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CALCULATION PACKAGE

CALCULATION NO: NUH 24PTH.0420	PROJECT NAME: NUHOMS® 24PTH Design
PROJECT NO: NUH 24PTH	CLIENT: Transnuclear, Inc.

CALCULATION TITLE:

NUHOMS®- 24PTH Air Flow Calculation of the HSM-H

NON-PROPRIETARY FOR INFORMATION ONLY

SUMMARY DESCRIPTION:

This calculation determines flow rates, exit air temperatures, and bulk temperatures for the NUHOMS®- HSM-H loaded with a 24PTH DSC.

This calculation was prepared by TN Hawthorne (Calculation No. 60977-2) under TN Hawthorne QA procedures. TN Fremont has reviewed this calculation and accepted it for use in the NUHOMS®-24PTH project *with the following comments/clarifications:*

1) *In the calculation cover sheet, the Project Name should read "NUHOMS 24PTH", not "NUHOMS 32PTH".*
2) *The ref. 5 drawing numbers (HSM-H-01 to HSM-H-06) have been renumbered as NUH-03-7001 sheets 1 to 10, Rev. 0). Any differences between the HSM-H-01 to –06 sketches and the NUH-03-7001 drawings have been addressed in the calculation.*

Note: In this calculation the generic HSM nomenclature is used to refer to the HSM-H.

REVISION	TOTAL PAGES AND DISKS (IF ANY)	NAMES AND INITIALS OF PREPARERS & DATES	NAMES AND INITIALS OF VERIFIERS & DATES	APPROVER NAME AND SIGNATURE	APPROVAL DATE
0	35 (2 cover sheets+33 main body) ~~1CD~~ *	N/A	N/A	Miguel M. Manrique	9/18/03
1	35 (2 cover sheets+33 main body) ~~1CD~~ *	N/A	N/A	Miguel M. Manrique Miguel A. Manrique	1/20/04

* Proprietary Information - Intentionally Left Out

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Form 3.1-1
Calculation Approval Sheet

Project Name: NUHOMS-32PTH Project #: 60977

Calculation Title: NUHOMS 32PTH – Air Flow Calculation

Calculation #: 60977-2 Draft/Revision #: 0 DCR #: ______

Number of pages: 33

Number of CDs attached: 1

If original issue, 10CFR72.48 review required?
[x] No (explain) [ ] Yes, SR No. ______
This calculation is performed to support ongoing license application

1. This calculation is complete and ready for independent review

Originator's Signature [signature] Date: 8/22/03

2. This calculation has been checked for consistency, completeness, and arithmetic correctness.

Checker Signature [signature] Date: 8/22/03

3. Calculation preparation and check complies with procedure - package is complete

PE's Signature [signature] Date: 8/25/03

1 - Objective

The purpose is to calculate the airflow rates, exit air temperatures, and bulk temperatures around the NUHOMS 24PTH DSC for normal and off-normal conditions.

2 – References

1. I.E. Idelchik, "Handbook of Hydraulic Resistance", 3rd Edition, 1994
2. Rohsenow, Hartnett, "Handbook of Heat Transfer Fundamentals", 2nd Edition, 1985
3. "ASHRAE Handbook, Fundamentals" – SI Edition, 1997
4. Calculation NUH004.0418, Rev. 3, "Standardized NUHOMS Air Flow Calculation"
5. NUHOMS HSM Model H, Drawings HSM-H-01 to HSM-H-06, Revision 0
6. ASHRAE Handbook Fundamentals 4th Edition, 1983
7. NUH24PTH.0101 Rev. 0, *Design Criteria Document for the NUHOMS 24PTH System*

3 – Discussion and Assumptions

The exit air temperature and bulk air temperatures around the DSC are determined for the NUHOMS-24PTH packaging with total decay heat loads of 24, 31.2, and 40.8kW. The exit air temperature and bulk air temperatures around the DSC will be used in the thermal analysis of the HSM to calculate the concrete and the DSC outer shell temperature distributions.

Ambient temperatures between 0-100°F are considered as normal storage conditions and the maximum daily temperature of 117°F is considered as the off-normal storage condition. The lowest ambient temperature is considered to be -40°F [7].

The temperature responses of the HSM and DSC due to the maximum daily temperature are relatively slow because of their large thermal inertia. Therefore, considering an average maximum temperature over a 24 hour period is reasonable to calculate the maximum component temperatures for the HSM and DSC using the steady state boundary conditions.

In order to calculate a daily average temperature given a maximum day temperature, a minimum daily range must be specified. From Table 1 in chapter 24 of reference [6], the minimum mean daily range in the contiguous United States is 27°F for a maximum summer ambient above 110°F. The method of calculating the daily average temperature is described in chapter 26.6 of reference [6]. In this method the hourly temperature is defined as:

$$T_{hour} = T_{max} - (\text{percentage of the daily range}) \times (\text{mean daily range})$$

The percentages of the daily range are shown as a function of day time in Table 3, chapter 26 of [6]. The average of the hourly temperatures over the 24 hour period gives the daily average temperature. The following table shows the calculated daily average temperature for a maximum day temperature of 117°F and a daily mean range of 27°F.

Maximum day temperature = 117°F
Minimum daily range = 27°F

Time, hr	% daily range [16]	T_{hour} (°F)		Time, hr	% daily range 16]	T_{hour} (°F)
1	87	93.5		13	11	114.0
2	92	92.2		14	3	116.2
3	96	91.1		15	0	117.0
4	99	90.3		16	3	116.2
5	100	90.0		17	10	114.3
6	98	90.5		18	21	111.3
7	93	91.9		19	34	107.8
8	84	94.3		20	47	104.3
9	71	97.8		21	58	101.3
10	56	101.9		22	68	98.6
11	39	106.5		23	76	96.5
12	23	110.8		24	82	94.9

Daily average temperature = 102°F

An ambient temperature of 105°F is used in this analysis to bound the maximum temperatures for normal and off-normal storage conditions.

To maximize the temperature gradients in the HSM concrete structure, ambient temperature of -40°F is considered for the off-normal cold storage condition. To provide temperature distribution for structural evaluation of the HSM, two cases are analyzed for 40.8kW decay heat load at 0 and 100°F ambient temperature

Dimensions of the HSM relevant of this calculation are shown in Figure 1. The shortest DSC length (186") is considered for this analysis to maximize the heat flux.

Following assumptions are considered in this calculation:

- The entire decay heat load is transferred through convection to the circulating air within the HSM. This assumption is conservative and justified, since the amount of heat conducting through the floor into the soil is negligible in comparison to the total decay heat load.
- The temperature rise around the DSC circumference is linear.
- The flow region around DSC is as long as the DSC length. The airflow over the top and bottom ends is not considered in this calculation.
- It is assumed that the screen provides at least 70% free area.

4 – Methodology

The technical approach in this calculation is the same as that in Reference 4. A brief description of the methodology is given below.

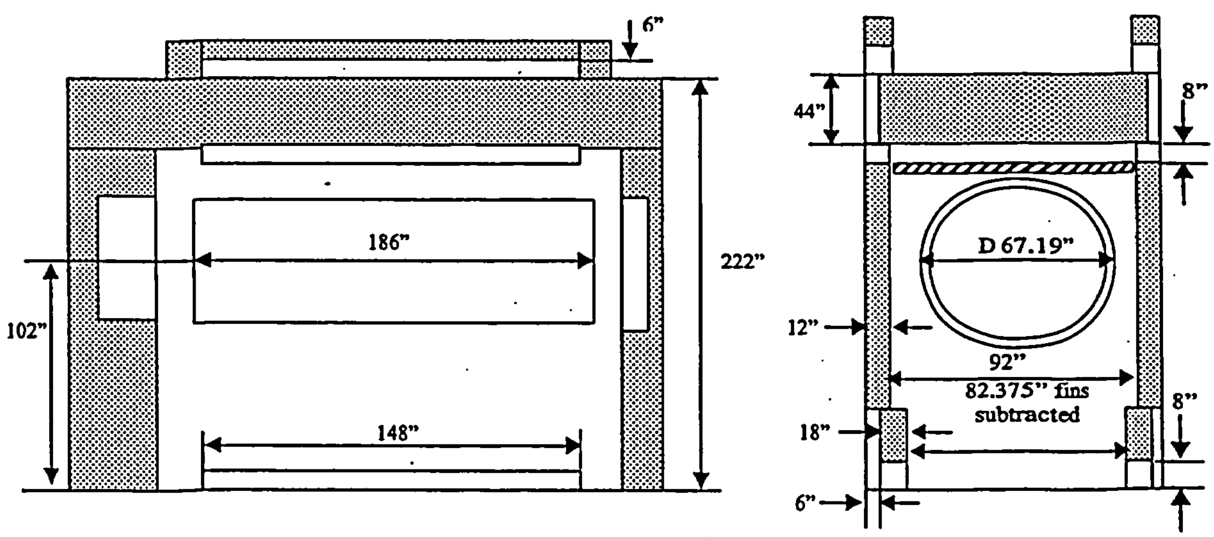
a. Determine the loss coefficients (K_{Ei}/A_{Ei}^2) for all of the flow regions inside the HSM from the air inlet to the air outlets.
b. Sum all of the calculated (K_{Ei}/A_{Ei}^2) values.
c. Calculate the temperature difference (ΔT) from the ambient air temperature to the exit air temperature.
d. Calculate the air mass flow rate based on the calculated ΔT.
e. Confirm that the stack pressure and dynamic pressure losses are balanced to create the airflow.
f. Calculate the bulk air temperature distribution around the DSC.

4.1– Loss coefficients

Calculation of the HSM loss coefficient is based on shape and geometry of flow paths and the ambient temperature. The sum of all (K_{Ei}/A_{Ei}^2) values for the NUHOMS 24PTH HSM is calculated as follows.

The figure below shows the cross section of the NUHOMS 24PTH HSM

Figure 1 – HSM cross section



In order to determine the loss coefficients, the HSM is divided into three flow regions. The regions are:

1. Region 1 – The air entrance between the two HSM's including the inlets into the HSM cavity.
2. Region 2 – The HSM cavity.
3. Region 3 – The HSM outlets to the exhaust at the top of the HSM.

Each flow region is divided into different sections based on their geometry. Flow sections include bends, entrance, exhaust, etc. The loss coefficients of each section are added together to form an equivalent loss coefficient as follows:

$$K_n = \Sigma \frac{C_i}{A_i^2} \qquad (1)$$

Where:

K_n = equivalent loss coefficient of region n (1/ft^4)
C_i = loss coefficient of section i
A_i = cross section area of section i (ft^2)

The total loss coefficient of the HSM is the sum of the three regional equivalent loss coefficients.

$$K_{HSM} = \sum_{1}^{3} K_i \qquad (2)$$

The loss coefficients for sections such as, fittings, bends, and cross sectional changes in each flow region are determined using the relations from References 1 and 3.

To calculate the loss coefficient due to channel roughness the following equation from Reference 1 is used.

$$\Delta p_{fr} = f \frac{L}{D_h} \frac{\rho v^2}{2} \qquad (3)$$

Where:

Δp_{fr} = friction losses in terms of total pressure (psi)
f = friction factor
L = channel length (in)
D_h = hydraulic diameter (in)
v = velocity (in/s)
ρ = density (lbm/in^3)

Hydraulic diameter is defined as follows from Reference 1.

$$D_h = \frac{4A}{P} \quad (4)$$

Where:

A = Channel area (in^2)

P = Perimeter of cross section (in)

The friction factor is calculated using Altshul-Tsal equation from Reference 3.

$$f' = 0.11\left(\frac{\varepsilon}{D_h} + \frac{68}{Re}\right)^{0.25} \quad (5)$$

If $f' \geq 0.018$: $f = f'$

If $f' < 0.018$: $f = 0.85f' + 0.0028$

Where:

f = friction factor

ε = material absolute roughness (in)

Re = Reynold's number = $\frac{\rho V D_h}{\mu}$

The absolute roughness of slag-concrete slabs is 1.0 - 1.5 mm [1]. For conservatism the concrete roughness of 1.5 mm (0.06 in.) is used for this calculation.

The loss coefficient for the channel is defined as follows:

$$C_{plenum} = \frac{f * L}{D_h} \quad (6)$$

Since the friction factor in a channel is a function of the Reynold's number, the mass flow rate and the temperature of the air must be known in each section to calculate the loss coefficient. An iterative method is required to determine the mass flow rate and the friction factor in each region.

4.2 – Temperature Difference between the ambient and exit

The temperature rise (ΔT_{HSM}) from the HSM air inlet (ambient temperature) to the HSM outlet (exit air temperature) is given by the following equation from Reference 4.

$$\Delta T_{HSM} = \left[\frac{\dot{Q}_i^2}{2gh} * \frac{T_s}{C_p{}^2 * \overline{\rho} * \rho_s * \Delta T_{avg}} * \Sigma \frac{K_{EI}}{(A_{EI})^2} \right]^{1/2} \qquad (7)$$

Where:

- T_s = Stack average air temperature (R) (see section 4.5)
- T_c = Ambient temperature (R)
- T_{exit} = Exit air temperature (R) = $T_c + \Delta T_{HSM}$
- $T_{avg} = (T_c + T_{exit}) / 2$ (R)
- ΔT_{avg} = Change in temperature across the stack height (h) = $T_s - T_c$
- $\dot{Q}$ = Total decay heat load (Btu/s)
- $\overline{\rho}$ = Average density of air at T_{avg} (lbm/in^3)
- ρ_s = Stack average density of air at T_s (lbm/in^3)
- h = vertical distance between the entrance and exhaust (in) = 222 in.
- C_p = Average specific heat at T_{avg} (Btu/lb-R)

Equation (7) must be solved by an iterative method, because the average temperature is initially unknown.

4.3– Mass Flow Rate

The entering air mass flow rate is calculated using the following equation based on the assumption that all the energy is dissipated only by convection to the circulating air within the HSM.

$$\dot{m} = \frac{\dot{Q}}{C_p * (T_{exit} - T_c)} \qquad (8)$$

Where:

- $\dot{Q}$ = The amount of energy dissipated (Btu/s)
- C_p = Average specific heat (Btu/lbm-R)
- T_c = Ambient temperature
- T_{exit} = Exit air temperature

4.4 - Pressure Balance

The stack pressure through the HSM is calculated by the following equation from Reference 4.

$$\Delta P_s = \frac{g}{g_c}\frac{\bar{\rho}}{\bar{T}}(T_{exit} - T_c)*h \qquad (9)$$

The dynamic pressure loss through the HSM is given by the following equation from Reference 4.

$$\Delta P_f = \frac{\dot{m}^2}{2*g_c*\bar{\rho}}\Sigma\frac{K_{Ei}}{(A_{Ei})^2} \qquad (10)$$

Where:

- K_{Ei} = Loss coefficients through different flow regions
- m_{Ei} = Mass flow rate of air (lbm/s)
- A_{Ei} = Cross sectional area of each flow region (ft^2)
- g_c = Gravitational constant ($ft\text{-}lbm/lbf\text{-}s^2$)

The stack pressure must be equal to or greater than the dynamic pressure loss to cause airflow within the HSM. The stack pressure and dynamic pressure loss are considered to be equal within this analysis. The equity of stack pressure and dynamic pressure is verified in section 5.

4.5- Bulk Air Temperature Distribution

The exit air temperature is calculated as follows:

$$T_{exit} = T_c + \Delta T_{HSM} \qquad (11)$$

The DSC outer surface is divided into eight equal regions along the DSC circumference in this analysis. These regions are shown in Figure 3.

It is assumed that the temperature rise in each region is equal, so that:

$$T_i = T_{i-1} + (\Delta T_{HSM}/8) \qquad (12)$$

Where:

- T_i = Temperature of air leaving region i.

It is assumed that the air temperature entering the first region is equal to the average of the ambient temperature and the temperature of the first region. In this case, the temperature of the air leaving region 8 is equal to the exit air temperature.

The temperature used to determine the properties inside the HSM cavity is called the stack average temperature. The following equation determines the stack average temperature.

$$T_s = \frac{\sum_{0}^{i}(T_i * V_i)}{\sum_{0}^{i}(V_i)} \qquad (13)$$

Where:

V_i = Volume of air region = $A_i * L_{DSC}$
A_i = HSM cavity cross sectional area – DSC cross sectional area

For ease of calculation, it is assumed that the flow region is as long as the DSC length (L_{DSC}). Factoring out L_{DSC} simplifies equation (21) to the following equation.

$$T_s = \frac{\sum_{0}^{i}(T_i * A_i)}{\sum_{0}^{i}(A_i)} \qquad (14)$$

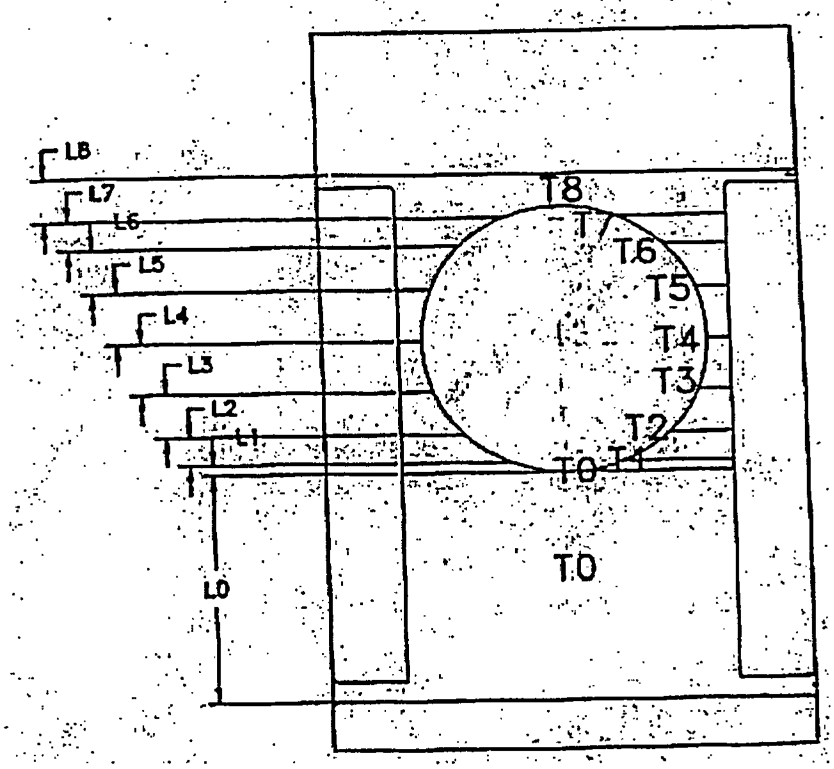
The height of each DSC region shown in Figure 3 is calculated using the same methodology from Reference 4. The following table shows the height for each region.

Height	Value (in)
L0	68.405
L1	2.557
L2	7.282
L3	10.899
L4	12.856
L5	12.856
L6	10.899
L7	7.282
L8	44.962

The resultant cross sectional area for each region is then:

Area	Value (in)
A_0	5635
A_1	166
A_2	322
A_3	289
A_4	217
A_5	217
A_6	289
A_7	322
A_8	3660

Figure 2 – DSC Regions in the HSM Cavity



5- Calculation and Results

5.1 – Loss Coefficients

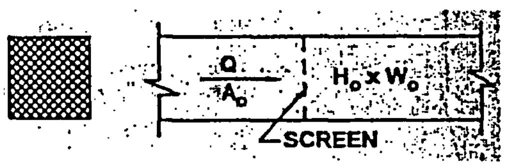
5.1.1 – Region 1

The dynamic losses in Region 1 are caused by the entrance effect, screen, contraction from the entrance area to the channel area, friction loss in the entrance channel, flow separation at the inlet openings, friction loss through inlet opening, and discharge into the cavity.

The loss coefficient at a sharp entrance is defined in Reference 3, Chapter 2, Table 3.

$C_{entrance} = 0.5$

The loss coefficient of the screen is determined using Reference 3, Chapter 32, CR6-1.



Where:

A_o = Cross sectional area of the channel = $H_o \times W_o$ = 30 in x 36 in = 1080 in^2
A_1 = Cross sectional area of the screen = A_o
n = percentage of free area in the screen = 70%
$A_1 / A_o = 1$

It gives:

$C_{screen} = 0.58$

The loss coefficient of the contraction at the front wall is defined in Reference 1, Chapter 5, p. 271, section 3.

$$\zeta_{loc} = \left(-0.0125n_0^4 + 0.0224n_0^3 - 0.00723n_0^2 + 0.00444n_0 - 0.00745\right) \times \left(\alpha_p^3 - 2\pi\alpha_p^2 - 10\alpha_p\right)$$

Where:

A_0 = Final contraction area = H_0 * W = 12*30 = 360 in^2
A_1 = Initial contraction area = H_1 * W = 30*40 = 1080 in^2
$n_0 = A_0/A_1 = 0.33$
α = Contraction angle in radians
$\alpha_p = 0.01745\alpha$

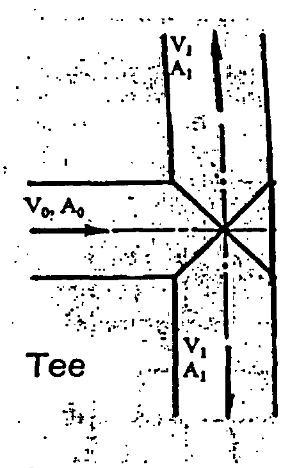
It gives:

Ccontr = 0.033

The loss coefficient due to friction loss in the entrance channel is calculated using equations (3) to (5) with:

L = HSM front wall thickness = 54 in.
A = Channel area = 30 in x 36 in = 1080 in^2
P = Perimeter of cross section = 2 x (30 in + 36 in) = 132 in.
D_h = 4*A/P = 37.72 in.

The loss coefficient due to the division of the flow between the two HSM's at the inlet openings is defined in Diagram 7-38, graph c from Reference 1.



Tee

The diagram gives a loss coefficient of 0.63 for the Tee shape branching based on the entrance velocity of V_0.

The above contraction coefficient is calculated based on the inlet opening area. Since the air entrance area is different from the inlet area, an interim sum is calculated.

$$Interim\ \ Sum = \frac{C_i}{(A_i)^2} \qquad (15)$$

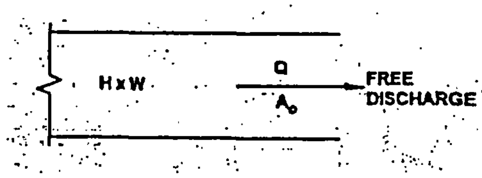
Where:

A_i = Reference area
C_i = Loss coefficient based on area A_i

The loss coefficient due to the friction in the inlet channel is calculated using equations (3) to (5).

L = HSM side wall thickness = 18 in.
A = Channel area = 8 in. x 148 in. = 1184 in^2
P = Perimeter of cross section = 2*(8 in + 148 in) = 312 in.
D_h = 15.2 in.

The loss coefficient due to the discharge into the HSM cavity is determined using Reference 3, Chapter 32, SR2-1.



Where:

H = Height of the inlet = 8 in.
W = Width of the inlet = 148 in.
H/W = 0.133

It gives:

C_{exp} = 1 for turbulent flow (see Table 1 for Re value)

Since the air entrance area is different from the inlet area, an equivalent loss coefficient for the inlet losses (friction loss and discharge) is calculated based on the entrance velocity using the equation (15).

Results of simultaneous, iterative solution of the above equations for region 1 are summarized in Table 1.

Table 1 – Loss Coefficients in Region 1

			24 kW		31.2 kW		40.8 kW			
Reference Area	Sections	Parameter	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Normal 0 °F	Normal 100 °F	Off-Normal 117 °F
Entrance area 30 x 36 = 1080 in^2	Entrance	$C_{entrance}$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Screen	C_{screen}	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
	Interim Sum	ΣC/A (in^{-4})	9.26e-7	9.26e-7	9.26e-7	9.26e-7	9.26e-7	9.26e-7	9.26e-7	9.26e-7
Contraction area 12 x 30 = 360 in^2	Friction loss in entrance channel	f_0	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
		Re_0	133708	76191	144843	82561	156887	131933	90817	89452
		C_{fr1}	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.014
	Contraction	A_{cont}	360	360	360	360	360	360	360	360
		$A_{entrance}$	1080	1080	1080	1080	1080	1080	1080	1080
		C_{contr}	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
	Tee	C_{T1}	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
	Interim Sum	ΣC/A (in^{-4})	5.23e-6	5.23e-6	5.23e-6	5.23e-6	5.23e-6	5.23e-6	5.23e-6	5.23e-6
Inlet area 8 x 148 = 1184 in^2	Inlet channel loss	f_1	0.033	0.035	0.032	0.035	0.032	0.033	0.034	0.034
		Re	17999	10257	19498	11114	21119	17764	12225	12042
		C_1	0.0387	0.0418	0.0383	0.0413	0.0380	0.033	0.034	0.034
	Discharge into HSM cavity	C_{exp}	1	1	1	1	1	1	1	1
	Interim Sum	ΣC/A (in^{-4})	7.41e-7	7.43e-7	7.41e-7	7.43e-7	7.40e-7	7.41e-7	7.42e-7	7.42e-7
	Equivalent loss coeff. for Region 1	K_1 (in^{-4})	1.72e-6	1.73e-6	1.72e-6	1.73e-6	1.72e-6	1.72e-6	1.73e-6	1.73e-6

Since there are two parallel streamlines within region 1, the following equation is the sum of one streamline

$$K_l = \Sigma \frac{C_l}{A_l^2} = S$$

Equation (A-6) from Appendix A is used to determine the total loss coefficient for region 1.

$$K_E = \frac{C_E}{A_E^2} = \frac{1}{\left(\Sigma \frac{A_l}{\sqrt{\Sigma C_l}}\right)^2} = \frac{1}{\left(2 \times \sqrt{\Sigma \frac{A_l^2}{C_l}}\right)^2} = \frac{S}{4} \qquad (16)$$

The results are shown below:

Decay Heat Load	Conditions		Equivalent loss coefficient Region K_l (ft^{-4})
24 kW	Off Normal Condition	-40°F	0.0357
	Off Normal Condition	117°F	0.0358
31.2 kW	Off Normal Condition	-40°F	0.0357
	Off Normal Condition	117°F	0.0358
40.8 kW	Off Normal Condition	-40°F	0.0357
	Normal Condition	0°F	0.0357
	Normal Condition	100°F	0.0358
	Off Normal Condition	117°F	0.0358

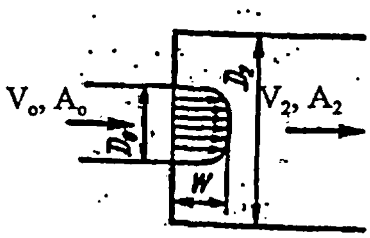
5.1.2 – Region 2

The air entering the HSM proceeds through the narrow portion of the HSM. The friction loss and transition of cavity cross section pertain to this portion.

The loss coefficient due to the friction in the narrow section is calculated using equations (3) to (5).

L = HSM section length = 32 in.
A = Channel area = 68 in. x 186 in. = 12648 in²
P = Perimeter of cross section = 2*(68 in + 186 in) = 508 in.
D_h = 99.6 in.

The loss coefficient due to the transition of cross sections between the narrow portion and the remaining portion of the HSM is defined in Diagram 4-1, from Reference 1.



Where:
- A_o = Cross sectional area of the narrow portion of the HSM = 68in x 186in=12648in²
- V_o = Velocity in the narrow portion of the HSM
- D_o = Hydraulic diameter of the narrow portion of the HSM
- A_2 = Cross sectional area of the remaining portion of the HSM
- A_2 = 82.3750 in x 186 in=15322 in²
- V_2 = Velocity in the remaining portion of the HSM
- D_2 = Hydraulic diameter of the remaining portion of the HSM

It gives:

$$\zeta = \left(1 - \frac{F_0}{F_2}\right)^2 + \frac{\zeta_{fr}}{n_{ar}}$$

$$n_{ar} = \frac{F_2}{F_0}$$

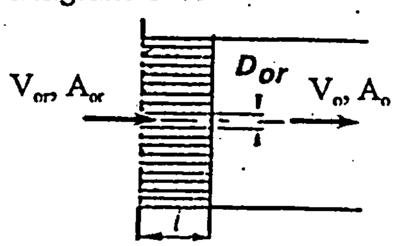
$$\zeta_{fr} = \text{loss due to friction}$$

The loss coefficient (ζ_{fr}) due to the friction in the transition section is calculated using equations (3) to (5).

L = Transition section length = 22 in.
A = Channel area = 82.375 in. x 186 in. = 1184 in^2
P = Perimeter of cross section = 2*(82.375 in + 186 in) = 312 in.
D_h = 114 in.

Following the narrow section, the air enters the remaining HSM cavity splits into three parallel streamlines. The first streamline passes through the slotted bar at the tope of the supporting structure. The second streamline goes through the round holes in the web of the supporting beam, and the third streamline bypasses the supporting structure. All three streamlines join at the side and pass over the upper half of the DSC. The joined streamline goes through the top heat shield and splits into two parallel streams and exits through the outlet openings. This flow path is considered as Region 2. The dynamic losses for the streamlines in Region 2 are calculated as follows.

The loss coefficient through the bar on the top flange of the DSC support beam is determined using Reference 1, Diagram 3-13



Where:

N = Number of slots = 45 [5]
W = Width of slot = 2 in.
H = Height of slot = 0.5 in.
A_{or} = Sum of all the areas of the slots = N*H*W = 45*0.5*2 = 45 in^2
D_{or} = Hydraulic diameter of the slot = 4*A/(2*(H+W)) = 0.8 in
V_{or} = Velocity through the slots
A_o = Total area = 186*1 = 186 in^2
V_o = Velocity of total area
l = Length of the slots = 4.04 in.

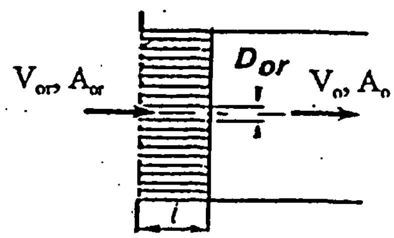
$$\bar{f} = \frac{A_{or}}{A_o} = 0.24$$

$$C_{bar} = \left[0.5 + \left(1-\bar{f}\right)^2 + \tau\left(1-\bar{f}\right) + \lambda\left(\frac{l}{d_h}\right)\right] \times \frac{1}{\bar{f}^2}$$

Losses due to friction are neglected, $\lambda\left(\frac{l}{d_h}\right)=0$

$l/D_{or} = 5.05$
$\tau = 0$ (from graph a – Diagram 3-13, Ref. 1)
$C_{bar} = 18.36$

The loss coefficient through the web of the DSC support beam is determined using Reference 1, Diagram 3-13



Where:

D_{or} = Diameter of the round hole = 6 in [5]
A_{or} = Sum of all the areas of the holes = $12*\pi*(6/2)^2 = 339\ in^2$
V_{or} = Velocity through the holes
A_o = Total area = 186*12.71 = 2364 in^2
V_o = Velocity of total area
l = Thickness of the holes = 0.55 in. [5]

$$\bar{f} = \frac{A_{or}}{A_o} = 0.14$$

$$C_{beam} = \left[0.5 + \left(1-\bar{f}\right)^2 + \tau\left(1-\bar{f}\right) + \lambda\left(\frac{l}{d_h}\right)\right] \times \frac{1}{\bar{f}^2}$$

Losses due to friction are neglected, $\lambda\left(\frac{l}{d_h}\right)=0$

$l/D_{or} = 0.09$
$\tau = 1.29$ (from graph a – Diagram 3-13, Ref. 1)
$C_{beam} = 113.5$

For streamline three only a contraction of flow area is considered to calculate the dynamic losses. The contraction occurs from the HSM cavity width to the free space between the DSC and the side heat shields. The width of the free space at the DSC side is 12" [5]. The HSM cavity width is 82.375" (see Figure 1). The beams of the supporting structure make a 30 angle to the horizontal level [5]. The angle is considered as the contraction angle for the streamline bypassing the support structure.

The loss coefficient due to the contraction around the DSC support structure is defined using Reference 1, page 271

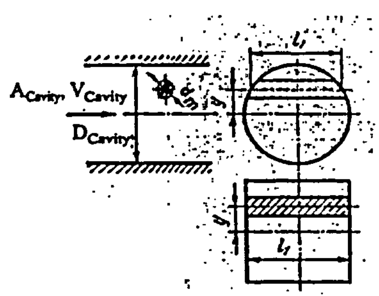
$$\zeta_{loc} \equiv \frac{\Delta p}{\rho w_0^2/2} = \left(-0.0125n_o^4 + 0.0224n_o^3 - 0.00723n_o^2 + 0.0044n_o - 0.00745\right)\times\left(\alpha_p^3 - 2\pi\alpha_p^2 - 10\alpha_p\right)$$

Where:

n_o = Contraction exit width/ contraction entrance width = 12/41.1875 = 0.29
α_p = Angle of contraction in radians = 0.52 Radians (30 Degrees)
ζ_{loc} = 0.043

Equation A-3 from Appendix A is used to calculate the equivalent loss coefficient of the parallel streamlines around the supporting structure.

The loss coefficient around the DSC is determined using Reference 1, Diagram 10-1.



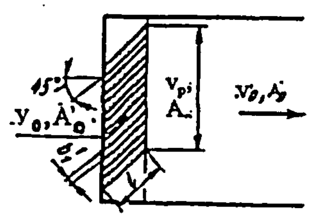
Where:

D_{Cavity} = Hydraulic diameter of HSM cavity = 114 in.
A_{Cavity} = HSM cavity cross sectional area = 82.375 * 186 = 15322 in^2
V_{Cavity}= Flow velocity (in/s) = $\dfrac{\dot{m}_0}{\rho_s A_{Cavity}}$
d_m = Cylinder diameter = 67.19 in.
y = distance between center of cylinder and center of channel = 0 in.
L_1 = Length of the cylinder = 186 in.
S_m = Cylinder frontal area = d_m * L_1 = 67.19 * 186 = 12974 in^2
Re' = ρ_s*V_{Cavity}*d_m/ μ_s
c_x = coefficient used for loss coefficient from graph a

$$C_{DSC} = c_x \frac{S_m / A_{Cavity}}{\left(1 - 0.5\, S_m / A_{Cavity}\right)^3}\left(1 - \frac{2y}{D_{Cavity}}\right)^{1/3}$$

In addition to the loss around the DSC, a loss due to friction in the remaining part of the HSM cavity is included.

The loss coefficient through the louvers is determined using Reference 1, Diagram 3-19.



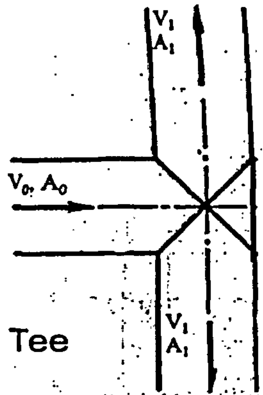
Where:

- $l = 2$ in
- $b_1' = 0.582$ in
- No. of openings = 76
- Louver length = 168 in
- A_o = Overall area = 82.375 in.* 186 in. = 15322 in^2
- A_{or} = Total orifice areas = 76 * 0.582 in. * 168 in. = 7431 in^2
- A_p = Overall louver area = 14196 in^2
- $k = 1.0$

$$C_{louv} = k\left[0.85 + \left(1 - \bar{f}\frac{F_p}{F_o}\right)^2 + \zeta_{fr}\right] \times \frac{1}{\bar{f}^2}\left(\frac{F_o}{F_p}\right)^2 = k\zeta'$$

$C_{louv} = 5.44$

The loss coefficient due to the division of the flow between the two outlets is defined in Diagram 7-38, graph c from Reference 1.



Tee

The diagram gives a loss coefficient of 0.63 for the Tee shape branching based on the entrance velocity of V_0.

Table 2 summarizes the results for Region 2.

Table 2 – Loss Coefficients in Region 2

			24 kW		31.2 kW		40.8 kW			
Reference Area	Sections	Parameter	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Normal 0 °F	Normal 100 °F	Off-Normal 117 °F
Narrow section area 80 x 186 = 14880 in²	Friction loss in narrow section	f	0.027	0.031	0.027	0.030	0.026	0.027	0.029	0.030
		Re	21109	12599	22950	13652	25942	21816	15017	14791
		C_{fr}	0.009	0.010	0.009	0.010	0.008	0.009	0.009	0.009
	Interim Sum	$\Sigma C/A^2$ (in^{-4})	5.4e-11	6.1e-11	5.4e-11	6.0e-11	5.3e-11	5.5e-11	5.9e-11	5.9e-11
	Transition of areas	A_{nar}	14880	14880	14880	14880	14880	14880	14880	14880
		A_{wide}	15322	15322	15322	15322	15322	15322	15322	15322
		C_{tra}	0.0305	0.0305	0.0305	0.0305	0.0305	0.0305	0.0305	0.0305
	Friction loss in transition section	f	0.027	0.031	0.027	0.030	0.026	0.027	0.030	0.030
		Re	20925	11924	22668	12921	24552	20647	14213	13999
		C_{fr}	0.005	0.006	0.005	0.006	0.005	0.005	0.006	0.006
	Interim Sum	$\Sigma C/A^2$ (in^{-4})	1.5e-10	1.6e-10	1.5e-10	1.6e-10	1.5e-10	1.5e-10	1.5e-10	1.5e-10
DSC Support structure	Loss around DSC support structure	C_{flange}	18.36	18.36	18.36	18.36	18.36	18.36	18.36	18.36
		C_{web}	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
		C_{cont}	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
	Equivalent loss coeff. through support structure	$K_{support}$ (in^{-4})	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9	2.1e-9
Wide section area 82.375 x 186 = 15322 in²	Cavity loss around DSC	Re'	11904	6798	12810	7321	1362	11560	7992	7871
		c_x	1.06	0.95	1.06	0.97	1.07	1.06	0.99	0.99
		A_{Cavity}	15322	15322	15322	15322	15322	15322	15322	15322
		C_{cavity}	4.16	3.75	4.18	3.81	4.20	4.16	3.89	3.87
	Friction loss in wide section	f	0.027	0.030	0.026	0.030	0.026	0.027	0.029	0.029
		Re	20230	11552	21770	12440	23388	19644	13581	13376
		C_{fr}	0.025	0.029	0.025	0.028	0.024	0.025	0.028	0.028
	Interim sum	$\Sigma C/A^2$ (in^{-4})	1.78e-8	1.61e-8	1.79e-8	1.63e-8	1.80e-8	1.78e-8	1.67e-8	1.66e-8
	Louver	C_{louv}	5.44	5.44	5.44	5.44	5.44	5.44	5.44	5.44
	Tee	C_{tee}	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
	Interim sum	$\Sigma C/A^2$ (in^{-4})	2.6e-8	2.6e-8	2.6e-8	2.6e-8	2.6e-8	2.6e-8	2.6e-8	2.6e-8
	Equivalent loss coeff. for Region 2	K_2 (in^{-4})	4.6E-8	4.4E-8	4.6E-8	4.5E-8	4.6E-8	4.6E-8	4.5E-8	4.5E-8

Equivalent loss coefficient for the supporting structure ($K_{support}$) is added to the equivalent loss coefficient for friction losses at narrow and transition sections. In addition, losses for DSC, louver, and Tee (K_{DSC}) are added to make the total loss coefficient in the HSM cavity (Region 2).

Decay Heat Load	Conditions	Ambient	Reference area (A_{Cavity}) (in^2)	Total loss coefficient K_2 (ft^{-4})
24 kW	Off Normal Condition	-40°F	15260	0.0010
	Off Normal Condition	117°F		0.0009
31.2 kW	Off Normal Condition	-40°F		0.0010
	Off Normal Condition	117°F		0.0009
40.8 kW	Off Normal Condition	-40°F		0.0010
	Normal Condition	0°F		0.0010
	Normal Condition	100°F		0.0009
	Off Normal Condition	117°F		0.0009

5.1.3 – Region 3

The dynamic losses in Region 3 are caused by the entrance effect, friction in the outlet opening, bend into the outlet channel, friction in the outlet channel, bend into ambient, screen, and exhaust to the ambient. The dynamic losses for the streamlines in Region 3 are calculated as follows

The loss coefficient at a sharp entrance is defined in Reference 3, Chapter 2, Table 3.

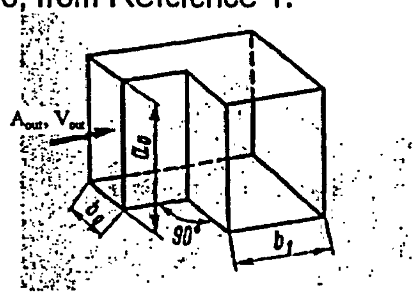
$C_{entrance} = 0.5$

The loss coefficient in the outlet opening due to friction is calculated using equation (3). The friction factor is calculated using equation (5).

L = HSM wall thickness = 12 in.

$$D_h = \frac{4(8*148)}{2(8+148)} = 15.2 \text{ in.}$$

The loss coefficient in the bends of the outlet to the space between the HSM's is calculated by using diagram 6-6, from Reference 1.



Where:

$a_0 = 148$ in
$b_0 = 8$ in
$b_1 = 4$ in
$b_1 / b_0 = 0.5$
$a_0 / b_0 = 18.5$

For rough walls ($\Delta > 0$) and $Re \geq 10^4$:

Δ = Material roughness = 0.06 in.
D_h = Hydraulic diameter = 15.18 in.

$$\zeta_{loc} = f\left(\frac{b_1}{b_0}, \frac{a_0}{b_0}\right) = 1.5, \text{ See graph a, Diagram 6-6, [1]}$$

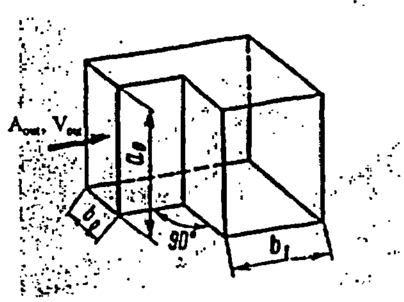
$k_{\Delta} = f(\,Re \,\&\, \bar{\Delta} = \Delta / D_h)$

$k_{Re} \approx 4.06 / Re^{0.118}$

$C_{Bend} = k_{\Delta} k_{Re} \zeta_{loc}$

The loss along the exhaust channel is calculated using equation (3). The friction factor is calculated using equation (5). The exhaust channel length is assumed to be equal to the outlet length (148"). The width of the exhaust channel is assumed to be 4" [5], which is half the distance between the adjacent HSM's.

The loss coefficient in the bend of the outlet to the ambient is calculated by using diagram 6-6, from Reference 1.



Where:

$a_0 = 148$ in

$b_0 = 4$ in

$b_1 = 6$ in

$b_1 / b_0 = 1.5$

$a_0 / b_0 = 37$

For rough walls ($\Delta > 0$) and $Re \geq 10^4$:

Δ = Material roughness = 0.06 in.

D_h = Hydraulic diameter = 7.79 in.

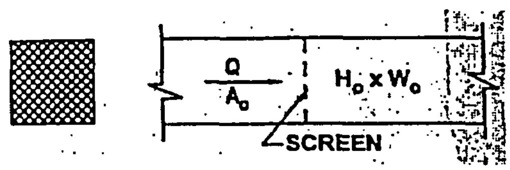
$\zeta_{loc} = f\left(\frac{b_1}{b_0}, \frac{a_0}{b_0}\right) = 0.62$, See graph a, Diagram 6-6, [1]

$k_{\Delta} = f(\,Re \,\&\, \bar{\Delta} = \Delta / D_h)$

$k_{Re} \approx 4.06 / Re^{0.118}$

$C_{Bend} = k_{\Delta} k_{Re} \zeta_{loc}$

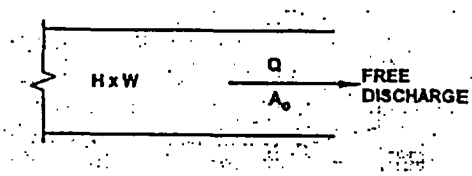
The loss coefficient of the screen is determined using Reference 3, Chapter 32, CR6-1.



Where:

A_o = Cross sectional area of the channel = H_o x W_o = 148 in x 6 in = 729 in^2
A_1 = Cross sectional area of the screen = A_o
n = percentage of free area in the screen = 70%
$A_1/A_o = 1$
$C_{screen} = 0.58$

The loss coefficient of the exhaust to the atmosphere is determined in Reference 3, Chapter 32, SR2-1.



Where:

H = 148 in.
W = 6 in.
H/W = .04
C_{exp} = 1 (for turbulent flow – see Table 3 for Re value)

Since the outlet area is different from the area between the adjacent HSM's, an equivalent loss coefficient for the exhaust channel between HSM's, the discharge to the atmosphere, and for the screen is calculated based on the outlet velocity using the equation (15).

Table 3 summarizes the results for Region 3.

Table 3 – Loss Coefficients in Region 3

			24 kW		31.2 kW		40.8 kW			
Reference Area	Sections	Parameter	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Off-Normal 117 °F	Off-Normal -40 °F	Normal 0 °F	Normal 100 °F	Off-Normal 117 °F
Outlet opening area 8 x 148 = 1184 in^2	Entrance	$C_{entrance}$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Friction loss in outlet channel	f_0	0.033	0.036	0.033	0.035	0.032	0.033	0.035	0.035
		V_0	19	19	21	21	24	24	24	24
		C_{ch1}	0.026	0.028	0.026	0.028	0.026	0.026	0.028	0.028
	Fist bend	Re	16713	9567	17849	10230	19000	15938	11072	10904
		k_Δ	1	1	1	1	1	1	1	1
		k_{Re}	1.29	1.38	1.28	1.37	1.27	1.30	1.35	1.36
		ζ	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
		C_{bend1}	1.93	2.06	1.92	2.05	1.90	1.94	2.03	2.03
	Interim Sum	$\Sigma C/A$ (in^{-4})	1.75e-6	1.85e-6	1.74e-6	1.84e-6	1.73e-6	1.76e-6	1.82e-6	1.83e-6
Exhaust channel area 4 x 148 = 592 in^2	Friction loss in exhaust channel	f_{exh}	0.036	0.038	0.036	0.038	0.036	0.036	0.038	0.038
		V_{exh}	39	39	43	43	48	48	47	47
		C_{exh}	0.23	0.25	0.23	0.24	0.23	0.23	0.24	0.24
	Second bend	Re	17152	9819	18319	10499	19500	16357	11364	11191
		K_Δ	1	1	1	1	1	1	1	1
		k_{Re}	1.28	1.37	1.27	1.36	1.27	1.29	1.35	1.35
		ζ	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
		C_{bend2}	0.79	0.84	0.78	0.84	0.78	0.79	0.83	0.83
	Interim Sum	$\Sigma C/A$ (in^{-4})	2.92e-6	3.11e-6	2.90e-6	3.08e-6	2.88e-6	2.93e-6	3.06e-6	3.06e-6
Exhaust area 6 x 148 = 888 in^2	Screen	C_{screen}	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
	Discharge to ambient	C_{exp}	1	1	1	1	1	1	1	1
	Interim Sum	$\Sigma C/A$ (in^{-4})	2.00e-6	2.00e-6	2.00e-6	2.00e-6	2.00e-6	2.00e-6	2.00e-6	2.00e-6
	Equivalent loss coeff. for Region 3	K_{R3} (in^{-4})	1.67e-6	1.74e-6	1.66e-6	1.73e-6	1.65e-6	1.68e-6	1.72e-6	1.72e-6

Since there are two parallel streamlines within region 3, the following equation is the sum of one streamline

$$K_i = \Sigma \frac{C_i}{A_i^2} = S$$

Equation (A-6) from Appendix A is used to determine the total loss coefficient for region 3.

$$K_E = \frac{C_E}{A_E^2} = \frac{1}{\left(\Sigma \frac{A_i}{\sqrt{\Sigma C_i}}\right)^2} = \frac{1}{\left(2 \times \sqrt{\Sigma \frac{A_i^2}{C_i}}\right)^2} = \frac{S}{4}$$

The equivalent loss coefficient for region 3 is

Decay Heat Load	Conditions	Ambient	Reference area (A_{Outlet}) (in^2)	Equivalent loss coefficient – Region 3 K_3 (ft^{-4})
24 kW	Off Normal Condition	-40°F	1184	0.0346
	Off Normal Condition	117°F		0.0361
31.2 kW	Off Normal Condition	-40°F		0.0344
	Off Normal Condition	117°F		0.0359
40.8 kW	Off Normal Condition	-40°F		0.0343
	Normal Condition	0°F		0.0347
	Normal Condition	100°F		0.0357
	Off Normal Condition	117°F		0.0357

The total equivalent loss coefficient for all three regions is

Decay Heat Load	Conditions	Ambient	Total equivalent loss coefficient K (ft^{-4})
24 kW	Off Normal Condition	-40°F	0.0713
	Off Normal Condition	117°F	0.0728
31.2 kW	Off Normal Condition	-40°F	0.0711
	Off Normal Condition	117°F	0.0726
40.8 kW	Off Normal Condition	-40°F	0.0710
	Normal Condition	0°F	0.0714
	Normal Condition	100°F	0.0724
	Off Normal Condition	117°F	0.0724

5.2 – Resultant HSM Temperature Difference

Solving equation (9) simultaneously with the loss coefficients for all three regions gives the following exit and stack air temperature for the normal and off-normal cases.

Decay Heat Load	Conditions	Ambient	ΔT_{HSM} (°F)	T_{exit} (°F)	T_s (°F)
24 kW	Off Normal Condition	-40°F	40	0	-22
	Off Normal Condition	117°F	55	160	130
31.2 kW	Off Normal Condition	-40°F	48	8	-19
	Off Normal Condition	117°F	66	171	135
40.8 kW	Off Normal Condition	-40°F	58	18	-14
	Normal Condition	0°F	64	64	29
	Normal Condition	100°F	79	179	135
	Off Normal Condition	117°F	80	185	141

5.3 – Mass Flow Rate

The mass flow rates are calculated using equation (16) for normal and off-normal cases. The results are listed below.

Decay Heat Load	Conditions	Ambient	Mass Flow Rate $\dot{m}_0$ (lbm/s)
24 kW	Off Normal Condition	-40°F	2.36
	Off Normal Condition	117°F	1.71
31.2 kW	Off Normal Condition	-40°F	2.56
	Off Normal Condition	117°F	1.86
40.8 kW	Off Normal Condition	-40°F	2.77
	Normal Condition	0°F	2.51
	Normal Condition	100°F	2.03
	Off Normal Condition	117°F	2.01

The air properties are interpolated from the data in Reference 2. The properties are listed in the table below.

	24 kW		31.2 kW		40.8 kW			
Air Properties[1]	Off Normal -40°F	Off Normal 117°F	Off Normal -40°F	Off Normal 117°F	Off Normal -40°F	Normal 0°F	Normal 100°F	Off Normal 117°F
ρ_c at T_c (lbm/in^3)	5.61E-5	4.05E-5	5.61E-05	4.05E-5	5.61E-5	5.14E-05	4.08E-5	4.05E-5
C_p at T_c (Btu/lbm F)	0.2405	0.2407	0.2405	0.2408	0.2405	0.2405	0.2407	0.2408
μ_c at T_c (lbm/in s)	8.41E-7	1.07E-6	8.41E-7	1.07E-6	8.41E-7	9.06E-7	1.06E-6	1.07E-6
ρ_s at T_s (lbm/in^3)	5.40E-5	3.91E-5	5.35E-05	3.88E-5	5.30E-5	4.80E-05	3.88E-5	3.84E-5
C_p at T_s (Btu/lbm F)	0.2405	0.2410	0.2405	0.2410	0.2405	0.2405	0.2410	0.2411
μ_s at T_s (lbm/in s)	8.70E-7	1.10E-6	8.76E-7	1.11E-6	8.83E-7	9.52E-7	1.11E-6	1.12E-6
ρ_{exit} at T_{exit} (lbm/in^3)	5.14E-5	3.73E-5	5.04E-05	3.67E-5	4.92E-5	4.39E-05	3.62E-5	3.59E-5
C_p at T_{exit} (Btu/lbm F)	0.2405	0.2413	0.2405	0.2414	0.2405	0.2405	0.2414	0.2415
μ_{exit} at T_{exit} (lbm/in s)	9.06E-7	1.15E-6	9.19E-7	1.16E-6	9.35E-7	1.01E-6	1.17E-6	1.18E-6

The following table lists the air properties from Reference 2.

Temperature		ρ		C_p		μ	
K	F	kg/m3	lbm/in3	kJ/kg K	Btu/lbm F	Pa-s	lbm/in s
100	-280	3.559	1.29E-04	1.032	0.2465	7.11E-06	3.98E-07
200	-100	1.745	6.31E-05	1.007	0.2405	1.33E-05	7.45E-07
300	80	1.161	4.20E-05	1.007	0.2405	1.85E-05	1.04E-06
400	260	0.871	3.15E-05	1.014	0.2422	2.30E-05	1.29E-06
500	440	0.696	2.52E-05	1.030	0.2460	2.70E-05	1.51E-06
600	620	0.580	2.10E-05	1.051	0.2510	3.06E-05	1.71E-06
800	980	0.435	1.57E-05	1.099	0.2625	3.70E-05	2.07E-06
1000	1340	0.348	1.26E-05	1.141	0.2725	4.24E-05	2.37E-06
1500	2240	0.232	8.39E-06	1.231	0.2940	5.57E-05	3.12E-06

[1] All properties are interpolated for each temperature.

5.4 – Confirmation of Pressure Balance

The calculated stack pressure and dynamic pressure losses are summarized in the following table.

Decay Heat Load	Conditions	Ambient	ΔP_s (psi)	ΔP_f (psi)
24 kW	Off Normal Condition	-40°F	0.0005	0.0005
	Off Normal Condition	117°F	0.0004	0.0003
31.2 kW	Off Normal Condition	-40°F	0.0006	0.0005
	Off Normal Condition	117°F	0.0004	0.0004
40.8 kW	Off Normal Condition	-40°F	0.0007	0.0006
	Normal Condition	0°F	0.0006	0.0006
	Normal Condition	100°F	0.0005	0.0005
	Off Normal Condition	117°F	0.0005	0.0005

5.5 – Bulk Temperatures

The following table shows the bulk temperatures at each of the eight specified regions on the DSC.

	24kW Amb. -40°F	24kW Amb. 117°F	31.2 kW Amb. -40°F	31.2 kW Amb. 117°F	40.8 kW Amb. -40°F	40.8 kW Amb. 0°F	40.8 kW Amb. 100°F	40.8 kW Amb. 117°F
Temp. Assignment	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)
T0	-37	108	-37	109	-36	4	105	110
T1	-35	112	-34	113	-33	8	110	115
T2	-30	119	-28	122	-25	16	120	125
T3	-25	126	-22	130	-18	24	130	135
T4	-20	133	-16	138	-11	32	140	145
T5	-15	139	-10	146	-4	40	149	155
T6	-10	145	-4	155	4	48	159	165
T7	-5	153	2	163	11	56	169	175
T8	0	160	8	171	18	64	179	185
Ts	-22	130	-19	135	-14	29	135	141

6.0 – Conclusion

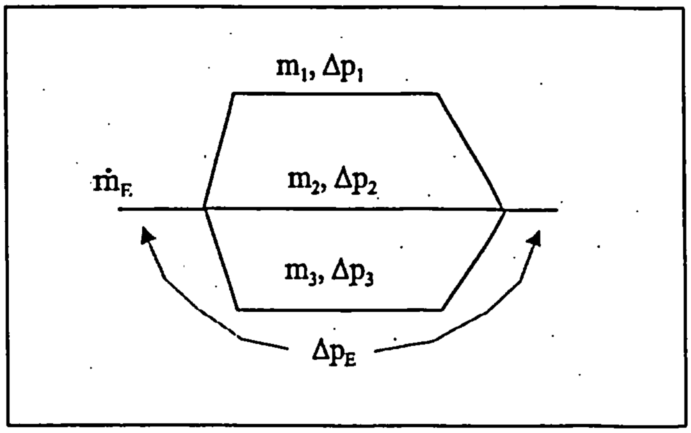
The following table summarizes the airflow rate, exit air temperature, total loss coefficient, and bulk temperature around the DSC for storage conditions.

	24kW Amb. -40°F	24kW Amb. 117°F	31.2 kW Amb. -40°F	31.2 kW Amb. 117°F	40.8 kW Amb. -40°F	40.8 kW Amb. 0°F	40.8 kW Amb. 100°F	40.8 kW Amb. 117°F
Airflow Rate (lbm/s)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)
T_{Exit} (F)	0	160	8	171	18	64	179	182
T_S (F)	-22	130	-19	135	-14	29	135	141
ΣK (ft^{-4})	0.0713	0.0728	0.0711	0.0726	0.0710	0.0714	0.0724	0.0724
Temp. Assignment	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)	Value (°F)
T0	-37	108	-37	109	-36	4	105	110
T1	-35	112	-34	113	-33	8	110	115
T2	-30	119	-28	122	-25	16	120	125
T3	-25	126	-22	130	-18	24	130	135
T4	-20	133	-16	138	-11	32	140	145
T5	-15	139	-10	146	-4	40	149	155
T6	-10	146	-4	155	4	48	159	165
T7	-5	153	2	163	11	56	169	175
T8	0	160	8	171	18	64	179	185

Appendix A

Derivation of the Equation for Calculation of the Equivalent Loss Coefficient in Parallel Paths

In an open system like the one shown below, the sum of mass flow rates in parallel paths must be equal to the entering mass flow rate. The continuity law requires that the pressure drop in parallel paths to be equal. These requirements are expressed in the following equations.



$$\dot{m}_E = \sum \dot{m}_j \qquad \text{(A-1)}$$

Where

$\dot{m}_E$ = Entering Mass Flow Rate

$\dot{m}_j$ = Mass Flow Rate of Flow Path j

$$\Delta p_E = \Delta p_j \qquad \text{(A-2)}$$

Where

Δp_E = Total Pressure Drop

Δp_j = Pressure Drop of the Path i

The relation between the pressure drop and the loss coefficient is given in Reference 1.

$$\Delta p_j = C_j \frac{\rho V_j^2}{2} \qquad \text{(A-3)}$$

Where

C_j = Total Loss Coefficient in Path i

ρ = Fluid Density

V_j = Fluid Velocity

A relation between the velocity (V_j) and mass flow rate can be written assuming a constant average density (ρ) for the fluid.

$$\dot{m}_j = \rho A_j V_j \qquad \text{(A-4)}$$

Substituting equation (A-4) into (A-2) can result in a relation between the entering mass flow rate and the flow rate in each parallel path as follows:

$$\frac{\dot{m}_J}{\dot{m}_E} = \frac{\sqrt{C_E}/A_E}{\sqrt{C_J}/A_J} \qquad \text{(A-5)}$$

Substitution of Equation (A-5) in Equation (A-1) and rearrangement of the parameters give:

$$\frac{C_E}{A_E^{2}} = \frac{1}{\left(\sum \frac{A_J}{\sqrt{C_J}}\right)^2} \qquad \text{(A-6)}$$