13.70
FLAT PLATES															
Vertical..............	1.82	2.13	2.40	2.70	2.99	3.30	4.00	4.79	5.70	6.72	7.86	9.18	10.64	12.25	14.06
HFU..................	2.00	2.35	2.65	2.97	3.26	3.59	4.31	5.12	6.04	7.07	8.21	9.54	11.01	12.63	14.45
HFD..................	1.58	1.85	2.09	2.36	2.63	2.93	3.61	4.38	5.27	6.27	7.40	8.71	10.16	11.76	13.57

HFU, horizontal, facing upward; HFD, horizontal, facing downward.

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Table 4.4.6 Thermal Conductivities of Insulating Materials for High Temperatures

Material	Bulk density, lb per cu ft	Max temp, deg F	100 F	300 F	500 F	1000 F	1500 F	2000 F
Asbestos paper, laminated	22.	400	0.038	0.042				
Asbestos paper, corrugated	16.	300	0.031	0.042				
Diatomaceous earth, silica, powder	18.7	1500	0.037	0.045	0.053	0.074		
Diatomaceous earth, asbestos and bonding material	18.	1600	0.045	0.049	0.053	0.065		
Fiberglas block, PF612	2.5	500	0.023	0.039				
Fiberglas block, PF614	4.25	500	0.021	0.033				
Fiberglas block, PF617	9.	500	0.020	0.033				
Fiberglas, metal mesh blanket, #900	......	1000	0.020	0.030	0.040			
Cellular glass blocks, ave. value	8.5	900	0.033	0.045	0.062			
Hydrous calcium silicate, "Kaylo"	11.	1200	0.032	0.038	0.045			
85% magnesia	12.	600	0.029	0.035				
Micro-quartz fiber, blanket	3.	3000	0.021	0.028	0.042	0.075	0.108	0.142
Potassium titanate, fibers	71.5	....	.....	0.022	0.024	0.030		
Rock wool, loose	8–12	....	0.027	0.038	0.049	0.078		
Zirconia grain	113.	3000	.....	.....	0.108	0.129	0.163	0.217

Table 4.4.7 Thermal Conductance across Air Spaces
Btu/(h) (ft²)—Reflective insulation

Air space, in	Direction of heat flow	Temp diff, deg F	Mean temp, deg F	Aluminum surfaces, $\epsilon = 0.05$	Ordinary surfaces, non-metallic, $\epsilon = 0.90$
Horizontal, ¾–4 across	Upward	20.	80.	0.60	1.35
Vertical, ¾–4 across	Across	20.	80.	0.49	1.19
Horizontal, ¾ across	Downward	20.	75.	0.30	1.08
Horizontal, 4 across	Downward	20.	80.	0.19	0.93

Values of K for N Rows Deep

N	1	2	3	4	5	6	7	10
K	0.24	0.25	0.27	0.29	0.30	0.31	0.32	0.33

Gas Flow Normal to a Single Tube, D_oG/μ_f from 1000 to 50,000:

$$h_m = 0.30C_pG^{0.6}/(D_o')^{0.4} \qquad (4.4.7a)$$

Fluid Flow Normal to a Bank of Staggered Tubes, D_oG_{max}/μ_f from 2000 to 40,000:

$$\frac{h_mD_o}{k_f} = K\left(\frac{C_p\mu}{k}\right)_f^{1/3}\left(\frac{D_oG_{max}}{\mu_f}\right)^{0.6} \qquad (4.4.8)$$

Water Flow Normal to a Bank of Staggered Tubes, D_oG_{max}/μ_f from 2000 to 40,000

$$h_m = 370(1 + 0.0067t_f)V_{sm}^{0.6}/(D_o')^{0.4} \qquad (4.4.8a)$$

For baffled exchangers, to allow for leakage of fluids around the baffles, use 60 percent of the values of h_m from Eq. (4.4.8); for tubes in line, deduct 25 percent from the values of h_m given by Eq. (4.4.8).

Water Flow in Layer Form over Horizontal Tubes, $4\Gamma/\mu < 2100$

$$h_{am} = 150(\Gamma/D_o')^{1/3} \qquad (4.4.9)$$

for Γ ranging from 100 to 1,000 lb of water per h per ft (each side).

Water Flow in Layer down Vertical Tubes, $w/\pi D > 500$

$$h_m = 120\Gamma^{1/3} \qquad (4.4.9a)$$

Heat Transfer to Gases Flowing at Very High Velocities If a nonreactive gas stream is brought to rest adiabatically, as at the true stagnation point of a blunt body, the temperature rise will be

$$t_s - t_\infty = V^2/2g_cJC_p \qquad (4.4.9b)$$

where t_s is the stagnation temperature and t_∞ is the temperature of the free stream moving at velocity V. At every other point on the body, the gas is brought to rest partly by pressure changes and partly by viscous effects in the boundary layer. In general, this process is not adiabatic, even though the body transfers no heat. The thermal conductivity of the gas will transfer heat from one layer of gas to another. At an insulated surface, the gas temperature will therefore be neither the free-stream temperature nor the stagnation temperature. In general, the rise in gas temperature will be given by the equation

	s_g
79	1.2140
00	1.1813
16	1.1529
28	1.1280

	s
sia)	
3.5	1.0547
0.8	1.0749
2.0	1.0904
3.5	1.1092
sia)	
5.4	1.0108
5.2	1.0398
4.3	1.0497
	1.0608
	1.0738

rt 66-104, 1966.

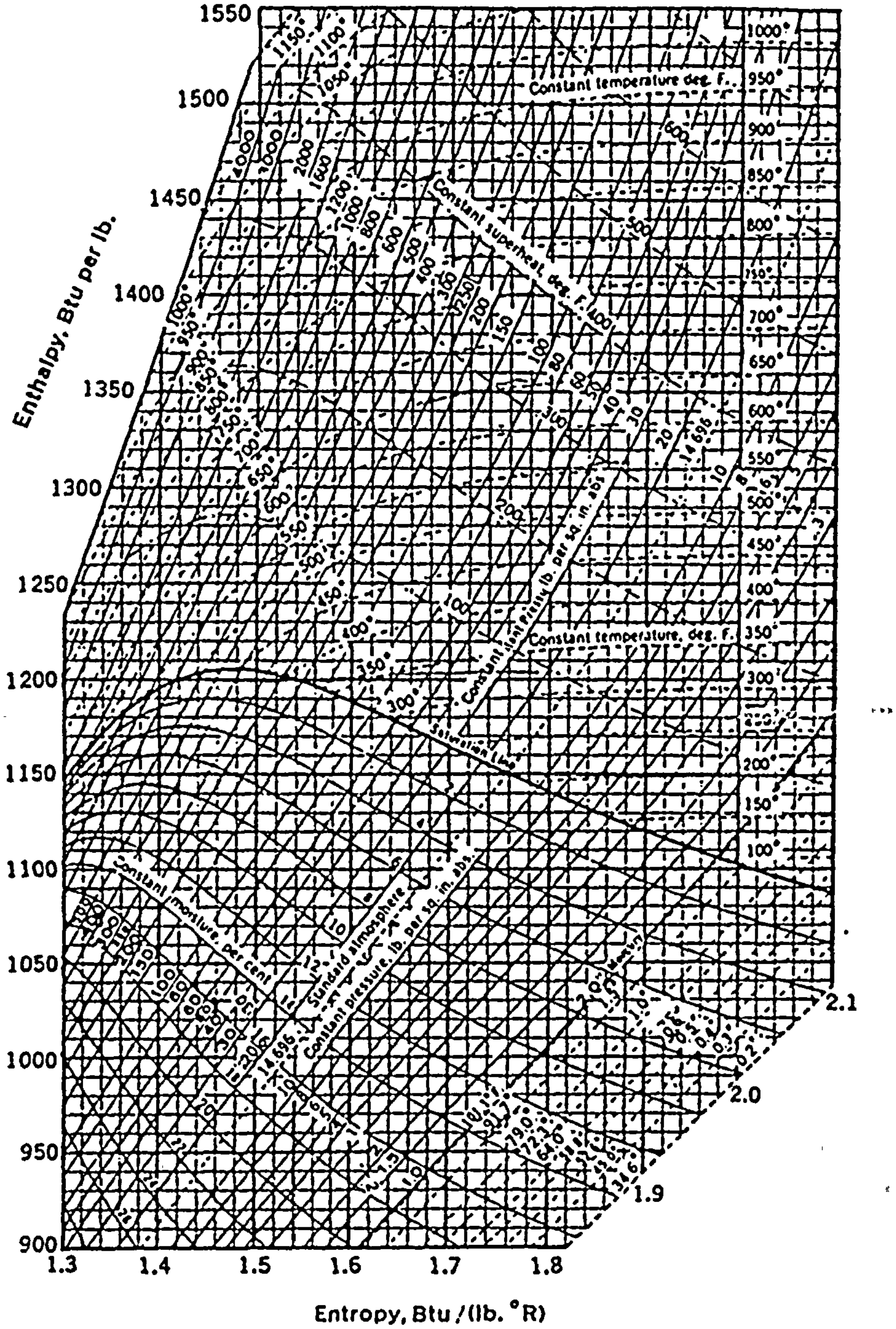

Figure A-25 Mollier diagram for steam. *Source:* J. H. Keenan and J. Keyes, "Thermodynamic Properties of Steam," Wiley, New York, 1936.

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...HERMAL CON-DUCTIVITY, k (W/m·K)	SPECIFIC HEAT, c_p (J/kg·K)
8	2040
3	1945
59	—
80	1340
40	2890
9	775
5	810
0	830
8	1105
0	745
3	2010
.6	—
27	800
2	1840
49	—
9	—
5	—
5	—
7	—
:	—
1	—
55	—
97	—
1	2720
7	2385
.5	2805
1	—
9	2385
.4	2720

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Table A.4 Thermophysical properties of gases at atmospheric pressure

T (K)	ρ (kg/m³)	c_p (kJ/kg·K)	$\mu \cdot 10^7$ (N·s/m²)	$\nu \cdot 10^6$ (m²/s)	$k \cdot 10^3$ (W/m·K)	$\alpha \cdot 10^6$ (m²/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728
1200	0.2902	1.175	473.0	162.9	76.3	224	0.728
1300	0.2679	1.189	496.0	185.1	82	238	0.719
1400	0.2488	1.207	530	213	91	303	0.703
1500	0.2322	1.230	557	240	100	350	0.685
1600	0.2177	1.248	584	268	106	390	0.688
1700	0.2049	1.267	611	298	113	435	0.685
1800	0.1935	1.286	637	329	120	482	0.683
1900	0.1833	1.307	663	362	128	534	0.677
2000	0.1741	1.337	689	396	137	589	0.672
2100	0.1658	1.372	715	431	147	646	0.667
2200	0.1582	1.417	740	468	160	714	0.655
2300	0.1513	1.478	766	506	175	783	0.647
2400	0.1448	1.558	792	547	196	869	0.630
2500	0.1389	1.665	818	589	222	960	0.613
3000	0.1135	2.726	955	841	486	1570	0.536
Ammonia (NH_3)							
300	0.6894	2.158	101.5	14.7	24.7	16.6	0.887
320	0.6448	2.170	109	16.9	27.2	19.4	0.870
340	0.6059	2.192	116.5	19.2	29.3	22.1	0.872
360	0.5716	2.221	124	21.7	31.6	24.9	0.872
380	0.5410	2.254	131	24.2	34.0	27.9	0.869
400	0.5136	2.287	138	26.9	37.0	31.5	0.853
420	0.4888	2.322	145	29.7	40.4	35.6	0.833
440	0.4664	2.357	152.5	32.7	43.5	39.6	0.826