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HEAT LOAD ON VESSEL WALL COOLANT STREAM

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HEAT LOAD ON VESSEL WALL COOLANT STREAM

The FTR vessel wall will be cooled with inlet primary coolant which bypasses the core and flows through an annulus formed by the vessel wall and the thermal barrier. Heat transfer to the by-pass coolant stream is by radial conduction from the surrounding sodium pool through the thermal barrier wall.

In the analysis, the temperature rise of the by-pass coolant stream was derived as a function of the wall thickness of the thermal barrier and the flow rate of the by-pass stream. The study was based on the following assumptions and conditions:

1. Gamma heating is negligible. (Calculations indicate gamma heating affects the by-pass stream temperature rise by about 1%.)
2. Sodium surface film resistances on the thermal barrier are negligible.
3. Axial conduction in the sodium and steel are negligible.
4. Heat losses on the outer vessel wall are negligible.
5. Temperature of sodium pool surrounding the thermal barrier increases linearly from the core inlet to the core outlet temperatures over the 15' active zone section.
6. Temperature of sodium pool above the active zone is equal to the core outlet temperature over the 20' outlet pool section.
7. Total length of the by-pass flow passage is 35'.
8. Diameter of the thermal barrier is 16'-6".
9. Total reactor flow rate is 40,000 gpm.
10. Physical properties:
 - a) Thermal conductivity stainless steel - 12.0 Btu/hr-ft °F
 - b) Density sodium - 51.5 lbs/ft³
 - c) Specific heat sodium - 0.30 Btu/lb-°F

The temperature rise in the by-pass stream was derived in two parts: (1) the active zone section, and (2) the outlet pool section. The heat balance written for the by-pass stream over the active zone section is:

$$WC_p \frac{dT}{dx} = U (T_s - T) \quad \dots (1)$$

Where T_s = Sodium pool temperature = $T_i + \frac{X}{L_i} (T_H - T_i)$

T_H = Outlet core coolant temperature

T_i = Inlet core coolant temperature

X = Axial distance

L_i = Total length of active zone section - 15'

W = By-pass stream flow rate

C_p = Specific heat sodium

U = Heat transfer coefficient (thermal barrier wall)

$$\frac{k\pi D}{\Delta X}$$

k = thermal conductivity stainless steel

D = Diameter thermal barrier

ΔX = Wall thickness thermal barrier

Eqn. (1) can be integrated between limits after multiplying

Eqn. (1) by $\frac{UX}{e WC_p}$. The appropriate boundary conditions are:

@ $X = 0$ $T = T_i$

@ $X = L_i$ $T = T_{L_i}$

integrating and reducing the solution to form a dimensionless temperature rise yields:

$$\frac{T_{L_1} - T_i}{T_H - T_i} = \frac{WC_p}{UL_1} \left[\frac{UL_1}{WC_p} - 1 + \exp \left(-\frac{UL_2}{WC_p} \right) \right] \quad (2)$$

In the outlet pool section the sodium pool temperature is constant and equals the core coolant outlet temperature.

The boundary conditions are:

$$@ X = 0 \quad T = T_{L_1}$$

$$@ X = L_2 \quad T = T_0$$

Integration of the heat balance equation and reducing the solution to a dimensionless temperature rise yields:

$$\frac{T_0 - T_{L_1}}{T_H - T_{L_1}} = \left[1 - \exp \left(-\frac{UL_2}{WC_p} \right) \right] \quad (3)$$

Equations (2) and (3) can then be solved simultaneously to derive the dimensionless ratio of the overall by-pass stream temperature rise to the core coolant temperature rise. The solution reduces to:

$$\frac{T_0 - T_i}{T_H - T_i} = \frac{WC_p}{UL_1} \exp \left(-\frac{UL_2}{WC_p} \right) \left[\frac{UL_1}{WC_p} - 1 + \exp \left(-\frac{UL_1}{WC_p} \right) \right] + (1 - \exp \left(-\frac{UL_2}{WC_p} \right)) \quad (4)$$

Dimensionless temperature rise ratios were computed for by-pass flow rates up to 10% of the total reactor flow and for thermal barrier wall thicknesses of: 1/2", 3/4", 1", 1-1/2", 2", and 2-1/2". The calculated results are tabulated below and shown in the attached figure.

		$\frac{T_0 - T_i}{T_H - T_i}$					
<u>% W</u>	<u>$\Delta X =$</u>	<u>1/2"</u>	<u>3/4"</u>	<u>1"</u>	<u>1-1/2"</u>	<u>2"</u>	<u>2-1/2"</u>
10		.583	.441	.353	.253	.198	.160
9		.622	.479	.386	.278	.219	.175
8		.662	.518	.421	.306	.242	.193
7		.712	.566	.467	.344	.268	.221
6		.764	.625	.518	.390	.307	.255
5		.823	.686	.584	.441	.356	.298
4		.883	.763	.663	.518	.422	.356
3		.941	.853	.764	.621	.518	.441
2		.985	.942	.884	.765	.664	.584
1		.999	.996	.981	.941	.884	.823
0		1.000	1.000	1.000	1.000	1.000	1.000

BYPASS FLOW - % TOTAL REACTOR FLOW
 (10% = 4000 gpm = 459 lb/sec)

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