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— RADAR —

REACTOR THERMAL AND HYDRAULIC
ANALYSIS DURING REACTOR FLOW
COASTDOWN

by

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RADAR — Reactor Thermal & Hydraulic Analysis
During Reactor Flow Coastdown

H. C. Cheatwood, J. R. Gloudemans, C. D. Morgan

Key Words: RADAR, Computer Program, Digital,
Analysis, Thermal — Hydraulic,
Reactor Coastdown

ABSTRACT

The RADAR digital computer program performs a thermal analysis of a slow reactor transient such as the loss of a primary pump. The code computes, as a function of time, fuel pin temperatures, cladding surface temperatures, critical heat flux ratios, and coolant thermodynamic conditions when given the fuel pin heat rate and either the channel flow or pressure drop as a function of time.

Because of the restriction to slow transients, RADAR requires very little computer time to analyze a typical problem. The run time for a typical case is 0.6 second per axial node per time step. Since the solution technique is implicit, there is no stability limitation on the size of the time increment.

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1. INTRODUCTION

An important phase in the thermal design of a nuclear power reactor is the determination of reactor coolant conditions during operational transients. One must obtain this information for the reactor coolant flow channels that represent the typical behavior (average channel) of the reactor and for the other channels that represent the extremes in heat generation, dimensions, and flow characteristics (hot channel). From the average channel calculations one can obtain the core pressure drop behavior, which may then be applied to the hot channel calculations in order to assess core safety.

RADAR is a digital computer code designed to handle slow reactor transients. This code will accept flow, power, and entering enthalpy as a function of time. It was written primarily to handle a reactor flow coastdown followed by a scram. The code is capable of analyzing the following types of problems:

1. Transient calculation of thermal and hydraulic parameters for a given channel in a core, knowing the flow as a function of time.
2. Transient calculation of thermal and hydraulic parameters for a given channel in a core, knowing the core pressure drop as a function of time.
3. Transient calculations involving the foregoing problems, in which the average channel sets the pressure drop; and the flow in the hot channel is iterated until the hot and average channel pressure drops are equivalent.

2. METHODS

The RADAR computer code considers three regions: the fuel pin, the cladding surrounding the fuel, and the reactor coolant. The regions are shown in Figure 1.

2.1. Fuel Pin Transients (Regions I and II)

In order to solve the transient effects on the fuel pin the following energy balance is applied at predetermined radial increments throughout the fuel and cladding:

$$\rho_{FC} c_p \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(rk \frac{\partial T}{\partial r} \right) + Q'''(t) \quad (1)$$

which takes into account the following assumptions:

1. The heat flow internal to the pin and cladding is one dimensional and normal to the pin surface.
2. Heat is generated uniformly in the fuel.

The following boundary conditions are applied to equation 1:

1. $\frac{dT}{dr} = 0$ at $r = 0$.

2. $k_L \left. \frac{dT}{dr} \right|_L = k_R \left. \frac{dT}{dr} \right|_R$

at interior boundaries, i.e., increments within the fuel or cladding.

3. $q_c = -k_L \left. \frac{dT}{dr} \right|_L = -k_R \left. \frac{dT}{dr} \right|_R$ and $\Delta T_G = \frac{q_c}{h_c}$

at the boundary between the fuel and cladding. The heat transfer coefficient between the cladding and fuel, h_c , is computed from the Ross and Stoute model as modified by Kjaerheim and Rolstadt.¹ See reference 2 for the details of this model.

$$4. \quad -k_L \left. \frac{dT}{dr} \right|_L = U(T_W - T_B)$$

at the cladding outer surface.

Figure 1. Regions Considered by RADAR

Equation 1 is solved implicitly for the temperatures at various radial increments in the fuel and cladding. Integrating (1) and writing a finite difference equation for each radial increment, a matrix of temperatures is obtained. This can be done both in the fuel and the cladding by applying the appropriate boundary conditions for each radial increment. The final solution is obtained by iterating until two consecutive temperature calculations of each of the radial increments are within a given error bound. Because this method is implicit, the solution does not require a specific time step to insure mathematical stability. This solution is expanded further in Appendix B.

2.2. Hydrodynamic Transients (Region III)

The hydraulic calculations are based on the following equations:

Conservation of Mass

$$\frac{\partial \rho_B}{\partial t} + \frac{\partial G}{\partial Z} = 0. \quad (2)$$

Conservation of Momentum

$$\frac{\partial G}{\partial t} + \frac{\partial (G^2 / \rho_B)}{\partial Z} = - \frac{\partial P}{\partial Z} - f \frac{|G| G}{2 \rho_B De} - \rho_B g. \quad (3)$$

Conservation of Energy

$$\frac{\partial H}{\partial t} = q / \rho - \frac{G}{\rho} \frac{\partial H}{\partial Z}. \quad (4)$$

Equation of State

$$T_B = T_B(\rho_B, H). \quad (5)$$

$$\rho_B = \rho_B(H, P). \quad (6)$$

The following assumptions, which are equivalent to the "single mass velocity model",³ are applied to equations 2 through 4 in order to obtain a solution:

1. $\frac{\partial G}{\partial Z} = 0 = \frac{\partial \rho_B}{\partial t}$
(neglect fluid expansion when handling the mass velocity profile).
2. $G = G(t)$.
3. $G \frac{\partial H}{\partial Z} = q$
for each time step.
4. Pressure remains at a mean operating pressure during a time step.

The analytical model contains a transient fuel pin response calculation, but the hydraulic model assumes that the flow rate is constant over the channel length during a time step (i.e., "steady-state" solution of energy, mass, and momentum balances at each time step). These assumptions imply that this model is only accurate for slow transients.

A code, SONAR, has been written which does not require assumptions 1 through 3 and thus is accurate for fast transients. SONAR results are not significantly different from RADAR results for the loss of pumps accident. SONAR runs much longer because of its increased complexity; therefore, RADAR is the desirable code to use unless extreme accuracy is required.

2.3. Channel Pressure Drop

Three different flow regimes are considered in calculating pressure drop: heat addition without boiling, local boiling, and bulk boiling. In general, the methods used in RADAR are extensions of the recommendations made in reference 4.

The energy equation for an incompressible fluid in steady flow with no shaft work and a constant flow area can be written in differential form as

$$\frac{G^2 dv}{g_c} + \frac{1}{v} g/g_c \cos\theta dz + dp + \frac{1}{v} \delta F = 0 \quad (7)$$

where

- G = mass velocity, $\text{lbm/ft}^2\text{-s}$,
- v = specific volume, ft^3/lbm ,
- g_c = constant in Newton's second law = $32.17 \text{ lbm-ft/lbf-s}^2$,
- g = local acceleration of gravity, ft/s^2 ,
- θ = angle that channel makes with the vertical,
- z = space dimension, ft ,
- p = pressure, lbf/ft^2 ,
- F = unrecoverable pressure losses, lbf-ft/lbm .

Integrating equation 7 over a small increment so that the coolant properties may be taken as average values gives

$$p_2 - p_1 = -\frac{1}{v} (z_2 - z_1) g/g_c \cos\theta - \frac{G^2}{g_c} (v_2 - v_1) - \Delta p_f - \Delta p_{SG} \quad (8)$$

where

- Δp_f = pressure drop due to friction,
- Δp_{SG} = pressure drop due to spacer grids.

The subscript 2 denotes the position downstream that makes the pressure loss negative as written.

The assumption that the coolant properties remain constant for the integrations performed above requires the use of small space increments in the calculation. Small space increments are generally desired by the designer anyway, and the maximum space increment normally used is about 4 inches. All of the thermodynamic properties are computed from curve fits to the 1967 ASME steam tables.

2.3.1. Heating Region

The frictional pressure drop is obtained from

$$\Delta p_f = \frac{f L v}{D_e} \frac{G^2}{2g_c} \quad (9)$$

where f , the Moody friction factor, is given by

$$f = f_{iso} [1 - 0.001914 \Delta T_f], \quad (10)$$

$$f_{iso} = \left\{ 2 \log_{10} \left[\frac{\epsilon_r / D_e}{3.715} - \frac{5.028}{Re} \log_{10} \left(\frac{\epsilon_r / D_e}{3.715} + \frac{16.76}{Re} \right) \right] \right\}^{-2}, \quad (11)$$

and

$$\Delta T_f = \frac{q''}{0.023 (k_B / D_e) Re^{0.8} Pr^{1/3}}$$

where

D_e = equivalent hydraulic diameter, ft,

ϵ_r = absolute roughness, ft,

$Re = GD_e / \mu$, Reynolds number,

$Pr = c_p \mu / k$, Prandtl number,

μ = viscosity, lbm/h-ft,

q'' = heat flux, Btu/h-ft².

The pressure drop due to the spacer grids is obtained from

$$\Delta p_{SG} = K_c v \frac{G^2}{2g_c} \quad (12)$$

where

$$K_c = C_K [1.4 - 2.4\sigma + \sigma^2]; \quad (13)$$

σ = ratio of flow area in the spacer grid to the unobstructed flow area in the tube region—The term $[1.4 - 2.4\sigma + \sigma^2]$ is a good fit to the Kays and London form loss curves at high Reynolds numbers comparable to those existing in PWR cores;

C_K = empirical adjustment factor to Kays and London losses—This factor is determined experimentally, since spacer grids do not act as simple expansions and contractions.

2.3.2. Local Boiling Region

The initiation of local boiling for the following pressure-drop calculations is defined by solving the nonboiling Colburn convection equation and the Jens and Lottes equation for wall temperature. Local boiling is considered to start when the Jens and Lottes wall temperature is less than that predicted by the Colburn equation. The Moody friction factor is given by

$$f = f_{iso} [1 - 0.0025 \Delta T^*] \left[1 + 0.76 \left(\frac{10^6}{G} \right)^{2/3} \bar{\psi} \right] \quad (14)$$

where $\bar{\psi} = 1 - \frac{\Delta T^*}{\Delta T_f}$, (15)

$$\Delta T^* = \frac{60 (q''/10^6)^{1/4}}{e^{P/900}}, \quad (16)$$

P = pressure, psia.

For the calculation of pressure drops due to acceleration, contractions, and expansions, the specific volume is given by

$$v = \frac{(1-x^*)^2}{1-\alpha} v_f + \frac{x^{*2}}{\alpha} v_g \quad (17)$$

where α = void fraction, as predicted in section 2.3,
 x^* = apparent quality as defined in section 2.3.

For the calculation of pressure drop due to friction and fluid head, the specific volume is given by

$$\frac{1}{v} = \frac{1-\alpha}{v_f} + \frac{\alpha}{v_g}. \quad (18)$$

2.3.3. Two-Phase Flow Region

The two-phase friction pressure drop equation follows the same form as the heating pressure drop equation, with the friction factor, f , calculated by

$$f = (f_{iso})_{sat} \left(\frac{f_{TPF}}{f_{iso}} \right) \left[\frac{\phi_{L.O.}^2}{(\phi_{L.O.})_{M.N.}^2} \right] \quad (19)$$

where $(f_{iso})_{sat} = f_{iso}$ evaluated at $\frac{GD}{\mu_{sat}}$;

$\left(\frac{f_{TPF}}{f_{iso}} \right)$ = Martinelli-Nelson local multiplier—tabular values as a function of pressure and quality are a fixed portion of the program;

$\left[\frac{\phi_{L.C.}^2}{(\phi_{L.O.})_{M.N.}^2} \right]$ = mass velocity correction multiplier for the Martinelli-Nelson friction multiplier—This is also built into the program in table form as a function of quality and mass velocity.

The specific volume of saturated liquid is used in calculating the frictional pressure drop; the specific volumes for calculating the other components of the pressure drop are computed in the same manner as in the local boiling region.

2.4. Void Fraction Model

The void model used in TEMP is a combination of Bowring's⁵ model with Zuber's⁶ correlation between the void fraction and quality. The Bowring model considers three different regions of forced convection boiling as defined in the following three subsections.

2.4.1. Highly Subcooled Boiling

In this region the bubbles adhere to the wall while moving upward through the channel. The highly subcooled region begins when the surface temperature of the cladding reaches the surface temperature predicted by the Jens and Lottes equation. The region ends when the subcooling decreases to a point where the bubbles break through the laminar sublayer and depart from the surface. That is, when

$$T_{\text{sat}} - T_{\text{bulk}} = \frac{\eta q''}{V} = \theta_d \quad (20)$$

where $\eta = 1.863 \times 10^5 (14 + 0.0068p)$,
 V = velocity of coolant, ft/s.

The void fraction in this region is computed in the manner of Maurer⁷ except that the end of the region is determined by equation 20 rather than a vapor layer thickness. The void fraction is given by

$$\alpha = \frac{P_h [q'' - h(T^* - T_{\text{bulk}})] \text{PrK}}{A_f [1.07 h^2 (T_{\text{sat}} - T_{\text{bulk}})]} \quad (21)$$

where P_h = heated perimeter, ft,
 q'' = heat flux at the point, Btu/h-ft²,
 h = heat transfer coefficient, Btu/h-ft² - F,
 T^* = surface temperature predicted by Jens & Lottes, F,
 Pr = Prandtl number evaluated at bulk temperature,
 T_{bulk} = bulk temperature of fluid, F,
 K = thermal conductivity evaluated at bulk temperature, Btu/h-ft°F,
 A_f = flow area, ft²,
 T_{sat} = saturation temperature of fluid, F.

The non-equilibrium quality at the end of the region is computed from the void fraction as follows:

$$x_d = \frac{1}{1 + \frac{\rho_f}{\rho_g} \left(\frac{1}{\alpha_d} - 1 \right)} \quad (22)$$

where α_d = void fraction at $T_{\text{sat}} - T_{\text{bulk}} = \theta_d$.

2.4.2. Slightly Subcooled Boiling

In this region the bubbles depart from the wall and are transported along the channel (condensation of the bubbles is neglected). This region transcends the point where the thermodynamic quality is zero. In general, this is the region of major concern in the design of pressurized water reactors.

The non-equilibrium quality in this region is computed from

$$x^* = x_d + \frac{P_h}{\dot{m} h_{fg}(1+\epsilon)} \int_{z_d}^z (\phi - \phi_{SP}) dz \quad (23)$$

where

h_{fg} = latent heat of vaporization,

$\frac{1}{1+\epsilon}$ = fraction of heat flux above the single-phase heat flux that actually goes to producing voids,

ϕ_{SP} = single phase heat flux = $0.7\phi - 0.915h\Delta T_{JL}$,

$\dot{m}$ = mass flow rate,

h = single-phase heat transfer coefficient,

P_h = heated perimeter,

ΔT_{JL} = Jens and Lottes' prediction of temperature difference between the surface and saturation.

The void fraction in this region is computed from

$$x = \frac{x^*}{C_o [x^* + \rho_g / \rho_f (1-x^*)] + \frac{38.3 A_f \rho_g}{\dot{m}} \left[\frac{\Sigma g g_c (\rho_f - \rho_g)}{\rho_f^2} \right]^{1/4}} \quad (24)$$

where

C_o = Zuber's distribution parameter,

A_f = the flow area, ft^2 ,

Σ = the surface tension, lbf/ft .

Equation 24 results from rearranging equations found in reference 2 and assuming bubbly turbulent flow in determining the relative velocity between the vapor and the fluid.

2.4.3. Bulk Boiling

In this region the bulk temperature is equal to the saturation temperature, and all the energy transferred to the fluid results in net vapor generation. Bulk boiling begins when the thermodynamic (heat balance) quality, x , is greater than the non-equilibrium quality, x^* . The void fraction in this region is computed using equation 23 with the thermodynamic quality, x , replacing x^* .

2.5. Film Boiling

RADAR is capable of computing fuel cladding temperature when the fuel pin has exceeded the critical heat flux (CHF). Either the B&W-2 or the W-3 critical heat flux correlation can be used to determine the transition to film boiling at a value of critical heat flux ratio specified in the input.

Experiments in which both nucleate and film boiling exist in the same test section have shown that a transition zone of approximately three hydraulic diameters in length exists between the two heat transfer regimes. When RADAR computes a CHF ratio equal to or less than the input minimum CHF ratio, film boiling is assumed to start at that location, and all down-stream locations will be in film boiling. Transition boiling is assumed for three hydraulic diameters downstream of the computed CHF location. Once a location is computed to be in the film boiling regime, it remains in film boiling for the remainder of the run.

As given by Tong,⁸ the correlation for heat transfer in the transition regime is

$$U = 890 + 16,860 \exp[-0.01 (T_w - T_s)].$$

Since RADAR is normally run for operating pressures in the 2200 psia range, the correlation of Bishop, Sandberg, and Tong⁹ was chosen as the most applicable one for the RADAR code:

$$\left(\frac{hD}{k}\right)_F = 0.0193 \left(\frac{DG}{\mu}\right)_F^{0.8} \left(\frac{C_p \mu}{k}\right)_F^{1.23} \left(\frac{\rho_g}{\rho_B}\right)^{0.68} \left(\frac{\rho_g}{\rho_f}\right)^{0.068}$$

where $\rho_B = \rho_g \alpha + \rho_f (1-\alpha)$ and α is determined from the homogeneous model.

3. PROGRAM LIMITATIONS AND EXECUTION TIME

3.1. Limitations

Radar has the following limitations:

1. Only a two-channel model of the core can be considered.
2. Reactor coolant must be water.
3. Transient response must be classified as relatively slow.
4. Quality—up to 40%.
5. Flow rate—turbulent.
6. Pressure—150 to 3000 psi.
7. Fuel channel must contain a whole fuel rod.
8. There can be no unheated portion of any channel.
9. Bulk temperature must be less than or equal to 1500 F.
10. Maximum of 20 radial increments in Region I.

3.2. Execution Time

The execution time of a RADAR run is primarily dependent upon three things:

1. Number of axial nodes.
2. Number of radial nodes.
3. Number of time steps.

Two examples are as follows:

1. A case with six axial nodes, eight radial nodes, and 13 time steps required 6.465 cp seconds and 14.449 pp seconds.
2. A more representative case with 21 axial nodes, 17 radial nodes, and 46 time steps required 52.013 cp seconds and 66.713 pp seconds.

4. RADAR INPUT

In the following input, reference is made to channel 1 and channel 2. The following definitions will aid in properly completing the input forms:

1. Channel 1 is the first channel to be operated on in the transient. If the user has chosen a single-channel model, then this channel is channel 1. In the single-channel model, the channel may be an average channel or a hot channel. There is also a choice of calculating pressure drop or flow rate as a function of time. Of course, one of the two must be known. There is also facility to do both during the transient (i.e., calculate a pressure drop with a known flow rate up to time X, and then compute a flow rate with time knowing the pressure drop from time X to the end of the transient).

2. Channel 2 input is used only if a two-channel flow distribution is desired (generally an average and a hot channel). In this case, channel 1 (average channel) is the first channel to be operated on. Flow rate, power, and the like are known functions of time for channel 1, and the resultant pressure drop is computed as a function of time. Channel 2 (hot channel) is the channel that is iterated to the average channel pressure drop. If this option is chosen, then the hot channel factors in the input are applied to channel 2.

<u>RADAR Input</u>			
<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
<u>Card G - 1st Card</u>			
2 - 80	LABEL	--	Job identification (alpha-numeric).
<u>Card G1</u>			
9 - 11	NTOTPT	--	Number of cards in section input.
<u>Card S1 (section input) NTOTPT of these</u>			
1 - 9	X(I)	inches	Distance axially along the channel.
10 - 20	AF(I)	sq in.	Flow areas of channel.
21 - 31	WP(I)	inches	Wetted perimeter of channel.
32 - 42	FLUX(I)	--	Axial flux profile normalized to 1.0.
43 - 53	CONTKI(I)	--	Form loss for change in flow area.
<u>Card G2</u>			
9 - 11	NTOTTM	--	Number of time cards to follow.
<u>Card TI (time table) NTOTTM of these</u>			
1 - 10	T(I)	seconds	Time.
11 - 20	FT(I)	--	Neutron power fraction (referenced to time zero).
21 - 30	GT(I)	--	Flow rate fraction (referenced to time zero).
31 - 40	HT(I)	--	Entering enthalpy fraction (referenced to time zero).
41 - 50	DELPG1(I)	psi	Pressure drop at each time.
51 - 60	PT(I)	psi	Core operating pressure at each time.
61 - 70	H2T(I)	--	Contact heat transfer coeff factors (Input if H(2) is input).

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
<u>Card G3</u>			
1 - 10	DELTAT(1)	seconds	Time increment to be used up to time TMAX(1).
11 - 20	DELTAT(2)	seconds	Time increment to be used up to time TMAX(2).
21 - 30	DELTAT(3)	seconds	Similar to above.
31 - 40	DELTAT(4)	seconds	Similar to above.
41 - 50	DELTAT(5)	seconds	Similar to above.
51 - 60	DELTAT(6)	seconds	Similar to above.
61 - 70	DELTAT(7)	seconds	Similar to above.
71 - 80	DELTAT(8)	seconds	Similar to above.
<u>Card G4</u>			
1 - 10	TMAX(1)	seconds	Final time for first time increment, DELTAT(1).
11 - 20	TMAX(2)	seconds	Final time for second time increment, DELTAT(2).
21 - 30	TMAX(3)	seconds	Similar to above.
31 - 40	TMAX(4)	seconds	Similar to above.
41 - 50	TMAX(5)	seconds	Similar to above.
51 - 60	TMAX(6)	seconds	Similar to above.
61 - 70	TMAX(7)	seconds	Similar to above.
71 - 80	TMAX(8)	seconds	Similar to above.
<u>Card G5</u>			
1 - 15	FINIS	seconds	Time at which transient will end.
16 - 30	DELPO	seconds	Time increment between printout.
31 - 45	TIMPIT	seconds	Time to begin iterating on pressure drop.
46 - 60	FLXSWT	--	0.0 - The original flux shape will be used throughout. 1.0 - There will be a flux shape change.
<u>Card G6</u>			
1 - 15	CH	--	Coefficient on the Colburn equation.

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
16 - 30	FBR	--	Burnout ratio at which the pin is assumed to be blanketed by steam.
31 - 45	ER	inches	Relative roughness of pin cladding surface.
46 - 60	PH	inches	Heated perimeter of channel 1.
61 - 75	UNEW	Btu/h-ft ² - ° F	Film coefficient. If 0.0 or blank, code will calculate.
<u>Card G7</u>			
1 - 15	HE1	Btu/lbm	Time zero entering enthalpy.
16 - 30	ACTL	inches	Active fuel length.
31 - 45	DRI	inches	Fuel rod diameter for channel 1.
46 - 60	DIF	inches	Fuel diameter for channel 1.
61 - 75	PI	inches	Pin pitch for channel 1.
<u>Card G8</u>			
1 - 15	FOP	--	Overpower at which the transient begins.
16 - 30	PPRAD	--	Radial peak-to-average power factor for channel 1.
31 - 45	PPLOC	--	Local peak-to-average power factor for channel 1.
46 - 60	FS	--	Burnout safety factor used in the burnout correlation.
61 - 75	AFT	sq in.	Tube flow area for channel 1.
<u>Card G9</u>			
1 - 15	WPT	inches	Wetted perimeter for channel 1.
16 - 30	W	lbm/h	Channel flow rate at time zero.
31 - 45	QBAR	Btu/h	Average pin heat rate for channel 1.
46 - 60	FNT	--	Fraction of total reactor power that is generated within the fuel rod.

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
<u>Card G10</u>			
5	L4	--	Choice of burnout correlation: 1 = BAWM. 2 = BAW2. 3 = W3-S. 4 = W3R. 5 = W3.
6 - 10	NUMINC(1)	--	Number of increments in fuel.
11 - 15	NUMINC(2)	--	Number of increments in cladding.
16 - 30	H(2)	Btu/h-ft ² - °F	Contact coefficient between fuel and cladding. If 0 or blank a value is computed using the TAFY model.
31 - 45	TCONST(1)	°F	Temperature guess in fuel.
46 - 60	TCONST(2)	°F	Temperature guess in cladding.
<u>Card G11</u>			
1 - 15	RH1(1)	lbm/ft ³	Fuel density.
16 - 30	RH1(2)	lbm/ft ³	Cladding density.
31 - 45	TEMAX(1)	°F	Cut off temperature for the fuel conductivity polynomial.
46 - 60	TEMAX(2)	°F	Cut off temperature for the cladding conductivity polynomial (above this temperature, conductivity is constant).

(Input Cards G12 - G14 if FLXSWT = 1)

<u>Card G12</u>			
1 - 10	BEGFLX	seconds	Time to begin flux change.
11 - 20	ENDFLX	seconds	Time to end flux change and revert to the original flux shape.
21 - 25	NUMFLX	--	No. of flux changes (maximum of 20).

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
		<u>Card G13</u>	
1 - 8	TIMEFLX(1)	seconds	Times at which the flux changes will occur. There will be "NUMFLX" values.
9 - 16			
17 - 24			
25 - 32			
33 - 40			
41 - 48			
49 - 56			
57 - 64			
65 - 72			
73 - 80			

		<u>Card G14</u>	
1 - 8	FLUX2(I, J)	--	Flux values at each of the given times. (J = 1, NUMFLX: I = 1, NTOTPT).
9 - 16			
17 - 24			
25 - 32			
33 - 40			
41 - 48			
49 - 56			
57 - 64			
65 - 72			
73 - 80			

(Input Cards G15 - G17 if H(2) = 0.0 or blank)

		<u>Card G15</u>	
1 - 15	RADICR	inches	Inside diameter of cladding.
16 - 30	BURNUP	MWd/MTU	Burnup.
31 - 45	PGASI	psia	Initial internal pin pressure.
46 - 60	VPLENU	cu in.	Volume of upper plenum.
61 - 75	VPLENL	cu in.	Volume of lower plenum.

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
<u>Card G16</u>			
1 - 15	RUFFL1	inches	Surface roughness of fuel.
16 - 30	RUFCL1	inches	Surface roughness of inside cladding.
31 - 45	CONGAS	Btu/h-ft- °F	Gap gas conductivity. (If 0.0 or blank, code will calculate.)
46 - 60	GMFILL	--	Gram moles of backfill gas (helium).
61 - 75	GMSORB	--	Gram moles of sorbed gas (air).

Card G17

1 - 15	GMFISS	--	Gram moles of fission gas (15.8% Kr, 84.2% Xe).
--------	--------	----	---

Card G18

10	NOPRINT	--	Choice of printout: 0 or blank—type 1 printout; 1 - type 2 printout.
15	N03	--	Choice of cutoff time: 1 - runs for all of hot channels; 0.0 or blank stops in hot channel after three successive time steps after finding the lowest minimum DNB point.
16 - 25	ALFA	--	Intensity of turbulence for W3S correlation for spacer factor calculation.

Card G19

(fuel conductivity polynomial coefficients)

1 - 10	FEE(1, 1)	Btu/h-ft ² - °F	Coefficient of T ⁰ .
11 - 20	FEE(1, 2)	Btu/h-ft ² - °F	Coefficient of T ¹ .
21 - 30	FEE(1, 3)	Btu/h-ft ² - °F	Coefficient of T ² .
31 - 40	FEE(1, 4)	Btu/h-ft ² - °F	Coefficient of T ³ .
41 - 50	FEE(1, 5)	Btu/h-ft ² - °F	Coefficient of T ⁴ .
51 - 60	FEE(1, 6)	Btu/h-ft ² - °F	Coefficient of T ⁵ .

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
61 - 70	FEE(1, 7)	Btu/h-ft ² - °F	Coefficient of T ⁶ .
71 - 80	FEE(1, 8)	Btu/h-ft ² - °F	Coefficient of T ⁷ .

Cards G20, G21, and G22 have the same format and description as G19 except that:

1. G20 is a polynomial describing the conductivity of the cladding.
2. G21 is a polynomial describing the specific heat of the fuel.
3. G22 is a polynomial describing the specific heat of the cladding.

Card G23

10	MAC	--	If MAC is: 0 - single-channel analysis. 1 - two-channel analysis.
----	-----	----	---

Card G24

1 - 12	FTHAP	--	If NM is: 0 - FTHAP = FQ = hot channel factor on film drop. 1 - FQ = hot channel factor on film drop.
13 - 24	FDHP	--	If NM is: 0 - FDHP = FΔT = hot channel factor on enthalpy rise. 1 - FDHP = 1.0.
25 - 36	FQ2PP	--	If NM is: 0 - FQ2PP = Fq'' = hot channel factor on heat flux. 1 - FQ2PP = overall factor on heat input = FQ.

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
37 - 48	FQHSL	--	If NM is: 0 - FQHSL $\geq$ FQ2PP (generally equals Fq''). 1 - FQHSL = local factor on heat flux = FQ''.
49 - 60	FDELH	--	Enthalpy multiplier.
61 - 65	NM	--	If NM is: 0 - old hot channel methods. 1 - new methods.

If a single channel is to be analyzed, card G24 is the final card of input. If a two-channel flow distribution is to be calculated, the following cards must be added for description of the second channel.

Card G25

1 - 5	NTOPT	--	If NTOPT = 0, section input is the same as for channel 1. Otherwise, NTOPT is the number of section cards to follow card G27.
6 - 20	DRI	inches	Diameter of fuel rod for channel 2.
21 - 35	DIF	inches	Diameter of fuel for channel 2.
36 - 50	PPRAD	--	Peak-to-average radial power factor for channel 2.
51 - 65	PPLOC	--	Peak-to-average local power factor for channel 2.

Card G26

1 - 15	AFT	sq in.	Tube flow area in channel 2.
16 - 30	WPT	inches	Tube wetted perimeter in channel 2.
31 - 45	QBAR	Btu/h	Average heat rate for channel 2.
46 - 60	PH	inches	Heated perimeter for channel 2.

<u>Column No.</u>	<u>Variable</u>	<u>Unit</u>	<u>Description</u>
<u>Card G27</u>			
(Input if H(2) is input)			
1 - 10	H2T(I)	--	Contact coefficient factors input as a function of time. Input 'NTOTTM' factors.
11 - 20	↓		
21 - 30			
31 - 40			
41 - 50			
51 - 60			
61 - 70			
71 - 80	↓		

Note: If NTOPT on card 25 is 0, then there is no more input. Otherwise, follow card G27 with NTOPT section cards identical in format to card SI.

5. RADAR OUTPUT

The input is printed out first. See the input directions for description of variables.

There are two types of output printout. The second type was put in as an option to make printout neater (i. e., delete rarely needed variables) and to reduce printout time.

Type 1

At each printout time step, the following parameters are printed out:

<u>Variable</u>	<u>Unit</u>	<u>Description</u>
TSEC	seconds	Time.
X	inches	Distance along channels.
Temperatures	°F	Temperatures at space increment boundaries beginning at center of fuel and ending with bulk fluid temperature.
CENTEMP	°F	Central fuel temperature.
SURTEMP	°F	Cladding outer surface temperature.
BULKTMP	°F	Bulk coolant temperature.
FLUXR	Btu/h-ft ²	Heat flux on the surface of the cladding [FLUXR is the average flux over increment ($X_i - X_{i-1}$)].
SUMFP	psi	Friction pressure drop summation.
SUMPA	psi	Acceleration pressure drop summation.
SUMPH	psi	Elevation pressure difference summation.
SUMPCE	psi	Contraction and expansion losses summation.
DNBR22	--	Departure from nucleate boiling ratio using the BAW-M correlation.

Variable	Unit	Description
DNBR2	--	Departure from nucleate boiling ratio using the BAW-2 correlation.
DNBRW3S	--	Departure from nucleate boiling ratio using W3S correlation.
DNBR33	--	Departure from nucleate boiling ratio using the W3-R correlation—uses FFACTD.
DNBR3	--	Departure from nucleate boiling ratio using the W3 correlation—uses FFACTR.
QOUT	Btu/h	The heat rate going into the coolant.
W	lbm/h	Channel flow rate at the time specified.
U	Btu/h-ft ² -°F	Film coefficient at time specified.
HI	Btu/lbm	Enthalpy of the coolant.
DELPT	psi	Total summation pressure drop to this point.

Type 2

At each time step during the transient, the following parameters are printed out:

TSEC	second	Time.
W	lbm/h	Channel flow rate.
X	inches	Distance along channel.
HI	Btu/lbm	Enthalpy of the coolant.
TB	°F	Bulk coolant temperature.
SURFT	°F	Cladding outer surface temperature.
TAVG	°F	Average fuel temperature.
CENTEMP	°F	Central fuel temperature.
H(2)	Btu/h-ft ² -°F	Contact coefficient.
Q2PS	Btu/h-ft ²	Local heat flux.
DELPT	psi	Total summation pressure drop to this point.
DNBR1	--	Departure from nucleate boiling ratio using each correlation.
.		
.		
DNBR5		

<u>Variable</u>	<u>Unit</u>	<u>Description</u>
FLUX / FLOW	--	Ratio of change in flux shape to change in flow rate (referenced to time zero).

Upon completion of the transient, the following parameters are printed as a function of time:

1. Total pressure drop, psi.
 2. Channel flow rate, lb/h.
 3. Minimum DNB ratio.
 4. Level of minimum DNB ratio.
 5. Flux-flow ratio.
- } for each correlation

6. NOMENCLATURE

Dimensions are noted by M = mass, L = length, θ = time, F = ML/θ^2 = Force, T = temperature, and H = $FL = ML^2/\theta^2$ = energy. Equations in the report are written in terms of a consistent set of units.

Symbol	Description	Dimensions
μ	Viscosity	$M/L\theta$
ρ	Density	M/L^3
c_p	Heat capacity	H/MT
t	Time	θ
k	Thermal conductivity	$H/TL\theta$
r	Radial dimension	L
Z	Axial dimension	L
Q'''	Internal heat generation	$H/\theta L^3$
ΔT_G	Gas temperature drop between fuel and cladding	T
h_c	Contact conductance	$H/\theta L^2 T$
A_{HT}	Heat transfer area at contact	L^2
U	Forced convection film coefficient	$H/\theta L^2 T$
G	Mass velocity	$M/L^2 \theta$
g_c	Gravitational constant	$ML/F\theta^2$
P	Pressure	F/L^2
f	Friction factor	None
D_e	Equivalent diameter	L
q	Heat rate per volume coolant	$H/\theta L^3$
H	Enthalpy	H/M
T	Temperature	T
q_c	Heat flux between fuel and cladding	$H/L^2 \theta$

Subscripts

L	Left
R	Right
FC	Fuel or cladding
B	Bulk coolant
W	Wall (outer cladding)
F	Saturated Fluid

7. REFERENCES

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APPENDIX A
Transient Fuel Pin Temperature Model
(Subroutine TRANS)

The basic equation is the general heat diffusion equation:

$$\frac{\partial}{\partial r} \left(r^a k \frac{\partial T}{\partial r} \right) + r^a \left(Q''' - \rho c \frac{\partial T}{\partial t} \right) = 0 \quad (A-1)$$

Where, when

- $a = 0$, equation A-1 applies to cartesian geometry.
- $a = 1$, equation A-1 applies to cylindrical geometry.
- $a = 2$, equation A-1 applies to spherical geometry.

This report is concerned only with the cylindrical geometry ($a = 1$) case, as subroutine TRANS applies only to cylindrical geometry. The remaining geometries can be developed in a manner similar to that for the cylindrical case, but further work must be done on subroutine TRANS.

It is assumed that the density (ρ), specific heat (c), and thermal conductivity (k) are functions of temperature but not of time or spatial location. Also, the heat generation (Q''') is assumed to be constant in the radial direction and a function of time only.

Integrating equation A-1 between radius A and B, we obtain

$$\int_A^B \frac{\partial}{\partial r} \left(r^a k \frac{\partial T}{\partial r} \right) + \int_A^B r^a \left(Q''' - \rho c \frac{\partial T}{\partial t} \right) = 0 \quad (A-2)$$

which, rewritten, becomes

$$r^a k \frac{\partial T}{\partial r} \Big|_A^B + \left[\left(Q''' - \rho c \frac{\partial T}{\partial t} \right) \frac{r^{a+1}}{a+1} \right]_A^B = 0$$

expanding

$$\begin{aligned} B^a \left(k \frac{\partial T}{\partial r} \right)_B - A^a \left(k \frac{\partial T}{\partial r} \right)_A + \frac{B^{a+1}}{a+1} \left(Q''' - \rho c \frac{\partial T}{\partial t} \right)_B \\ - \frac{A^{a+1}}{a+1} \left(Q''' - \rho c \frac{\partial T}{\partial t} \right)_A = 0 \end{aligned} \quad (A-3)$$

Since only temperature (T) is a function of spatial location, the heat generation, density, and specific heat can be evaluated as an average between points A and B.

Thus (A-3) becomes

$$B^a \left(k \frac{\partial T}{\partial r} \right)_B - A^a \left(k \frac{\partial T}{\partial r} \right)_A + \frac{(B^{a+1} - A^{a+1})}{a+1} \cdot \left(Q''' - \rho c \frac{\partial T}{\partial t} \right)_{A,B} = 0 \quad (A-4)$$

Three different forms of equation A-4 can be obtained, depending on the radius A and B.

1. For an ordinary point, r_i , and at time t_n ,

equation A-4 can be written as

$$\begin{aligned} \left(\frac{r_i + r_{i+1}}{2} \right)^a \left[k_{i+1/2} \left(\frac{T_{i+1,n} - T_{i,n}}{r_{i+1} - r_i} \right) \right] - \left(\frac{r_{i-1} + r_i}{2} \right)^a \left[k_{i-1/2} \left(\frac{T_{i,n} - T_{i-1,n}}{r_i - r_{i-1}} \right) \right] \\ + \frac{1}{a+1} \left[\left(\frac{r_i + r_{i+1}}{2} \right)^{a+1} - \left(\frac{r_{i-1} + r_i}{2} \right)^{a+1} \right] \cdot \left[Q'''_i - \rho_i c_i \left(\frac{T_{i,n} - T_{i,n-1}}{t_n - t_{n-1}} \right) \right] = 0 \end{aligned} \quad (A-5)$$

2. For a boundary condition on the left side:

Equation A-4 can be written as

$$\left(A + \frac{\Delta r}{2}\right)^a \left[k_B \left(\frac{T_{i+1,n} - T_{i,n}}{\Delta r} \right) \right] - A^a \left(k \frac{\partial T}{\partial r} \right)_A + \frac{1}{a+1} \left[\left(A + \frac{\Delta r}{2}\right)^{a+1} - A^{a+1} \right] \\ \left[Q_{i+1/4}''' - \rho_{i+1/4} \cdot c_{i+1/4} \left(\frac{T_{i+1,n} - T_{i+1,n-1} + 3T_{i,n} - 3T_{i,n-1}}{4t_n - 4t_{n-1}} \right) \right] = 0 \quad (A-6)$$

with the boundary condition

$$-\left(k \frac{\partial T}{\partial r}\right)_i = h_i (T_{i,n} - T_{i-1,n})$$

3. For a boundary condition on the right side

Equation A-4 can be written as

$$B^a \left(k \frac{\partial T}{\partial r} \right)_B - \left(B - \frac{\Delta r}{2}\right)^a \left[k_A \left(\frac{T_{i,n} - T_{i-1,n}}{\Delta r} \right) \right] + \frac{1}{a+1} \left[B^{a+1} - \left(B - \frac{\Delta r}{2}\right)^{a+1} \right] \\ \cdot \left[Q_{i-1/4}''' - \rho_{i-1/4} \cdot c_{i-1/4} \left(\frac{3T_{i,n} - 3T_{i,n-1} + T_{i-1,n} - T_{i-1,n-1}}{4t_n - 4t_{n-1}} \right) \right] = 0 \quad (A-7)$$

with the boundary condition

$$-\left(k \frac{\partial T}{\partial r}\right)_{i+1} = h_{i+1} (T_{i+1,n} - T_{i,n})$$

Equations A-5, A-6, and A-7 are solved using a matrix and an iterative procedure. These equations can be written for each i point in the following manner:

$$A_i T_{i-1} + B_i T_i + C_i T_{i+1} = D_i \quad (\text{A-8})$$

For m regions in the body, the equation defined by equation A-8 can be rewritten as:

$$\begin{pmatrix} B_1 & C_1 & 0 & \dots & \dots & \dots \\ A_2 & B_2 & C_2 & 0 & \dots & \dots \\ 0 & A_3 & B_3 & C_3 & 0 & \dots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & A_m \quad B_m \end{pmatrix} \begin{pmatrix} T_1 \\ T_2 \\ T_3 \\ \vdots \\ \vdots \\ T_m \end{pmatrix} = \begin{pmatrix} D_1 \\ D_2 \\ D_3 \\ \vdots \\ \vdots \\ D_m \end{pmatrix}$$

Several methods may be used to solve this matrix. Among them, one has Crout reduction, Gaussian elimination, matrix inversion, etc. The method chosen was the Crout reduction scheme.

If the matrix is written in the augmented matrix form:

$$\begin{pmatrix} B_1 & C_1 & 0 & \dots & \dots & \dots & D_1 \\ A_2 & B_2 & C_2 & \dots & \dots & \dots & D_2 \\ 0 & A_3 & B_3 & C_3 & \dots & \dots & D_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & A_m \quad B_m \dots & D_m \end{pmatrix} = [A]$$

By appropriate transformation of the rows and columns of the matrix $[A]$, the following augmented matrix is obtained

$$\begin{pmatrix} 1 & C'_1 & 0 & \dots & \dots & \dots & D'_1 \\ 0 & 1 & C'_2 & 0 & \dots & \dots & D'_2 \\ 0 & 0 & 1 & C'_3 & \dots & \dots & D'_3 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ & & & 1 & C'_{m-1} & \dots & D'_{m-1} \\ & & & & 1 & \dots & D'_m \end{pmatrix} = [A']$$

where

$$\begin{array}{ll}
 C'_1 = C_1/B_1 & D'_1 = -D_1/B_1 \\
 C'_2 = C_2/(B_2 - C'_1 * A_2) & D'_2 = [-D_2 - (D'_1 * A_2)]/(B_2 - C'_1 * A_2) \\
 C'_3 = C_3/(B_3 - C'_2 * A_3) & D'_3 = [-D_3 - (D'_2 * A_3)]/(B_3 - C'_2 * A_3) \\
 \vdots & \vdots \\
 & D'_4 = [-D_4 - (D'_3 * A_4)]/(B_4 - C'_3 * A_4)
 \end{array}$$

From here, the method is identical to the "back solution" of the Gaussian elimination scheme where we determine $T_1, \dots, T_m$. For example:

$$\begin{array}{l}
 T_m = D'_m \\
 T_{m-1} = D'_{m-1} - C'_{m-1} \cdot T_m \\
 T_{m-2} = D'_{m-2} - C'_{m-2} \cdot T_{m-1} \\
 \vdots \\
 \cdot
 \end{array}$$

After obtaining the temperatures at the radial increments, they are compared with the previous (or guessed) solution. If two succeeding temperatures for each radial increment are within some convergence criteria, ϵ , a solution has then been obtained. The ϵ can be any value, but is usually much less than 1.0.

APPENDIX B
Comparison of TRANS (Fuel Pin Heat
Conduction Subroutine) With
Analytical Solutions

The transient conduction calculations of RADAR (the TRANS subroutine) were verified by formulating a representative problem, deriving an analytical solution, and comparing the analytical results to those of RADAR. These comparisons were made while varying each governing parameter of the representative problem.

The representative problem chosen was a step function change of heat generation from 100,000 Btu/h to 200,000 Btu/h. An analytical solution for a fuel pin was possible if constant properties were used, $(\rho C_p)_{\text{fuel}} = (\rho C_p)_{\text{clad}}$, and there was continuity of temperature at the fuel-cladding interface. The representative problem is shown in Figure B-1.

Figure B-1. Representative Problem

	<u>Fuel</u>	<u>Cladding</u>	<u>Coolant</u>
Fuel Rod Centerline	Step function heat source:		
	(initial, $t \leq 0$)		
	$q_i = 100,000 \text{ Btu/h}$		
	(final, $t > 0$)		
	$q_f = 200,000 \text{ Btu/h}$		
	Fuel properties:	Cladding properties:	Coolant properties:
	thermal conductivity	thermal conductivity	temperature
	$k_f = 1.5 \text{ Btu/h-ft-}^\circ\text{F}$	$k_c = 10.5 \text{ Btu/h-ft-}^\circ\text{F}$	$T_{\text{bulk}} = 560\text{F}$
	density	density	film coefficient
	$\rho_f = 640 \text{ lbm/ft}^3$	$\rho_c = 544 \text{ lbm/ft}^3$	$h = 7500 \text{ Btu/h-ft}^2\text{-}^\circ\text{F}$
	specific heat	specific heat	
	$c_f = 0.085 \text{ Btu/lbm-}^\circ\text{F}$	$c_c = 0.1 \text{ Btu/lbm-}^\circ\text{F}$	

The physical boundary conditions of this problem are as follows:

1. The temperature profile is symmetric about the fuel rod centerline.
2. The fuel and cladding temperatures are equal at the fuel-cladding interface.
3. The heat transferred from the fuel is equal to the heat transferred to the cladding, at the fuel-cladding interface.

4. The heat conducted through the cladding at the cladding surface is equal to the heat transferred through the film.

The approximations inherent in this problem are as follows:

1. Axial heat transfer is negligible.
2. The thermal resistance of the fuel-cladding interface is negligible.
3. The film convective heat transfer coefficient is constant.
4. The bulk fluid temperature is constant.
5. The fuel and cladding properties are constant.

RADAR requires only the first approximation.

The analytical solution utilizes the "steady-state method" of Myers,* in which the normalized temperature $u(r, \theta)$ is decomposed into a time-independent portion $\tilde{u}(r)$ and a time-dependent component $v(r, \theta)$. Thus, the $u(r, \theta)$ solutions of inhomogeneous partial differential equations are obtained by combinations of the $\tilde{u}(r)$ solutions of the inhomogeneous ordinary differential equations and the $v(r, \theta)$ solutions of the homogeneous partial differential equations (with homogeneous boundary conditions at the extremes $\bar{r} = 0$ and $\bar{r} = 1$). Figure B-2 shows the nondimensionalized problem.

Figure B-2. Nondimensionalized Problem

*G. E. Myers, Analytical Methods in Conduction Heat Transfer, McGraw-Hill Book Company, New York (1971).

where

$$Q \triangleq \frac{q''' R^2}{k^-} = \frac{q_i}{\pi \rho^2 L k^-} \quad \gamma = \frac{k^-}{k^+}$$

$$\theta \triangleq \frac{a t}{R^2} \quad \kappa^2 = a^+ / a^-$$

$$H \triangleq \frac{h R}{k^+}$$

$$u(\bar{r}, \theta) = T(r, t) - T_{\text{bulk}}$$

$$\bar{r} = \frac{r}{R}$$

and superscript "-" refers to fuel and superscript "+" refers to cladding.

Cylinder function orthogonality over the interval $0 \leq \bar{r} \leq 1$ is obtained for $\kappa^2 = 1/\gamma$; i. e., for $(\rho C)_{\text{clad}} = (\rho C)_{\text{fuel}}$. This is very nearly true for Zircaloy and UO_2 , and in determining the representative problem this condition was imposed. In the fuel region ($0 \leq \bar{r} \leq \rho$), the exact solution for $\theta \geq 0$ is

$$T(\bar{r}, \theta) = u(\bar{r}, \theta) + T_{\text{bulk}}$$

$$u(\bar{r}, \theta) = \tilde{u}(\bar{r}) + v(\bar{r}, \theta)$$

$$\tilde{u}(\bar{r}) = \frac{Q_f \rho^2}{4H} \left\{ H \left[1 - \left(\frac{\bar{r}}{\rho} \right)^2 \right] + 2\gamma \left[1 - H \ln(\rho) \right] \right\}$$

$$v(\bar{r}, \theta) = \sum_{n=1}^{\infty} C_n \phi_n J_0(\kappa \lambda_n \bar{r}) e^{-\lambda_n^2 \theta}.$$

In the cladding region ($\rho \leq \bar{r} \leq 1$), the solution for $\theta \geq 0$ is

$$T(\bar{r}, \theta) = u(\bar{r}, \theta) + T_{\text{bulk}}$$

$$u(\bar{r}, \theta) = \tilde{u}(\bar{r}) + v(\bar{r}, \theta)$$

$$\tilde{u}(\bar{r}) = \frac{Q_f \rho^2 \gamma}{2H} [1 - H \ln(\bar{r})]$$

$$v(\bar{r}, \theta) = \sum_{n=1}^{\infty} C_n [\theta_n J_0(\lambda_n \bar{r}) - \psi_n Y_0(\lambda_n \bar{r})] e^{-\lambda_n^2 \theta}$$

where Q_f , ρ , H , $\bar{r}$, γ , and κ are defined as before, and

$$\phi_n = J_1(\lambda_n \rho) Y_0(\lambda_n \rho) - J_0(\lambda_n \rho) Y_1(\lambda_n \rho)$$

$$\theta_n = \gamma \kappa J_1(\kappa \lambda_n \rho) Y_0(\lambda_n \rho) - J_0(\kappa \lambda_n \rho) Y_1(\lambda_n \rho)$$

$$\psi_n = \gamma \kappa J_1(\kappa \lambda_n \rho) J_0(\lambda_n \rho) - J_0(\kappa \lambda_n \rho) J_1(\lambda_n \rho)$$

$$C_n = \frac{-2\rho\gamma\Delta Q [\theta_n J_1(\lambda_n \rho) - \psi_n Y_1(\lambda_n \rho)]}{\lambda_n^3 \left\{ \rho^2 [\theta_n J_1(\lambda_n \rho) - \psi_n Y_1(\lambda_n \rho)]^2 \left(\frac{1}{\gamma} - 1 \right) + [\theta_n J_0(\lambda_n \rho) - \psi_n Y_0(\lambda_n \rho)]^2 \left(\frac{H^2}{\lambda_n^2} + 1 \right) \right\}}$$

$$n = 1, 2, 3, \dots$$

θ is the nondimensional time, t :

$$\theta = \frac{a^+ t}{R^2} = \left(\frac{\kappa}{\rho c} \right)_{\text{clad}} \frac{t}{R^2}.$$

ΔQ is the heat-source difference,

$$\Delta Q = Q_f - Q_i$$

where eigenvalues λ_n satisfy the (convective) condition

$$\lambda_n [\theta_n J_1(\lambda_n) - \psi_n Y_1(\lambda_n)] = H [\theta_n J_0(\lambda_n) - \psi_n Y_0(\lambda_n)]$$

$$n = 1, 2, 3, \dots$$

and where $J_n(x)$ are Bessel functions of the first kind of order n and $Y_n(x)$ are Bessel functions of the second kind of order n .

The exact solution was encoded by using the first 10 eigenvalues to build the solution and was compared to a RADAR run with two cladding nodes and 15 fuel nodes. The time steps were 0.02 s from 0 to 0.2 s, 0.2 to 1 s, 0.5 to 5 s, 1 to 10 s, 5 to 20 s, and 20-second increments from 20 to 60 s. Each governing parameter of the representative case was separately varied. The analytical solutions are compared with those of RADAR in Table B-1.

Comparisons of the analytical case with the "nominal" RADAR case, which is typical of fuel pin modeling, show good agreement (less than a 20 degree difference between centerline temperature). Additional accuracy can be obtained by increasing the number of nodes or by decreasing the time step.

Table B-1. Comparison of RADAR and Analytical Results

Case description							Maximum percentage RADAR-to-analytical temperature difference							
No.	Parameter	Change increase	Change decrease	From	To	Units	$\% \frac{\Delta T}{T}$ final initial	$\Delta T(^{\circ}F)$	Fuel center- line	Midway in fuel	Fuel-clad interface	Clad surface	Time, s	Notes
1	(Nominal case)						-3.9	-18.8	X				15	1
2	Fuel radius		X	0.185	0.1075	inches	-4.2	-4.1			X		5	
3	Rod radius	X		0.215	0.370	inches	-5.2	-4.9			X		15	
4	Rod height	X		141.0	282.0	inches	-3.9	-9.3	X				15	
5	Initial heat rate	X		10^5	2×10^5	Btu/h	-3.9	-37.6	X				15	
6	Heat rate change	X		X2	X3	--	-3.9	-37.8	X				15	
7	Heat rate change		X	X2	X1/2	--	5.7	0.3				X	15	
8	Fuel conductivity		X	1.5	0.75	Btu/h-ft- $^{\circ}F$	-5.3	-49.2	X				40	
9	Fuel density	X		640.0	1280.0	lbm/ft 3	-5.4	-26.1	X				40	2
10	Fuel heat capacity	X		0.085	0.170	Btu/lbm- $^{\circ}F$	-5.4	-26.1	X				40	2
11	Clad conductivity	X		10.5	21.0	Btu/h-ft- $^{\circ}F$	-3.8	-18.8	X				15	
12	Clad density		X	544.0	272.0	lbm/ft 3	-3.9	-18.8	X				15	2
13	Clad heat capacity		X	0.1	0.05	Btu/lbm- $^{\circ}F$	-3.9	-18.8	X				15	2
14	Film coefficient	X		7500.0	15000.0	Btu/h-ft 2 - $^{\circ}F$	+5.6	0.3				X	0	
15	Fluid temperature		X	560.0	500.0	F	-3.9	-18.8	X				15	
16	Clad conductivity		X	10.5	1.5	Btu/h-ft $^{\circ}F$	-4.0	-24.2	X				15	
17	Eigenvalues	X		10.0	20.0	--	-3.9	-18.8	X				15	3
18	Radial increments	X		2.0	4.0	--	-3.7	-3.5			X		15	4
19	Time increments	X		30.0	60.0	--	-2.4	-11.3	X				5	
20	Time increments		X	30.0	15.0	--	-5.4	-26.0	X				5	

- Notes: 1. The nominal case is that shown in Figure E-1.
2. Cases 2, 10, 12 and 13 compared the results of RADAR to those of the approximate analytical solution. The exact analytical solution did not apply because density and heat capacity of the fuel and clad were being varied independently.
3. Case 17 used 20 eigenvalues to formulate the analytical solution of the nominal case (case 1) with little change of the results. Ten eigenvalues were used in the other analytical solutions.
4. Case 18 is RADAR case 3 rerun with 5 clad nodes vice 3 nodes of case 3. Maximum percentage temperature error decreased from 5.2 to 3.7%.
5. Cases 19 and 20 are the nominal case (case 1) rerun with varied RADAR time increments. The common time steps were 0.02 second increments from time 0 to 0.2 seconds, 0.2 second increments to 1 second, 0.5 to 5, 1 to 10, 5 to 20, and 20 second increments to time 60 seconds. Cases 19 and 20 utilized time steps one-half and twice as long, respectively. Maximum temperature differences at fuel centerline were 5.4, 3.9 and 2.4% for successively finer time increments, cases 20, 1, and 19 respectively. All three cases had 3.1% difference at time zero on the clad surface.

APPENDIX C
Program Flow

Figure C-1. RADAR Flow Chart

APPENDIX D
Sample Case

INPUT

AXIAL NODE DATA

NUMBER OF NODES IS 39

X	AF	HP	FLUX	CONTK
0.	1.77404000E-01	1.35088400E+00	1.00000000E-01	0.
7.48000000E-01	1.77404000E-01	1.35088400E+00	1.20000000E-01	7.79500000E-01
2.18800000E+00	1.77404000E-01	1.35088400E+00	1.50000000E-01	-4.90000000E-02
4.00000000E+00	1.77404000E-01	1.35088400E+00	1.79440000E-01	0.
1.00000000E+01	1.77404000E-01	1.35088400E+00	3.21438070E-01	0.
1.60000000E+01	1.77404000E-01	1.35088400E+00	3.68668840E-01	0.
2.19080000E+01	1.77404000E-01	1.35088400E+00	4.84655890E-01	7.79500000E-01
2.34380000E+01	1.77404000E-01	1.35088400E+00	5.20024230E-01	-4.90000000E-02
2.83000000E+01	1.77404000E-01	1.35088400E+00	6.57178970E-01	0.
3.33430000E+01	1.77404000E-01	1.35088400E+00	8.08838060E-01	0.
3.82960000E+01	1.77404000E-01	1.35088400E+00	9.67863700E-01	0.
4.32480000E+01	1.77404000E-01	1.35088400E+00	1.12249614E+00	7.79500000E-01
4.46880000E+01	1.77404000E-01	1.35088400E+00	1.15574379E+00	-4.90000000E-02
4.95400000E+01	1.77404000E-01	1.35088400E+00	1.30538030E+00	0.
5.45930000E+01	1.77404000E-01	1.35088400E+00	1.42690176E+00	0.
5.95450000E+01	1.77404000E-01	1.35088400E+00	1.52609978E+00	0.
6.44980000E+01	1.77404000E-01	1.35088400E+00	1.60016637E+00	7.79500000E-01
6.59380000E+01	1.77404000E-01	1.35088400E+00	1.61675450E+00	-4.90000000E-02
7.08900000E+01	1.77404000E-01	1.35088400E+00	1.65652114E+00	0.
7.58430000E+01	1.77404000E-01	1.35088400E+00	1.65998763E+00	0.
8.07960000E+01	1.77404000E-01	1.35088400E+00	1.65814457E+00	0.
8.57480000E+01	1.77404000E-01	1.35088400E+00	1.62007119E+00	7.79500000E-01
8.71880000E+01	1.77404000E-01	1.35088400E+00	1.60397605E+00	-4.90000000E-02
9.21400000E+01	1.77404000E-01	1.35088400E+00	1.53156374E+00	0.
9.70930000E+01	1.77404000E-01	1.35088400E+00	1.43398972E+00	0.
1.02046000E+02	1.77404000E-01	1.35088400E+00	1.31367397E+00	-0.
1.06998000E+02	1.77404000E-01	1.35088400E+00	1.17503704E+00	-0.
1.09439000E+02	1.77404000E-01	1.35088400E+00	1.13201010E+00	7.79500000E-01
1.13390000E+02	1.77404000E-01	1.35088400E+00	9.77852890E-01	-4.90000000E-02
1.18343000E+02	1.77404000E-01	1.35088400E+00	8.19795830E-01	0.
1.23296000E+02	1.77404000E-01	1.35088400E+00	6.66510850E-01	0.
1.28248000E+02	1.77404000E-01	1.35088400E+00	5.28048420E-01	7.79500000E-01
1.29688000E+02	1.77404000E-01	1.35088400E+00	4.92159291E-01	-4.90000000E-02
1.35792000E+02	1.77404000E-01	1.35088400E+00	3.71686299E-01	0.
1.41836000E+02	1.77404000E-01	1.35088400E+00	3.21523940E-01	0.
1.48000000E+02	1.77404000E-01	1.35088400E+00	1.56800000E-01	-0.
1.49498000E+02	1.77404000E-01	1.35088400E+00	1.40000000E-01	7.79500000E-01
1.50938000E+02	1.77404000E-01	1.35088400E+00	1.20000000E-01	-4.90000000E-02
1.53126000E+02	1.77404000E-01	1.35088400E+00	1.00000000E-01	0.

[illegible]

AVERAGE CHANNEL DATA

GEOMETRY		SYSTEM	
ACTIVE LENGTH	1.531260E+02 INCHES	ENTERING ENTHALPY	5.560000E+02 BTU/LBM
TUBE FLOW AREA	1.774940E-01 SQ.IN.	MASS FLOW RATE	3.190000E+03 LBM/HR
COLBURN FACTOR	1.280095E+00	SYSTEM PRESSURE	2.135000E+03 PSI
HEATED PERIMETER	1.350884E+00 INCHES		
PIN PITCH	5.680000E-01 INCHES		
WETTED PERIMETER	1.350884E+00 INCHES		

CLAD DATA

NUMBER OF RADIAL INCREMENTS	2	SURFACE ROUGHNESS	6.300000E-05 INCHES
MAX. CLAD TEMPERATURE	1.400000E+03 DEG. F	CLAD TEMPERATURE GUESS	6.000000E+02 DEG. F
DIAMETER OF CLAD	4.300000E-01 INCHES	CONTACT COEFFICIENT BETWEEN FUEL AND CLAD	1.000000E+03 BTU/HR-SQ.FT-DEG.F
DENSITY OF CLAD	4.100000E+02 LBM/CU.FT		
CONDUCTIVITY POLYNOMIAL:			
K = 7.970000E+00 + 3.160000E-03 T + -0.		T2 + -0.	T3
SPECIFIC HEAT POLYNOMIAL:			
CP = 6.880000E-02 + 2.072600E-05 T + -0.		T2 + -0.	T3

FUEL DATA

NUMBER OF RADIAL INCREMENTS	7	DENSITY OF FUEL	6.395000E+02 LBM/CU.FT
MAX. FUEL TEMPERATURE	5.081000E+03 DEG. F	FUEL TEMPERATURE GUESS	2.000000E+03 DEG. F
DIAMETER OF FUEL	3.700000E-01 INCHES	AVERAGE HEAT RATE	2.690705E+05 BTU/HR
PERCENT HEAT GENERATED	9.730000E+01		
CONDUCTIVITY POLYNOMIAL:			
K = 5.155000E+00 + -4.417500E-03 T + 1.974200E-06 T2 + -4.019000E-10 T3 + 3.125600E-14 T4 + -0. T5 + -0. T6			
SPECIFIC HEAT POLYNOMIAL:			
CP = 5.946200E-02 + 1.594000E-05 T + -2.830000E-09 T2 + -0. T3 + -0. T4 + -0. T5 + -0. T6			

AVERAGE CHANNEL FACTORS

USE OLD METHODS

FACTOR ON FILM DROP	1.000000E+00	LOCAL PEAKING FACTOR	1.000000E+00
FACTOR ON ENTHALPY	1.000000E+00	RADIAL PEAKING FACTOR	1.000000E+00
OVERALL FACTOR ON HEAT FLUX	1.000000E+00	BURNOUT SAFETY FACTOR	1.000000E+00
LOCAL FACTOR ON HEAT FLUX	1.000000E+00	DNB RATIO-PIN BLANKETED	1.000000E-01
OVERPOWER	1.080000E+00		

THE TWO FOLLOWING SUBROUTINES WILL BE USED TO FIND THE MINIMUM DNB RATIO

1. WILFR
2. BAW2

Example of Type 2
Printout

TIME = 0.1000 SEC.

X	HT	TP	SURFT	CENTEMP	C2PS	W	QFLPT	DNBR	DNBR
DISTANCE ALONG CHANNEL (IN.)	ENTHALPY (BTU/LB)	BULK COOLANT TEMPERATURE (DEG. F)	CLAD SURFACE TEMPERATURE (DEG. F)	FUEL CENTER TEMPERATURE (DEG. F)	LOCAL HEAT FLUX (BTU/HR-SQ.FT)	CHANNEL FLOWRATE (LB/HR)	TOTAL PRESSURE DROP (PSI)	(BAND)	(WILFR)
.75	555.05	557.05	559.92	555.78	24275.42	3190.00	-0.9841	74.0500	292.9648
2.10	555.17	557.15	560.66	580.49	31344.27	3190.00	-1.0120	60.5568	146.7279
4.70	556.35	557.29	561.55	708.73	36097.54	3190.00	-1.1214	49.7030	96.6306
11.10	557.27	558.01	564.24	794.84	65025.36	3190.00	-1.4134	27.2102	43.0093
15.00	559.53	559.00	567.60	896.76	74579.91	3190.00	-1.8452	22.5969	27.4562
22.00	560.10	561.23	570.85	990.08	98043.53	3190.00	-3.1499	17.3703	20.0176
23.44	561.54	561.57	573.62	1081.12	105198.37	3190.00	-3.1773	16.2439	18.6711
28.30	562.32	561.96	576.75	1190.80	132944.11	3190.00	-3.4754	12.7430	14.8083
33.34	564.54	563.68	582.11	1390.05	163826.30	3190.00	-3.7733	10.2277	11.9104
38.30	567.24	565.76	588.07	1624.78	195794.12	3190.00	-4.0709	8.4403	9.7307
43.25	570.40	568.19	594.40	1881.35	227075.51	3190.00	-5.3232	7.1625	8.0860
44.50	571.41	568.96	598.57	2052.43	235824.30	3190.00	-5.3495	6.8598	7.6867
49.64	575.15	571.80	602.75	2215.47	264072.08	3190.00	-5.6468	6.0170	6.5311
54.50	579.29	574.92	609.10	2454.00	288655.28	3190.00	-5.9442	5.3951	5.6419
59.55	583.76	578.26	615.15	2659.51	308722.56	3190.00	-6.2418	4.9358	4.9509
64.50	588.49	581.75	620.77	2823.09	323705.87	3190.00	-7.5159	4.5990	4.4084
65.94	589.91	582.79	624.17	2909.54	327061.57	3190.00	-7.5410	4.5167	4.2728
70.89	594.86	586.40	627.18	2964.70	335106.17	3190.00	-7.8392	4.3021	3.8705
75.84	599.90	590.02	631.40	3018.97	337830.37	3190.00	-8.1380	4.1574	3.5484
80.80	604.94	593.59	634.94	3025.98	335434.58	3190.00	-8.4373	4.0752	3.2890
85.75	609.90	597.06	637.74	2985.76	327732.52	3190.00	-9.7417	4.0546	3.0796
87.10	611.32	598.05	639.22	2939.70	324476.55	3190.00	-9.7657	4.0582	3.0266
92.14	615.07	601.32	640.15	2862.18	309827.49	3190.00	-10.0664	4.1273	2.8694
97.10	620.56	604.36	641.04	2712.12	290068.91	3190.00	-10.3678	4.2743	2.7422
102.05	624.72	607.15	641.09	2510.22	265749.85	3190.00	-10.6697	4.5191	2.6435
107.00	628.48	609.65	640.35	2291.55	237704.28	3190.00	-12.0037	4.8897	2.5684
108.44	629.50	610.32	639.57	2134.30	229000.13	3190.00	-12.0267	5.0249	2.5505
113.30	632.69	612.40	638.39	1967.06	197814.88	3190.00	-12.3296	5.6257	2.5014
118.34	635.42	614.16	636.28	1713.36	165840.71	3190.00	-12.6328	6.4843	2.4698
123.30	637.67	615.61	633.88	1477.69	134831.90	3190.00	-12.9362	7.7094	2.4533
128.25	639.48	616.76	631.43	1274.98	106821.63	3190.00	-14.2887	9.4399	2.4496
129.69	639.92	617.05	629.92	1162.52	99561.43	3190.00	-14.3109	10.0703	2.4506
135.70	641.54	618.07	628.57	1067.09	75190.33	3190.00	-14.6849	13.1594	2.4624
141.90	642.83	618.88	627.31	968.80	65042.73	3190.00	-15.0590	16.0698	2.4816
148.00	643.72	619.44	625.25	852.30	31719.88	3190.00	-15.4330	24.3526	2.5106
149.50	643.86	619.53	623.26	759.90	28321.32	3190.00	-16.5812	28.3690	2.5198
150.94	643.97	619.60	622.87	741.84	24275.42	3190.00	-16.6129	32.6934	2.5290
153.17	644.12	619.69	622.45	722.45	20229.51	3190.00	-16.7369	40.3208	2.5437

FLUX/FLOW = 1.0000

TIME = .1000 SEC.

X	HI	TR	SURFT	CENTEMP	Q2PS	W	DELPT	DNBR	DNBR
DISTANCE ALONG CHANNEL (IN.)	ENTHALPY (BTU/LB)	BULK COOLANT TEMPERATURE (DEG. F)	CLAD SURFACE TEMPERATURE (DEG. F)	FUEL CENTER TEMPERATURE (DEG. F)	LOCAL HEAT FLUX (BTU/HR-SQ.FT)	CHANNEL FLOWRATE (LB/HR)	TOTAL PRESSURE DROP (PSI)	(RAW2)	(WILFR)
.75	556.05	557.05	559.96	656.78	24192.82	3110.25	-9.9366	73.8772	280.4871
2.19	556.17	557.15	560.68	680.49	30286.83	3110.25	-9.9551	60.3267	145.7572
4.30	556.36	557.30	561.56	708.73	36055.42	3110.25	-1.0717	49.4584	95.6626
10.00	557.31	558.04	564.07	794.84	65562.02	3110.25	-1.4243	26.9344	42.3629
16.00	558.62	559.07	567.39	896.76	75147.95	3110.25	-1.7766	22.2888	26.9767
22.00	560.23	560.32	570.61	990.08	98730.12	3110.25	-3.0256	17.1383	19.6543
23.44	560.68	560.68	573.77	1081.12	104795.53	3110.25	-3.0536	16.1212	18.3407
28.39	562.52	562.11	576.56	1190.80	133505.25	3110.25	-3.3439	12.6197	14.5667
33.34	564.81	563.89	581.88	1390.05	164481.08	3110.25	-3.6341	10.1173	11.7165
38.30	567.58	566.02	587.81	1624.78	196527.14	3110.25	-3.9239	8.3492	9.5732
43.25	570.83	568.52	594.12	1881.35	227859.37	3110.25	-5.1218	7.0951	7.9561
44.69	571.86	569.30	598.99	2052.43	234715.85	3110.25	-5.1487	6.8125	7.5655
49.64	575.71	572.23	602.45	2215.47	264882.48	3110.25	-5.4383	5.9603	6.4334
54.59	579.97	575.43	608.81	2454.00	289431.03	3110.25	-5.7278	5.3360	5.5576
59.55	584.56	578.85	614.90	2659.51	309422.40	3110.25	-6.0175	4.8812	4.8771
64.50	589.43	582.44	620.55	2823.09	324290.53	3110.25	-7.2367	4.5475	4.3432
65.94	590.87	583.49	624.93	2909.54	325057.89	3110.25	-7.2625	4.4802	4.2106
70.80	595.96	587.19	627.03	2964.70	335508.73	3110.25	-7.5528	4.2615	3.8165
75.84	601.13	590.89	631.32	3018.97	338048.97	3110.25	-7.8436	4.1098	3.4992
80.80	606.30	594.55	634.94	3025.98	335449.18	3110.25	-8.1350	4.0277	3.2439
85.75	611.38	598.09	637.82	2985.76	327529.23	3110.25	-9.3437	4.0068	3.0379
97.19	612.83	599.09	640.24	2939.70	321791.18	3110.25	-9.4084	4.0197	2.9861
92.14	617.69	602.42	640.34	2862.18	309346.97	3110.25	-9.7010	4.0878	2.9313
97.00	622.28	605.52	641.32	2712.12	289361.53	3110.25	-9.9343	4.2245	2.7074
102.05	626.53	608.36	641.46	2519.22	264821.40	3110.25	-10.2480	4.4661	2.6104
107.00	630.38	610.80	640.81	2291.56	236566.46	3110.25	-11.5657	4.8337	2.5368
108.44	631.41	611.57	640.69	2134.30	226118.72	3110.25	-11.5393	4.9769	2.5195
113.39	634.66	613.68	638.95	1967.06	196442.89	3110.25	-11.8840	5.5806	2.4721
118.34	637.43	615.46	636.92	1713.36	164307.36	3110.25	-12.1789	6.4255	2.4414
123.30	639.71	616.91	634.59	1477.69	133164.86	3110.25	-12.4739	7.6504	2.4258
128.25	641.53	618.06	632.20	1274.98	105045.25	3110.25	-13.7294	9.3932	2.4228
129.60	641.98	618.35	630.98	1162.52	96894.07	3110.25	-13.7922	10.0480	2.4241
135.79	643.59	619.36	629.33	1067.09	77495.08	3110.25	-14.1558	13.2095	2.4369
141.90	644.88	620.17	628.10	968.80	63117.29	3110.25	-14.5195	16.1994	2.4567
148.00	645.76	620.71	626.10	852.30	50279.38	3110.25	-14.8330	24.6909	2.4862
149.50	645.88	620.70	624.24	759.00	35925.89	3110.25	-15.9797	29.0020	2.4956
150.34	645.99	620.86	623.84	741.84	21946.27	3110.25	-16.0120	33.8731	2.5050
153.13	646.12	620.94	623.39	722.45	17981.60	3110.25	-16.1123	42.6976	2.5200

FLUX/FLOW = 4.0256

TIME = .2000 SEC.

X	HI	T9	SURFT	CENTEMP	Q2PS	W	DELPT	DNBR	DNBR
DISTANCE ALONG CHANNEL (IN.)	ENTHALPY (BTU/LB)	CLLK COOLANT TEMPERATURE (DEG. F)	CLAD SURFACE TEMPERATURE (DEG. F)	FUEL CENTER TEMPERATURE (DEG. F)	LOCAL HEAT FLUX (BTU/HR-SQ.FT)	CHANNEL FLOWRATE (LB/HR)	TOTAL PRESSURE DROP (PSI)	(BAW2)	(WILFR)
.75	556.05	557.05	560.01	656.78	24107.19	3030.50	-0.8903	73.7040	277.9812
2.10	556.18	557.15	560.74	680.49	30153.76	3030.50	-0.9194	60.1865	144.1068
4.00	556.37	557.30	561.64	708.73	35879.41	3030.50	-1.0232	49.3670	94.8784
10.00	557.33	558.06	564.15	794.84	64918.59	3030.50	-1.3667	26.9134	42.1316
16.00	558.66	559.10	567.51	896.76	74414.55	3030.50	-1.7098	22.3721	26.8669
22.00	560.30	560.39	570.78	990.08	97770.38	3030.50	-2.9042	17.1972	19.5843
23.44	560.76	560.75	574.05	1081.12	104338.70	3030.50	-2.9329	16.1286	18.2719
28.30	562.63	562.20	576.81	1190.80	132365.98	3030.50	-3.2157	12.6383	14.5037
33.34	564.96	564.00	582.21	1390.05	163075.62	3030.50	-3.4982	10.1372	11.6671
38.30	567.78	566.18	588.22	1624.78	194846.98	3030.50	-3.7805	8.3647	9.5334
43.25	571.09	568.72	594.62	1881.35	225911.61	3030.50	-4.9250	7.0970	7.9234
44.69	572.14	569.52	599.68	2052.43	233661.42	3030.50	-4.9527	6.8100	7.5335
49.64	576.06	572.49	603.07	2215.47	262606.64	3030.50	-5.2346	5.9644	6.4042
54.59	580.39	575.75	609.52	2454.00	286947.77	3030.50	-5.5165	5.3422	5.5330
59.55	585.07	579.23	615.69	2659.51	306771.62	3030.50	-5.7985	4.9854	4.8560
64.50	590.01	582.87	621.43	2823.09	321516.53	3030.50	-6.9636	4.5498	4.3247
65.94	591.49	583.95	626.04	2909.54	323554.58	3030.50	-6.9901	4.4747	4.1923
70.80	596.67	587.70	628.00	2964.70	332626.25	3030.50	-7.2726	4.2573	3.7992
75.84	601.93	591.46	632.36	3018.97	335146.19	3030.50	-7.5556	4.1079	3.4836
80.80	607.19	595.17	636.03	3025.98	332567.73	3030.50	-7.8391	4.0241	3.2296
85.75	612.36	598.77	638.96	2985.76	324711.30	3030.50	-9.0328	4.0013	3.0247
87.10	613.84	599.79	641.58	2939.70	320216.59	3030.50	-9.0581	4.0088	2.9730
92.14	618.78	603.16	641.52	2962.18	306556.95	3030.50	-9.3428	4.0748	2.8186
97.09	623.46	606.31	642.51	2712.12	296825.18	3030.50	-9.6280	4.2134	2.6953
102.05	627.78	609.10	642.66	2519.22	262471.02	3030.50	-9.9137	4.4527	2.5990
107.00	631.69	611.75	642.00	2291.56	234427.18	3030.50	-11.1353	4.8170	2.5258
108.44	632.74	612.43	641.98	2134.30	224839.54	3030.50	-11.1596	4.9550	2.5085
113.70	636.05	614.57	640.12	1967.06	194589.86	3030.50	-11.4460	5.5518	2.4612
118.34	638.86	616.37	638.05	1713.36	162688.20	3030.50	-11.7327	6.3972	2.4309
123.30	641.17	617.84	635.69	1477.69	131768.86	3030.50	-12.0194	7.6173	2.4154
128.25	643.03	619.01	633.26	1274.98	103848.12	3030.50	-13.2582	9.3543	2.4126
129.60	643.48	619.20	632.06	1162.52	95042.16	3030.50	-13.2817	10.0018	2.4139
135.79	645.12	620.31	630.33	1067.09	72435.00	3030.50	-13.6350	13.1626	2.4267
141.00	646.42	621.12	629.08	968.80	62096.84	3030.50	-13.9884	16.1975	2.4468
148.00	647.29	621.67	627.05	852.30	29667.81	3030.50	-14.3416	24.6975	2.4763
149.50	647.42	621.75	625.18	759.90	25303.76	3030.50	-15.3971	29.0255	2.4857
150.04	647.53	621.81	624.77	741.84	21347.58	3030.50	-15.4101	33.9461	2.4952
153.13	647.66	621.80	624.31	722.45	17386.87	3030.50	-15.5366	42.8414	2.5102

FLUX/FLOW = 1.0526

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Babcock & Wilcox

TIME = .3000 SEC.

X	HI	TS	SURFT	CENTEMP	QZPS	W	DELOT	DNBR	JNBR
DISTANCE ALONG CHANNEL (IN.)	ENTHALPY (BTU/LB)	PULK COOLANT TEMPERATURE (DEG. F)	CLAD SURFACE TEMPERATURE (DEG. F)	FUEL CENTER TEMPERATURE (DEG. F)	LOCAL HEAT FLUX (BTU/HR-SQ.FT)	CHANNEL FLOWRATE (LB/HR)	TOTAL PRESSURE DROP (PSI)	(BAWP)	(WILFP)
.75	556.05	557.06	560.07	656.78	24054.76	2950.75	-8.4451	73.4189	275.0290
2.10	556.18	557.16	560.81	680.49	30078.96	2950.75	-8.9749	59.9332	142.5935
4.70	556.38	557.31	561.72	708.73	35783.37	2950.75	-9.9760	49.1642	93.9964
10.00	557.36	558.30	564.28	794.84	46634.70	2950.75	-1.3105	26.9473	41.7357
16.00	558.72	559.15	567.70	906.76	74078.39	2950.75	-1.6447	22.3324	26.6284
22.00	560.47	560.46	571.02	990.08	97315.53	2950.75	-2.7860	17.1638	19.4154
23.44	560.87	561.83	574.38	1081.12	104029.55	2950.75	-2.8153	16.0418	18.1136
28.30	562.78	562.32	577.17	1190.80	131792.11	2950.75	-3.0906	12.6049	14.3764
33.34	565.16	564.15	582.66	1390.05	162361.39	2950.75	-3.3658	10.1114	11.5657
38.70	568.05	566.28	588.73	1624.79	193984.45	2950.75	-3.6407	8.3422	9.4512
43.25	571.42	569.98	595.30	1881.35	224899.95	2950.75	-4.2333	7.0767	7.8556
44.69	572.51	569.80	600.51	2052.43	232915.46	2950.75	-4.2616	6.7858	7.4688
49.64	576.51	572.83	603.91	2215.47	261409.61	2950.75	-5.0360	5.9441	6.3488
54.59	580.94	576.16	610.48	2454.00	285620.37	2950.75	-5.3105	5.3237	5.4856
59.55	585.72	579.71	616.76	2659.51	305329.45	2950.75	-5.5850	4.8669	4.8147
64.50	590.78	583.42	622.60	2823.09	319978.13	2950.75	-6.6375	4.5308	4.2882
69.94	592.29	584.53	627.36	2909.54	322402.40	2950.75	-6.7246	4.4533	4.1569
70.99	597.58	588.35	629.30	2964.70	330992.26	2950.75	-6.9496	4.2359	3.7670
75.84	602.95	592.19	633.73	3018.97	333462.63	2950.75	-7.2750	4.0865	3.4544
80.90	608.33	595.97	637.47	3025.98	330855.31	2950.75	-7.5508	4.0013	3.2028
85.75	613.61	599.63	640.44	2985.76	322991.94	2950.75	-8.6910	3.9765	2.9997
87.10	615.12	600.67	643.16	2939.70	318878.73	2950.75	-8.7169	3.9819	2.9485
92.14	620.17	604.11	643.04	2862.18	304960.71	2950.75	-8.9338	4.0453	2.7954
97.30	624.94	607.31	644.05	2712.12	285172.24	2950.75	-9.2712	4.1821	2.6734
102.95	629.36	610.23	644.19	2519.22	260881.05	2950.75	-9.5490	4.4174	2.5780
107.10	633.35	612.82	643.50	2291.56	232916.92	2950.75	-10.7164	4.7767	2.5056
108.44	634.42	613.52	643.51	2134.30	223583.35	2950.75	-10.7413	4.9118	2.4884
113.30	637.80	615.69	641.58	1967.06	193200.11	2950.75	-11.0197	5.5009	2.4417
118.34	640.66	617.51	639.47	1713.36	161400.28	2950.75	-11.2983	6.3392	2.4118
123.30	643.12	619.00	637.05	1477.69	130582.77	2950.75	-11.5770	7.5491	2.3967
128.25	644.90	620.18	634.57	1274.90	102754.71	2950.75	-12.7610	9.2750	2.3942
129.69	645.36	620.47	633.36	1162.52	95012.19	2950.75	-12.7850	9.9184	2.3955
135.70	647.02	621.40	631.57	1067.09	71427.15	2950.75	-13.1284	13.0764	2.4036
141.90	648.33	622.30	630.29	968.80	61063.17	2950.75	-13.4716	16.1477	2.4288
148.00	649.21	622.85	628.21	952.30	28986.38	2950.75	-13.9148	24.6359	2.4585
149.50	649.34	622.93	626.30	759.90	24427.42	2950.75	-14.8109	29.0021	2.4679
150.94	649.44	622.90	625.99	741.84	20497.91	2950.75	-14.8344	34.0348	2.4774
153.13	649.57	623.07	625.42	722.45	16553.01	2950.75	-14.9573	43.2263	2.4924

FLUX/FLOW = 1.0911

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Babcock & Wilcox

TIME (SEC.)	TOTAL PRESSURE DROP (PSI)	CHANNEL FLOWRATE (LB/HR)	SMALLEST DNB RATIO (BAW2)	LEVEL OF DNB RATIO (IN.)	SMALLEST DNB RATIO (WILFR)	LEVEL OF DNB RATIO (IN.)	FLUX/FLOW RATIO
0.0000	-16.7369	3190.0000	4.0546	85.7480	2.4496	128.2480	1.0000
.1000	-16.1323	3110.2500	4.9068	85.7480	2.4229	128.2480	1.0256
.2000	-15.5366	3030.5000	4.0013	85.7480	2.4126	128.2480	1.0526
.3000	-14.9573	2950.7500	3.9765	85.7480	2.3942	128.2480	1.0811

Example of Type 1
Printout

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = .748IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
6.57886616E+02	6.56513440E+02	6.52405600E+02	6.45599015E+02	6.36103408E+02	6.24010588E+02	
6.12383486E+02	5.22702942E+02	5.66172257E+02	5.62957157E+02	5.53963756E+02	5.57032826E+02	
CENTEMP= 6.57886616E+02	SUPTEMP= 5.59963756E+02	BULKTMP= 5.57032826E+02	FLUXR = 2.24305661E+04			
SUMMP = -2.49957322E-02	SUMPA = -1.39992874E-04	SUMPH = -2.00510776E-02	SUMPC = -3.38954911E-01			
DNBR = 7.37162771E+01	DNBR2 = 7.22756920E+01	DNBRI = 0.	DNBRW = 2.7705619E+02			
DNBR3 = 7.17425531E+01	DNUT = 7.39083480E+06	W = 3.19000700E+03	U = 7.67352786E+03			
	HT = 5.5605046E+02	DELPT = -9.84132775E-01				

TIME = 1.000SEC.

DISTANCE DOWN CHANNEL = 2.188IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
6.81870734E+02	6.80155652E+02	6.75127860E+02	6.66515497E+02	6.54696481E+02	6.39657263E+02	
6.21510956E+02	6.20301081E+02	5.64313013E+02	5.64364570E+02	5.60697035E+02	5.57100101E+02	
CENTEMP= 6.81870734E+02	SUPTEMP= 5.60637035E+02	BULKTMP= 5.57100101E+02	FLUXR = 2.76020584E+04			
SUMMP = -7.70170290E-02	SUMPA = -4.70897951E-04	SUMPH = -5.96483102E-02	SUMPC = -8.79872431E-01			
DNBR = 5.86270171E+01	DNBR2 = 5.91055916E+01	DNBRI = 0.	DNBRW = 1.46337858E+02			
DNBR3 = 5.73598177E+01	DNUT = 4.16147007E+06	W = 3.19000000E+03	U = 7.67377399E+03			
	HT = 5.56170977E+02	DELPT = -1.01200956E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 4.000IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
7.10443976E+02	7.08312189E+02	7.01937413E+02	6.91380903E+02	6.76743072E+02	6.58161029E+02	
6.35805231E+02	6.09875360E+02	5.70854173E+02	5.66054399E+02	5.61594917E+02	5.57219696E+02	
CENTEMP= 7.10443976E+02	SUPTEMP= 5.61594917E+02	BULKTMP= 5.57219696E+02	FLUXR = 3.35763705E+04			
SUMMP = -1.33745485E-01	SUMPA = -9.77696860E-04	SUMPH = -1.07208052E-01	SUMPC = -8.79872431E-01			
DNBR = 4.92495058E+01	DNBR2 = 4.95117136E+01	DNBRI = 0.	DNBRW = 9.45956097E+01			
DNBR3 = 4.81715577E+01	DNUT = 5.06220809E+06	W = 3.19000000E+03	U = 7.67421148E+03			
	HT = 5.56354851E+02	DELPT = -1.12140367E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 10.000IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
7.97600718E+02	7.94140604E+02	7.83812082E+02	7.66770698E+02	7.43269069E+02	7.13647842E+02	
6.78223266E+02	6.37772127E+02	5.78382784E+02	5.71092462E+02	5.64313753E+02	5.57656152E+02	
CENTEMP= 7.97600718E+02	SUPTEMP= 5.64313753E+02	BULKTMP= 5.57656152E+02	FLUXR = 5.11024580E+04			
SUMMP = -3.32193553E-01	SUMPA = -3.53803765E-03	SUMPH = -2.67999666E-01	SUMPC = -8.79872431E-01			
DNBR = 2.72452788E+01	DNBR2 = 2.65572945E+01	DNBRI = 0.	DNBRW = 4.21035639E+01			
DNBR3 = 2.65147704E+01	DNUT = 7.70456343E+06	W = 3.19000000E+03	U = 7.67580702E+03			
	HT = 5.57291573E+02	DELPT = -1.48339369E+00				

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 16.000IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
2.118288865E+02	8.45688646E+02	8.91378267E+02	8.55223672E+02	8.21750711E+02	7.77659891E+02
7.26790110E+02	6.60084342E+02	5.87994356E+02	5.77053484E+02	5.6709282E+02	5.59521913E+02
CENTEMP= 9.09828886E+02					
SUMP= -5.20782167E-01		SUMP= 5.5779282E+02		BULKTEMP= 5.58521913E+02	
DNBP= 2.36437335E+01		DNBP= -7.88979559E-02		SUMPH= -4.28387895E-01	
DNBP3= 2.37528895E+01		DNBP= 2.29534589E+01		DNBPI= 0.	
		DNBP= 1.06365387E+07		W= 3.19000000E+03	
		HT= 5.59560947E+02		DELPT= -1.84513229E+00	
				FLUXR= 7.05495230E+04	
				SUMPCE= -8.79872431E-01	
				DNBRW= 2.68779467E+01	
				U= 7.67968883E+03	

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 21.998IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
9.95410974E+02	8.38635270E+02	8.68490592E+02	8.35515119E+02	8.91572302E+02	8.34802455E+02
7.60554471E+02	6.96394608E+02	5.84923395E+02	5.82534006E+02	5.71996143E+02	5.59641893E+02
CENTEMP= 9.95410974E+02					
SUMP= -7.26618451E-01		SUMP= 5.70996143E+02		BULKTEMP= 5.59641893E+02	
DNBP= 1.79788714E+01		SUMPH= -1.15077425E-02		SUMPH= -5.88558282E-01	
DNBP3= 1.73229154E+01		DNBP= 1.69517272E+01		DNBPI= 0.	
		DNBP= 1.31521963E+07		W= 3.19000000E+03	
		HT= 5.60142378E+02		DELPT= -3.14994285E+00	
				FLUXR= 8.72352556E+04	
				SUMPCE= -1.82325837E+00	
				DNBRW= 1.95959939E+01	
				U= 7.68305295E+03	

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 23.438IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.18774586E+03	1.17928158E+03	1.05415886E+03	1.01317170E+03	9.57592824E+02	8.89092545E+02
8.93624670E+02	7.21288936E+02	6.01924343E+02	5.87365472E+02	5.73797832E+02	5.60434693E+02
CENTEMP= 1.08774586E+03					
SUMP= -7.73695972E-01		SUMP= 5.73797832E+02		BULKTEMP= 5.60434693E+02	
DNBP= 1.65349667E+01		SUMPH= -1.27621710E-02		SUMPH= -6.26966913E-01	
DNBP3= 1.61723717E+01		DNBP= 1.58522583E+01		DNBPI= 0.	
		DNBP= 1.54850196E+07		W= 3.19000000E+03	
		HT= 5.60593391E+02		DELPT= -3.1728952E+00	
				FLUXR= 1.02708294E+05	
				SUMPCE= -1.76387447E+00	
				DNBRW= 1.82779024E+01	
				U= 7.68594038E+03	

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 28.390IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.19904242E+03	1.18840270E+03	1.15702281E+03	1.10595165E+03	1.03703420E+03	9.52853164E+02
8.56176740E+02	7.40722254E+02	6.09959508E+02	5.92837208E+02	5.7961833E+02	5.61310471E+02
CENTEMP= 1.19904242E+03					
SUMP= -9.34776613E-01		SUMP= 5.76961833E+02		BULKTEMP= 5.61310471E+02	
DNBP= 1.30762169E+01		SUMPH= -1.78417057E-02		SUMPH= -7.58877500E-01	
DNBP3= 1.26774536E+01		DNBP= 1.24740601E+01		DNBPI= 0.	
		DNBP= 1.81440981E+07		W= 3.19000000E+03	
		HT= 5.62320590E+02		DELPT= -3.47577029E+00	
				FLUXR= 1.20345302E+05	
				SUMPCE= -1.76387447E+00	
				DNBRW= 1.44964394E+01	
				U= 7.68912658E+03	

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 33.343 IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.40135417E+02	1.38663684E+03	1.34312880E+03	1.27274785E+03	1.17861473E+03	1.06485265E+03
9.35219075E+02	7.27579872E+02	6.23245943E+02	5.02109614E+02	5.82372541E+02	5.62882476E+02
CENTEMP= 1.40135417E+02	SURTEMP= 5.82372541E+02	BULKTEMP= 5.62882476E+02	FLUXR = 1.49972925E+05		
SUMFP = -1.09464715E+02	SUMPA = -2.42300851E-02	SUMPH = -8.90503452E-01	SUMPC = -1.76387447E+00		
DNBP = 1.05126345E+01	DNBP2 = 9.97958345E+00	DNBPI = 0.	DNBRW = 1.16595750E+01		
DNBP3 = 1.01663352E+01	DNUT = 2.26109654E+07	W = 3.19000000E+02	U = 7.69483954E+03		
	HT = 5.64635677E+02	DELPT = -3.77325515E+00			

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 38.295 IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.63076962E+03	1.61999589E+03	1.56159068E+03	1.46735400E+03	1.34202954E+03	1.19212101E+03
1.02523022E+03	8.48071061E+02	6.37766477E+02	5.12254265E+02	5.88399210E+02	5.64802920E+02
CENTEMP= 1.63076962E+03	SURTEMP= 5.88399210E+02	BULKTEMP= 5.64802920E+02	FLUXR = 1.81734177E+05		
SUMFP = -1.25322675E+02	SUMPA = -3.20576431E-02	SUMPH = -1.02174558E+00	SUMPC = -1.76387447E+00		
DNBP = 8.71079794E+00	DNBP2 = 8.23467649E+00	DNBPI = 0.	DNBRW = 9.52581402E+00		
DNBP3 = 9.38494423E+00	DNUT = 2.73995136E+07	W = 3.19000000E+03	U = 7.70181152E+03		
	HT = 5.67356228E+02	DELPT = -4.07090375E+00			

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 43.248 IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.90027717E+02	1.87498692E+03	1.80020122E+03	1.67939176E+03	1.51888667E+03	1.32802987E+03
1.118226163E+03	9.01007274E+02	6.52649515E+02	5.22770843E+02	5.94795981E+02	5.67079363E+02
CENTEMP= 1.90027717E+02	SURTEMP= 5.94795981E+02	BULKTEMP= 5.67079363E+02	FLUXR = 2.13697164E+05		
SUMFP = -1.41054094E+02	SUMPA = -4.13833740E-02	SUMPH = -1.15250116E+00	SUMPC = -2.71890561E+00		
DNBP = 7.41829058E+00	DNBP2 = 5.98709328E+00	DNBPI = 0.	DNBRW = 7.91575566E+00		
DNBP3 = 7.10554430E+00	DNUT = 3.22184767E+07	W = 3.19000000E+03	U = 7.71007339E+03		
	HT = 5.70554617E+02	DELPT = -5.32334009E+00			

TIME = 0.000500.

DISTANCE DOWN CHANNEL = 44.688 IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
2.07385724E+03	2.04501673E+03	1.95957402E+03	1.82119971E+03	1.63697009E+03	1.41808359E+03
1.17893020E+03	9.34064366E+02	6.62203937E+02	5.29581332E+02	5.93012110E+02	5.68694780E+02
CENTEMP= 2.07385724E+03	SURTEMP= 5.99012110E+02	BULKTEMP= 5.68694780E+02	FLUXR = 2.33926415E+05		
SUMFP = -1.45672776E+02	SUMPA = -4.43905248E-02	SUMPH = -1.19042810E+00	SUMPC = -2.65974631E+00		
DNBP = 7.11477195E+00	DNBP2 = 5.69154746E+00	DNBPI = 0.	DNBRW = 7.52483639E+00		
DNBP3 = 6.80532097E+00	DNUT = 3.52683799E+07	W = 3.19000000E+03	U = 7.71593060E+03		
	HT = 5.71572725E+02	DELPT = -5.34964270E+00			

TIME = 3.000000.

DISTANCE DOWN CHANNEL = 49.649IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.23417821E+02	2.20734250E+02	2.11182685E+03	1.05779338E+03	1.75030911E+03	1.50429113E+03	
1.23640471E+03	2.64918784E+02	6.71730317E+02	6.26187659E+02	6.03232116E+02	5.70519899E+02	
CFNTMP= 2.23417821E+02	SUPTMP= 6.03232116E+02	BULKTMP= 5.70519899E+02	FLUXR = 2.52622635E+05			
SUMFP = -1.61297677E+00	SUMPA = -5.56334255E-02	SUMPH = -1.32047737E+00	SUMPC = -2.55874631E+00			
DNBP = 5.25362047E+00	DNBP2 = 5.86842309E+00	DNBPI = 0.	DNBRW = 6.39351172E+00			
DNBP3 = 5.25371201E+00	QOUT = 3.89871525E+07	W = 3.19000000E+03	U = 7.72257774E+03			
	HI = 5.75353799E+02	DELPT = -5.64693313E+00				

TIME = 4.000000.

DISTANCE DOWN CHANNEL = 54.593IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.48070312E+02	2.44413303E+02	2.33532917E+03	2.15751238E+03	1.31819581E+03	1.63194545E+03	
1.32096354E+02	1.09937591E+03	6.84708975E+02	6.45997618E+02	6.09549037E+02	5.73531055E+02	
CFNTMP= 2.48070312E+02	SUPTMP= 6.09549037E+02	BULKTMP= 5.73531055E+02	FLUXR = 2.79320774E+05			
SUMFP = -1.76733519E+00	SUMPA = -6.93086791E-02	SUMPH = -1.44992310E+00	SUMPC = -2.65874631E+00			
DNBP = 5.63137139E+00	DNBP2 = 5.26989057E+00	DNBPI = 0.	DNBRW = 5.52310446E+00			
DNBP3 = 5.32087578E+00	QOUT = 4.21123504E+07	W = 3.19000000E+03	U = 7.73356745E+03			
	HI = 5.73535126E+02	DELPT = -5.94431328E+00				

TIME = 5.000000.

DISTANCE DOWN CHANNEL = 59.546IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.68864177E+03	2.64845104E+03	2.52860264E+03	2.33186510E+03	2.06526178E+03	1.74416013E+03	
1.79477177E+02	1.04749871E+03	6.96659513E+02	6.54953447E+02	6.15766659E+02	5.76791401E+02	
CFNTMP= 2.68864177E+03	SUPTMP= 6.15766659E+02	BULKTMP= 5.76791401E+02	FLUXR = 3.01884892E+05			
SUMFP = -1.92212853E+00	SUMPA = -8.22893286E-02	SUMPH = -1.57867452E+00	SUMPC = -2.65874631E+00			
DNBP = 5.16917338E+00	DNBP2 = 4.81204081E+00	DNBPI = 0.	DNBRW = 4.84659419E+00			
DNBP3 = 4.84934566E+00	QOUT = 4.55142744E+07	W = 3.19000000E+03	U = 7.74555216E+03			
	HI = 5.84054327E+02	DELPT = -6.24183869E+00				

TIME = 6.000000.

DISTANCE DOWN CHANNEL = 64.498IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.85404940E+03	2.81110218E+02	2.68286586E+03	2.47171664E+03	2.19406638E+03	1.83536965E+03	
1.45475254E+02	1.07828698E+02	7.06861721E+02	6.62833063E+02	6.21435844E+02	5.80241980E+02	
CFNTMP= 2.85404940E+03	SUPTMP= 6.21435844E+02	BULKTMP= 5.80241980E+02	FLUXR = 3.19597706E+05			
SUMFP = -2.07575253E+00	SUMPA = -9.74176873E-02	SUMPH = -1.70665026E+00	SUMPC = -3.63561903E+00			
DNBP = 4.83284530E+00	DNBP2 = 4.48254107E+00	DNBPI = 0.	DNBRW = 4.31553687E+00			
DNBP3 = 4.83891277E+00	QOUT = 4.81847820E+07	W = 3.19000000E+03	U = 7.75938135E+03			
	HI = 5.88827722E+02	DELPT = -7.51649545E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 65.939IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.34144119E+02	2.80707772E+03	2.76453514E+03	2.54599467E+03	2.2+749714E+03	1.89434797E+03	
1.49703930E+02	1.10484370E+03	7.12648940E+02	6.67416636E+02	6.2+872970E+02	5.82531301E+02	
CFNTEMP= 2.34144119E+02	SUPTEMP= 6.24972970E+02	BULKTMP= 5.82531301E+02	FLUXR = 3.28865324E+05			
SUMFP = -2.12173455E+00	SUMPA = -1.12012699E-01	SUMPH = -1.74371792E+00	SUMPCF = -3.57404638E+00			
DNAP = 4.75451390E+00	DNAP2 = 4.40203634E+00	DNAP1 = 0.	DNAPW = 4.18286112E+00			
DNAP3 = 4.61560597E+00	DNUT = 4.95820328E+07	W = 3.19000000E+03	U = 7.76094289E+03			
	HT = 5.91269128E+02	DELPT = -7.54151166E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 70.890IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.99718494E+02	2.90104573E+03	2.81674605E+03	2.59364393E+03	2.29843026E+03	1.91623277E+03	
1.57830629E+02	1.10609832E+03	7.17118107E+02	6.71152168E+02	6.27909364E+02	5.84875852E+02	
CFNTEMP= 2.99718494E+02	SUPTEMP= 6.27909364E+02	BULKTMP= 5.84875852E+02	FLUXR = 3.34026464E+05			
SUMFP = -2.27668944E+00	SUMPA = -1.8345217E-01	SUMPH = -1.87066119E+00	SUMPCF = -3.57404638E+00			
DNAP = 4.54220598E+00	DNAP2 = 4.19173393E+00	DNAP1 = 0.	DNAPW = 3.78899198E+00			
DNAP3 = 4.18340367E+00	DNUT = 5.04506225E+07	W = 3.19000000E+03	U = 7.77595069E+03			
	HT = 5.95277358E+02	DELPT = -7.83974223E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 75.843IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
3.05201499E+02	3.00595128E+03	2.96824735E+03	2.64084484E+03	2.32927630E+03	1.94842070E+03	
1.53016240E+02	1.11791166E+03	7.22696938E+02	6.76059484E+02	6.32176895E+02	5.88523292E+02	
CFNTEMP= 3.05201499E+02	SUPTEMP= 6.32176895E+02	BULKTMP= 5.88523292E+02	FLUXR = 3.40068479E+05			
SUMFP = -2.43222222E+00	SUMPA = -1.52839907E-01	SUMPH = -1.99679510E+00	SUMPCF = -3.57404638E+00			
DNAP = 4.43653510E+00	DNAP2 = 4.04949872E+00	DNAP1 = 0.	DNAPW = 3.47366328E+00			
DNAP3 = 4.02342206E+00	DNUT = 5.12710986E+07	W = 3.19000000E+03	U = 7.79015830E+03			
	HT = 6.11368165E+02	DELPT = -9.13853106E+00				

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL = 80.796IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
3.05007470E+02	3.01297732E+03	2.97516775E+03	2.64756531E+03	2.33564391E+03	1.95417228E+03	
1.53497194E+02	1.12161965E+03	7.26212052E+02	6.79602899E+02	6.35748009E+02	5.92154725E+02	
CFNTEMP= 3.05007470E+02	SUPTEMP= 6.35748009E+02	BULKTMP= 5.92154725E+02	FLUXR = 3.40234442E+05			
SUMFP = -2.58922811E+00	SUMPA = -1.52839907E-01	SUMPH = -2.12207698E+00	SUMPCF = -3.57404638E+00			
DNAP = 4.33833125E+00	DNAP2 = 3.96820333E+00	DNAP1 = 0.	DNAPW = 3.21976384E+00			
DNAP3 = 3.22527574E+00	DNUT = 5.12961203E+07	W = 3.19000000E+03	U = 7.80674436E+03			
	HT = 6.15461456E+02	DELPT = -8.43789128E+00				

TIME = 0.000550.

DISTANCE DOWN CHANNEL = 85.749IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
3.01840182E+02	2.47305925E+02	2.83753205E+02	2.61780886E+02	2.30750108E+02	1.93341911E+03
1.52266717E+02	1.11702571E+02	2.27618566E+02	6.81733636E+02	6.33570112E+02	5.95712090E+02
CFNTTMP= 3.01840182E+02	SURFTMP= 6.78570112E+02	BULKTMP= 5.95712090E+02	FLUXR = 3.35131492E+05		
SUMFP = -2.74678678E+00	SUMPA = -1.70502276E-01	SUMPH = -2.24647703E+00	SUMPC = -4.57940665E+00		
DNBR = 4.33275589E+00	DNBR2 = 3.94669858E+00	DNBR1 = 0.	DNBRW = 3.01479019E+00		
DNBR3 = 3.89209885E+00	DNUT = 5.05267640E+07	W = 3.19000000E+02	U = 7.81957441E+03		
	HT = 6.10477344E+02	DELPT = -9.74317295E+00			

TIME = 0.000550.

DISTANCE DOWN CHANNEL = 87.188IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
2.97183122E+02	2.2271486E+02	2.79428944E+02	2.57482983E+02	2.27471717E+02	1.97882403E+03
1.59747251E+02	1.1065860E+02	2.27617097E+02	6.82495676E+02	6.4060334E+02	5.97962150E+02
CFNTTMP= 2.97183122E+02	SURFTMP= 6.4060334E+02	BULKTMP= 5.97962150E+02	FLUXR = 3.29593852E+05		
SUMFP = -2.73227276E+00	SUMPA = -1.75639735E-01	SUMPH = -2.28249178E+00	SUMPC = -4.51602840E+00		
DNBR = 4.35426434E+00	DNBR2 = 3.94977410E+00	DNBR1 = 0.	DNBRW = 2.96289279E+00		
DNBR3 = 3.89431222E+00	DNUT = 4.36918708E+07	W = 3.19000000E+02	U = 7.82315912E+03		
	HT = 6.11911821E+02	DELPT = -9.76713368E+00			

TIME = 0.000550.

DISTANCE DOWN CHANNEL = 92.140IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
2.89345025E+02	2.85029651E+02	2.72140281E+02	2.50899959E+02	2.21915791E+02	1.86682210E+03
1.48099814E+02	1.05868487E+02	2.26158730E+02	6.82264505E+02	6.40998752E+02	6.00106753E+02
CFNTTMP= 2.89345025E+02	SURFTMP= 6.40998752E+02	BULKTMP= 6.00106753E+02	FLUXR = 3.20545749E+05		
SUMFP = -2.95294720E+00	SUMPA = -1.93110078E-01	SUMPH = -2.40580297E+00	SUMPC = -4.51602840E+00		
DNBR = 4.45842180E+00	DNBR2 = 4.01548956E+00	DNBR1 = 0.	DNBRW = 2.80796187E+00		
DNBR3 = 3.95278887E+00	DNUT = 4.83277155E+07	W = 3.19000000E+02	U = 7.83883784E+03		
	HT = 6.16709405E+02	DELPT = -1.00678887E+01			

TIME = 0.000550.

DISTANCE DOWN CHANNEL = 97.093IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
2.74169362E+02	2.70113834E+02	2.59037688E+02	2.38177866E+02	2.1198243E+02	1.78581936E+03
1.42955292E+02	1.07478750E+02	2.22468918E+02	6.80923329E+02	6.41893285E+02	6.03292227E+02
CFNTTMP= 2.74169362E+02	SURFTMP= 6.41893285E+02	BULKTMP= 6.03292227E+02	FLUXR = 3.03157850E+05		
SUMFP = -3.11492048E+00	SUMPA = -2.10060842E-01	SUMPH = -2.52832577E+00	SUMPC = -4.51602840E+00		
DNBR = 4.65235345E+00	DNBR2 = 4.15683864E+00	DNBR1 = 0.	DNBRW = 2.68448769E+00		
DNBR3 = 4.09548117E+00	DNUT = 4.57061345E+07	W = 3.19000000E+02	U = 7.85361504E+03		
	HT = 6.21247652E+02	DELPT = -1.03693355E+01			

TIME = 0.000000.

DISTANCE DOWN CHANNEL =100.046IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.54651424E+03	2.50251357E+03	2.39773281E+03	2.21891298E+03	1.97529049E+03	1.68262380E+03	
1.36747465E+03	1.14700011E+03	7.16658496E+02	6.78117897E+02	6.41935911E+02	6.06236578E+02	
CFNTMP= 2.54651424E+03	SJTEMP= 6.41935911E+02	BULKMP= 6.06236578E+02	FLUXR = 2.80883012E+05			
SUMMP = -3.27217681E+03	SUMPA = -2.26152895E+01	SUMPH = -2.65037783E+00	SUMPC = -4.51502840E+00			
QNGP = 4.04139545E+03	QNGP2 = 4.29303810E+00	QNGP1 = 0.	QNGPW = 2.58780588E+00			
QNGP3 = 4.34724784E+00	QNGT = 4.23478844E+07	W = 3.19000000E+03	U = 7.96802090E+03			
	HT = 6.25452466E+02	DELPT = -1.06713659E+01				

TIME = 0.000000.

DISTANCE DOWN CHANNEL =106.999IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.31522712E+03	2.24322051E+03	2.18623318E+03	2.02805334E+03	1.81589573E+03	1.56239938E+03	
1.28557067E+03	1.0463117E+03	7.09953240E+02	6.73975738E+02	6.41180923E+02	6.0901399E+02	
CFNTMP= 2.31522712E+03	SJTEMP= 6.41180923E+02	BULKMP= 6.08901399E+02	FLUXR = 2.54420543E+05			
SUMMP = -3.4456117E+00	SUMPA = -2.41062232E+01	SUMPH = -2.77109195E+00	SUMPC = -5.54889217E+00			
QNGP = 5.46430371E+00	QNGP2 = 4.75107356E+00	QNGP1 = 0.	QNGPW = 2.51426244E+00			
QNGP3 = 4.72821280E+00	QNGT = 3.83582177E+07	W = 3.19000000E+03	U = 7.88179369E+03			
	HT = 6.29260360E+02	DELPT = -1.20067066E+01				

TIME = 0.000000.

DISTANCE DOWN CHANNEL =108.439IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
2.15662863E+03	2.12707962E+03	2.03944147E+03	1.89712707E+03	1.70695245E+03	1.48015621E+03	
1.23175267E+03	0.77771120E+03	7.03276251E+02	6.70807251E+02	6.43387347E+02	6.10496355E+02	
CFNTMP= 2.15662863E+03	SJTEMP= 6.40387347E+02	BULKMP= 6.10496355E+02	FLUXR = 2.35849073E+05			
SUMMP = -3.49466692E+00	SUMPA = -2.45138082E+01	SUMPH = -2.80615445E+00	SUMPC = -5.48380958E+00			
QNGP = 5.46430371E+00	QNGP2 = 4.88179644E+00	QNGP1 = 1.	QNGPW = 2.49675096E+00			
QNGP3 = 4.87215419E+00	QNGT = 3.55582533E+07	W = 3.19000000E+03	U = 7.89030612E+03			
	HT = 6.31296835E+02	DELPT = -1.20296680E+01				

TIME = 0.000000.

DISTANCE DOWN CHANNEL =113.390IN.

STEADY STATE CALCULATIONS

		TEMPERATURES (DEGREES F)				
1.99701235E+03	1.96091874E+03	1.88365655E+03	1.75854269E+03	1.59179828E+03	1.39294263E+03	
1.1740673E+03	0.47444568E+03	6.95776686E+02	6.6703227E+02	6.39193569E+02	6.11884668E+02	
CFNTMP= 1.99701235E+03	SJTEMP= 6.39193569E+02	BULKMP= 6.11884668E+02	FLUXR = 2.15690968E+05			
SUMMP = -3.66437209E+00	SUMPA = -2.58117691E+01	SUMPH = -2.92634774E+00	SUMPC = -5.48380958E+00			
QNGP = 5.42426325E+00	QNGP2 = 5.46280112E+00	QNGP1 = 0.	QNGPW = 2.44876260E+00			
QNGP3 = 5.51125070E+00	QNGT = 3.25190765E+07	W = 3.19000000E+03	U = 7.89819290E+03			
	HT = 6.33515066E+02	DELPT = -1.23326542E+01				

TIME = 0.000000.

DISTANCE DOWN CHANNEL = 118.343IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.72949290E+07	1.73893860E+03	1.84777546E+03	1.54908813E+03	1.41760058E+03	1.26010492E+03
1.98473860E+02	9.00702770E+02	6.86218334E+02	5.60211433E+02	6.37058476E+02	6.13823964E+02

CFNTEMP= 1.72949290E+07	SUPTEMP= 6.37058476E+02	BULKTEMP= 6.13823964E+02	FLUXR = 1.83773351E+05
SUMFP = -3.83676430E+00	SUMPA = -2.69378230E-01	SUMPH = -3.04601991E+00	SUMPCE = -5.48380958E+00
DNBP = 7.55474178E+00	DNBP2 = 6.29324630E+00	DNBPI = 0.	DNBPH = 2.41778986E+00
DNBP3 = 6.44345516E+00	DNBT = 2.77069538E+07	W = 3.19000000E+03	U = 7.90949921E+03
	HT = 6.36266143E+02	DELPT = -1.26359720E+01	

TIME = 0.000000.

DISTANCE DOWN CHANNEL = 123.236IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.49014038E+07	1.47459497E+03	1.42961769E+03	1.35419375E+03	1.25459866E+03	1.13423329E+03
0.98242521E+02	9.51941307E+02	6.75356691E+02	6.54292837E+02	6.34625989E+02	6.15439480E+02

CFNTEMP= 1.49014038E+07	SUPTEMP= 6.34625989E+02	BULKTEMP= 6.15439480E+02	FLUXR = 1.51944903E+05
SUMFP = -4.91158577E+00	SUMPA = -2.78831949E-01	SUMPH = -3.16522992E+00	SUMPCE = -5.48380958E+00
DNBP = 2.18137918E+00	DNBP2 = 7.47839331E+00	DNBPI = 0.	DNBPH = 2.40163094E+00
DNBP3 = 2.79337160E+00	DNBT = 2.29082746E+07	W = 3.19000000E+03	U = 7.91936143E+03
	HT = 6.38540750E+02	DELPT = -1.29344572E+01	

TIME = 0.000000.

DISTANCE DOWN CHANNEL = 128.248IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.28430262E+07	1.27301505E+03	1.23956980E+03	1.18520352E+03	1.11191512E+03	1.02234531E+03
9.19578021E+02	9.06977337E+02	6.64954600E+02	6.47989862E+02	6.32152469E+02	6.16748262E+02

CFNTEMP= 1.28430262E+07	SUPTEMP= 6.32152469E+02	BULKTEMP= 6.16748262E+02	FLUXR = 1.22119610E+05
SUMFP = -4.18859354E+00	SUMPA = -2.86525362E-01	SUMPH = -3.28403608E+00	SUMPCE = -6.53439436E+00
DNBP = 1.14764878E+01	DNBP2 = 9.15230649E+00	DNBPI = 0.	DNBPH = 2.39802097E+00
DNBP3 = 2.78337321E+00	DNBT = 1.84116052E+07	W = 3.19000000E+03	U = 7.92767884E+03
	HT = 6.40368505E+02	DELPT = -1.42935493E+01	

TIME = 0.000000.

DISTANCE DOWN CHANNEL = 129.688IN.

STEADY STATE CALCULATIONS

TEMPERATURES (DEGREES F)					
1.17014910E+07	1.16111097E+03	1.13428745E+03	1.09053905E+03	1.03125060E+03	9.58250238E+02
8.73687455E+02	7.70278521E+02	6.58670031E+02	6.44151589E+02	6.30620954E+02	6.17472877E+02

CFNTEMP= 1.17014910E+07	SUPTEMP= 6.30620954E+02	BULKTEMP= 6.17472877E+02	FLUXR = 1.04295677E+05
SUMFP = -4.24045137E+00	SUMPA = -2.88440757E-01	SUMPH = -3.31852222E+00	SUMPCE = -6.46824960E+00
DNBP = 1.22834262E+01	DNBP2 = 9.76212872E+00	DNBPI = 0.	DNBPH = 2.39302361E+00
DNBP3 = 1.03757640E+01	DNBT = 1.57247446E+07	W = 3.19000000E+03	U = 7.93239007E+03
	HT = 6.40392247E+02	DELPT = -1.43156727E+01	

TIME = 0.000SEC.

DISTANCE DOWN CHANNEL =135.792IN.

STEADY STATE CALCULATIONS

1.07334121E+02	1.06612657E+02	1.04468040E+02	1.00968641E+02	9.61784748E+02	9.02521171E+02
8.33274111E+02	7.55665184E+02	6.53333713E+02	6.40722009E+02	6.23257239E+02	6.13133587E+02
CFNTMP= 1.07334121E+02	SURTEMP= 6.29257293E+02	BULKTMP= 6.18130587E+02	FLUXR = 8.83108004E+04		
SUMF= -4.46171537E+00	SUMPA = -2.95402053E-01	SUMPH = -3.46446515E+00	SUMPC = -5.46324960E+00		
QNR= 1.61224712E+01	QNR2 = 1.27525843E+01	QNR3I = 0.	QNRW = 2.41756410E+00		
QNR3 = 1.35737385E+01	QOUT = 1.33147530E+07	W = 3.19000010E+03	U = 7.93682789E+03		
	HT = 6.42451649E+02	DELPT = -1.46898321E+01			

TIME = 0.003SEC.

DISTANCE DOWN CHANNEL =141.896IN.

STEADY STATE CALCULATIONS

9.73685651E+02	9.68258246E+02	9.52094590E+02	9.25545124E+02	8.81176356E+02	8.43744436E+02
7.99158718E+02	7.29437116E+02	6.47078432E+02	6.37183837E+02	6.27976724E+02	6.19054982E+02
CFNTMP= 9.73685651E+02	SURTEMP= 6.2976724E+02	BULKTMP= 6.19054982E+02	FLUXR = 7.08667749E+04		
SUMF= -4.68468933E+00	SUMPA = -3.91033833E-01	SUMPH = -3.61006978E+00	SUMPC = -6.46324960E+00		
QNR= 1.85957745E+01	QNR2 = 1.55800441E+01	QNR3I = 0.	QNRW = 2.42935942E+00		
QNR3 = 1.55324381E+01	QOUT = 1.06843699E+07	W = 3.19000010E+03	U = 7.94315423E+03		
	HT = 6.43759051E+02	DELPT = -1.50640411E+01			

TIME = 0.009SEC.

DISTANCE DOWN CHANNEL =148.000IN.

STEADY STATE CALCULATIONS

8.55643737E+02	8.52190823E+02	8.41882899E+02	8.24870771E+02	8.01400708E+02	7.71605205E+02
7.36491926E+02	6.95929819E+02	6.39101262E+02	6.32259919E+02	6.25899836E+02	6.19747481E+02
CFNTMP= 8.55643737E+02	SURTEMP= 6.25899836E+02	BULKTMP= 6.19747481E+02	FLUXR = 4.88389826E+04		
SUMF= -4.90957785E+00	SUMPA = -3.04946721E-01	SUMPH = -3.75541608E+00	SUMPC = -6.46324960E+00		
QNR= 3.77500322E+01	QNR2 = 2.35519289E+01	QNR3I = 0.	QNRW = 2.45767952E+00		
QNR3 = 3.16332324E+01	QOUT = 7.37235209E+06	W = 3.19000010E+03	U = 7.94801068E+03		
	HT = 6.44661175E+02	DELPT = -1.54381903E+01			

TIME = 0.013SEC.

DISTANCE DOWN CHANNEL =149.498IN.

STEADY STATE CALCULATIONS

7.62029234E+02	7.51096767E+02	7.54106893E+02	7.44182798E+02	7.33411662E+02	7.12912848E+02
6.91835284E+02	6.67354215E+02	6.22092102E+02	6.27839352E+02	6.23888890E+02	6.20072463E+02
CFNTMP= 7.62029234E+02	SURTEMP= 6.23888890E+02	BULKTMP= 6.20072463E+02	FLUXR = 3.03341818E+04		
SUMF= -4.96513224E+00	SUMPA = -3.05544641E-01	SUMPH = -3.79105651E+00	SUMPC = -7.52624787E+00		
QNR= 4.22532629E+01	QNR2 = 2.74148420E+01	QNR3I = 0.	QNRW = 2.46571188E+00		
QNR3 = 3.53895135E+01	QOUT = 4.5745440E+06	W = 3.19000010E+03	U = 7.95132081E+03		
	HT = 6.44799743E+02	DELPT = -1.65879813E+01			

TIME = .111SEC.

DISTANCE DOWN CHANNEL = 150.93IN.

STEADY STATE CALCULATIONS

7.43825128E+02	7.47104369E+02	7.36915590E+02	7.28328731E+02	7.15399552E+02	7.01218329E+02
6.82898118E+02	6.61572581E+02	6.39682590E+02	6.26955780E+02	6.23494429E+02	6.20151437E+02
CENTEMP= 7.43825128E+02	SUPTEMP= 6.23494429E+02	BULKTMP= 6.20151437E+02	FLUXR = 2.65797599E+04		
SUMFP = -5.81861293E+00	SUMPA = -7.96048591E-01	SUMPH = -3.82531005E+00	SUMPCE = -7.45367153E+00		
DNBP = 4.92711715E+01	DNBP2 = 3.15791957E+01	DNBPI = 0.	DNBRW = 2.47576583E+00		
DNBP3 = 4.12499322E+01	DNOUT = 4.00735021E+06	W = 3.19000000E+03	U = 7.95088872E+03		
	HT = 6.44914231E+02	DELPT = -1.66096422E+01			

TIME = .0.000SEC.

DISTANCE DOWN CHANNEL = 153.126IN.

STEADY STATE CALCULATIONS

7.24205861E+02	7.22762634E+02	7.18442348E+02	7.11273034E+02	7.01300894E+02	6.88589547E+02
6.73218084E+02	6.55284264E+02	6.2914579E+02	6.25991872E+02	6.23062388E+02	6.20233914E+02
CENTEMP= 7.24205861E+02	SUPTEMP= 6.23062388E+02	BULKTMP= 6.20233914E+02	FLUXR = 2.24905661E+04		
SUMFP = -3.93998531E+00	SUMPA = -7.06597015E-01	SUMPH = -3.87734536E+00	SUMPCE = -7.45367153E+00		
DNBP = 5.97771129E+01	DNBP2 = 3.89321917E+01	DNBPI = 0.	DNBRW = 2.49912641E+00		
DNBP3 = 4.94431717E+01	DNOUT = 3.29082489E+06	W = 3.19000000E+03	U = 7.95148359E+03		
	HT = 6.45062962E+02	DELPT = -1.67436992E+01			

TIME = .100SEC.

DISTANCE DOWN CHANNEL = .748IN.

TRANSIENT CALCULATIONS

6.57885617E+02	6.56513443E+02	6.52405607E+02	6.45588043E+02	6.36103509E+02	6.24010970E+02
6.02384959E+02	5.92315585E+02	5.66191308E+02	5.62975885E+02	5.59994074E+02	5.57012818E+02
CENTEMP= 6.57885617E+02	SUPTEMP= 5.59994074E+02	BULKTMP= 5.57012818E+02	FLUXR = 2.24127446E+04		
SUMFP = -2.38054941E-02	SUMPA = -1.35982386E-04	SUMPH = -2.00510545E-02	SUMPCE = -3.92087166E-01		
DNBP = 7.31434338E+01	DNBP2 = 7.21066097E+01	DNBPI = 0.	DNBRW = 2.74558296E+02		
DNBP3 = 7.08985352E+01	DNOUT = 3.39083480E+06	W = 3.10936480E+03	U = 7.51788583E+03		
	HT = 5.56051384E+02	DELPT = -9.36079707E-01			

TIME = .100SEC.

DISTANCE DOWN CHANNEL = 2.188IN.

TRANSIENT CALCULATIONS

6.81870736E+02	6.80155655E+02	6.75723875E+02	6.66515515E+02	6.54695549E+02	6.39657524E+02
6.21511269E+02	6.02315585E+02	5.68326195E+02	5.64381297E+02	5.61718013E+02	5.57053731E+02
CENTEMP= 6.81870736E+02	SUPTEMP= 5.60718013E+02	BULKTMP= 5.57053731E+02	FLUXR = 2.75481953E+04		
SUMFP = -6.95649257E-02	SUMPA = -4.57886672E-04	SUMPH = -5.86481835E-02	SUMPCE = -3.35953591E-01		
DNBP = 5.83037231E+01	DNBP2 = 5.8880770E+01	DNBPI = 0.	DNBRW = 1.42284741E+02		
DNBP3 = .65317927E+01	DNOUT = 4.16147207E+06	W = 3.10936480E+03	U = 7.51803249E+03		
	HT = 5.56174990E+02	DELPT = -2.64624486E-01			