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SIMULATION OF COOLANT
TRANSPORT AND HEAT
EXCHANGE IN PIPE RUNS

HANFORD ENGINEERING DEVELOPMENT LABORATORY
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by

H. G. Johnson

May, 1975

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ABSTRACT

Pipe runs for sodium coolant systems are satisfactorily simulated by simplified models with no more than 24 axial by 3 radial nodes, consisting of coolant, pipe wall and ambient nodal points. Heat losses from the insulated pipe to its surroundings are included by a constant heat transfer resistance from the pipe's outside surface to the ambient. The best accuracy for simplified models is obtained by simulating the $\partial T/\partial X$ derivative by three-point difference approximations. An explicit numerical integration method is used with these simplified models.

The simplified models are checked against detailed 48 axial by 5 or 8 radial node reference models, which use a four-point Adams-Moulton predictor-corrector numerical integration method.

A generalized computer program, which is based on the selected simplified model, has been written for incorporation as a subroutine in reactor/heat transport system simulation codes.

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INTRODUCTION

All reactor system simulation models necessarily must include piping models. During the design stage of a project, it is sometimes acceptable to allow for coolant transport only, disregarding heating/cooling effects entirely. But for analyzing system process performance for normal perturbations and various upset events, it is necessary that heat exchange between the coolant, pipe wall, insulation and surroundings be also accounted for, otherwise significant inaccuracies may occur for process control and plant protection trips which are temperature-dependent.

This study was carried out to develop a simplified pipe model for accurate heat transfer and coolant transport simulation. The developed model could be used to replace the pipe model, which is based on coolant transport only, in an existing reactor/heat transport system program.⁽⁴⁾

SUMMARY

A relatively simple model is developed for simulation of heat transfer and coolant transport for insulated piping runs between components. Satisfactory accuracy is obtained using only 3 radial nodes and no more than 24 axial nodes. Coolant, pipe wall and a constant temperature ambient node are the three radial nodal points. The model uses an explicit numerical integration scheme, with variable time steps depending on limiting values for numerical stability. The $\partial T / \partial X$ derivatives in the coolant heat balance equations are best approximated by a three-point difference formula.

The selected simplified model includes constant heat transfer resistance from the pipe's outer surface to the ambient nodal point, which is at constant temperature with distance, but not necessarily time. The model works equally well with or without a gas gap between the pipe and insulation. For sodium piping systems at high temperatures, the gas gap resistance is unimportant because of the high radiation heat transfer across the gap such that the insulation's inside surface temperature is nearly equal to the pipe's outside surface. On the other hand, for low temperature systems, the gas gap may be treated as having a heat transfer resistance equal to insulation of the same dimensional characteristics. These simplifications are practical because the

coolant and pipe wall temperatures are quite insensitive to what is happening on the outside of the pipe during transients.

As a rough rule of thumb, the number of axial nodes should be about equal to the coolant transport time at the design flow rate of the coolant in the pipe. Thus, only a few axial nodes are needed for short pipe runs.

The simplified models are checked against a detailed 48 axial by 5 radial node reference model, which uses an implicit, four-point, predictor/corrector numerical integration method. The five radial nodes are coolant, pipe wall, insulation, insulation surface and ambient. This five-node model gives coolant and pipe wall temperatures which agree within 0.5°F of corresponding temperatures using a more complex eight-radial node model. The three additional nodes are pipe outside surface, gas gap, and insulation inside surface. Because sodium systems at high temperatures are investigated, the gas gap resistance to heat transfer is neglected in the five radial node reference model.

The outlet coolant temperatures by the selected simplified explicit solution model, for a variety of transients and piping systems, differ from the reference by no more than 5°F at any given time; the simplified model's temperatures also lead or lag the reference by no more than five seconds for any given temperature. The selected simplified model is judged to be satisfactory on the basis of these small differences.

The selected simplified model is used in the development of a generalized computer program for simulation of heat transfer and coolant transport. It has been written as a subroutine for incorporation in an overall reactor/heat transport system simulation code.⁽⁴⁾ The subroutine is programmed for positive or negative flow rates in any pipe run between components. It is to be used only for insulated pipes, which may or may not contain a gas gap between the pipe and insulation. Pipe runs between components may be divided into as many as four connecting and continuous legs, each with its own ambient temperature and dimensional data. This subdivision of pipe runs provides for good utilization of computer memory, which might otherwise be wasted.

PIPE MODEL SELECTION

The objective of this study is to develop a simplified, yet accurate, pipe model for proper simulation of heat exchange and coolant transport. Because of the large number of individual pipe runs between components in the heat transport system, it is essential that the number of axial and radial nodes in any computer model be minimized to avoid an unacceptable burden on the computer's memory locations and to enable realistic computational times.

Reference Model for Comparison

A prerequisite to model selection is the development of a detailed reference model for comparison purposes. The selected reference model, which includes 48 axial and 5 radial nodes, is set up for an implicit solution of the set of ordinary differential equations using a fourth order Adams-Moulton predictor-corrector routine⁽¹⁾ for numerical integration. Preliminary computer runs were made considering 6, 12, 24, and finally 48 axial nodes, with all other parameters fixed. Significant differences were observed between the 6-, 12- and 24-node models, but the 24-node model was seen to be essentially identical to the one with 48 nodes, which means that 48 axial nodes is certainly sufficient for the reference model. The tolerance on the truncation error is set very small for the reference cases to eliminate numerical errors as far as practicable; the maximum allowable absolute difference between the predicted and corrected temperatures is only 0.01°F.

The radial nodal points are coolant, pipe wall, insulation, insulation surface, and ambient.

The basic heat balance equations are given in equations (1) through (4) wherein axial heat conduction and mixing are neglected, and a constant ambient temperature with distance is assumed. The flow rate is constant with distance for the nearly incompressible liquid sodium coolant.

$$(V\rho C)_{cj} \dot{T}_{cj} = -(WC)_{cj} \frac{\partial T_{cj}}{\partial x} - (UA')_{c/pj} (T_{cj} - T_{pj}) \quad (1)$$

$$(V\rho C)_{pj} \dot{T}_{pj} = (UA')_{c/pj} (T_{cj} - T_{pj}) - (UA')_{p/ij} (T_{pj} - T_{ij}) \quad (2)$$

$$(V\rho C)_{ij} \dot{T}_{ij} = (UA')_{p/ij} (T_{pj} - T_{ij}) - (UA')_{i/sj} (T_{ij} - T_{sj}) \quad (3)$$

$$0 = (UA')_{i/su} (T_{ij} - T_{sj}) - (UA')_{s/aj} (T_{sj} - T_a) \quad (4)$$

where

A' = unit heat transfer area, sq ft/ft

C = specific heat, Btu/lb-°F

T = temperature, °F

U = overall heat transfer coefficient, Btu/(sec-sq ft-°F)

V' = unit volume, cu ft/ft

W = coolant flow rate, lb/sec

ρ = density, lb/cu ft

and subscripts,

a = ambient

c = coolant

c/p = coolant to pipe

i = insulation

i/s = insulation to surface

j = axial nodal location

p = pipe

p/i = pipe to insulation

s = surface

s/a = surface to ambient.

The partial derivative $\partial T_c / \partial x$ is approximated by three-point formula alternating between central and backward differences as recommended in reference (2):

for even numbered nodal points,

$$\frac{\partial T_{cj}}{\partial x} = \frac{T_{cj+1} - T_{cj-1}}{2\Delta X} \quad (5)$$

and for odd numbered nodal points,

$$\frac{\partial T_{cj}}{\partial X} = \frac{3T_{cj} - 4T_{cj-1} + T_{cj-2}}{2\Delta X}$$

where

ΔX = node length, ft.

Model convention is that flow is positive in the direction of increasing axial nodal point numbers.

Sketch of Reference Model

An even number of nodes is a requirement in order that the last node, JEND, is odd and therefore consistent with the use of the backward difference formula for uneven-numbered nodal points.

Physical properties and heat transfer coefficients are determined using local temperatures, instead of being based on average axial temperatures.

A modified Lyon's equation is used for the coolant film coefficient

$$Nu_c = 5.0 + 0.025(\bar{\psi}Pe_c)^{0.8} \quad (7)$$

$$= \frac{h_c D_i}{K_c} \quad (8)$$

where

Nu = Nusselt number

Pe = Peclet number

$\bar{\psi}$ = average value of ratio of diffusivity for heat transfer
to diffusivity for momentum transfer

D_i = pipe inside diameter, ft

h_c = film coefficient, Btu/(sec-sq ft-°F)

K_c = coolant thermal conductivity, Btu/(sec-ft-°F).

The $\bar{\psi}$ corrector term is evaluated as a function of Reynolds number by the method of Dwyer. ⁽³⁾

The overall heat transfer coefficients are as follows:

$$\frac{1}{U_{c/p}} = \frac{1}{h_c} + \frac{D_i}{2K_p} \ln \frac{D_p}{D_i} \quad (9)$$

$$\frac{1}{U_{p/i}} = \frac{D_o}{2K_p} \ln \frac{D_o}{D_p} + \frac{D_o}{2K_i} \ln \frac{D_{in}}{D_o} \quad (10)$$

$$U_{i/s} = \frac{K_i}{\frac{D_s}{2} \ln \frac{D_s}{D_{in}}} \quad (11)$$

$$U_{s/a} = h_{sc} + h_{sr} \quad (12)$$

where

- D_i = pipe inside diameter, ft
- D_{in} = diameter at centerline of insulation, ft
- D_o = pipe outside diameter, ft
- D_p = diameter at centerline of pipe wall, ft
- D_s = insulation outside diameter, ft
- h_{sc} = convection heat transfer coefficient at insulation surface, Btu/(sec-sq ft-°F)
- h_{sr} = equivalent radiation heat transfer coefficient from insulation surface, Btu/(sec-sq ft-°F)
- K = thermal conductivity, Btu/(sec-ft-°F)

The insulation surface coefficients are temperature dependent:

$$h_{sc} = 0.27(T_{sj} - T_a)^{0.25} \quad (13)$$

$$h_{sr} = \frac{0.173 \times 10^{-8} \mathfrak{F} \left[(460 + T_{sj})^4 - (460 + T_a)^4 \right]}{T_{sj} - T_a} \quad (14)$$

A value of 0.4236 is used for the overall interchange factor for the two surfaces.

A gas gap may be found between the pipe outside surface and insulation in some installations. The heat accumulation term can be ignored for the gas, and its effect on overall heat transfer allowed for in the overall coefficients. In this case, equations (2) and (3) can be replaced by:

$$(V\rho C)_{pj} \dot{T}_{pj} = (UA')_{c/pj} (T_{cj} - T_{pj}) - (UA')^*_{p/ij} (T_{pj} - T_{ij}) \quad (2A)$$

$$(V\rho C)_{ij} \dot{T}_{ij} = (UA')^*_{p/ij} (T_{pj} - T_{ij}) - (UA')_{i/sj} (T_{ij} - T_{sj}) \quad (3A)$$

where

$$(UA')^*_{p/ij} = \frac{D}{N} \quad (15)$$

$$D = \left(UA'_{p/s_1} UA'_{s_1/g} UA'_{g/s_2} UA'_{s_2/i} + UA'_{p/s_1} UA'_{s_1/s_2} UA'_{s_1/g} UA'_{s_2/i} + \right. \\ \left. UA'_{p/s_1} UA'_{s_1/s_2} UA'_{g/s_2} UA'_{s_2/i} \right)_j \quad (15A)$$

$$N = \left(UA'_{p/s_1} UA'_{s_1/g} UA'_{s_1/s_2} + UA'_{p/s_1} UA'_{s_1/g} UA'_{g/s_2} + \right. \\ UA'_{p/s_1} UA'_{s_1/g} UA'_{s_2/i} + UA'_{p/s_1} UA'_{g/s_2} UA'_{s_1/s_2} + \\ UA'_{p/s_1} UA'_{g/s_2} UA'_{s_2/i} + UA'_{s_1/g} UA'_{g/s_2} UA'_{s_2/i} + \\ \left. UA'_{s_1/s_2} UA'_{s_1/g} UA'_{s_2/i} + UA'_{s_1/s_2} UA'_{g/s_2} UA'_{s_2/i} \right)_j \quad (15B)$$

subscripts,

- g = gas gap node
- s₁ = outside surface of pipe node
- s₂ = inside surface of insulation node.

The composite UA coefficient of equation (15) results from the series/parallel heat transfer with radiation across the gap and conduction (or convection) to and from the surfaces to the gas. It is derived, along with equations (2A) and (3A), assuming zero heat storage for the surface nodes and gas gap node. Good approximations of the temperature-dependent heat transfer and radiation coefficients can be obtained using the pipe node temperature, thus eliminating the need to compute actual surface and gas temperatures.

A series of computer runs was made to determine the importance of explicitly including the gas gap resistance in the calculational model. It was found that all axial coolant and pipe wall transient temperatures are

within 0.5°F of the values calculated by an eight-radial node model, based on equations (2A) and (3A) if a 1-inch gas gap is assumed to have the same heat transfer resistance as insulation of the same dimensional characteristics. Better agreement results by neglecting the gas gap resistance entirely for the relatively high temperature sodium coolant system. In the latter case, the difference is less than 0.1°F. It is concluded that a five-radial node model is completely satisfactory as the reference model for pipe systems with or without a gas gap between the pipe and insulation.

Initial exploratory studies were made using the detailed reference model to see what simplifications might be made concerning heat transfer calculations and additional simplifications on the number of radial nodes. These studies were done using the following set of conditions:

- 28-inch OD x 27.25-inch ID x 150-ft long pipe
- Down ramp on sodium inlet temperature from 1000 to 800°F from zero to 10 seconds
- Down ramp on coolant flow rate from 1600 to 160 lb/second from 2 to 27 seconds
- 4-inch insulation thickness and no gas gap
- 0.075 Btu/(hr-ft-°F) insulation conductivity
- 100°F ambient temperature
- 12 axial nodes.

The unimportance of using local physical properties and local heat transfer coefficients is established by comparing a computer run with local conditions used versus a run in which volume average temperatures are used for physical properties and heat transfer. Computer output shows that there is less than a 1°F difference between corresponding temperatures at any given time for the two comparative cases. This small difference is judged to be insignificant.

Examination of computer output for these exploratory runs also shows that the insulation and insulation surface temperatures are quite insensitive to what is happening inside the pipes, at least for the first six minutes of the transient: the runs were stopped at that time. It suggests that the initial steady-state insulation temperature could be used as a constant temperature heat sink throughout the transient, or that the heat transfer resistance from

the pipe wall surface to the ambient could be kept constant throughout the transient at the initial steady-state value. The latter assumption is preferable because it probably can be applied with reasonably good accuracy even for long transients and for cases in which the coolant temperature decays to values below the initial insulation temperature. The difference in transient results is insignificant between the two assumptions for the conditions of the exploratory computer runs.

A three-radial node model of coolant, pipe wall, and constant insulation is checked against a detailed twelve-axial, five-radial node model with the results shown in Figure 1. Also shown is the result of a still further possible simplification of lumping coolant and pipe wall together (i.e., combining equations (1) and (2) by assuming the same temperature exists for coolant and pipe wall); this produces a two-radial node model including a constant insulation node temperature. As shown in Figure 1, the two-node model is inadequate, but the three-node model is very satisfactory, being in nearly perfect agreement with the detailed five-radial node model.

The suggested simplifications on the use of average properties and heat transfer coefficients and three radial nodes are included in the development of the rectangular integration model to be used in the heat transport system (HTS) simulation.

The inadequacy of a pure transport delay model is also shown in Figure 1. A transport delay model may be satisfactory for simulations directed toward component design in that the rate of temperature change may be conservatively high, but it is an inadequate model when system process performance is to be determined.

Rectangular Integration Models

The pipe models developed here are to be incorporated in a reactor/HTS FFTF model which will make extensive use of the LMFBR Demonstration Plant Simulation Model (DEMO), which is described in reference (4). The explicit rectangular integration method for pipe simulation is selected because it is the method used in the DEMO computer program for the other components. An important consideration in this pipe model development is that the main part

FIG. 1. COOLANT OUTLET TEMPERATURES. 2,3,5 RADIAL NODES
 PHYSICAL PROPS. AND HEAT TRANSFER BASED ON AVG. TEMPERATURES.
 DOWN RAMPS ON COOLANT INLET TEMPERATURE AND FLOW.
 12 AXIAL NODES USED.

of the reactor/HTS simulation will be operating with a relatively small, fixed integration time step as compared to a much larger allowable time step for pipe calculations. Hence, in order to minimize computer run times, the pipe models are developed to use a time step for each pipe leg in the HTS model different than that used for other components or processes, and including other pipe legs.

The previously suggested simplifications are used whenever they can be justified. Thus, to start with, the rectangular integration models are arranged for three radial nodes, including a fixed sink temperature node in both time and distance and physical properties and heat transfer coefficients are based on volume average coolant and pipe wall temperatures. The preliminary exploratory computer runs using the reference model show that the insulation, pipe wall, and coolant temperatures are nearly constant with distance for the heavily insulated pipes and for a wide range of flow rates. These early runs also show that there is less than a 1°F temperature difference between the coolant and pipe wall at steady-state conditions. As a result, for simplicity, initial conditions are set up for all coolant and pipe wall node temperatures equal to the inlet coolant temperature, and the corresponding insulation and surface temperatures are calculated accordingly using the heat transfer equations (10) through (14).

The criteria for acceptance of any simplified model is on the degree of comparison to the 48 axial by 5 radial node reference model with its use of local temperatures for physical properties and heat transfer coefficients at each nodal point. Two things must be satisfied before the simplified model is judged to be satisfactory.

1. The coolant temperature difference at any point in time between corresponding points is less than about 5°F . This tolerance is consistent with the accuracy of actual temperature measurements of sodium coolant in HTS pipes at the temperature levels of interest here. The measurement error is about twice the tolerance (i.e., about 10°F).
2. The simplified model's outlet sodium temperature must not lead or lag the reference model's temperature by more than about 5 seconds.

This is especially important at the start of the transients in order to get good initial representation of coolant transport time.

Finite difference forms of equations (1) through (4) are arranged as shown below using an explicit formulation on a model with the coolant nodes staggered relative to the pipe wall nodes (see sketch below), and for a constant heat transfer resistance from the pipe wall outside surface to the ambient. It is necessary to assume a zero heat storage term for the insulation in the development of the three radial node model. Equation (16) includes a two-point difference approximation of the $\partial T / \partial X$ derivative.

$$\begin{aligned}
 & \frac{(V\rho C)_c}{\Delta t} \left[\frac{(T'_{cj} - T_{cj}) + (T'_{cj-1} - T_{cj-1})}{2} \right] = \\
 & - WC_c \left[\frac{(T'_{cj} - T'_{cj-1}) + (T_{cj} - T_{cj-1})}{2} \right] \\
 & - \frac{(UA)_{c/p}}{2} \left\{ \left[\frac{T'_{cj} + T'_{cj-1}}{2} - T_{pj} \right] + \left[\frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \right] \right\} \quad (16)
 \end{aligned}$$

$$\begin{aligned}
 & \frac{(V\rho C)_p}{\Delta t} \left[\frac{(T'_{pj} - T_{pj}) + (T'_{pj-1} - T_{pj-1})}{2} \right] = \\
 & \frac{(UA)_{c/p}}{2} \left\{ \left[\frac{T'_{cj} + T'_{cj-1}}{2} - T'_{pj} \right] + \left[\frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \right] \right\} \\
 & - (UA)_{p/i} \left[\frac{(T'_{pj} - T'_{ij}) + (T_{pj} - T_{ij})}{2} \right] \quad (17)
 \end{aligned}$$

$$(UA)_{p/i} \left[\frac{(T'_{pj} - T'_{ij}) + (T_{pj} - T_{ij})}{2} \right] =$$

$$(UA)_{i/s} \left[\frac{(T'_{ij} - T'_{sj}) + (T_{ij} - T_{sj})}{2} \right] \quad (18)$$

$$(UA)_{i/s} \left[\frac{(T'_{ij} - T'_{sj}) + (T_{ij} - T_{sj})}{2} \right] =$$

$$(UA)_{s/a} \left[\frac{(T'_{sj} - T'_a) + (T_{sj} - T_a)}{2} \right] \quad (19)$$

where

t = time seconds

V = volume per node, cu ft

Δt = integration time step, seconds

and prime denotes values at new time $t + \Delta t$ while unprimed values are at time t .
Other terms are as defined before.

Sketch of Staggered Node Model

By assuming that temperature gradients at time t and $t + \Delta t$ are the same (a good approximation as $\Delta t \rightarrow 0$), it then follows that,

$$T'_{cj} - T'_{cj-1} \approx T_{cj} - T_{cj-1} \quad (20)$$

$$\frac{T'_{cj} + T'_{cj-1}}{2} - T'_{pj} \approx \frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \quad (21)$$

$$T'_{pj} - T'_{ij} \approx T_{pj} - T_{ij} \quad (22)$$

$$T'_{ij} - T'_{sj} \approx T_{ij} - T_{sj} \quad (23)$$

and

$$T'_{sj} - T'_a \approx T_{sj} - T_a \quad (24)$$

Putting Equations (20) through (24) into Equations (16) through (19) and treating (20)-(24) as equalities, results in a set of equations which enables an explicit determination of temperatures at time $t + \Delta t$:

$$\frac{(V\rho C)_c}{\Delta t} [T'_{cj} - T_{cj}] = -WC_c [T_{cj} - T_{cj-1}] - (UA)_{c/p} \left[\frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \right] \quad (25)$$

$$\frac{(V\rho C)_p}{\Delta t} [T'_{pj} - T_{pj}] = (UA)_{c/p} \left[\frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \right] - (UA)_{p/i} [T_{pj} - T_{ij}] \quad (26)$$

$$0 = (UA)_{p/i} [T_{pj} - T_{ij}] - (UA)_{i/s} [T_{ij} - T_{sj}] \quad (27)$$

$$0 = (UA)_{i/s} [T_{ij} - T_{sj}] - (UA)_{s/a} [T_{sj} - T_a] \quad (28)$$

T_{sj} and T_{ij} are eliminated by substitution of (27) and (28) into (26) to give:

$$\frac{(V\rho C)_p}{\Delta t} [T'_{pj} - T_{pj}] = (UA)_{c/p} \left[\frac{T_{cj} + T_{cj-1}}{2} - T_{pj} \right] - (UA)_{p/a} [T_{pj} - T_a] \quad (29)$$

where

$$(UA)_{p/a} = \frac{(UA)_{p/i} (UA)_{i/s} (UA)_{s/a}}{(UA)_{p/i} (UA)_{i/s} + (UA)_{p/i} (UA)_{s/a} + (UA)_{i/s} (UA)_{s/a}} \quad (30)$$

Rearranging Equations (25) and (29) yields,

$$\begin{aligned} T'_{cj} = & \left[1 - \frac{WC_c \Delta t}{(V\rho C)_c} - \frac{(UA)_{c/p} \Delta t}{2(V\rho C)_c} \right] T_{cj} + \left[\frac{WC_c \Delta t}{(V\rho C)_c} - \frac{(UA)_{c/p} \Delta t}{2(V\rho C)_c} \right] T_{cj-1} \\ & + \frac{(UA)_{c/p} \Delta t}{(V\rho C)_c} T_{pj} \end{aligned} \quad (31)$$

and

$$\begin{aligned} T'_{pj} = & \left[1 - \frac{(UA)_{c/p} \Delta t}{(V\rho C)_p} - \frac{(UA)_{p/a} \Delta t}{(V\rho C)_p} \right] T_{pj} + \frac{(UA)_{c/p} \Delta t}{2(V\rho C)_p} [T_{cj} + T_{cj-1}] \\ & + \frac{(UA)_{p/a} \Delta t}{(V\rho C)_p} T_a \end{aligned} \quad (32)$$

Equations (31) and (32) are used in the explicit solution for the case of constant heat transfer resistance from the pipe's outside surface to the ambient.

An equation similar to (32) results if a constant insulation temperature is assumed. For this case,

$$T'_{pj} = \left[1 - \frac{(UA)_{c/p} \Delta t}{(V\rho C)_p} - \frac{(UA)_{p/i} \Delta t}{(V\rho C)_p} \right] T_{pj} + \frac{(UA)_{c/p} \Delta t}{2(V\rho C)_p} [T_{cj} + T_{cj-1}]$$

$$+ \frac{(UA)_{p/i} \Delta t}{(V\rho C)_p} T_i \quad (33)$$

Thus, Equations (31 and (33) would be used in the explicit solution for the assumption of constant insulation temperature.

For numerical stability it is necessary that the temperature coefficients in Equations (31), (32), and (33) are never negative. The coefficient for T_{cj} in Equation (31) will be equal to or greater than zero if,

$$\Delta t \geq \frac{(V\rho C)_c}{WC_c + (UA)_{c/p}/2} \quad (34)$$

The T_{cj-1} coefficient can only be positive or zero if,

$$WC_c \geq (UA)_{c/p}/2 \quad (35)$$

It is unlikely that $(UA)_{c/p}/2$ will exceed WC_c , but if it should happen, the computer program is coded to set $(UA)_{cp} = 2WC_c$.

The T_{pj} coefficient in Equations (32) and (33) will be equal to or greater than zero if, in Equation (32),

$$\Delta t \geq \frac{(V\rho C)_p}{(UA)_{c/p} + (UA)_{p/a}} \quad (36)$$

or, for Equation (33),

$$\Delta t \geq \frac{(V\rho C)_p}{(UA)_{c/p} + (UA)_{p/i}} \quad (37)$$

The inequalities of Equations (34), (35), and (36) or (37) are continuously checked in all of the pipe heat models using the rectangular integration method to make certain the time step is small enough for stability.

About 100 different cases were run in the course of the model development work based on Equations (16) through (37). The number of axial nodes was varied from as few as 6 to as many as 624 for the sets of conditions given in Table 1. Most work was done using Condition IA for the 16 in. by 450 ft long pipe, which appeared to be the most difficult configuration to simulate because of its long transport time. Once a satisfactory model was found for this particular situation, the selected model was then checked for the other sets of conditions. The pipe sizes and lengths are typical of those found in the FFTF's HTS.

Model A

Model A is the name given the model which programs Equations (31) and (33) and uses inequalities (34), (35), and (37). Model A was first tried with a fixed small time step, which is much smaller than the limiting values for stability. Of course, stable solutions result, but accuracy is poor unless a large number of axial nodes are specified. Results of a series of computer runs are shown in Figure 2. The maximum temperature error at any given time is about 16°F for the 12 axial node Model A, 12°F for 24 nodes, 5°F for 48 nodes, and 3°F for 96 nodes. The Model A pipe end temperatures lead the reference case by from 15 to about 40 seconds at the start of the transient. The conclusion concerning Model A with a fixed small integration time step is that it cannot meet the selection criteria unless a very large number of axial nodes (over 96) are used. Results could be improved if the lead time could be reduced.

An explanation of the stated errors and curves drawn in Figure 2 and all subsequent figures of computer results is needed. The curves are drawn by hand by overlaying the computer's Calcomp plots from the several separate runs on to these report figures. Thus, the curves of this report are not exact duplicates of the computer output. The quoted errors are determined from the actual computer output though. Hence, a reader may not get the same errors if he scales these report figures.

Cases were rerun using Model A except this time the integration time step was allowed to vary as determined by inequalities (34) and (37). To assure a stable solution, the right-hand sides of the inequalities are

TABLE 1

SETS OF CONDITIONS USED IN MODEL DEVELOPMENT

Parameter	Conditions Set									
	IA	IB	IC	ID	IE	IIA	IIB	IIIA	IIIB	IVA
Pipe OD, in.	16.	16.	16.	16.	16.	28.	28.	8.625	8.625	3.5
ID, in.	15.25	15.25	15.25	15.25	15.25	27.25	27.25	7.981	7.981	3.068
Length, ft	450.	450.	450.	450.	450.	150.	150.	75.	75.	150.
Insulation Thickness, in.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.
Insulation Conductivity, Btu/(hr-ft-°F)	.075	.075	.075	.075	.075	.075	.075	.075	.075	.075
Inlet Coolant Temperature	(1A)	(1A)	(1B)	(1C)	(1D)	(1A)	(1A)	(1A)	(1A)	(1A)
Coolant Flow Rate, lb/sec.	(2A)	Constant 1600	(2B)	(2A)	Constant 160	(2A)	Constant 1600	(2C)	Constant 400	(2D)

Inlet Coolant Ramps:

(1A) Ramp, 1000 to 800°F between 0 and 10 sec.

(1B) Ramp, 1000 to 800°F between 0 and 10 sec., hold at 800 for 90 secs., ramp to 1000 between 100 and 150 sec.

(1C) Delayed Ramp, 1000 to 800°F between 70 and 110 sec.

(1D) Ramp, 1000 to 800°F between 0 and 40 sec.

(2A) Ramp, 1600 to 160 lb/sec. between 2 and 27 sec.

(2B) Ramp, 1600 to 160 lb/sec. between 2 and 27 sec., hold at 160 for 73 secs., ramp to 1600 between 100 and 110 sec.

(2C) Ramp, 400 to 40 lb/sec. between 2 and 27 sec.

(2D) Ramp, 31.6 to 3.16 lb/sec. between 2 and 27 sec.

FIG. 2. MODEL A SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
FIXED INTEGRATION TIME STEP OF .1 SECONDS.
TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
DOWN RAMPS IN 16 IN. X 450 FT PIPE.

multiplied by 0.99 before selecting the minimum of the two possible calculated time steps:

$$\tau_2 = \frac{.99 (V\rho C)_c}{WC_c + (UA)_{c/p}/2} \quad (38)$$

τ_1 from Equation (36) is,

$$\tau_1 = \frac{.99 (V\rho C)_p}{(UA)_{c/p} + (UA)_{p/a}} \quad (39)$$

τ_1 from Equation (37) is,

$$\tau_1 = \frac{.99 (V\rho C)_p}{(UA)_{c/p} + (UA)_{p/i}} \quad (39A)$$

$$\Delta t = \text{MINIMUM } (\tau_1, \tau_2) \quad (40)$$

The results of this series of runs are tabulated in Table 2 and are shown in Figure 3 for the 12, 24, and 48 axial node cases.

TABLE 2

MODEL A SODIUM OUTLET ERRORS WITH THE INTEGRATION TIME STEP EQUAL TO 0.99 OF THE LIMITING STABILITY VALUE AND FOR TABLE 1 CONDITIONS SET IA

<u>Number of Axial Nodes</u>	<u>Maximum Temperature Error, °F</u>	<u>Maximum Lead Time Error (Model A Leads the Reference), seconds</u>
12	20	23
24	10	15
48	8	8
96	5	4
210	2	0
624	0	0

As before, the model meets the selection criteria only for a large number of axial nodes. The 624 axial node case, which agrees perfectly with the reference detail model, helps to substantiate the credibility of the reference model because good results should be expected for such an enormous number of axial nodes.

FIG. 3. MODEL A SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 INTEGRATION TIME STEP AT .99 OF STABILITY LIMIT.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 DOWN RAMPS IN 16 IN. X 450 FT PIPE.

Model B

The lead time problem with Model A could possibly be eliminated by performing the temperature integrations only as each node is refilled with incoming coolant. Model B does just that by integrating the flow rate and comparing it to the volume of a single node. The volumes of all nodes are equal. The volume integration is only approximate in that the incoming coolant flow rate is only known at the start of the time span of the temperature integration. Thus, the approximate time to fill a node is determined directly by:

$$\Delta t = \frac{V_{\text{node}}}{W/\bar{\rho}} \quad (41)$$

where

- Δt = node refill time, seconds
- V_{node} = coolant node volume, cu ft
- W = coolant flow rate at the start of the node refilling process, lb/sec
- $\bar{\rho}$ = average coolant density based on volume average pipe leg temperature at the start of the node refilling process, lb/cu ft.

The concept of a constant heat transfer resistance from the pipe's outside surface to the ambient is used with Model B; therefore, the numerical integrations by Equations (31), (32), (35), (38), (39), and (40) are performed at the Δt time intervals.

Results are given in Table 3 for several axial node cases and the results are shown in Figure 4 for the 12, 24, and 48 node cases.

It is apparent that Model B overcorrects the Model A lead time problem. The fact that Model A leads while Model B lags suggests that a combination of the two models might give a model which can meet the selection criteria with a reasonably few number of axial nodes.

TABLE 3

MODEL B SODIUM OUTLET ERRORS WITH THE INTEGRATION TIME STEP EQUAL TO 0.99 OF THE LIMITING STABILITY VALUE AND FOR TABLE 1 CONDITIONS SET IA

<u>Number of Axial Nodes</u>	<u>Maximum Temperature Error, °F</u>	<u>Maximum Lag Time Error (Model B Lags the Reference), seconds</u>
12	20	50
24	11	25
48	7	15
96	5	10
210	3	3

Model C

Model C is a combination of the A and B models. Model B is used until the entire pipe leg is once refilled with coolant after the temperature transient starts; Model A is used thereafter.

Results are tabulated in Table 4 and shown in Figure 5 for 6, 12, and 24 axial nodes. The model selection criteria is met, for this particular set of conditions, with 24 nodes.

TABLE 4

MODEL C SODIUM OUTLET ERRORS WITH TABLE 1 CONDITIONS SET IA

<u>Number of Axial Nodes</u>	<u>Maximum Temperature Error, °F</u>	<u>Maximum Lead Time Error (Model C Leads the Reference), seconds</u>
6	20	30
12	10	10
24	5	5

Additional Verification of Model C

Several additional computer runs were made with Model C to check out its performance for a variety of alternative conditions, as listed in Table 1. A reference case, using the detailed 48 axial x 5 radial node, implicit solution model, was run for each set of conditions. Results are tabulated in Table 5 and are shown in Figures 6 through 14.

FIG. 4. MODEL B SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 INTEGRATION TIME STEP AT .99 OF STABILITY LIMIT.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 DOWN RAMPS IN 16 IN. X 450 FT PIPE.

FIG. 5. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 COMBINES FEATURES OF A AND B MODELS.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 DOWN RAMP IN 16 IN. X 450 FT PIPE.

TABLE 5

FINAL CHECKOUT OF MODEL C

Conditions Set As Defined In Table 1	Pipe Size OD x Length	Forcing Ramps T = Temperature F = Flow (See Table 1)	Number Axial Nodes	Maximum Outlet Coolant Errors Relative to Reference Case		Initial Steady State Transport Time, seconds
				Temperature, °F	Lead or Lag Time, seconds	
IA	16" x 450'	T&F down	6	20	30 (lead)	18
			12	10	10 (lead)	
			24	5	5 (lead)	
IB	16" x 450'	T down; F constant @ 1600 lb/sec	6	14	3 (lag)	18
			12	9	2 (lag)	
			24	5	1 (lag)	
IC	16" x 450'	T&F down, then back to initial	6	16	25 (lead)	18
			12	10	15 (lead)	
			24	4	5 (lead)	
ID	16" x 450'	T&F down; T ramp delayed	6	22	50 (lead)	18
			12	10	20 (lead)	
			24	3	5 (lead)	
IE	16" x 450'	T down; F constant @ 160 lb/sec	6	72	100 (lag)	180
			12	40	50 (lag)	
			24	22	16 (lag)	
			96	7	5 (lag)	
			192	2	2 (lag)	
IIA	28" x 150'	T&F down	6	40	35 (lead)	19
			12	20	15 (lead)	
			24	8	8 (lead)	
IIB	28" x 150'	T down; F constant @ 1600 lb/sec	6	8	3 (lag)	19
			12	7	3 (lag)	
			24	5	2 (lag)	
IIIA	8" x 75'	T&F down	6	5	2 (lag)	3
			12	1	1 (lag)	
			24	0	0	
IIIB	8" x 75'	T down; F constant @ 400 lb/sec	6	0	0	3
			12	0	0	
			24	0	0	
IVA	3" x 150'	T&F down	6	15	40 (lag)	13
			12	5	8 (lag)	
			24	0	0	

FIG. 6. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
TRANSIENT BASED ON CONDITIONS SET IB, TABLE 1.
CONSTANT FLOW RATE OF 1600 LB/SEC.
200 F INLET COOLANT TEMPERATURE DOWN RAMP.

FIG. 7. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 TRANSIENT BASED ON CONDITIONS SET IC, TABLE 1.
 DOWN/UP RAMPS ON FLOW RATE.
 DOWN/UP RAMPS ON INLET SODIUM TEMPERATURE.

FIG. 8. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 TRANSIENT BASED ON CONDITIONS SET ID, TABLE 1.
 INLET COOLANT TEMP. RAMP OF 1000 TO 800 DEG F FROM 70 TO 110 SEC
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG. 9. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED.
 TRANSIENT BASED ON CONDITIONS SET 1E, TABLE 1.
 RAMP INLET COOLANT TEMPERATURE AT -5 DEG./SEC FROM 0 TO 40 SEC
 FLOW CONSTANT AT 160 LB/SEC.

FIG. 10. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED
TRANSIENT BASED ON CONDITIONS SET IIA, TABLE 1.
200 F INLET COOLANT TEMPERATURE DOWN RAMP.
FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG. 11. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED
TRANSIENT BASED ON CONDITIONS SET IIB, TABLE 1.
200 F INLET COOLANT TEMPERATURE DOWN RAMP.
CONSTANT FLOW RATE OF 1600 LB/SEC.

FIG. 12. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED
 TRANSIENT BASED ON CONDITIONS SET IIIA, TABLE 1.
 200 F INLET COOLANT TEMPERATURE DOWN RAMP.
 FLOW RAMP OF 400 TO 40 LB/SEC FROM 2 TO 27 SEC.

FIG. 13. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED
 TRANSIENT BASED ON CONDITIONS SET IIIB, TABLE 1.
 200 F INLET COOLANT TEMPERATURE DOWN RAMP.
 FLOW CONSTANT AT 400 LB/SEC.

FIG. 14. MODEL C SODIUM OUTLET TEMPERATURES. AXIAL NODES VARIED
 TRANSIENT BASED ON CONDITIONS SET IVA, TABLE 1.
 200 F INLET COOLANT TEMPERATURE DOWN RAMP.
 RAMP FLOW FROM 31.6 TO 3.16 LB/SEC FROM 2 TO 27 SEC.

A 24 axial node model is satisfactory in most cases. Exceptions are for condition sets IE and IIA. Indications are that the minimum number of axial nodes for meeting the selection criteria is related to the coolant transport time. For example, 6 nodes are sufficient for the 75 ft runs of 8 in. pipe of condition sets IIIA and IIIB, wherein the initial transport time is about 3 seconds. The data of Table 5 can be used to arrive at a rough rule of thumb on axial node selection: The number of axial nodes used in Model C for a given pipe leg should be at least as great as the instantaneous coolant transport time during the time of the major temperature change.

Additional model development work continues because the number of nodes to satisfy condition set IE is impractical, but Model C appears to be generally satisfactory otherwise.

Model A1

Model A1 is similar to Model A except that the 2 point difference approximation of $\partial T / \partial x$ in Model A is replaced by the alternating 3 point approximation, which is also used in the reference model. The stability criteria for Model A1 is changed accordingly.

For convenience, the pipe wall nodes and coolant nodes are in line, rather than staggered as they are in Models A, B and C. The Model A1 equations, which replace Equations (31) and (32) are then,

$$T'_{cj} = \left[1 - \frac{(UA)_{c/p} \Delta t}{(V\rho C)_c} \right] T_{cj} + \frac{WC_c \Delta t}{2(V\rho C)_c} T_{cj-1} - \frac{WC_c \Delta t}{2(V\rho C)_c} T_{cj+1} + \frac{(UA)_{c/p} \Delta t}{(V\rho C)_c} T_{pj} \quad (42)$$

(for even nodes $j = 2, 4, 6 \dots j_{\text{end}-1}$)

and

$$T_{cj} = \left[1 - \frac{1.5 WC_c \Delta t}{(V\rho C)_c} - \frac{(UA)_{c/p} \Delta t}{(V\rho C)_c} \right] T_{cj} + \frac{2 WC_c \Delta t}{(V\rho C)_c} T_{cj-1} - \frac{WC_c \Delta t}{2(V\rho C)_c} T_{cj-2} + \frac{(UA)_{c/p} \Delta t}{(V\rho C)_c} T_{pj} \quad (43)$$

(for odd nodes 3, 5, 7 ... j_{end})

and

$$T_{pj} = \left[1 - \frac{(UA)_{c/p} \Delta t}{(V\rho C)_p} - \frac{(UA)_{p/a} \Delta t}{(V\rho C)_p} \right] T_{pj} + \frac{(UA)_{c/p} \Delta t}{(V\rho C)_p} T_{cj} + \frac{(UA)_{p/a} \Delta t}{(V\rho C)_p} T_a \quad (44)$$

for the pipe nodes.

To assure positive coefficients on the T_{cj} and T_{pj} terms, it is necessary that these limits are met:

$$\Delta t \leq \frac{(V\rho C)_c}{(UA)_{c/p}} \quad (45)$$

$$\Delta t \leq \frac{(V\rho C)_c}{1.5 WC_c + (UA)_{c/p}} \quad (46)$$

$$\Delta t \leq \frac{(V\rho C)_p}{(UA)_{c/p} + (UA)_{p/a}} \quad (47)$$

The effect of the negative coefficients for the T_{cj+1} term of Equation (42) and T_{cj-2} term of Equation (43) on stability is uncertain. As discussed later, these terms apparently play an important part in the selection of maximum Δt 's for stable solutions.

Model A1 was first checked out with a fixed, small 0.1 second, time step. Cases with from 6 to 96 axial nodes were run with the results as tabulated in Table 6 and as shown in Figure 15.

TABLE 6

MODEL A1 SODIUM OUTLET TEMPERATURES WITH A FIXED 0.1 SECOND
INTEGRATION TIME STEP AND FOR TABLE 1 CONDITIONS SET IA

<u>Number of Axial Nodes</u>	<u>Maximum Temperature Error, °F</u>	<u>Maximum Lead/Lag Time Error, seconds</u>
6	10	32 (lead)
12	3	10 (lead)
24	1	2 (lag)
48	0	0
96	(Unstable solution developing--See Figure 15)	

Comparison of these data with similar data for Models A, B and C shows that Model A1 may be the most accurate of the models tested so far. However, indications are that Model A1 may need to operate with more restrictive stability requirements than Models A, B, or C; the 96 node Model A1 case is essentially unstable as shown in Figure 15, whereas there are no indications of instability with Models A, B, or C, even with up to 624 axial nodes. More restrictive stability limits result in longer problem execution times, but other than that there are no disadvantages with small integration time steps.

Next, runs were made with variable integration time steps using the limits established by Equations (45) and (47) and variations of Equation (46); the WC_c multiplier in Equation (46) was studied in steps of 1.5, 2.5, 5.0, and 10.0. Results are shown in Figure 16. The instability shown by the case with the 1.5 multiplier on the WC_c term indicates that stability is not guaranteed by Equation (46). Apparently, the negative coefficients for the T_{cj+1} and T_{cj-2} terms in (42) and (43) enter into the stability limiting Δt . The development of an exact analytical expression for stability was unsuccessful. Instead, a criteria is established by trial and error by varying the WC_c multiplier in Equation (46). Results indicate that the instability threshold multiplier value is about 5, for 48 or less nodes. A value of 10 is specified to be safe.

FIG. 15. MODEL A1 SODIUM OUTLET TEMPERATURES.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG. 16. MODEL A1. USE STABILITY LIMIT. SODIUM OUTLET TEMP.
TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

A series of runs was made for all conditions listed in Table 1, using Model A1 with the limiting Δt given by,

$$\Delta t = \frac{(V\rho C)_c}{10 WC_c + (UA)_{c/p}} \quad (48)$$

These results are shown in Figures 17 through 26 and key data are tabulated in Table 7. The model selection criteria is met with 24 nodes without exception for all cases. As in the case of Model C, 6 nodes are sufficient for the pipe runs with the short transport times.

Model C1

Although computer run times are not excessive with Model A1, with its relatively tight Δt limitation, it would be worthwhile to run even faster if errors can be kept small enough. Thus, Model C1 was created as a variation of Model C, in which Model C1 uses the 3-point difference approximations in place of the 2-point differences of Model C. Model C1 would run faster than Model A1 because integrations are only done as each node is refilled, until the time the entire pipe is refilled. However, as shown in Figure 27, large errors resulted for cases run using Equation (48) for stability. Further work with Model C1 was abandoned.

Selection of Simplified Model

The selection of the simplified model is between Model C and Model A1. Model A1 is the more accurate of the two models, but computer execution time is somewhat greater than for Model C. Computer execution times for cases run to 360 seconds with 24 axial nodes, under set IA conditions, are about 3.28 and 6.28 seconds for Models C and A1, respectively. With these rapid computer run times, the difference in execution times between the two models is judged to be unimportant. Therefore, Model A1 is the final choice because of its superior overall accuracy, which can be easily seen by comparing the error data included in Tables 5 and 7.

FIG. 17. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG. 18. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET 1B, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 FLOW RATE CONSTANT AT 1600 LB/SEC.

FIG. 19. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET IC, TABLE 1.
 DOWN/UP RAMPS ON INLET SODIUM TEMPERATURE.
 DOWN/UP RAMPS ON FLOW RATE.

FIG. 20. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET ID, TABLE 1.
 1000 TO 800 F TEMPERATURE RAMP FROM 70 TO 110 SEC.
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG.21. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET IE, TABLE 1.
 INLET COOLANT TEMP. RAMP OF 1000 TO 800 DEG F FROM 0 TO 40 SEC
 CONSTANT FLOW RATE OF 160 LB/SEC.

FIG. 22 . MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET IIA, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

FIG. 23. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
TRANSIENT BASED ON CONDITIONS SET IIB, TABLE 1.
INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
FLOW RATE CONSTANT AT 1600 LB/SEC.

FIG. 24. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
TRANSIENT BASED ON CONDITIONS SET IIIA, TABLE 1.
INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
FLOW RAMP OF 400 TO 40 LB/SEC FROM 2 TO 27 SEC.

FIG. 25. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
TRANSIENT BASED ON CONDITIONS SET IIIB, TABLE 1.
INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
FLOW CONSTANT AT 400 LB/SEC.

FIG. 26. MODEL A1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET IVA, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 RAMP FLOW FROM 31.6 TO 3.16 LB/SEC FROM 2 TO 27 SEC.

TABLE 7

FINAL CHECKOUT OF MODEL A1

Conditions Set As Defined In Table 1	Pipe Size OD x Length	Forcing Ramps T = Temperature F = Flow (See Table 1)	Number Axial Nodes	Maximum Outlet Coolant Errors Relative to Reference Case		Initial Steady State Transport Time, seconds
				Temperature, °F	Lead or Lag Time, seconds	
IA	16" x 450'	T&F down	6	8	20 (lead)	18
			12	2	10 (lead)	
			24	0	0	
IB	16" x 450'	T down; F constant @ 1600 lb/sec	6	10	2 (lead)	18
			12	4	2 (lead)	
			24	3	1 (lag)	
IC	16" x 450'	T&F down; then back to initial	6	8	25 (lead)	18
			12	2	10 (lead)	
			24	1	5 (lead)	
ID	16" x 450'	T&F down; T ramp delayed	6	12	20 (lag)	18
			12	5	4 (lag)	
			24	2	3 (lag)	
IE	16" x 450'	T down; F constant @ 160 lb/sec	6	14	20 (lead/lag)	180
			12	6	5 (lag)	
			24	4	3 (lag)	
IIA	28" x 150'	T&F down	6	12	15 (lag)	19
			12	4	15 (lead)	
			24	2	5 (lead)	
IIB	28" x 150'	T down; F constant @ 1600 lb/sec	6	10	4 (lead/lag)	19
			12	6	2 (lead/lag)	
			24	4	2 (lead)	
IIIA	8" x 75'	T&F down	6	1	2 (lead)	3
			12	1	2 (lead)	
			24	0	0	
IIIB	8" x 75'	T down; F constant @ 400 lb/sec	6	0	0	3
			12	0	0	
			24	0	0	
IVA	3" x 150'	T&F down	6	8	15 (lead/lag)	13
			12	6	10 (lag)	
			24	4	5 (lag)	

FIG. 27. MODEL C1 WITH STABILITY LIMITS. SODIUM OUTLET TEMP.
 TRANSIENT BASED ON CONDITIONS SET 1A, TABLE 1.
 INLET COOLANT TEMP RAMP OF 1000 TO 800 F FROM 0 TO 10 SEC
 FLOW RAMP OF 1600 TO 160 LB/SEC FROM 2 TO 27 SEC.

GENERALIZED PIPE SUBROUTINE

The subroutine, named PIPE, for determining coolant and pipe wall temperatures as a function of time and distance for pipe legs between FFTF components is based on Model A1. Key features of PIPE are listed in Table 8.

Some amplification of paragraph four in Table 8 is necessary. The FFTF's heat transport system (HTS) model is visualized to have about 29 individual pipe runs between components for the models with two identical HTS circuits representing the three actual circuits. The 29 runs allow for two dump heat exchanger module models in each of the two modeled secondary loops. Included in the pipe run count are runs to and from temperature sensors which are used for process control and/or plant protection trips, runs to and from a pipe break, and runs to and from tee junctions and/or area changes. Several of these runs are short in length and can be satisfactorily modeled by six or eight axial nodes. Thus, for good utilization of computer memory, the PIPE subroutine is dimensioned for 53 pipe legs with 8 axial nodes (or 9 nodal points) per leg. This is in place of say 29 pipe runs with 25 nodal points each. Note there is a distinction between pipe legs and pipe runs; several pipe legs may be combined to form a single pipe run (between components). The code allows for up to four legs in series to form a run, with a maximum of 32 nodes total. Fifty-one legs appear to be needed for the FFTF's model of the HTS considering node requirements for acceptable accuracy (24 nodes for long runs with long coolant transport times, 16 nodes for intermediate lengths, and 8 nodes for short runs with short transport times). Two spare legs have been allowed.

PIPE and its related subroutines and functions require a large amount of computer storage capacity. If a computer storage problem arises when PIPE is incorporated into DEMO, some relief is possible by decreasing the maximum number of axial nodal points and/or the number of legs. About 212 locations are eliminated by dimensioning for 7 axial nodal points instead of 9, and about 50 locations are eliminated by each reduction of one leg. Of course, these reductions increase calculated temperature errors.

TABLE 8

KEY FEATURES OF PIPE SUBROUTINE

1. It is based on pipe Model A1.
 - a. Explicit, numerical integration method used.
 - b. $\partial T/\partial X$ approximated by alternating three-point difference formula; central difference for even nodal points; backward difference for odd nodal points.
 - c. Stability of computations virtually assured by built-in time step limits.
 - d. Models three radial nodes, including an ambient temperature node where temperature is constant with distance. The other two nodes are sodium and pipe wall. The ambient temperature can vary with time, if known.
 - e. The heat transfer resistance from the pipe's outside surface to the ambient temperature node is constant in time and distance.
2. Coded for positive or negative flows in any pipe run between components, but initial steady-state flow rates must be positive. Model convention is for positive flow to be in the direction of increasing axial nodal point numbers.
3. Cases can be executed using basic dimensional inputs from a data deck or execution can be done starting with default values in which case the leg data cards in the input data deck are omitted. To facilitate the inclusion of data statement default values in subsequent computer runs, punched card output can be specified by input integer control. Default values are provided for dimensional constants and initial condition values. Runs can be made using the dimensional constants alone or in combination with the initial condition values. Initial conditions are determined whenever default values are not applicable.
4. Dimensioned for up to 53 separate pipe legs with a maximum of 8 nodes per leg. Up to 4 legs can be in series to form a single pipe run between components (i.e., allows up to 32 nodes for any given pipe run).
5. Integrations are done at time steps different than that used in the MAIN Program. Usually the PIPE time step will be much greater than the MAIN Program step.
6. Outgoing pipe leg coolant temperatures are provided at the MAIN Program time intervals by second degree polynomial interpolation of PIPE subroutine data. Reports and plots of these output temperatures are based on the interpolated values.
7. Complete temperature data can be reported at specified intervals within the PIPE subroutine by integer control input.
8. The flow rate in each pipe leg of a series of continuing legs is based on the flow in the first leg of the series.
9. The heat transfer resistance across a gas gap, if it exists between the pipe and insulation, is neglected. This simplification is justified for FFTF sodium systems because of the high radiation heat transfer between the two surfaces in which the insulation's inside surface temperature is nearly equal to the pipe's outside surface temperature. If the PIPE subroutine is used for low temperature systems, it would be best to assume that the gap resistance is the same as an insulation resistance of the same thickness, by letting XINSUL equal the combined gap plus resistance thicknesses and setting XGAP equal to 0.
10. If desired, the integration time step in the PIPE subroutine can be limited to a numerically small input specified value.

In order to debug the PIPE subroutine, it is necessary to write a stand-in main program and stand-in routines to provide forcing coolant flow and temperature data as functions of main program time. DEMO will provide these inputs once the PIPE subroutine is incorporated in it. MAIN is the name given the stand-in main program and FORCE is the name given the stand-in routine for coolant input flow rate and temperature data. MAIN, FORCE, and PIPE are used in conjunction with four other subroutines and/or functions, which are listed and described in Table 9. Flow charts of these programs, except for FIND and PHIF, are shown in Figures 28 through 32. The symbols used in these charts and in the program are listed in the MAIN program and PIPE subroutine listings included in Appendix A.

The program is written in Fortran for a Control Data Corporation CYBER 74-18 computer.

Input Data for Program MAIN

The input data are read in from the MAIN program by a series of six-card types. Provisions are made to run a single case only, because it is unlikely that multiple DEMO cases will be run. Input cards are arranged as follows:

1. First card - Case identification information: 7A10 format.
2. Second card - Program controls in the order given: free form input.

DTAU	MAIN program integration time step, sec.
ENDTME	Run stop time, sec.
IREPTX	Reporting interval for MAIN program output. Data reported every IREPTX time steps of MAIN.
IPLOTX	Plot data storage interval. Data stored every IPLOTX time step of MAIN.
NDEBUG	Control integer for reporting all temperature data from PIPE subroutine.
	NDEBUG=0 By-pass reports
	NDEBUG=K Report data every K time steps of PIPE (K $\leq$ 1).

TABLE 9

AUXILIARY SUBROUTINES AND FUNCTIONS FOR PIPE

Name of Function or Subroutine	Description
LEG	<p>LEG is a subroutine which does the following:</p> <ol style="list-style-type: none"> 1. Linear interpolation of MAIN program data to give incoming sodium temperature and flow rate at the time used in the PIPE subroutine. 2. Calls PIPE subroutine for transient calculations. 3. Second degree polynomial interpolation of PIPE data to give outgoing sodium temperature at the time of the MAIN program.
UCOEF	<p>UCOEF is a subroutine to provide (1) physical property data for sodium and stainless steel pipe wall as a function of the volumetric average temperatures at each time plane of the PIPE subroutine, (2) corresponding heat transfer coefficients, and (3) products of overall coefficients times surface areas.</p>
FIND	<p>FIND is a general purpose binomial interpolation function to search a two-dimensional array and to return the interpolated value corresponding to a one-dimensional argument. Specifically, it is used here with PHIF to give the heat transfer correction function ϕ, from tabulated data included in PHIF.</p>
PHIF	<p>PHIF is a function which provides an eddy diffusivity correction factor ϕ for the liquid metal Nusselt Number equation (7). By the method of Dwyer,⁽³⁾</p>

$$\bar{\psi} = 1 - \frac{\phi}{Pr}, \text{ where}$$

Pr = Prandtl number

$$\phi = 1.82 / \left(\frac{\epsilon_m}{\epsilon_v} \right)^{1.4}.$$

```

graph TD
    ENTER[ENTER] --> READ[READ IN AND WRITE OUT INPUT:  
• CASE IDENTIFICATION  
• DATE  
• PROGRAM CONTROLS  
• PIPE DIMENSIONAL DATA*  
• PLOT TITLES & CURVE INFO.  
INITIALIZE TIME AND CONTROL INTEGERS]
    READ --> DOFOR[DO FOR ALL LEGS]
    DOFOR --> CALLFORCE1{{CALL FORCE**}}
    CALLFORCE1 --> CALLPIPE1{{CALL PIPE  
N = 1}}
    CALLPIPE1 --> WRITEINIT[WRITE INITIAL CONDITIONS, ALL LEGS]
    WRITEINIT --> CALLPIPE3{{CALL PIPE  
N = 3}}
    CALLPIPE3 --> 180_1[180]
    180_1 --> 100[100]
    100 --> TIME[TIME = TIME + DTAU]
    TIME --> IS_TIME{IS  
TIME > ENDTIME  
?}
    IS_TIME -- Y --> 200[200]
    IS_TIME -- N --> I0[I = 0]
    I0 --> IINC[I = I + 1]
    IINC --> 169[169]
    169 --> CALLFORCE2{{CALL FORCE}}
    CALLFORCE2 --> IS_FLOW{IS  
FLOW > 0  
?}
    IS_FLOW -- N --> 119[119]
    IS_FLOW -- Y --> CALLLEG1{{CALL LEG}}
    CALLLEG1 --> IS_IPIP{IS  
I = MAXPIP  
?}
    IS_IPIP -- Y --> 180_2[180]
    IS_IPIP -- N --> IINC
    CALLLEG1 --> IS_M_INDEX{IS  
M = INDEX  
?}
    IS_M_INDEX -- Y --> IMEND[I = MEND]
    IMEND --> 169
    IS_M_INDEX -- N --> MDEC[M = M - 1  
T OUT (M) = T IN (M + 1)]
    MDEC --> CALLLEG1
    180_2 --> 180[180]
    180 --> 100[100]
    100 --> 200[200]
    200 --> 100
    119 --> 119_1[119 (FOR NEGATIVE FLOW)]
    119_1 --> INDEX[INDEX = I  
M = INDEX + 4, DEPENDS  
ON JTYP (LEG)  
MEND = M]
    INDEX --> CALLLEG1

```

Figure 29. FORCE Flow Chart

Figure 30. LEG Flow Chart

Figure 32. UCOEF Flow Chart

NOPLTS Total number of plots to be made.

IDEFLT Designates source of input data and punched output control:

 IDEFLT=0 Get basic inputs from input data deck and by-pass punched output.

 IDEFLT=1 Get basic inputs from input data deck and punch out dimensional constants and initial values.

 IDEFLT=2 Use default input data values and by-pass punched output.

 IDEFLT=3 Use default dimensional constants and calculate initial values and punch them out.

 IDEFLT=4 Use default dimensional constants, calculate initial values but by-pass all punched output.

3. Third card - Pipe leg dimensional and other fixed data, in the order given: free form input.

 IPIPE Leg number

 NODES Number of axial nodes. Must be an even number of 8 or less.

 JTYP Type of junction at the start of the leg:

 JTYP=0 for leg joined to a component.

 JTYP=1 for a continuing leg of the same ID.

 MAXSTP Maximum allowable integration time step in PIPE subroutine, sec.

 TCELL Initial temperature of space around the pipe leg, °F.

 OD Pipe leg outside diameter, in.

 ID Pipe leg inside diameter, in.

 LNTH Pipe leg length, ft.

 KINSUL Insulation thermal conductivity, Btu/(hr-ft-°F).

 XINSUL Insulation thickness, in.

 XGAP Gas gap thickness between pipe and insulation, in.

Provide one card for each leg. Program convention requires that continuing legs be numbered consecutively and that all type 3 data cards

be arranged in consecutive numerical order by leg number, starting with 1. If IDEFLT $\geq$ 2, omit the third card type data cards from the data deck.

4. Fourth card type in free form input: a-1 followed by 10 zeros all separated by commas. This single card denotes the end of the leg data as a check that the third card types have been entered properly. If IDEFLT $\geq$ 2, omit the fourth card type from the data deck.
5. Fifth card type. Plot heading cards with 7A10 format. The first card gives the first line of the headings for all plots. Subsequent cards give a second line in the headings for the individual plots.
6. Sixth card type in free form input. This single card enters curve identification coordinates for plot legends.

The stand-in MAIN program is set up to plot temperatures for 10 or less legs on individual plots. Outgoing and incoming leg coolant temperatures are drawn on each plot. Up to 1000 points can be plotted for each variable. Plotting is done using DISSPLA⁽⁵⁾, with the commands as shown near the end of the MAIN program listing.

Program MAIN and its subroutines and functions were debugged by checking output against similar output from the computer runs using Model A1.

REFERENCES

1. B. T. Fairchild, H. R. Wengrow, F. P. May, AMOS, Numerical Integration of Differential Equations with The Adams-Moulton-Shell Method, Department of Chemical Engineering, University of Florida, Gainesville, Florida, March, 1965.
2. A. L. Gunby, Intermediate Heat Exchanger Modeling for FFTF Simulation, BNWL-1367, Battelle-Northwest, Richland, Washington, May, 1970.
3. D. E. Dwyer, "Eddy Transport in Liquid Metal Heat Transfer," J. AIChE, 9, p. 261, 1963.
4. LMFBR Demonstration Plant Simulation Model, DEMO, WARD-D-0005, Rev. 2, Westinghouse Electric Corporation, Madison, Pennsylvania, July 30, 1974.
5. DISSPLA Beginners and Intermediate Manual (Version 1), Integrated Software Systems Corporation, San Diego, California, October, 1973.

APPENDIX A

PROGRAM LISTING

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Subroutine UCOEF	A-33

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```

      FUNCTION FIND(DATA,ROWS,COLS,X,Y,VAL)
      INTEGER ROWS, COLS, X, Y, XROW,YROW, XCOL,YCOL
      LOGICAL LOGIC
      DIMENSION DATA(ROWS,COLS)
      VALUE = ABS(VAL)
      IF (X) 1,2,3
1     XROW = -X

      YROW = Y
      MAXP = COLS
      LOGIC = .FALSE.
      IF (DATA(XROW,MAXP-1)-DATA(XROW,MAXP)) 20,2,21
20    IF (VALUE-DATA(XROW,MAXP)) 4,18,18
21    IF (VALUE-DATA(XROW,MAXP)) 18,18,4
15    IF (YROW) 31,31,30
30    BIND=DATA(YROW,MAXP)
      GO TO 16
2     FIND = -1.0E+38
      GO TO 13
20    3     XCOL = X
      YCOL = Y
      MAXP = ROWS
      LOGIC = .TRUE.
      IF (DATA(MAXP-1,XCOL)-DATA(MAXP,XCOL)) 22,2,23
25    22 IF (VALUE-DATA(MAXP,XCOL)) 4,19,19
23    23 IF (VALUE-DATA(MAXP,XCOL)) 19,19,4
19    IF (YCOL) 31,31,32
31    FIND=FLOAT(MAXP)
      GO TO 13
30    32 BIND=DATA(MAXP,YCOL)
      GO TO 16
4     J1 = 1
      J3 = MAXP
5     J2 = (J1+J3)/2
35    IF (LOGIC) GO TO 5
      A = (VALUE - DATA(XROW,J1))/(DATA(XROW,J2) - DATA(XROW,J1))
      GO TO 7
6     A = (VALUE - DATA(J1,XCOL))/(DATA(J2,XCOL) - DATA(J1,XCOL))
7     IF (A - 1.0) 8,10,9
40    8 IF (J2-J1 .LE. 1) GO TO 10
      J3 = J2
      GO TO 5
9     IF (J3-J2 .LE. 1) GO TO 10
      J1 = J2
      GO TO 5
45    10 J2 = MIN0(MAXP-1,J2)
      J2 = MAX0(2,J2)
      IF (LOGIC) GO TO 11
      X1 = DATA(XROW,J2-1)
      X2 = DATA(XROW,J2)
      X3 = DATA(XROW,J2+1)
      IF (YROW) 34,34,33
70    33 Y1 = DATA(YROW,J2-1)
      Y2 = DATA(YROW,J2)
      Y3 = DATA(YROW,J2+1)
85    GO TO 12
11    X1 = DATA(J2-1,XCOL)

```

```

      FIND      2
      FIND      3
      FIND      4
      FIND      5
      FIND      6
      FIND      7
      FIND      8
      FIND      9
      FIND     10
      FIND     11
      FIND     12
      FIND     13
      FIND     14
      FIND     15
      FIND     16
      FIND     17
      FIND     18
      FIND     19
      FIND     20
      FIND     21
      FIND     22
      FIND     23
      FIND     24
      FIND     25
      FIND     26
      FIND     27
      FIND     28
      FIND     29
      FIND     30
      FIND     31
      FIND     32
      FIND     33
      FIND     34
      FIND     35
      FIND     36
      FIND     37
      FIND     38
      FIND     39
      FIND     40
      FIND     41
      FIND     42
      FIND     43
      FIND     44
      FIND     45
      FIND     46
      FIND     47
      FIND     48
      FIND     49
      FIND     50
      FIND     51
      FIND     52
      FIND     53
      FIND     54
      FIND     55
      FIND     56
      FIND     57
      FIND     58

```

FUNCTION FIND

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```

        X2 = DATA(J2,XCOL)
        X3 = DATA(J2+1,XCOL)
60      IF(YCOL) 34,34,35
        34 JJJ=J2-1
           Y1=FLOAT(JJJ)
           Y2=FLOAT(J2)
           JJJ=J2+1
65      Y3=FLOAT(JJJ)
           GO TO 12
        35 Y1 = DATA(J2-1,YCOL)
           Y2 = DATA(J2,YCOL)
           Y3 = DATA(J2+1,YCOL)
70      12 C = ((Y3-Y2)/(X3-X2) - (Y2-Y1)/(X2-X1))/(X3-X1)
           B = (Y3-Y2)/(X3-X2) - C*(X3+X2)
           A = Y2 - X2*(B + C*X2)
           BIND = A + VALUE*(B + VALUE*C)
           IF(BIND) 15,15,16
75      15 FIND=0.
           GO TO 13
        16 IF(VAL) 14,17,17
        14 FIND=-BIND
           GO TO 13
        80      17 FIND = BIND
        13 RETURN
           END

```

```

        FIND      59
        FIND      60
        FIND      61
        FIND      62
        FIND      63
        FIND      64
        FIND      65
        FIND      66
        FIND      67
        FIND      68
        FIND      69
        FIND      70
        FIND      71
        FIND      72
        FIND      73
        FIND      74
        FIND      75
        FIND      76
        FIND      77
        FIND      78
        FIND      79
        FIND      80
        FIND      81
        FIND      82
        FIND      83

```

A-3


```

      SUBROUTINE FORCE(WX,TIN,TOUT,TIME,I)
      C FORCE PROVIDES FLOW RATE AND INCOMING SODIUM TEMPERATURES FOR ALL
      C PIPE LEGS, AS A FUNCTION OF TIME.
      C
      C I          PIPE LEG NUMBER.
      C
      C SEE PIPE SUBROUTINE FOR DEFINITION OF OTHER TERMS.
      C
      C THIS DEBJG RUN SET UP FOR 10 PIPE LEGS.
      C DEBUG FORCING DATA SET UP FOR FLOW REVERSAL IN CONTINUING AND
      C CONNECTING LEGS 4,5,6, AND WITH + FLOW ONLY IN ALL OTHER LEGS.
      C
      C      DIMENSION TIN(53),TOUT(53),WX(53)
      C      GO TO (100,2200,2200,400,2200,600,700,800,2200,2200),I
      C DATA FOR PIPE LEG 1 FOLLOWS.
      C DOWN RAMP TO 10 PERCENT FLOW OVER 25 SEC. STARTING AT 2 SEC.
      C      100 WX(1)=160.
      C      IF (TIME.LE.2.) WX(1)=1600.
      C      IF (TIME.GT.2..AND.TIME.LT.27.) WX(1)=1715.2-57.5*TIME
      C FLOW IS + SO TIN NEEDED AS COOLANT INPUT TO LEG 1.
      C DOWN RAMP FROM 1000 TO 800 F IN 10 SEC. FROM ZERO TIME.
      C      TIN(1)=1000.-20.*TIME
      C      IF (TIME.GT.10.) TIN(1)=800.
      C      GO TO 2200
      C DATA FOR PIPE LEG 4 FOLLOWS.
      C DOWN RAMP FROM 1600 TO 160 LB/SEC FROM 2 TO 27 SEC ,THEN RAMP FROM
      C 160 TO -160 AT 100 TO 150 SEC.
      C      400 WX(4)=160.
      C      WX(4)=160.
      C      IF (TIME.LE.2.) WX(4)=1600.
      C      IF (TIME.GT.2..AND.TIME.LT.27.) WX(4)=1715.2-57.6*TIME
      C      IF (TIME.GT.100..AND.TIME.LT.150.) WX(4)=800.-6.4*TIME
      C      IF (TIME.GE.150.) WX(4)=-160.
      C      IF (WX(4).GE.0.) GO TO 401
      C      GO TO 2200
      C FLOW IS + SO TIN NEEDED AS COOLANT INLET TEMP TO LEG.
      C      401 TIN(4)=1000.-20.*TIME
      C      IF (TIME.GT.10.) TIN(4)=800.
      C      GO TO 2200
      C DATA FOR PIPE LEG 6 FOLLOWS.
      C      600 IF (WX(6).GE.0.) GO TO 2200
      C FLOW IS NEGATIVE SO PROVIDE INLET COOLANT TEMP TO END OF THIS PIPE LEG
      C RAMP TOUT FROM 908 TO 700 F FROM 125 TO 225 SEC
      C      TOUT(6)=1249.-2.44*TIME
      C      IF (TIME.GT.225.) TOUT(6)=700.
      C      GO TO 2200
      C DATA FOR PIPE LEG 7 FOLLOWS.
      C DOWN RAMP TO 10 PERCENT FLOW OVER 25 SEC. STARTING AT 2 SEC.
      C      700 WX(7)=40.
      C      IF (TIME.LE.2.) WX(7)=400.
      C      IF (TIME.GT.2..AND.TIME.LT.27.) WX(7)=429.8-14.4*TIME
      C FLOW IS + SO TIN NEEDED AS COOLANT INPUT TO LEG 7.
      C DOWN RAMP FROM 1000 TO 800 F IN 10 SEC. FROM ZERO TIME.
      C      TIN(7)=1000.-20.*TIME
      C      IF (TIME.GT.10.) TIN(7)=800.
      C      GO TO 2200
      C DATA FOR PIPE LEG 8 FOLLOWS.

```

```

      FORCE 2
      FORCE 3
      FORCE 4
      FORCE 5
      FORCE 6
      FORCE 7
      FORCE 8
      FORCE 9
      FORCE 10
      FORCE 11
      FORCE 12
      FORCE 13
      FORCE 14
      FORCE 15
      FORCE 16
      FORCE 17
      FORCE 18
      FORCE 19
      FORCE 20
      FORCE 21
      FORCE 22
      FORCE 23
      FORCE 24
      FORCE 25
      FORCE 26
      FORCE 27
      FORCE 28
      FORCE 29
      FORCE 30
      FORCE 31
      FORCE 32
      FORCE 33
      FORCE 34
      FORCE 35
      FORCE 36
      FORCE 37
      FORCE 38
      FORCE 39
      FORCE 40
      FORCE 41
      FORCE 42
      FORCE 43
      FORCE 44
      FORCE 45
      FORCE 46
      FORCE 47
      FORCE 48
      FORCE 49
      FORCE 50
      FORCE 51
      FORCE 52
      FORCE 53
      FORCE 54
      FORCE 55
      FORCE 56
      FORCE 57
      FORCE 58

```

SUBROUTINE FORCE

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FTN 4.2+74351

04/03/75 13.35.03.

60 C DOWN RAMP TO 10 PERCENT FLOW OVER 25 SEC. STARTING AT 2 SEC.
800 WX(8)=3.16
IF(TIME.LE.2.) WX(8)=31.6
IF(TIME.GT.2..AND.TIME.LT.27.) WX(8)=33.8752-1.1376*TIME
C FLOW IS + SO TIN NEEDED AS COOLANT INPUT TO LEG 8.
C DOWN RAMP FROM 1000 TO 800 F IN 10 SEC. FROM ZERO TIME.
65 TIN(8)=1000.-20.*TIME
IF(TIME.GT.10.) TIN(8)=800.
2200 RETURN
END

FORCE 59
FORCE 60
FORCE 61
FORCE 62
FORCE 63
FORCE 64
FORCE 65
FORCE 66
FORCE 67
FORCE 68

SUBROUTINE LEG(I,TIME,TME,DTAU,WX,WRATE,WSAV,TIN,TOUT,TISAV, LEG 2
 1 TOSAV,TX,TM1,AONE,BONE,CONE,ATWO,BTWO,CTWO,IDEFLT, LEG 3
 2 MAXPIP,NDEBUG) LEG 4
 C REFER TO PIPE SUBROUTINE FOR DEFINITION OF SYMBOLES. LEG 5
 C LEG 6
 C LEG 7
 COMMON/PIPE1/ ID(53),KINSUL(53),LNTH(53),MAXSTP(53),OD(53), LEG 8
 1 TCELL(53),TINSUL(53),TSURF(53),XGAP(53),XINSUL(53) LEG 9
 COMMON/PIPE2/JEND(53),JTOP(53),NODES(53) LEG 10
 10 DIMENSION AONE(53),ATWO(53),BONE(53),BTWO(53), LEG 11
 1 CONE(53),CTWO(53),TIN(53),TISAV(53), LEG 12
 2 TME(53),TM1(53),TOSAV(53),TOUT(53), LEG 13
 3 TX(2, 9,53),WRATE(53),WSAV(53),WX(53) LEG 14
 IF(TIME.LT.TME(I)) GO TO 30 LEG 15
 15 XTXX=(TME(I)-TM1(I))/DTAU LEG 16
 C LINEAR INTERPOLATION FOR FLOW AND INCOMING COOLANT TEMPERATURES AT LEG 17
 C TIME TME. LEG 18
 WRATE(I)=WSAV(I)+XTXX*(WX(I)-WSAV(I)) LEG 19
 IF(WRATE(I).LT.0.) GO TO 10 LEG 20
 20 TX(1,1,I)=TISAV(I)+XTXX*(TIN(I)-TISAV(I)) LEG 21
 GO TO 20 LEG 22
 10 JTOP=JEND(I) LEG 23
 TX(1,JTOP,I)=TOSAV(I)+XTXX*(TOUT(I)-TOSAV(I)) LEG 24
 20 CONTINUE LEG 25
 C LEG 26
 C CALL PIPE FOR UPDATE OF TEMPERATURE DATA. LEG 27
 C LEG 28
 CALL PIPE(2,I,NDEBUG,IDEFLT,WRATE,TME,TX,AONE,BONE,CONE,ATWO,BTWO, LEG 29
 1 CTWO,MAXPIP) LEG 30
 30 XXAA=TIME**2 LEG 31
 C INTERPOLATE WITH SECOND DEGREE POLYNOMIAL IN TIME AT DTAU STEPS. LEG 32
 IF(WX(I).LT.0.) GO TO 40 LEG 33
 TOUT(I)=AONE(I)+BONE(I)*TIME+CONE(I)*XXAA LEG 34
 GO TO 50 LEG 35
 40 TIN(I)=ATWO(I)+BTWO(I)*TIME+CTWO(I)*XXAA LEG 36
 50 WSAV(I)=WX(I) LEG 37
 C SAVES PRECEDING TIME DATA FOR LATER LINEAR INTERPOLATION ON FLOW AND LEG 38
 C TEMPERATURES AT TIME TME. LEG 39
 TISAV(I)=TIN(I) LEG 40
 40 TOSAV(I)=TOUT(I) LEG 41
 TM1(I)=TME LEG 42
 RETURN LEG 43
 END LEG 44

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PROGRAM MAIN(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,PUNCH)      MAIN      2
C MAIN IS A STANDIN PROGRAM FOR THE ARD DEMO PLANT CODE FOR DEBUGGING      MAIN      3
C THE PIPE SUBROUTINE FOR COOLANT TRANSPORT AND COOLANT HEATING/COOLING.  MAIN      4
C                                                                           MAIN      5
5 C                                                                           MAIN      6
C                                                                           MAIN      7
C THIS DEBJG RUN IS SET JP FOR 10 PIPE LEGS. FLOW IS POSITIVE IN ALL      MAIN      8
C LEGS EXCEPT 4,5, AND 6 IN WHICH THERE IS A FLOW REVERSAL. THE FORCE    MAIN      9
C SUBROUTINE IS ARRANGED ACCORDINGLY.                                     MAIN     10
C                                                                           MAIN     11
10 C                                                                           MAIN     12
C LIST OF SYMBOLS FOR THE MAIN PROGRAM.                                  MAIN     13
C                                                                           MAIN     14
C REFER TO PIPE SUBROUTINE FOR SYMBOLS NOT INCLUDED HERE.               MAIN     15
C                                                                           MAIN     16
15 C ENDTME      PROGRAM RUN STOP TIME,SEC.                             MAIN     17
C H            PLOT HEADING                                             MAIN     18
C              H(1,1) FIRST HEADING LINE FOR ALL PLOTS.                 MAIN     19
C              H(1,K+1) SECOND HEADING LINE FOR KTH PLOT.               MAIN     20
C IDENT         CASE IDENTIFICATION.                                     MAIN     21
C IPLOT         PLOT CONTROL INTEGER.                                    MAIN     22
C IPLOTX        PLOT DATA STORAGE CONTROL INTEGER. DATA STORED EVERY  MAIN     23
C              IPLOTX TIMES OF THE MAIN PROGRAM.                       MAIN     24
C IREPT         REPORTING CONTROL INTEGER.                               MAIN     25
C IREPTX        DATA REPORT CONTROL INTEGER. DATA REPORTED EVERY      MAIN     26
25 C              IREPTX TIMES OF THE MAIN PROGRAM.                     MAIN     27
C ITIME        COUNTS NUMBER OF CALCULATIONS AT DTAU STEPS IN MAIN PROG.  MAIN     28
C NOPLTS       TOTAL NUMBER OF PLOTS TO BE MADE.                       MAIN     29
C NPCT        COUNTS THE NUMBER OF TIMES PLOT DATA ARE STORED.         MAIN     30
C PLT1        STORED COOLANT TEMP. AT START OF PIPE FOR PLOT,F.         MAIN     31
30 C PLT2        STORED COOLANT TEMP. AT END OF PIPE FOR PLOT,F.         MAIN     32
C PLT1X       COORDINATE FOR CURVE IDENTIFICATION IN PLOT LEGEND.       MAIN     33
C PLT1Y       COORDINATE FOR CURVE IDENTIFICATION IN PLOT LEGEND.       MAIN     34
C PLT2Y       COORDINATE FOR CURVE IDENTIFICATION IN PLOT LEGEND.       MAIN     35
C TIMEPL      TIME PLOT DATA STORED,SEC.                               MAIN     36
35 C                                                                           MAIN     37
C COMMON/PIPE1/ ID(53),<INSUL(53),LNTH(53),MAXSTP(53),OD(53),          MAIN     38
1   TCELL(53),TINSUL(53),TSURF(53),XGAP(53),XINSUL(53)                MAIN     39
C COMMON/PIPE2/JEND(53),JTY(53),NODS(53)                               MAIN     40
C                                                                           MAIN     41
40 C H DIMENSION IS SET JP FOR A TOTAL OF 10 PLOTS, WITH NO MORE THAN 70  MAIN     42
C CHARACTERS PER HEADING LINE.                                          MAIN     43
C DIMENSION H(7,11),IDENT(7),PLT1(10,1000),PLT2(10,1000),PLT1X(2),    MAIN     44
1   PLT1Y(2),PLT2Y(2),PLT11(1000),PLT22(1000),TIMEPL(1000)          MAIN     45
C ABOVE DIMENSIONS USED FOR CASE IDENTIFICATION AND PLOTTING ONLY.      MAIN     46
45 C DIMENSION AONE( 53),ATWO( 53),BONE( 53),BTWO( 53),                MAIN     47
1   CONE( 53),CTWO( 53),TIN( 53),TISAV( 53),                          MAIN     48
2   TNE( 53),T41( 53),TOSAV( 53),TOUT( 53),                          MAIN     49
3   TX(2, 9,53),WRATE( 53),WSAV( 53),WX( 53)                          MAIN     50
C REAL ID,KINSUL,LNTH,MAXSTP                                           MAIN     51
50 C                                                                           MAIN     52
C                                                                           MAIN     53
C DATA STATEMENT CARDS FOR WX,TIN AND MAXPIP ARE D.FAULT VALUES. THEIR  MAIN     54
C USE DEPENDS ON THE SPECIFIED VALUE FOR IDEFLT.                       MAIN     55
C                                                                           MAIN     56
55 C                                                                           MAIN     57
C DATA (WX(I),I=1,53)/                                                MAIN     58
X .16000000E+04, .16000000E+04, .10000000E+04, .16000000E+04,

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60      X .10000000E+04, .16000000E+04, .+0000000L+03, .31600000E+02, MAIN 59
      X .31600000E+02, .31600000E+02, 0., 0., 0., MAIN 60
      X 0., 0., 0., 0., 0., MAIN 61
      X 0., 0., 0., 0., 0., MAIN 62
      X 0., 0., 0., 0., 0., MAIN 63
      X 0., 0., 0., 0., 0., MAIN 64
      X 0., 0., 0., 0., 0., MAIN 65
65      X 0., 0., 0., 0., 0., MAIN 66
      X 0., 0., 0., 0., 0., MAIN 67
      X 0., 0., 0., 0., 0., MAIN 68
      X 0., 0., 0., 0., 0., MAIN 69
      X 0., 0., 0., 0., 0., MAIN 70
70      X 0., / MAIN 71
      DATA (TIN(I),I=1,53)/ MAIN 72
      X .10000000E+04, .10000000E+04, .10000000E+04, .10000000E+04, MAIN 73
      X .10000000E+04, .10000000E+04, .10000000E+04, .10000000E+04, MAIN 74
75      X .10000000E+04, .10000000E+04, 0., 0., 0., MAIN 75
      X 0., 0., 0., 0., 0., MAIN 76
      X 0., 0., 0., 0., 0., MAIN 77
      X 0., 0., 0., 0., 0., MAIN 78
      X 0., 0., 0., 0., 0., MAIN 79
      X 0., 0., 0., 0., 0., MAIN 80
80      X 0., 0., 0., 0., 0., MAIN 81
      X 0., 0., 0., 0., 0., MAIN 82
      X 0., 0., 0., 0., 0., MAIN 83
      X 0., 0., 0., 0., 0., MAIN 84
      X 0., 0., 0., 0., 0., MAIN 85
85      X 0., / MAIN 86
      DATA MAXPIP/10/ MAIN 87
C MAIN 88
C MAXPIP DEFAULT VALUE IS SET TO 10 FOR DEBUG RUNS WITH A 10 LEG MODEL. MAIN 89
C CORRECT THE DATA STATEMENT VALUE AFTER THE HEAT TRANSPORT SYSTEM MODEL MAIN 90
90 C IS FIXED. MAIN 91
C MAIN 92
      CALL DATE(ETAD) MAIN 93
      CALL CALCOM MAIN 94
C MAIN 95
95 C READ IN DATA AND WRITE IT BACK OUT. MAIN 96
C MAIN 97
      READ(5,1008) IDENT MAIN 98
      1008 FORMAT(7A10) MAIN 99
      WRITE(6,1011) IDENT,ETAD MAIN 100
100 1011 FORMAT(1H1,"PIPE ROUTINE DEBUG RESULTS."//1X,7A10,30X,"DATE ",A10/ MAIN 101
      1/) MAIN 102
      READ*,DTAU,ENDTME,IREPTX,IPLJTX,NDEBUG,NOPLOTS,IDEFLT MAIN 103
      WRITE(6,1010) DTAU,ENDTME,IREPTX,IPLJTX,NDEBUG,NOPLOTS,IDEFLT MAIN 104
105 1010 FORMAT(1H,"MAIN PROGRAM TIME STEP IS",F10.6," SECONDS. THE RUN W MAIN 105
      11LL BE STOPPED WHEN THE TIME EXCEEDS",F10.2," SECONDS."//1X,"RESULT MAIN 106
      2S WILL BE REPORTED EVERY",I5," TIMES AND PLOTTED EVERY",I5," TIMES MAIN 107
      3. NDEBUG IS",I3," AND THERE ARE TO BE",I3," PLOTS. IDEFLT IS",I2,/ MAIN 108
      4/) MAIN 109
C MAIN 110
110 C OMIT LEG DATA CARDS AND FOLLOWING -1 CARD FROM DATA DECK IF IDEFLT= MAIN 111
      C 2,3, OK 4. MAIN 112
C MAIN 113
      IF(IDEFLT.GE.2) GO TO 40 MAIN 114
      CC 10 I=1,54 MAIN 115

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115	IF(I.EQ.54) GO TO 15	MAIN	115
	READ*,IPIPE,NODES(I),JTYPE(I),MAXSTP(I),TCELL(I),OD(I),ID(I),	MAIN	117
	1 LNTH(I),KINSUL(I),XINSUL(I),XGAP(I)	MAIN	118
	C	MAIN	119
	C DENOTE THE END OF PIPE LEG DATA BY A CARD PUNCHED WITH A -1 (IN	MAIN	120
120	C COLUMNS 1 AND 2 SAY) FOR IPIPE FOLLOWED BY 10 ZEROS, ALL SEPARATED BY	MAIN	121
	C COMMAS.	MAIN	122
	C	MAIN	123
	30 IF(IPIPE.LT.0) GO TO 20	MAIN	124
	IF(IPIPE.NE.I) GO TO 25	MAIN	125
125	GO TO 10	MAIN	126
	15 READ(5,1001) IPIPE	MAIN	127
	1001 FORMAT(I2)	MAIN	128
	GO TO 30	MAIN	129
	10 CONTINUE	MAIN	130
130	20 MAXPIP=I-1	MAIN	131
	GO TO 40	MAIN	132
	25 WRITE(6,1002) I	MAIN	133
	1002 FORMAT(1H,"INCORRECT ORDERING OF INPUT DATA AT CARD NUMBER",I3,".	MAIN	134
	1 EXIT CALLED."/)	MAIN	135
135	CALL EXIT	MAIN	136
	40 WRITE(6,1003) MAXPIP	MAIN	137
	1003 FORMAT(1H,"INPUT PIPE DATA CARD VALUES FOR",I3," PIPE LEGS IN THE	MAIN	138
	1 HTS MODEL."/1X,"LEG NO. NODES JTYPE MAXSTP TCELL OD	MAIN	139
	2 ID LNTH KINSUL XINSUL XGAP "/)	MAIN	140
140	DO 50 I=1,MAXPIP	MAIN	141
	PRINT(6,1004) I,NODES(I),JTYPE(I),MAXSTP(I),TCELL(I),OD(I),	MAIN	142
	1 ID(I),LNTH(I),KINSUL(I),XINSUL(I),XGAP(I)	MAIN	143
	1004 FORMAT(3I6,8F10.4)	MAIN	144
	50 CONTINUE	MAIN	145
145	JTOP=NOPLTS+1	MAIN	146
	DO 48 J=1,JTOP	MAIN	147
	READ(5,1020) (H(I,J),I=1,7)	MAIN	148
	48 CONTINUE	MAIN	149
	1020 FORMAT(7A10)	MAIN	150
150	WRITE(6,1021)	MAIN	151
	1021 FORMAT(" PLOT HEADING CARDS."/)	MAIN	152
	DO 49 J=1,JTOP	MAIN	153
	49 WRITE(6,1019) (H(I,J),I=1,7)	MAIN	154
	1019 FORMAT(10X,7A10)	MAIN	155
155	READ*,(PLT1X(M),M=1,2),(PLT1Y(M),M=1,2),(PLT2Y(M),M=1,2)	MAIN	156
	WRITE(6,1025) (PLT1X(M),M=1,2),(PLT1Y(M),M=1,2),(PLT2Y(M),M=1,2)	MAIN	157
	1025 FORMAT(" PLOT LEGEND CARD "/OF10.2)	MAIN	158
	TIME=0.	MAIN	159
	ITIME=0	MAIN	160
160	IFLOT=1	MAIN	161
	IREPT=1	MAIN	162
	NFCT=0	MAIN	163
	M=0	MAIN	164
	IF(IDEFLT.EQ.2) GO TO 53	MAIN	165
165	CALL FORCE(WX,TIN,TOUT,TIME,1)	MAIN	166
	C	MAIN	167
	C FORCE IS SUBROUTINE WHICH PROVIDES FLOW RATE AND INCOMING COOLANT	MAIN	168
	C TEMPERATURES AS FUNCTION OF TIME FOR ALL PIPE LEGS.	MAIN	169
	C	MAIN	170
170	53 DO 51 I=1,MAXPIP	MAIN	171
	TX(1,1,I)=TIN(I)	MAIN	172

	C		MAIN	173
	C	CALL PIPE FOR INITIAL CONDITIONS.	MAIN	174
	C		MAIN	175
175		CALL PIPE(1,I,NDEBUG,IDEFLT,WX ,TME,TX,ACNE,BONE,CONE,ATWO,BTWO,	MAIN	176
	1	CTWO,MAXPIP)	MAIN	177
	C		MAIN	178
	C	INITIALIZE SOME CONDITIONS AND TIMES.	MAIN	179
	C		MAIN	180
180		TME(I)=0.	MAIN	181
		TM1(I)=0.	MAIN	182
		WSAV(I)=WX(I)	MAIN	183
		TISAV(I)=TX(1,1,I)	MAIN	184
		TOUT(I)=TIN(I)	MAIN	185
185		JTOP=JEND(I)	MAIN	186
		TOSAV(I)=TX(1,JTOP,I)	MAIN	187
		IF(I.EQ.MAXPIP) GO TO 54	MAIN	188
		IF(JTYP(I+1).EQ.0) GO TO 52	MAIN	189
		WX(I+1)=WX(I)	MAIN	190
190		TIN(I+1)=TOUT(I)	MAIN	191
		GO TO 51	MAIN	192
	52	M=I+1	MAIN	193
		IF(IDEFLT.EQ.2) GO TO 51	MAIN	194
		CALL FORCE(WX,TIN,TOUT,TIME,M)	MAIN	195
195		51 CONTINUE	MAIN	195
	54	WRITE(6,1013)	MAIN	197
	1013	FORMAT(1H1,"CALCULATED INITIAL VALUES FOLLOW----"/)	MAIN	198
		WRITE(6,1006)	MAIN	199
	1006	FORMAT(1H0,"INITIAL DATA FOR PIPE LEGS"/15X,"..... T	MAIN	200
200		1TEMPERATURES,DEG. F. FLOW RATE "/6X,"PIPE LEG SODIUM	MAIN	201
	2	PIPE WALL INSULATION SURFACE AMBIENT LB/SEC "/)	MAIN	202
	DO 60	K=1,MAXPIP	MAIN	203
		WRITE(6,1005) K,TX(1,1,K),TX(2,1,K),TINSUL(K),TSURF(K),TCELL(K),	MAIN	204
	1	WX(K)	MAIN	205
205		1005 FORMAT(1I10,F12.2,5F10.2)	MAIN	206
	C		MAIN	207
	C	CALL PIPE TO INITIALIZE INTERPOLATION COEFFICIENTS SO THAT INITIAL	MAIN	208
	C	VARIABLES, WHICH ARE NO LONGER NEEDED, CAN BE EQUIVALENCED TO THESE	MAIN	209
	C	INTERPOLATION COEFFICIENTS.	MAIN	210
210	C		MAIN	211
	60	CALL PIPE(3,K,NDEBUG,IDEFLT,WX ,TME,TX,ACNE,BONE,CONE,ATWO,BTWO,	MAIN	212
	1	CTWO,MAXPIP)	MAIN	213
		GO TO 180	MAIN	214
	C		MAIN	215
215	C	MAIN PROGRAM TRANSIENT CALCULATIONS FOLLOW.....	MAIN	216
	C		MAIN	217
	100	TIME=TIME+DTAU	MAIN	218
		IF(TIME.GT.ENDTME) GO TO 200	MAIN	219
		I=0	MAIN	220
220	169	I=I+1	MAIN	221
		IF(JTYP(I).EQ.1) GO TO 170	MAIN	222
		GO TO(101,102,103,104,105,106,107,108,109,110),I	MAIN	223
	C		MAIN	224
	C	THIS DEBUG RUN IS SET JP FOR ONLY 10 LEGS. THE ABOVE GO TO MUST BE	MAIN	225
225	C	CHANGED IF THE NO. OF LEGS IS NOT 10. ALSO THE REFERRED TO STATEMENTS	MAIN	226
	C	OF THE GO TO MUST BE ADDED.	MAIN	227
	C		MAIN	228
	C	CALL LEG FOR UPDATING TEMPERATURES.	MAIN	229

	C		MAIN	230
230		170 CALL LEG(I,TIME,TME,DTAU,WX,WRATE,WSAV,TIN,TOUT,TISAV,TOSAV,TX,	MAIN	231
		1 TH1,AONE,BONE,CONE,ATWO,BTWO,CTWO,IDEFLT,MAXPIP,NDEBUG)	MAIN	232
		IF(I.EQ.MAXPIP) GO TO 180	MAIN	233
		IF(JTYP(I+1).EQ.0) GO TO 169	MAIN	234
		WX(I+1)=WX(I)	MAIN	235
235		TIN(I+1)=TOUT(I)	MAIN	236
		GO TO 159	MAIN	237
		101 CALL FORCE(WX,TIN,TOUT,TIME,1)	MAIN	238
		IF(WX(1).GE.0.) GO TO 170	MAIN	239
		GO TO 160	MAIN	240
240		102 CALL FORCE(WX,TIN,TOUT,TIME,2)	MAIN	241
		IF(WX(2).GE.0.) GO TO 170	MAIN	242
		GO TO 160	MAIN	243
		103 CALL FORCE(WX,TIN,TOUT,TIME,3)	MAIN	244
		IF(WX(3).GE.0.) GO TO 170	MAIN	245
245		GO TO 160	MAIN	246
		104 CALL FORCE(WX,TIN,TOUT,TIME,4)	MAIN	247
		IF(WX(4).GE.0.) GO TO 170	MAIN	248
		GO TO 160	MAIN	249
		105 CALL FORCE(WX,TIN,TOUT,TIME,5)	MAIN	250
250		IF(WX(5).GE.0.) GO TO 170	MAIN	251
		GO TO 160	MAIN	252
		106 CALL FORCE(WX,TIN,TOUT,TIME,6)	MAIN	253
		IF(WX(6).GE.0.) GO TO 170	MAIN	254
		GO TO 160	MAIN	255
A-11 255		107 CALL FORCE(WX,TIN,TOUT,TIME,7)	MAIN	256
		IF(WX(7).GE.0.) GO TO 170	MAIN	257
		GO TO 160	MAIN	258
		108 CALL FORCE(WX,TIN,TOUT,TIME,8)	MAIN	259
		IF(WX(8).GE.0.) GO TO 170	MAIN	260
260		GO TO 160	MAIN	261
		109 CALL FORCE(WX,TIN,TOUT,TIME,9)	MAIN	262
		IF(WX(9).GE.0.) GO TO 170	MAIN	263
		GO TO 160	MAIN	264
		110 CALL FORCE(WX,TIN,TOUT,TIME,10)	MAIN	265
265		IF(WX(10).GE.0.) GO TO 170	MAIN	266
		160 INDEX=I	MAIN	267
	C		MAIN	268
	C	FLOW IS NOW NEGATIVE. FIND LAST LEG OF SERIES OF CONTINUING LEGS IF	MAIN	269
	C	ANY, SO THAT CALCULATIONS CAN BE MADE BACKWARDS FROM THE LAST LEG TO	MAIN	270
270	C	THE STARTING LEG OF THE SERIES.	MAIN	271
	C		MAIN	272
		II=I+4	MAIN	273
		DC 161 M=I,II	MAIN	274
		WX(M)=WX(INDEX)	MAIN	275
275		IF(JTYP(M+1).EQ.0,OR,M.EQ.MAXPIP) GO TO 162	MAIN	276
		161 CONTINUE	MAIN	277
		162 MEND=M	MAIN	278
	C		MAIN	279
	C	MEND IS LAST LEG OF SERIES STARTING WITH INDEX	MAIN	280
280		IF(MEND.EQ.INDEX) GO TO 170	MAIN	281
		CALL FORCE(WX,TIN,TOUT,TIME,MEND)	MAIN	282
	C	CALL TO FORCE PROVIDES INLET COOLANT TEMP TO END OF LAST NODE OF	MAIN	283
	C	LAST LEG OF SERIES OF CONTINUING LEGS.	MAIN	284
		103 CALL LEG(M,TIME,TME,DTAU,WX,WRATE,WSAV,TIN,TOUT,TISAV,TOSAV,TX,	MAIN	285
285		1 TH1,AONE,BONE,CONE,ATWO,BTWO,CTWO,IDEFLT,MAXPIP,NDEBUG)	MAIN	286

A-12

	IF(M.EQ.INDEX) GO TO 164	MAIN	287
	M=M-1	MAIN	288
	TOUT(M)=TIN(M+1)	MAIN	289
	GO TO 163	MAIN	290
290	164 I=MEND	MAIN	291
	IF(I.EQ.MAXPIP) GO TO 180	MAIN	292
	GO TO 169	MAIN	293
	180 ITIME=ITIME+1	MAIN	294
	IF(IREPT.NE.ITIME) GO TO 182	MAIN	295
295	C	MAIN	296
	C WRITE REPORTS OF COOLANT TEMPERATURES IF CALLED FOR BY IREPTX REPORT	MAIN	297
	C -ING FREQUENCY.	MAIN	298
	C	MAIN	299
	WRITE(6,1026) TIME	MAIN	300
300	1026 FORMAT(1H1,2X,"TIME=",F10.3," SECONDS. PIPE LEG DATA."//)	MAIN	301
	WRITE(6,1022)	MAIN	302
	1022 FORMAT(11X,"COOLANT TEMPERATURES, DEG.F., AT FLOW	MAIN	303
	12X,"LEG 22X,"NO. INLET OUTLET RATE LB/SEC."	MAIN	304
305	DO 181 I=1,MAXPIP	MAIN	305
	WRITE(6,1028) I,TIN(I), TOUT(I),WX(I)	MAIN	306
	1028 FORMAT(I5,F15.3,9X,F10.3,8X,F10.3)	MAIN	307
	181 CONTINUE	MAIN	308
	IREPT=IREPT+IREPTX	MAIN	309
310	182 IF(IPLT.NE.ITIME) GO TO 100	MAIN	310
	C	MAIN	311
	C STORE PLOT INFORMATION IF CALLED FOR BY IPLTX STORAGE FREQUENCY.	MAIN	312
	C	MAIN	313
	NPCT=NPCT+1	MAIN	314
315	TIMEPL(NPCT)=TIME	MAIN	315
	IPLT=IPLT+IPLTX	MAIN	316
	DO 183 I=1,MAXPIP	MAIN	317
	PLT1(I,NPCT)=TIN(I)	MAIN	318
	PLT2(I,NPCT)=TOUT(I)	MAIN	319
320	183 CONTINUE	MAIN	320
	185 GO TO 100	MAIN	321
	200 DO 250 K=1,NOPLOTS	MAIN	322
	C	MAIN	323
	C PLOT RESULTS.	MAIN	324
325	C	MAIN	325
	DO 220 KK=1,NPCT	MAIN	326
	PLT11(KK)=PLT1(K,KK)	MAIN	327
	PLT22(KK)=PLT2(K,KK)	MAIN	328
	220 CONTINUE	MAIN	329
330	CALL TITLE(1H,-1,"TIME,SECONDS",100,"TEMPERATURE,DEG.F.",100,9,	MAIN	330
	1,6.)	MAIN	331
	CALL HEADIN(H(1,1),100,2,2)	MAIN	332
	J=K+1	MAIN	333
	CALL HEADIN(H(1,J),100,2,2)	MAIN	334
335	CALL INTAXS	MAIN	335
	CALL GRAF(0.,40.,360.,500.,100.,1100.)	MAIN	336
	CALL BLNK1(3.3,6.4,.8,1.4,1)	MAIN	337
	CALL GRID(1,1)	MAIN	338
	CALL RESET("BLNCS")	MAIN	339
340	CALL CURVE(TIMEPL,PLT22,NPCT,0)	MAIN	340
	CALL CURVE(PLT1X,PLT1Y,2,0)	MAIN	341
	CALL DASH	MAIN	342
		MAIN	343

PROGRAM MAIN

74/74 OPT=1

FTN 4.2+74351

04/03/75 13.35.15.

345 CALL CURVE(TIMEPL,PLT11,NPCT,0)
CALL CURVE(PLT1X,PLT2Y,2,0)
CALL RESET("DASH")
CALL MESSAG("PIPE OUTLET3",100,5.,1.15)
CALL MESSAG("PIPE INLET3",100,5.,.9)
CALL FRAME
CALL ENOPL(K)
350 250 CONTINUE
CALL DONEPL
CALL EXIT
END

MAIN 344
MAIN 345
MAIN 346
MAIN 347
MAIN 348
MAIN 349
MAIN 350
MAIN 351
MAIN 352
MAIN 353
MAIN 354

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      FUNCTION PHIF(NRE,P)
      FUNCTION PHIF RETURNS THE MAXIMUM EDDY REYNOLDS NUMBER CORRECTOR
      NRE IS REYNOLDS NUMBER
      P IS HEAT EXCHANGER PITCH-TO-DIAMETER RATIO. FOR THE TUBE SIDE.
      USE P=Q.

      DIMENSION X(2,3),PHI(18,5)
      REAL NRE
      DATA (X(2,J),J=1,3)/1.300,1.375,1.700/

      PHI(I,J) IS MAXIMUM EDDY REYNOLDS NUMBER CORRECTOR FUNCTION.
      J=1 FOR REYNOLDS NUMBER
      J=2 FOR TUBES
      J=3 FOR PITCH-TO-DIAMETER RATIO OF 1.300
      J=4 FOR PITCH-TO-DIAMETER RATIO OF 1.375
      J=5 FOR PITCH-TO-DIAMETER RATIO OF 1.700

      DATA (PHI(I,1),I=1,18)/3.000E+3,5.000E+3,7.000E+3,1.000E+4,
1      2.000E+4,4.000E+4,7.000E+4,1.000E+5,
2      2.000E+5,4.000E+5,7.000E+5,1.000E+6,
3      2.000E+6,4.000E+6,7.000E+6,1.000E+7,
4      2.000E+7,5.000E+7/
      DATA (PHI(I,2),I=1,18)/5.200E-2,3.250E-2,2.400E-2,1.450E-2,
25      6.800E-3,3.000E-3,1.490E-3,8.800E-4,
1      3.570E-4,1.400E-4,6.600E-5,3.900E-5,
2      1.490E-5,5.400E-6,2.400E-6,1.390E-6,
3      4.750E-7,1.560E-7/
      DATA (PHI(I,3),I=1,18)/1.700E-1,1.100E-1,8.400E-2,6.000E-2,
30      2.900E-2,1.400E-2,6.800E-3,4.200E-3,
1      1.700E-3,6.600E-4,3.000E-4,1.900E-4,
2      7.000E-5,2.500E-5,1.010E-5,5.800E-6,
3      2.810E-6,4.700E-7/
      DATA (PHI(I,4),I=1,18)/1.900E-1,1.300E-1,9.500E-2,6.700E-2,
35      3.200E-2,1.400E-2,7.400E-3,4.700E-3,
1      1.900E-3,7.800E-4,3.500E-4,2.060E-4,
2      8.200E-5,2.580E-5,1.200E-5,7.000E-6,
3      2.400E-6,5.300E-7/
      DATA (PHI(I,5),I=1,18)/2.400E-1,1.600E-1,1.200E-1,8.600E-2,
40      4.300E-2,2.000E-2,1.010E-2,6.500E-3,
1      2.700E-3,1.070E-3,5.000E-4,3.000E-4,
2      2.200E-4,4.600E-5,2.070E-4,6.800E-5,
3      4.400E-5,1.070E-5/
100  FORMAT(1H0/5X65HPITCH-TO-DIAMETER RATIO IS LESS THAN 1.3 OR GREATER
45  1R THAN 1.7, P= E15.7/
      25X77HTHE MAXIMUM EDDY REYNOLDS NUMBER CORRECTOR IS NOT DEFINED FOR
      3THIS VALUE OF P./
      45X47HEXIT WILL BE CALLED FROM FUNCTION PHIF. NRE IS E15.7 )
      IF (P) 10,1,2
      1 PHIF=FIND(PHI,18,5,1,2,NRE)
      GO TO 11
      2 IF(P-1.3) 10,3,4
      3 PHIF=FIND(PHI,18,5,1,3,NRE)
      GO TO 11
      4 IF(P-1.375) 6,5,6
      5 PHIF=FIND(PHI,18,5,1,4,NRE)
      GO TO 11
      5 PHIF=FIND(PHI,18,5,1,5,NRE)
      GO TO 11

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FUNCTION PHIF

74/74 OPT=1

FTN 4.2+74351

04/03/75 13.35.26.

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60      6 IF (P-1.7) 8,7,10
        7 PHIF=FINO(PHI,18,5,1,5,NRE)
        GO TO 11
        8 DC 9 JJ=1,3
        K=JJ+2
        9 X(2,JJ)=FINO(PHI,18,5,1,K,NRE)
        PHIF=FINO(X,2,3,1,2,P)
        GO TO 11
65      10 WRITE (6,100) P,NRE
        CALL EXIT
        11 RETURN
        END

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PHIF 59
PHIF 60
PHIF 61
PHIF 62
PHIF 63
PHIF 64
PHIF 65
PHIF 66
PHIF 67
PHIF 68
PHIF 69
PHIF 70

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      SUBROUTINE PIPE(N,IPIPE,NDEBUG,IDEFLT,MY,TME,TX,AONE,BONE,CONE, PIPE      2
      1   ATWO,BTWO,CTWO,MAXPIP) PIPE      3
C PIPE SUBROUTINE CALCULATES SODIUM, PIPE WALL AND INSULATION TEMPERAT- PIPE      4
C URES FOR INITIAL CONDITIONS AND SODIUM AND PIPE WALL TEMPERATURES AS PIPE      5
C FUNCTIONS OF TIME FOR CONSTANT AMBIENT TEMPERATURE. PIPE      6
5  C LIST OF SYMBOLS FOR PIPE AND OTHER SUBROUTINES AND MAIN PROGRAM.... PIPE      7
C PIPE      8
C PIPE      9
C A      NODE HEAT TRANSFER SURFACE AREA/3600.,SQFT-HR/SEC. PIPE      10
10 C AONE  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      11
C ATWC  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      12
C AJ    NODE HEAT TRANSFER SURFACE AT INSULATION SURFACE/3600, PIPE      13
C       SQFT-HR/SEC. PIPE      14
C BONE  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      15
15 C BTWO  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      16
C C     SPECIFIC HEAT,BTU/(LB-F) PIPE      17
C CONE  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      18
C CTWO  COEFFICIENT FOR SECOND DEG. POLYNOMIAL INTERPOLATION. PIPE      19
C DELTAX NODE LENGTH,FT. PIPE      20
20 C DELTME INTEGRATION TIME STEP,SEC. PIPE      21
C DVRA  3600*ID/FLW AREA FOR REYNOLDS NO., SEC/(FT-HR) PIPE      22
C DTAU  TIME STEP IN MAIN PROGRAM,SEC. PIPE      23
C HCOUT CONVECTION HEAT TRANSFER COEFFICIENT AT INSULATION OUTSIDE PIPE      24
C       SURFACE,BTU/(HR-SQFT-F), PIPE      25
25 C HI    SODIUM FILM COEFFICIENT,BTU/(HR-SQFT-F). PIPE      26
C HFOUT  RADIATION HEAT TRANSFER COEFFICIENT TO AMBIENT FROM PIPE      27
C       INSULATION SURFACE,BTU/(HR-SQFT-F). PIPE      28
C I      RADIAL NODE LOCATION.... PIPE      29
C       I=1 SODIUM OR SODIUM TO PIPE WALL NODE. PIPE      30
30 C       I=2 PIPE WALL OR PIPE WALL NODE TO OUTSIDE PIPE. PIPE      31
C       I=3 INSULATION INSIDE SURFACE TO AVG. DIA. PIPE      32
C ICALC  COUNTS NUMBER OF TIMES TRANSIENT CALCULATIONS MADE IN PIPE      33
C       PIPE SUBROUTINE. PIPE      34
C ID     PIPE ID,IN. PIPE      35
35 C IDEFLT DESIGNATES SOURCE OF INPUT DATA AND PUNCHED OUTPUT CONTROL PIPE      36
C       IDEFLT=0 GET BASIC INPUTS FROM INPUT DATA DECK AND PIPE      37
C       BY-PASS PUNCHED OUTPUT. PIPE      38
C       IDEFLT=1 GET BASIC INPUTS FROM INPUT DATA DECK AND PIPE      39
C       PUNCH OUT DIMENSIONAL CONSTANTS AND INITIAL PIPE      40
40 C       VALUES. PIPE      41
C       IDEFLT=2 USE DEFAULT INPUT DATA VALUES AND BY-PASS PIPE      42
C       PUNCHED OUTPUT. PIPE      43
C       IDEFLT=3 USE DEFAULT DIMENSIONAL CONSTANTS AND PIPE      44
C       CALCULATE INITIAL VALUES AND PUNCH THEM OUT PIPE      45
45 C       IDEFLT=4 USE DEFAULT DIMENSIONAL CONSTANTS, CALCULA- PIPE      46
C       TE INITIAL VALUES BUT BY-PASS ALL PUNCHED PIPE      47
C       OUTPUT. PIPE      48
C INDEX  LEG NUMBER FOR FIRST LEG IN A SERIES OF CONTINUING PIPE PIPE      49
C       LEGS. PIPE      50
50 C IPIPE  LEG IDENTIFICATION NUMBER. PIPE      51
C IZ     AN ARRAY FOR INTEGER DIMENSIONAL CONSTANTS PUNCHED CARD PIPE      52
C       OUTPUT. IZ IS EQUIVALENT TO BLOCK COMMON /PIPE2/. PIPE      53
C       FOR EXAMPLE.... PIPE      54
C       (IZ(I,1),I=1,53) ARE VALUES FOR JEND. PIPE      55
55 C       (IZ(I,3),I=1,53) ARE VALUES FOR NODES. PIPE      56
C J      AXIAL NODAL POINT PIPE      57
C JEND  NODAL POINT NUMBER AT END OF PIPE LEG. PIPE      58

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	C	JTOP	NODAL POINT NO. AT END OF PIPE LEG.	PIPE	59
	C	JTYP	TYPE OF JUNCTION AT START OF PIPE LEG....	PIPE	60
60	C		JTYP=0 LEG CONNECTS TO A COMPONENT.	PIPE	61
	C		JTYP=1 LEG IS CONTINUING.	PIPE	62
	C	KINSUL	INSULATION THERMAL CONDUCTIVITY,BTU/(HR-FT-F)	PIPE	63
	C	KH	THERMAL CONDUCTIVITY,BTU/(HR-FT-F)	PIPE	64
	C	LNTH	PIPE LEG LENGTH,FT.	PIPE	65
65	C	MAXPIP	TOTAL NUMBER OF LEGS IN THE SYSTEM BEING MODELED.	PIPE	66
	C	MAXSTP	MAXIMUM ALLOWABLE INTEGRATION TIME STEP,SEC.	PIPE	67
	C	MEND	LEG NUMBER FOR LAST LEG IN A SERIES OF CONTINUING PIPE LEGS.	PIPE	68
	C			PIPE	69
	C	N	PIPE SUBROUTINE ARGUMENT....	PIPE	70
70	C		N=1 PERFORM INITIAL VALUES CALCULATIONS.	PIPE	71
	C		N=2 PERFORM TRANSIENT CALCULATIONS.	PIPE	72
	C		N=3 INITIALIZE INTERPOLATION COEFFICIENTS.	PIPE	73
	C	NCALC	CONTROL INTEGER FOR FREQUENCY OF DEBUG REPORTING IN THE PIPE SUBROUTINE.	PIPE	74
75	C	NODEBUG	WRITE CONTROL FOR COMPLETE TEMPERATURE DATA IN PIPE SUBROUTINE.	PIPE	75
	C			PIPE	77
	C		NODEBUG=0 REPORTS BY-PASSED.	PIPE	78
	C		NODEBUG=K REPORT EVERY K CALCULATIONS IN PIPE.	PIPE	79
80	C	NINIT	COUNTS ITERATIONS FOR INITIAL CONDITIONS.	PIPE	80
	C	NODES	NUMBER OF AXIAL NODES IN A LEG.	PIPE	81
	C	NUNO	NUSSELT NUMBER.	PIPE	82
	C	OD	PIPE OD,IN.	PIPE	83
	C	PENO	PECLET NUMBER.	PIPE	84
A-17	C	PHIS	EDDY DIFFUSIVITY CORRECTOR FUNCTION FOR PSIS.	PIPE	85
85	C	PIOVR4	PI/4.	PIPE	86
	C	PRND	PRANDTL NUMBER.	PIPE	87
	C	PSIS	CORRECTOR ON PECLET NUMBER IN MODIFIED LYONS EQUATION.	PIPE	88
	C		CORRECTOR BY THE METHOD OF DWYER,AICHE J,9,P261,1963.	PIPE	89
90	C	RENO	REYNOLDS NUMBER.	PIPE	90
	C	RESIS	HEAT TRANSFER RESISTANCE TERM,FT.	PIPE	91
	C	RESIS4	HEAT TRANSFER RESISTANCE TERM FOR INSULATION,FT.	PIPE	92
	C	RHO	DENSITY,LB/CUFT.	PIPE	93
	C	START	PRECEEDING TIME-ONE STEP BACK ON TME,SEC.	PIPE	94
	C	START2	PREVIOUS TIME-TWO STEPS BACK ON TME,SEC.	PIPE	95
95	C	TAU1	LIMITING TIME STEP FOR STABILITY OF PIPE EQUATION,SEC.	PIPE	96
	C	TAU2	LIMITING TIME STEP FOR STABILITY OF SODIUM EQUATIONS,SEC.	PIPE	97
	C	TBAR1	VOLUME AVERAGE SODIUM TEMPERATURE,F.	PIPE	98
	C	TBAR2	VOLUME AVERAGE PIPE WALL TEMPERATURE,F.	PIPE	99
	C	TCELL	AMBIENT TEMPERATURE OF SPACE AROUND THE PIPE LEG,F.	PIPE	100
100	C	TME	TIME IN MAIN PROGRAM,SEC.	PIPE	101
	C	TIN	COOLANT TEMP. AT START OF PIPE,F.	PIPE	102
	C	TINSUL	INSULATION NODE INITIAL TEMPERATURE,F.	PIPE	103
	C	TISAV	COOLANT TEMP. AT START OF PIPE AT PRECEEDING TIME OF MAIN PROGRAM,F.	PIPE	104
	C			PIPE	105
105	C	TME	TIME IN PIPE SUBROUTINE,SEC.	PIPE	105
	C	TM1	PRECEEDING TIME OF MAIN PROGRAM,SEC.	PIPE	107
	C	TOSAV	COOLANT TEMP. AT END OF PIPE AT PRECEEDING TIME OF MAIN PROGRAM,F.	PIPE	108
	C			PIPE	109
	C	TOUT	COOLANT TEMP. AT END OF PIPE,F.	PIPE	110
110	C	TSAV1A	COOLANT TEMPERATURE AT END OF PIPE AT PRECEEDING TIME,TME,F.	PIPE	111
	C			PIPE	112
	C	TSAV1B	COOLANT TEMPERATURE AT START OF PIPE AT PRECEEDING TIME,TME,F.	PIPE	113
	C			PIPE	114
	C	TSAV2A	COOLANT TEMPERATURE AT END OF PIPE AT PREVIOUS TIME-TWO	PIPE	115

115	C	STEPS BACK ON TME,F.	PIPE	116
	C	TSV2B COOLANT TEMPERATURE AT START OF PIPE AT PREVIOUS TIME-TWO	PIPE	117
	C	STEPS BACK ON TME,F.	PIPE	118
	C	TSURF INSULATION SURFACE NODE INITIAL TEMPERATURE,F.	PIPE	119
	C	TX TEMPERATURE,F.	PIPE	120
120	C	UA PRODUCT OF OVERALL U AND SURFACE,BTU/(SEC-F)	PIPE	121
	C	UAPA UA PRODUCT FOR HEAT TRANSFER FROM PIPE NODE TO AMBIENT, BTU/(SEC-F)	PIPE	122
	C	VOLNA VOLUME OF SODIUM NODE,CUFT.	PIPE	123
	C	WRATE SODIUM FLOW RATE,LB/SEC. (AS USED IN PIPE SUBROUTINE)	PIPE	124
125	C	WSAV FLOW RATE AT PRECEDING TIME OF MAIN PROG.,LB/SEC.	PIPE	125
	C	WTC HEAT STORAGE TERM,BTU/F.	PIPE	126
	C	WTPIPE WEIGHT OF PIPE WALL NODE,LBS.	PIPE	127
	C	WX SODIUM FLOW RATE,LB/SEC. (AS USED IN MAIN PROGRAM)	PIPE	128
	C	WY SODIUM FLOW RATE,LB/SEC. (AS USED IN PIPE SUBROUTINE)	PIPE	129
130	C	XD1 PIPE ID,FT.	PIPE	130
	C	XD2 PIPE OD,FT.	PIPE	131
	C	XD3 INSULATION ID,FT.	PIPE	132
	C	XD4 INSULATION OD,FT.	PIPE	133
	C	XGAP GAS GAP THICKNESS BETWEEN PIPE AND INSULATION,IN.	PIPE	134
135	C	XINSUL INSULATION THICKNESS,IN.	PIPE	135
	C	XNODES REAL NO. VALUE OF NUMBER OF AXIAL NODES.	PIPE	136
	C	XT1 TEMPORARY SYMBOL FOR COOLANT TEMP.,F.	PIPE	137
	C	XT11 TEMPORARY SYMBOL FOR COOLANT TEMP.,F.	PIPE	138
	C	XT2 TEMPORARY SYMBOL FOR PIPE WALL TEMP.,F.	PIPE	139
140	C	XT22 TEMPORARY SYMBOL FOR PIPE WALL TEMP.,F.	PIPE	140
	C	Y AN ARRAY FOR DIMENSIONAL CONSTANTS AND INITIAL VALUES	PIPE	141
	C	PUNCHED CARD OUTPUT. Y IS EQUIVALENCED TO LABELED COMMON	PIPE	142
	C	/PIPE3/.	PIPE	143
	C	FOR EXAMPLE...	PIPE	144
145	C	(Y(I,J),I=1,53,J=1,2) ARE VALUES FOR A.	PIPE	145
	C	(Y(I,21),I=1,53) ARE VALUES FOR XNODES.	PIPE	146
	C	Z AN ARRAY FOR DIMENSIONAL CONSTANTS AND INITIAL VALUES	PIPE	147
	C	PUNCHED CARD OUTPUT. Z IS EQUIVALENCED TO LABELED COMMON	PIPE	148
	C	/PIPE1/.	PIPE	149
150	C	FOR EXAMPLE...	PIPE	150
	C	(Z(I,1),I=1,53) ARE VALUES FOR ID.	PIPE	151
	C	(Z(I,10),I=1,53) ARE VALUES FOR XINSUL.	PIPE	152
	C		PIPE	153
	C		PIPE	154
155	C	COMMON/PIPE1/ ID(53),KINSUL(53),LNTH(53),MAXSTP(53),OD(53),	PIPE	155
	1	TCELL(53),TINSUL(53),TSURF(53),XGAP(53),XINSUL(53)	PIPE	156
	C	COMMON/PIPE2/JEND(53),JTYPE(53),NODES(53)	PIPE	157
	C	COMMON/PIPE3/ A(2,53),C(2,53),DELTA(53),DOVRA(53),RESIS(3,53),	PIPE	158
	1	RHO1(53),UA(2,53),UAPA(53),UXX(53),UY(53),VOLNA(53)	PIPE	159
	2	,WTC(2,53),WTPIPE(53),XD1(53),XNODES(53)	PIPE	160
160	C	DIMENSION AONE(53),ATWO(53),BONE(53),BTWO(53),	PIPE	161
	1	CONE(53),CTWO(53),ICALC(53),NCALC(53),	PIPE	162
	2	START(53),START2(53),TME(53),TSAV1A(53),	PIPE	163
	3	TSV1B(53),TSV2A(53),TSV2B(53),TX(2, 9,53),	PIPE	164
	+	WY(53)	PIPE	165
165	C	DIMENSION IZ(53,3),Y(53,21),Z(53,10)	PIPE	166
	C	EQUIVALENCE(ID,Z),(JEND,IZ),(A,Y)	PIPE	167
	C	EQUIVALENCE(OD,TSV1A),(ID,TSV1B),(LNTH,TSV2A),	PIPE	168
	1	(XINSUL,TSV2B),(TINSUL,START),(TSURF,START2),	PIPE	169
	2	(XGAP,ICALC),(NODES,NCALC)	PIPE	170
170	C	REAL ID,KINSUL,LNTH,MAXSTP	PIPE	171
	C	DATA PI0VR4/.785398/,PI/3.14159/	PIPE	172

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230      X 0.      , 0.      , 0.      , 0.      , PIPE      230
      X 0.      , 0.      , 0.      , 0.      , PIPE      231
      X 0.      , 0.      , 0.      , 0.      , PIPE      232
      X 0.      , 0.      , 0.      , 0.      , PIPE      233
      X 0.      , 0.      , 0.      , 0.      , PIPE      234
      X 0.      , 0.      , 0.      , 0.      , PIPE      235
235      X 0.      , 0.      , 0.      , 0.      , PIPE      236
      X 0.      , /      , PIPE      237
      DATA (Z(I, 5), I=1, 53)/
      X .16000000E+02, .16000000E+02, .16000000E+02, .28000000E+02, PIPE      238
      X .28000000E+02, .28000000E+02, .86250000E+01, .35000000E+01, PIPE      239
240      X .35000000E+01, .35000000E+01, 0.      , 0.      , PIPE      240
      X 0.      , 0.      , 0.      , 0.      , PIPE      241
      X 0.      , 0.      , 0.      , 0.      , PIPE      242
      X 0.      , 0.      , 0.      , 0.      , PIPE      243
      X 0.      , 0.      , 0.      , 0.      , PIPE      244
245      X 0.      , 0.      , 0.      , 0.      , PIPE      245
      X 0.      , 0.      , 0.      , 0.      , PIPE      246
      X 0.      , 0.      , 0.      , 0.      , PIPE      247
      X 0.      , 0.      , 0.      , 0.      , PIPE      248
      X 0.      , 0.      , 0.      , 0.      , PIPE      249
      X 0.      , 0.      , 0.      , 0.      , PIPE      250
250      X 0.      , 0.      , 0.      , 0.      , PIPE      251
      X 0.      , /      , PIPE      252
      DATA (Z(I, 6), I=1, 53)/
      X .10000000E+03, .10000000E+03, .10000000E+03, .10000000E+03, PIPE      253
      X .10000000E+03, .10000000E+03, .10000000E+03, .10000000E+03, PIPE      254
255      X .10000000E+03, .10000000E+03, 0.      , 0.      , PIPE      255
      X 0.      , 0.      , 0.      , 0.      , PIPE      256
      X 0.      , 0.      , 0.      , 0.      , PIPE      257
      X 0.      , 0.      , 0.      , 0.      , PIPE      258
      X 0.      , 0.      , 0.      , 0.      , PIPE      259
260      X 0.      , 0.      , 0.      , 0.      , PIPE      260
      X 0.      , 0.      , 0.      , 0.      , PIPE      261
      X 0.      , 0.      , 0.      , 0.      , PIPE      262
      X 0.      , 0.      , 0.      , 0.      , PIPE      263
      X 0.      , 0.      , 0.      , 0.      , PIPE      264
      X 0.      , 0.      , 0.      , 0.      , PIPE      265
265      X 0.      , 0.      , 0.      , 0.      , PIPE      266
      X 0.      , /      , PIPE      267
      DATA (Z(I, 7), I=1, 53)/
      X .58450528E+03, .58450528E+03, .58450528E+03, .59698386E+03, PIPE      268
      X .59698386E+03, .59698386E+03, .56572087E+03, .53243975E+03, PIPE      269
270      X .53243975E+03, .53243975E+03, 0.      , 0.      , PIPE      270
      X 0.      , 0.      , 0.      , 0.      , PIPE      271
      X 0.      , 0.      , 0.      , 0.      , PIPE      272
      X 0.      , 0.      , 0.      , 0.      , PIPE      273
      X 0.      , 0.      , 0.      , 0.      , PIPE      274
275      X 0.      , 0.      , 0.      , 0.      , PIPE      275
      X 0.      , 0.      , 0.      , 0.      , PIPE      276
      X 0.      , 0.      , 0.      , 0.      , PIPE      277
      X 0.      , 0.      , 0.      , 0.      , PIPE      278
      X 0.      , 0.      , 0.      , 0.      , PIPE      279
      X 0.      , 0.      , 0.      , 0.      , PIPE      280
280      X 0.      , 0.      , 0.      , 0.      , PIPE      281
      X 0.      , /      , PIPE      282
      DATA (Z(I, 8), I=1, 53)/
      X .22492235E+03, .22492235E+03, .22492235E+03, .22937383E+03, PIPE      283
      X .22937383E+03, .22937383E+03, .21854242E+03, .20805760E+03, PIPE      284
285      X .20805760E+03, .20805760E+03, 0.      , 0.      , PIPE      285

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SUBROUTINE PIPE

74/74 OPT=1

FTN 4.2+74351

04/03/75 13.35.29.

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	X 0.	, 0.	, 0.	, 0.	, PIPE	287
	X 0.	, 0.	, 0.	, 0.	, PIPE	288
	X 0.	, 0.	, 0.	, 0.	, PIPE	289
	X 0.	, 0.	, 0.	, 0.	, PIPE	290
290	X 0.	, 0.	, 0.	, 0.	, PIPE	291
	X 0.	, 0.	, 0.	, 0.	, PIPE	292
	X 0.	, 0.	, 0.	, 0.	, PIPE	293
	X 0.	, 0.	, 0.	, 0.	, PIPE	294
	X 0.	, 0.	, 0.	, 0.	, PIPE	295
295	X 0.	, 0.	, 0.	, 0.	, PIPE	296
	X 0.	/			, PIPE	297
	DATA (Z(I, 9), I=1, 53)/				, PIPE	298
	X .10000000E+01,	.10000000E+01,	.10000000E+01,	.10000000E+01,	, PIPE	299
	X .10000000E+01,	.10000000E+01,	.10000000E+01,	.10000000E+01,	, PIPE	300
300	X .10000000E+01,	.10000000E+01,	0.	0.	, PIPE	301
	X 0.	, 0.	, 0.	, 0.	, PIPE	302
	X 0.	, 0.	, 0.	, 0.	, PIPE	303
	X 0.	, 0.	, 0.	, 0.	, PIPE	304
	X 0.	, 0.	, 0.	, 0.	, PIPE	305
305	X 0.	, 0.	, 0.	, 0.	, PIPE	306
	X 0.	, 0.	, 0.	, 0.	, PIPE	307
	X 0.	, 0.	, 0.	, 0.	, PIPE	308
	X 0.	, 0.	, 0.	, 0.	, PIPE	309
	X 0.	, 0.	, 0.	, 0.	, PIPE	310
310	X 0.	, 0.	, 0.	, 0.	, PIPE	311
	X 0.	/			, PIPE	312
	DATA (Z(I, 10), I=1, 53)/				, PIPE	313
	X .30000000E+01,	.30000000E+01,	.30000000E+01,	.30000000E+01,	, PIPE	314
	X .30000000E+01,	.30000000E+01,	.30000000E+01,	.30000000E+01,	, PIPE	315
315	X .30000000E+01,	.30000000E+01,	0.	0.	, PIPE	316
	X 0.	, 0.	, 0.	, 0.	, PIPE	317
	X 0.	, 0.	, 0.	, 0.	, PIPE	318
	X 0.	, 0.	, 0.	, 0.	, PIPE	319
	X 0.	, 0.	, 0.	, 0.	, PIPE	320
320	X 0.	, 0.	, 0.	, 0.	, PIPE	321
	X 0.	, 0.	, 0.	, 0.	, PIPE	322
	X 0.	, 0.	, 0.	, 0.	, PIPE	323
	X 0.	, 0.	, 0.	, 0.	, PIPE	324
	X 0.	, 0.	, 0.	, 0.	, PIPE	325
325	X 0.	, 0.	, 0.	, 0.	, PIPE	326
	X 0.	/			, PIPE	327
	DATA (Y(I, 1), I=1, 53)/				, PIPE	328
	X .20793944E-01,	.21816597E-01,	.20793944E-01,	.21816597E-01,	, PIPE	329
	X .20793944E-01,	.21816597E-01,	.12385464E-01,	.12726348E-01,	, PIPE	330
330	X .12385464E-01,	.12726348E-01,	.12385464E-01,	.12726348E-01,	, PIPE	331
	X .54411957E-02,	.58802547E-02,	.13944442E-02,	.15907935E-02,	, PIPE	332
	X .13944442E-02,	.15907935E-02,	.13944442E-02,	.15907935E-02,	, PIPE	333
	X 0.	, 0.	, 0.	, 0.	, PIPE	334
	X 0.	, 0.	, 0.	, 0.	, PIPE	335
335	X 0.	, 0.	, 0.	, 0.	, PIPE	336
	X 0.	, 0.	, 0.	, 0.	, PIPE	337
	X 0.	, 0.	, 0.	, 0.	, PIPE	338
	X 0.	, 0.	, 0.	, 0.	, PIPE	339
	X 0.	, 0.	, 0.	, 0.	, PIPE	340
340	X 0.	, 0.	, 0.	, 0.	, PIPE	341
	X 0.	/			, PIPE	342
	DATA (Y(I, 2), I=1, 53)/				, PIPE	343

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345      X 0.      , 0.      , 0.      , 0.      , PIPE      344
      X 0.      , 0.      , 0.      , 0.      , PIPE      345
      X 0.      , 0.      , 0.      , 0.      , PIPE      346
      X 0.      , 0.      , 0.      , 0.      , PIPE      347
      X 0.      , 0.      , 0.      , 0.      , PIPE      348
      X 0.      , 0.      , 0.      , 0.      , PIPE      349
350      X 0.      , 0.      , 0.      , 0.      , PIPE      350
      X 0.      , 0.      , 0.      , 0.      , PIPE      351
      X 0.      , 0.      , 0.      , 0.      , PIPE      352
      X 0.      , 0.      , 0.      , 0.      , PIPE      353
      X 0.      , 0.      , 0.      , 0.      , PIPE      354
355      X 0.      , 0.      , 0.      , 0.      , PIPE      355
      X 0.      , 0.      , 0.      , 0.      , PIPE      356
      X 0.      , /      , PIPE      357
      DATA (Y(I, 3), I=1, 53)/
      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      358
      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      359
360      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      360
      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      361
      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      362
      X .30060000E+00, .13625000E+00, .30060000E+00, .13625000E+00, PIPE      363
      X 0.      , 0.      , 0.      , 0.      , PIPE      364
      X 0.      , 0.      , 0.      , 0.      , PIPE      365
365      X 0.      , 0.      , 0.      , 0.      , PIPE      365
      X 0.      , 0.      , 0.      , 0.      , PIPE      367
      X 0.      , 0.      , 0.      , 0.      , PIPE      368
      X 0.      , 0.      , 0.      , 0.      , PIPE      369
      X 0.      , 0.      , 0.      , 0.      , PIPE      370
370      X 0.      , 0.      , 0.      , 0.      , PIPE      371
      X 0.      , /      , PIPE      372
      DATA (Y(I, 4), I=1, 53)/
      X 0.      , 0.      , 0.      , 0.      , PIPE      373
      X 0.      , 0.      , 0.      , 0.      , PIPE      374
375      X 0.      , 0.      , 0.      , 0.      , PIPE      375
      X 0.      , 0.      , 0.      , 0.      , PIPE      376
      X 0.      , 0.      , 0.      , 0.      , PIPE      377
      X 0.      , 0.      , 0.      , 0.      , PIPE      378
      X 0.      , 0.      , 0.      , 0.      , PIPE      379
380      X 0.      , 0.      , 0.      , 0.      , PIPE      380
      X 0.      , 0.      , 0.      , 0.      , PIPE      381
      X 0.      , 0.      , 0.      , 0.      , PIPE      382
      X 0.      , 0.      , 0.      , 0.      , PIPE      383
      X 0.      , 0.      , 0.      , 0.      , PIPE      384
385      X 0.      , 0.      , 0.      , 0.      , PIPE      385
      X 0.      , 0.      , 0.      , 0.      , PIPE      386
      X 0.      , /      , PIPE      387
      DATA (Y(I, 5), I=1, 53)/
      X .18750000E+02, .18750000E+02, .18750000E+02, .62500000E+01, PIPE      388
      X .62500000E+01, .62500000E+01, .93750000E+01, .62500000E+01, PIPE      389
390      X .62500000E+01, .62500000E+01, 0.      , 0.      , PIPE      390
      X 0.      , 0.      , 0.      , 0.      , PIPE      392
      X 0.      , 0.      , 0.      , 0.      , PIPE      393
      X 0.      , 0.      , 0.      , 0.      , PIPE      394
395      X 0.      , 0.      , 0.      , 0.      , PIPE      395
      X 0.      , 0.      , 0.      , 0.      , PIPE      396
      X 0.      , 0.      , 0.      , 0.      , PIPE      397
      X 0.      , 0.      , 0.      , 0.      , PIPE      398
      X 0.      , 0.      , 0.      , 0.      , PIPE      399
      X 0.      , 0.      , 0.      , 0.      , PIPE      400

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400	X 0.	, 0.	, 0.	, 0.	, PIPE	401
	X 0.	/			PIPE	402
					PIPE	403
	DATA (Y(I, 6), I=1, 53)/				PIPE	404
	X .36068170E+04,	.36068170E+04,	.36068170E+04,	.20184939E+04,	PIPE	405
405	X .20184939E+04,	.20184939E+04,	.68918631E+04,	.17928279E+05,	PIPE	406
	X .17928279E+05,	.17928279E+05,	0.	, 0.	PIPE	407
	X 0.	, 0.	, 0.	, 0.	PIPE	408
	X 0.	, 0.	, 0.	, 0.	PIPE	409
	X 0.	, 0.	, 0.	, 0.	PIPE	410
410	X 0.	, 0.	, 0.	, 0.	PIPE	411
	X 0.	, 0.	, 0.	, 0.	PIPE	412
	X 0.	, 0.	, 0.	, 0.	PIPE	413
	X 0.	, 0.	, 0.	, 0.	PIPE	414
	X 0.	, 0.	, 0.	, 0.	PIPE	415
415	X 0.	, 0.	, 0.	, 0.	PIPE	416
	X 0.	, 0.	, 0.	, 0.	PIPE	417
	X 0.	/			PIPE	418
	DATA (Y(I, 7), I=1, 53)/				PIPE	419
	X .15435982E-01,	.15811018E-01,	.10276712E+00,	.15435982E-01,	PIPE	420
420	X .15811018E-01,	.10276712E+00,	.15435982E-01,	.15811018E-01,	PIPE	421
	X .10276712E+00,	.15518465E-01,	.15730575E-01,	.11119521E+00,	PIPE	422
	X .15518465E-01,	.15730575E-01,	.11119521E+00,	.15518465E-01,	PIPE	423
	X .15730575E-01,	.11119521E+00,	.13153080E-01,	.13673524E-01,	PIPE	424
	X .89375350E-01,	.86973081E-02,	.92896966E-02,	.63483885E-01,	PIPE	425
425	X .86973081E-02,	.92896966E-02,	.63483885E-01,	.86973081E-02,	PIPE	426
	X .92896966E-02,	.63483885E-01,	0.	, 0.	PIPE	427
	X 0.	, 0.	, 0.	, 0.	PIPE	428
	X 0.	, 0.	, 0.	, 0.	PIPE	429
	X 0.	, 0.	, 0.	, 0.	PIPE	430
430	X 0.	, 0.	, 0.	, 0.	PIPE	431
	X 0.	, 0.	, 0.	, 0.	PIPE	432
	X 0.	/			PIPE	433
	DATA (Y(I, 8), I=1, 53)/				PIPE	434
	X 0.	, 0.	, 0.	, 0.	PIPE	435
435	X 0.	, 0.	, 0.	, 0.	PIPE	436
	X 0.	, 0.	, 0.	, 0.	PIPE	437
	X 0.	, 0.	, 0.	, 0.	PIPE	438
	X 0.	, 0.	, 0.	, 0.	PIPE	439
	X 0.	, 0.	, 0.	, 0.	PIPE	440
440	X 0.	, 0.	, 0.	, 0.	PIPE	441
	X 0.	, 0.	, 0.	, 0.	PIPE	442
	X 0.	, 0.	, 0.	, 0.	PIPE	443
	X 0.	, 0.	, 0.	, 0.	PIPE	444
	X 0.	, 0.	, 0.	, 0.	PIPE	445
445	X 0.	, 0.	, 0.	, 0.	PIPE	446
	X 0.	, 0.	, 0.	, 0.	PIPE	447
	X 0.	/			PIPE	448
	DATA (Y(I, 9), I=1, 53)/				PIPE	449
	X 0.	, 0.	, 0.	, 0.	PIPE	450
450	X 0.	, 0.	, 0.	, 0.	PIPE	451
	X 0.	, 0.	, 0.	, 0.	PIPE	452
	X 0.	, 0.	, 0.	, 0.	PIPE	453
	X 0.	, 0.	, 0.	, 0.	PIPE	454
	X 0.	, 0.	, 0.	, 0.	PIPE	455
455	X 0.	, 0.	, 0.	, 0.	PIPE	456
	X 0.	, 0.	, 0.	, 0.	PIPE	457

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460 X 0. , 0. , 0. , 0. , PIPE 458
 X 0. , 0. , 0. , 0. , PIPE 459
 X 0. , 0. , 0. , 0. , PIPE 460
 X 0. , 0. , 0. , 0. , PIPE 461
 X 0. , 0. , 0. , 0. , PIPE 462
 X 0. / PIPE 463
 DATA (Y(I,10),I=1,53)/ PIPE 464
 465 X .51389150E+02, .51389150E+02, .51389150E+02, .51389150E+02, PIPE 465
 X .51389150E+02, .51389150E+02, .51389150E+02, .51389150E+02, PIPE 466
 X .51389150E+02, .51389150E+02, 0. , 0. , PIPE 467
 X 0. , 0. , 0. , 0. , PIPE 468
 X 0. , 0. , 0. , 0. , PIPE 469
 470 X 0. , 0. , 0. , 0. , PIPE 470
 X 0. , 0. , 0. , 0. , PIPE 471
 X 0. , 0. , 0. , 0. , PIPE 472
 X 0. , 0. , 0. , 0. , PIPE 473
 X 0. , 0. , 0. , 0. , PIPE 474
 475 X 0. , 0. , 0. , 0. , PIPE 475
 X 0. , 0. , 0. , 0. , PIPE 476
 X 0. , 0. , 0. , 0. , PIPE 477
 X 0. / PIPE 478
 DATA (Y(I,11),I=1,53)/ PIPE 479
 480 X .13972398E+02, .15907053E-01, .13972398E+02, .15907053E-01, PIPE 480
 X .13972398E+02, .15907053E-01, .64279684E+01, .85764420E-02, PIPE 481
 X .64279684E+01, .85764420E-02, .64279684E+01, .85764420E-02, PIPE 482
 X .42368430E+01, .49298935E-02, .14453925E+01, .18777033E-02, PIPE 483
 X .14453925E+01, .18777033E-02, .14453925E+01, .18777033E-02, PIPE 484
 485 X 0. , 0. , 0. , 0. , PIPE 485
 X 0. , 0. , 0. , 0. , PIPE 486
 X 0. , 0. , 0. , 0. , PIPE 487
 X 0. , 0. , 0. , 0. , PIPE 488
 X 0. , 0. , 0. , 0. , PIPE 489
 490 X 0. , 0. , 0. , 0. , PIPE 490
 X 0. , 0. , 0. , 0. , PIPE 491
 X 0. , 0. , 0. , 0. , PIPE 492
 X 0. / PIPE 493
 DATA (Y(I,12),I=1,53)/ PIPE 494
 495 X 0. , 0. , 0. , 0. , PIPE 495
 X 0. , 0. , 0. , 0. , PIPE 496
 X 0. , 0. , 0. , 0. , PIPE 497
 X 0. , 0. , 0. , 0. , PIPE 498
 X 0. , 0. , 0. , 0. , PIPE 499
 500 X 0. , 0. , 0. , 0. , PIPE 500
 X 0. , 0. , 0. , 0. , PIPE 501
 X 0. , 0. , 0. , 0. , PIPE 502
 X 0. , 0. , 0. , 0. , PIPE 503
 X 0. , 0. , 0. , 0. , PIPE 504
 505 X 0. , 0. , 0. , 0. , PIPE 505
 X 0. , 0. , 0. , 0. , PIPE 506
 X 0. , 0. , 0. , 0. , PIPE 507
 X 0. / PIPE 508
 DATA (Y(I,13),I=1,53)/ PIPE 509
 510 X .73436626E-02, .73436626E-02, .73436626E-02, .38404939E-02, PIPE 510
 X .38404939E-02, .38404939E-02, .23788332E-02, .97548826E-03, PIPE 511
 X .97548826E-03, .97548826E-03, 0. , 0. , PIPE 512
 X 0. , 0. , 0. , 0. , PIPE 513
 X 0. , 0. , 0. , 0. , PIPE 514

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515	X 0.	, 0.	, 0.	, 0.	, PIPE	515
	X 0.	, 0.	, 0.	, 0.	, PIPE	516
	X 0.	, 0.	, 0.	, 0.	, PIPE	517
	X 0.	, 0.	, 0.	, 0.	, PIPE	518
	X 0.	, 0.	, 0.	, 0.	, PIPE	519
520	X 0.	, 0.	, 0.	, 0.	, PIPE	520
	X 0.	, 0.	, 0.	, 0.	, PIPE	521
	X 0.	, 0.	, 0.	, 0.	, PIPE	522
	X 0.	/			, PIPE	523
	DATA (Y(I,14),I=1,53)/				, PIPE	524
525	X .97245882E-03,	.97245882E-03,	.97245882E-03,	.25120334E-03,	, PIPE	525
	X .25120334E-03,	.25120334E-03,	.11137468E-03,	.21989576E-04,	, PIPE	526
	X .21989576E-04,	.21989576E-04,	0.	, 0.	, PIPE	527
	X 0.	, 0.	, 0.	, 0.	, PIPE	528
	X 0.	, 0.	, 0.	, 0.	, PIPE	529
	X 0.	, 0.	, 0.	, 0.	, PIPE	530
530	X 0.	, 0.	, 0.	, 0.	, PIPE	531
	X 0.	, 0.	, 0.	, 0.	, PIPE	532
	X 0.	, 0.	, 0.	, 0.	, PIPE	533
	X 0.	, 0.	, 0.	, 0.	, PIPE	534
	X 0.	, 0.	, 0.	, 0.	, PIPE	535
535	X 0.	, 0.	, 0.	, 0.	, PIPE	536
	X 0.	, 0.	, 0.	, 0.	, PIPE	537
	X 0.	/			, PIPE	538
	DATA (Y(I,15),I=1,53)/				, PIPE	539
A-25 540	X .71287685E-01,	.71287685E-01,	.71287685E-01,	.36119198E-01,	, PIPE	540
	X .36119198E-01,	.36119198E-01,	.24227336E-01,	.10831233E-01,	, PIPE	541
	X .10831233E-01,	.10831233E-01,	0.	, 0.	, PIPE	542
	X 0.	, 0.	, 0.	, 0.	, PIPE	543
	X 0.	, 0.	, 0.	, 0.	, PIPE	544
	X 0.	, 0.	, 0.	, 0.	, PIPE	545
545	X 0.	, 0.	, 0.	, 0.	, PIPE	546
	X 0.	, 0.	, 0.	, 0.	, PIPE	547
	X 0.	, 0.	, 0.	, 0.	, PIPE	548
	X 0.	, 0.	, 0.	, 0.	, PIPE	549
	X 0.	, 0.	, 0.	, 0.	, PIPE	550
550	X 0.	, 0.	, 0.	, 0.	, PIPE	551
	X 0.	, 0.	, 0.	, 0.	, PIPE	552
	X 0.	/			, PIPE	553
	DATA (Y(I,16),I=1,53)/				, PIPE	554
555	X .23783089E+02,	.23783089E+02,	.23783089E+02,	.25312808E+02,	, PIPE	555
	X .25312808E+02,	.25312808E+02,	.32569658E+01,	.32086181E+00,	, PIPE	556
	X .32086181E+00,	.32086181E+00,	0.	, 0.	, PIPE	557
	X 0.	, 0.	, 0.	, 0.	, PIPE	558
	X 0.	, 0.	, 0.	, 0.	, PIPE	559
	X 0.	, 0.	, 0.	, 0.	, PIPE	560
560	X 0.	, 0.	, 0.	, 0.	, PIPE	561
	X 0.	, 0.	, 0.	, 0.	, PIPE	562
	X 0.	, 0.	, 0.	, 0.	, PIPE	563
	X 0.	, 0.	, 0.	, 0.	, PIPE	564
	X 0.	, 0.	, 0.	, 0.	, PIPE	565
565	X 0.	, 0.	, 0.	, 0.	, PIPE	566
	X 0.	, 0.	, 0.	, 0.	, PIPE	567
	X 0.	/			, PIPE	568
	DATA (Y(I,17),I=1,53)/				, PIPE	569
570	X .36739113E+03,	.16001933E+03,	.36739113E+03,	.16001933E+03,	, PIPE	570
	X .36739113E+03,	.16001933E+03,	.39102159E+03,	.94304725E+02,	, PIPE	571

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X .33102159E+03, .34304725E+02, .39102159E+03, .94304725E+02, PIPE 572
X .50312235E+02, .36507498E+02, .43565380E+01, .64573867E+01, PIPE 573
X .49505380E+01, .64573867E+01, .49565380E+01, .64573867E+01, PIPE 574
X 0., 0., 0., 0., PIPE 575
X 0., 0., 0., 0., PIPE 576
X 0., 0., 0., 0., PIPE 577
X 0., 0., 0., 0., PIPE 578
X 0., 0., 0., 0., PIPE 579
X 0., 0., 0., 0., PIPE 580
X 0., 0., 0., 0., PIPE 581
X 0., 0., 0., 0., PIPE 582
X 0., 0., 0., 0., PIPE 583
DATA (Y(I,18),I=1,53)/ PIPE 584
X 0., 0., 0., 0., PIPE 585
X 0., 0., 0., 0., PIPE 586
X 0., 0., 0., 0., PIPE 587
X 0., 0., 0., 0., PIPE 588
X 0., 0., 0., 0., PIPE 589
X 0., 0., 0., 0., PIPE 590
X 0., 0., 0., 0., PIPE 591
X 0., 0., 0., 0., PIPE 592
X 0., 0., 0., 0., PIPE 593
X 0., 0., 0., 0., PIPE 594
X 0., 0., 0., 0., PIPE 595
X 0., 0., 0., 0., PIPE 596
X 0., 0., 0., 0., PIPE 597
X 0., 0., 0., 0., PIPE 598
DATA (Y(I,19),I=1,53)/ PIPE 599
X .11744538E+04, .11744538E+04, .11744538E+04, .69214477E+03, PIPE 600
X .69214477E+03, .69214477E+03, .26794494E+03, .47393664E+02, PIPE 601
X .47393664E+02, .47393664E+02, 0., 0., PIPE 602
X 0., 0., 0., 0., PIPE 603
X 0., 0., 0., 0., PIPE 604
X 0., 0., 0., 0., PIPE 605
X 0., 0., 0., 0., PIPE 606
X 0., 0., 0., 0., PIPE 607
X 0., 0., 0., 0., PIPE 608
X 0., 0., 0., 0., PIPE 609
X 0., 0., 0., 0., PIPE 610
X 0., 0., 0., 0., PIPE 611
X 0., 0., 0., 0., PIPE 612
X 0., 0., 0., 0., PIPE 613
DATA (Y(I,20),I=1,53)/ PIPE 614
X .12708333E+01, .12708333E+01, .12708333E+01, .22708333E+01, PIPE 615
X .22708333E+01, .22708333E+01, .66508333E+00, .25566667E+00, PIPE 616
X .25566667E+00, .25566667E+00, 0., 0., PIPE 617
X 0., 0., 0., 0., PIPE 618
X 0., 0., 0., 0., PIPE 619
X 0., 0., 0., 0., PIPE 620
X 0., 0., 0., 0., PIPE 621
X 0., 0., 0., 0., PIPE 622
X 0., 0., 0., 0., PIPE 623
X 0., 0., 0., 0., PIPE 624
X 0., 0., 0., 0., PIPE 625
X 0., 0., 0., 0., PIPE 626
X 0., 0., 0., 0., PIPE 627
X 0., 0., 0., 0., PIPE 628

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      DATA (Y(I,21),I=1,53)/
630      X .80000000E+01, .80000000E+01, .80000000E+01, .80000000E+01,
      X .80000000E+01, .80000000E+01, .80000000E+01, .80000000E+01,
      X .80000000E+01, .80000000E+01, 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
635      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
640      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      X 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
      DATA (IZ(I, 1),I=1,53)/
645      X 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      DATA (IZ(I, 2),I=1,53)/
650      X 0, 1, 1, 0, 1, 1, 0, 0, 1, 1, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      DATA (IZ(I, 3),I=1,53)/
655      X 8, 8, 8, 8, 8, 8, 8, 8, 8, 8, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
660      X 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
      C
      C
      GO TO(1,100,300),N
      C CALCULATE CONSTANTS WHICH ARE INDEPENDENT OF TIME.
665      1 J=IDEFLT+1
      I=IPIPE
      GO TO (2,2,8055,8050,8060),J
      2 TME(I)=0.
      UYY(I)=1.
670      C UYY SET TO 1. INITIALLY ONLY TO PREVENT DIVISION BY ZERO THE FIRST
      C TIME THE UOJEF SUBROUTINE IS ENTERED IN CASE THE DEFAULT UYY(I) =0.
      XNOD=S(I)=FLOAT(NODES(I))
      XD1(I)=ID(I)/12.
      XD2=JD(I)/12.
675      XD3=(OD(I)+2.*XGAP(I))/12.
      XD4=(OD(I)+2.*XGAP(I)+2.*XINSUL(I))/12.
      XAV=(XD1(I)+XD2)/2.
      RESIS(1,I)=ALOG(XAV/XD1(I))*XD1(I)/2.
      RESIS(2,I)=ALOG(XD2/XAV)*XD2/2.
680      XAV=(XD3+XD4)/2.
      RESIS(3,I)=ALOG(XAV/XD3)*XD2/2.
      RESIS4=ALOG(XD4/XAV)*XD4/2.
      DOVRA(I)=3600./(PI*DOVR+XD1(I))
      JEND(I)=NODES(I)+1
      PIPE 629
      PIPE 630
      PIPE 631
      PIPE 632
      PIPE 633
      PIPE 634
      PIPE 635
      PIPE 636
      PIPE 637
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      PIPE 672
      PIPE 673
      PIPE 674
      PIPE 675
      PIPE 676
      PIPE 677
      PIPE 678
      PIPE 679
      PIPE 680
      PIPE 681
      PIPE 682
      PIPE 683
      PIPE 684
      PIPE 685

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665      DELTAX(I)=LNTH(I)/FLOAT(NODES(I))
      A(1,I)=PI*XD1(I)/3600.*DELTAX(I)
      A(2,I)=PI*XD2/3600.*DELTAX(I)
      A3=PI*XD4/3600.*DELTAX(I)
      VOLNA(I)=PIOVR4*XD1(I)**2*DELTAX(I)
690      WTPICE(I)=PIOVR4*(XD2**2-XD1(I)**2)*490.*DELTAX(I)
      C USE 490 LB/CU FT AS DENSITY OF S/S PIPE WALL.
      C
      C CALCULATE INITIAL TEMPERATURES FOR 5 RADIAL NODES, INCLUDING A
      C CONSTANT AMBIENT TEMP. NODE. FOR SIMPLICITY, YET WITH REASONABLE
695      C ACCURACY, NEGLECT THE SMALL DIFFERENCES BETWEEN INITIAL SODIUM AND
      C PIPE WALL TEMPERATURES AND TEMPERATURE CHANGES WITH DISTANCE.
      C
      3 NINIT=1
      C
      C ITERATE FOR INITIAL TEMPERATURES OF INSULATION AND SURFACE NODAL
      C POINTS.
      C
      JTOP=JEND(I)
      DO 20 J=2,JTOP
705      TX(1,J,I)=TX(1,1,I)
      20 TX(2,J,I)=TX(1,1,I)
      TX(2,1,I)=TX(1,1,I)
      TSURF(I)=TCELL(I)+50.
      TINSUL(I)=.5*(TX(1,1,I)+TSURF(I))
      CALL UCODEF(TX,WY,I)
      UA3=KINSUL(I)/RESIS4*A3
      21 HROUT=.27*ABS(TSURF(I)-TCELL(I))**.25
      IF(TSURF(I).EQ.TCELL(I)) GO TO 23
      HROUT=.07329*((460.+TSURF(I))/100.)**4-((460.+TCELL(I))/100.)
715      1 **4)/(TSURF(I)-TCELL(I))
      GO TO 24
      23 HROUT=.2932E-8*(460.+TCELL(I))**3
      24 UA4=(HROUT+HROUT)*A3
      TINSUL(I)=(UA(2,I)*TX(1,1,I)+UA3*UA4*TCELL(I))/(UA3+UA4)
720      1 )/(UA(2,I)+UA3-UA3**2/(UA3+UA4))
      TSURF(I)=(UA3*TINSUL(I)+UA4*TCELL(I))/(UA3+UA4)
      IF(NINIT.EQ.7) GO TO 10
      NINIT=NINIT+1
      GO TO 21
725      10 CONTINUE
      C
      C CALCULATE CONSTANT HEAT TRANSFER RESISTANCE FACTORS FOR PIPE SURFACE
      C TO AMBIENT.
      C
730      UXX(I)=UA3*UA4
      UYY(I)=UA3+UA4
      UAPA(I)=UA(2,I)*UXX(I)/(UXX(I)+UYY(I)*UA(2,I))
      IF(I.NE.MAXPIP) RETURN
      C
735      C PUNCHED CARD OUTPUT IF CALLED FOR BY IDEFLT. BY-PASSED IF IDEFLT
      C EQUALS 0,2, OR 4.
      C
      M=IDEFLT+1
      GO TO(8050,8002,8050,8004,8050),M
740      8002 WRITE(6,8000)
      8000 FORMAT(1H1,"PUNCHED CARD OUTPUT IS AS FOLLOWS...."//)

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PIPE 686
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PIPE 741
PIPE 742

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74/74 OPT=1

FTN 4.2+74351

04/03/75 13.35.29.

	WRITE(6,8001)	PIPE	743
	8001 FORMAT (1X,"CONSTANTS AND INITIAL VALUES PUNCHED CARD OUTPUT.")	PIPE	744
745	PUNCH 8001	PIPE	745
	GC TO 8005	PIPE	746
	8004 WRITE(6,8000)	PIPE	747
	WRITE(6,8003)	PIPE	748
	8003 FORMAT (1X,"INITIAL VALUES ONLY PUNCHED CARD OUTPUT.")	PIPE	749
	PUNCH 8003	PIPE	750
750	8005 DO 8020 J=1,10	PIPE	751
	IF(IDEFLT.NE.3) GC TO 8006	PIPE	752
	GO TO(8020,8020,8020,8020,8006,8006,8006,8020,8020),J	PIPE	753
	8006 WRITE(6,8011) J	PIPE	754
	8011 FORMAT(6X,"DATA (Z(I,",I2,"),I=1,53)/")	PIPE	755
755	PUNCH 8011,J	PIPE	756
	WRITE(6,8012) (Z(M,J),M=1,52)	PIPE	757
	8012 FORMAT(5X,"X",E15.8," ",E15.8," ",E15.8," ",E15.8," ")	PIPE	758
	PUNCH 8012,(Z(M,J),M=1,52)	PIPE	759
	WRITE(6,8013) Z(53,J)	PIPE	760
760	8013 FORMAT(5X,"X",E15.8,"/")	PIPE	761
	PUNCH 8013,Z(53,J)	PIPE	762
	8020 CONTINUE	PIPE	763
	DO 8040 J=1,21	PIPE	764
	IF(IDEFLT.NE.3) GO TO 8032	PIPE	765
765	GO TO(8040,8040,8032,8032,8040,8040,8040,8040,8040,8032,8032,	PIPE	766
	1 8032,8032,8032,8032,8040,8032,8032,8040,8040,8040),J	PIPE	767
	8032 WRITE(6,8033) J	PIPE	768
	8033 FORMAT(6X,"DATA (Y(I,",I2,"),I=1,53)/")	PIPE	769
	PUNCH 8033,J	PIPE	770
770	WRITE(6,8012) (Y(M,J),M=1,52)	PIPE	771
	PUNCH 8012,(Y(M,J),M=1,52)	PIPE	772
	WRITE(6,8013) Y(53,J)	PIPE	773
	PUNCH 8013,Y(53,J)	PIPE	774
	8040 CONTINUE	PIPE	775
775	IF(IDEFLT.EQ.3) GO TO 8024	PIPE	776
	DO 8023 J=1,3	PIPE	777
	WRITE(6,8015) J	PIPE	778
	8015 FORMAT(6X,"DATA (IZ(I,",I2,"),I=1,53)/")	PIPE	779
	PUNCH 8015,J	PIPE	780
780	WRITE(6,8016) (IZ(M,J),M=1,48)	PIPE	781
	8016 FORMAT(5X,"X",I4," ",I4," ",I4," ",I4," ",I4," ",I4," ",I4," ",I4," "	PIPE	782
	1","I4," ",I4," ",I4," ",I4," ")	PIPE	783
	PUNCH 8016,(IZ(M,J),M=1,48)	PIPE	784
	WRITE(6,8017) (IZ(M,J),M=49,53)	PIPE	785
785	8017 FORMAT(5X,"X",I4," ",I4," ",I4," ",I4," ",I4," ")	PIPE	786
	PUNCH 8017,(IZ(M,J),M=49,53)	PIPE	787
	8023 CONTINUE	PIPE	788
	C	PIPE	789
	C NOTE THAT INITIAL FLOW RATE AND INLET COOLANT TEMP-	PIPE	790
790	C ERATURE DATA ARE PUNCHED OUT IN PIPE BUT THESE PUNCH-	PIPE	791
	C ED CARDS ARE TO BE INSERTED INTO THE MAIN PROGRAM	PIPE	792
	C DATA STATEMENT RATHER THAN IN THE PIPE SUBROUTINE.	PIPE	793
	C	PIPE	794
	8024 WRITE(6,8025)	PIPE	795
795	8025 FORMAT(5X,"DATA (WX(I),I=1,53)/")	PIPE	796
	PUNCH 8025	PIPE	797
	WRITE(6,8012) (WX(M),M=1,52)	PIPE	798
	PUNCH 8012 ,(WX(M),M=1,52)	PIPE	799

A-30

	WRITE(6,8013) WY(53)	PIPE	800
800	PUNCH 8013,WY(53)	PIPE	801
	WRITE(6,8030)	PIPE	802
	8030 FORMAT(5X,"DATA (TIV(I),I=1,53)/")	PIPE	803
	PUNCH 8030	PIPE	804
	WRITE(6,8012) (TX(1,1,M),M=1,52)	PIPE	805
805	PUNCH 8012 , (TX(1,1,M),M=1,52)	PIPE	806
	WRITE(6,8013) TX(1,1,53)	PIPE	807
	PUNCH 8013, TX(1,1,53)	PIPE	808
	8050 RETURN	PIPE	809
	C	PIPE	810
810	C SET UP INITIAL SODIUM AND PIPE WALL TEMPERATURES IF IDEFLT=2	PIPE	811
	C	PIPE	812
	8055 JTOP=JEND(I)	PIPE	813
	CC 8055 J=2,JTOP	PIPE	814
	TX(1,J,I)=TX(1,1,I)	PIPE	815
815	8056 TX(2,J,I)=TX(1,1,I)	PIPE	816
	TX(2,1,I)=TX(1,1,I)	PIPE	817
	RETURN	PIPE	818
	C	PIPE	819
	C SET UP INITIAL CONDITIONS IF IDEFLT=3 OR 4 FOR DEFAULT DIMENSIONAL	PIPE	820
820	C CONSTANT VALUES USED.	PIPE	821
	C	PIPE	822
	8060 XD3=(OD(I)+2.*XGAP(I))/12.	PIPE	823
	XD4=(OD(I)+2.*XGAP(I)+2.*XINSUL(I))/12.	PIPE	824
	XAV=(XD3+XD4)/2.	PIPE	825
825	RESIS4=ALOG(XD4/XAV)*XD4/2.	PIPE	826
	A3=PI*XD4/3600.*DELTAX(I)	PIPE	827
	GO TO 3	PIPE	828
	C	PIPE	829
	C TRANSIENT CALCULATIONS FOLLOW-----	PIPE	830
830	C	PIPE	831
	100 CALL UCDEF(TX,WY,IPIPE)	PIPE	832
	C	PIPE	833
	C UPDATE TEMPERATURES OF COOLANT AND PIPE WALL FOR NEXT TME	PIPE	834
	C	PIPE	835
835	JTOP=JEND(IPIPE)	PIPE	835
	XXA=WY(IPIPE)*C(1,IPIPE)	PIPE	837
	C	PIPE	838
	C CALCULATE LIMITING TIME STEPS FOR NUMERICAL STABILITY.	PIPE	839
	C	PIPE	840
840	TAU1=WTC(2,IPIPE)/(UA(1,IPIPE)+JAPA(IPIPE))*0.99	PIPE	841
	TAU2=.99*WTC(1,IPIPE)/(10.*ABS(XXA)+UA(1,IPIPE))	PIPE	842
	DELTME=AMIN1(TAU1,TAU2,MAXSTP(IPIPE))	PIPE	843
	XXB=DELTME/WTC(1,IPIPE)	PIPE	844
	XXC=DELTME/WTC(2,IPIPE)	PIPE	845
845	XXD=XXA*XXB	PIPE	846
	XXE=XXB*UA(1,IPIPE)	PIPE	847
	XXF=1.5*XXA+UA(1,IPIPE)	PIPE	848
	CC 230 J=1,JTOP	PIPE	849
	C	PIPE	850
850	C UPDATE COOLANT AND PIPE WALL TEMPERATURES.	PIPE	851
	C	PIPE	852
	M=MOD(J,2)+1	PIPE	853
	GO TO (202,201),M	PIPE	854
	C J IS EVEN....	PIPE	855
855	202 XT11=TX(1,J,IPIPE)*(1.-XXE)+(TX(1,J-1,IPIPE)-TX(1,J+1,IPIPE))	PIPE	855

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      1 *XXD/2.+TX(2,J,IPIPE)*XXE
      GO TO 203
C J IS CDD....
      201 IF(WY(IPIPE).GE.0.) GO TO 204
860 C FLOW IS NEGATIVE....
      IF(J.EQ.JTOP) GO TO 203
      XT11=TX(1,J,IPIPE)*(1.-XXB*(-1.5*XXA+UA(1,IPIPE)))+
      1 (.5*TX(1,J+2,IPIPE)-2.*TX(1,J+1,IPIPE))*XXD+TX(2,J,IPIPE)*XXE
      GO TO 203
865 C FLOW IS POSITIVE....
      204 IF(J.EQ.1) GO TO 203
      XT11=TX(1,J,IPIPE)*(1.-XXB*XXF)+(2.*TX(1,J-1,IPIPE)-.5*TX(1,J-2,
      1 IPIPE))*XXD+TX(2,J,IPIPE)*XXE
      203 XT22=TX(2,J,IPIPE)*(1.-XXC*(UA(1,IPIPE)+UAPA(IPIPE)))+
870 1 TX(1,J,IPIPE)*XXC*UA(1,IPIPE)+TCELL(IPIPE)*XXC*UAPA(IPIPE)
      IF(J.EQ.1) GO TO 229
      IF(J.EQ.2.AND.WY(IPIPE).GE.0.) GO TO 228
      TX(1,J-1,IPIPE)=XT11
      228 TX(2,J-1,IPIPE)=XT2
875 229 XT1=XT11
      XT2=XT22
      230 CONTINUE
      IF(WY(IPIPE).LT.0.) GO TO 231
      TX(1,JTOP,IPIPE)=XT11
880 231 TX(2,JTOP,IPIPE)=XT22
C
C UPDATE TIME OF PIPE SUBROUTINE FOR ABOVE CALCULATED TEMPERATURES.
C
      TME(IPIPE)=TME(IPIPE)+DELTME
      ICALC(IPIPE)=ICALC(IPIPE)+1
885 IF(NDEBUG.EQ.0) GO TO 236
      IF(ICALC(IPIPE).NE.NCALC(IPIPE)) GO TO 236
C
C REPORT TEMPERATURE AND FLOW DATA IF CALLED FOR BY NDEBUD AND NCALC
890 C REPORTING FREQUENCY.
C
      WRITE(6,9001) TME(IPIPE),IPIPE,WY(IPIPE),TAU1,TAU2,DELTME,
      1 MAXSTP(IPIPE)
      9001 FORMAT(1H0,"REPORT OF COOLANT AND PIPE WALL TEMPERATURES AT PIPE R
      1OUTINE TIME,TME =",F12.4," SECONDS FOR LEG",I4/10X,"FLOW RATE IS",
      2F10.2," LB/SEC."/10X,"TAU1,TAU2,DELTME,MAXSTP VALUES ARE",4F12.6,/
      3/)
      WRITE(6,9006)
      9006 FORMAT(" *****NOTE THAT THE FLOW RATE AND INCOMING COOLANT TEM
      1PERATURE VALUES ARE NOT AT TIME TME AS ARE ALL OTHER VALUES."/10X,
      2"THE FLOW AND INCOMING TEMPERATURE ARE NOT YET KNOWN SO THEY ARE G
      3IVEN FOR THE PRECEEDING TME.*****",/)
      WRITE(6,9002)
      9002 FORMAT(1H,"COOLANT TEMPERATURES FROM INLET TO OUTLET AT EACH NODA
      1L POINT"/)
      JTOP=JEND(IPIPE)
      WRITE(6,9003) (TX(1,J,IPIPE),J=1,JTOP)
      9003 FORMAT(8F15.2)
      IF(JTOP.GT.8) JTOP=8
      910 WRITE(6,9004) (TX(2,J,IPIPE),J=1,JTOP)
      9004 FORMAT(1H0,"PIPE WALL TEMPERATURES FROM INLET TO OUTLET AT EACH NO
      1DAL POINT "/8F15.2)

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PIPE 857
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PIPE 911
PIPE 912
PIPE 913

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	IF(JEND(IPIPE).LT.8) GO TO 236	PIPE	914
	JTOP=JEND(IPIPE)	PIPE	915
915	WRITE(6,9005) (TX(2,J,IPIPE),J=3,JTOP)	PIPE	916
	9005 FORMAT(8F15.2)	PIPE	917
	NCALC(IPIPE)=NCALC(IPIPE)+NDEBUG	PIPE	918
236	CONTINUE	PIPE	919
	JTOP=JEND(IPIPE)	PIPE	920
920	XAX=START(IPIPE)-START2(IPIPE)	PIPE	921
	XBX=TSV1A(IPIPE)-TSV2A(IPIPE)	PIPE	922
	XCX=TME(IPIPE)-START(IPIPE)	PIPE	923
	XDX=START(IPIPE)**2-START2(IPIPE)**2	PIPE	924
	XEX=XBX/XAX	PIPE	925
925	AFX=XDX/XAX	PIPE	925
	XGX=(TME(IPIPE)**2-START(IPIPE)**2)/XCX	PIPE	927
	XHX=TME(IPIPE)**2	PIPE	928
	C UPDATE INTERPOLATION COEFFICIENTS.	PIPE	929
930	C	PIPE	930
	CONE(IPIPE)=(XEX-(TX(1,JTOP,IPIPE)-TSV1A(IPIPE))/XCX)/(AFX-XGX)	PIPE	931
	BONE(IPIPE)=XEX-CONE(IPIPE)*AFX	PIPE	932
	ACNE(IPIPE)=TX(1,JTOP,IPIPE)-BONE(IPIPE)*TME(IPIPE)-CONE(IPIPE)*	PIPE	933
	1 XHX	PIPE	934
935	XBX=TSV1B(IPIPE)-TSV2B(IPIPE)	PIPE	935
	XEX=XBX/XAX	PIPE	936
	CTWO(IPIPE)=(XEX-(TX(1,1,IPIPE)-TSV1B(IPIPE))/XCX)/(AFX-XGX)	PIPE	937
	BTWO(IPIPE)=XEX-CTWO(IPIPE)*AFX	PIPE	938
	ATWO(IPIPE)=TX(1,1,IPIPE)-BTWO(IPIPE)*TME(IPIPE)-CTWO(IPIPE)*XHX	PIPE	939
940	TSV2A(IPIPE)=TSV1A(IPIPE)	PIPE	940
	TSV2B(IPIPE)=TSV1B(IPIPE)	PIPE	941
	TSV1A(IPIPE)=TX(1,JTOP,IPIPE)	PIPE	942
	TSV1B(IPIPE)=TX(1,1,IPIPE)	PIPE	943
	START2(IPIPE)=START(IPIPE)	PIPE	944
945	START(IPIPE)=TME(IPIPE)	PIPE	945
	RETURN	PIPE	946
	300 ICALC(IPIPE)=0	PIPE	947
	C INITIALIZE INTERPOLATION FORMULA DATA WHICH ARE EQUIVALENCED TO NO	PIPE	948
950	C LONGER NEEDED INPUT DATA AND SOME INITIAL VALUES.	PIPE	949
	C	PIPE	950
	NCALC(IPIPE)=1	PIPE	951
	START(IPIPE)=0.	PIPE	952
	START2(IPIPE)=-1.	PIPE	953
955	JTOP=JEND(IPIPE)	PIPE	954
	TSV1A(IPIPE)=TX(1,JTOP,IPIPE)	PIPE	955
	TSV2A(IPIPE)=TX(1,JTOP,IPIPE)	PIPE	956
	TSV1B(IPIPE)=TX(1,1,IPIPE)	PIPE	957
	TSV2B(IPIPE)=TX(1,1,IPIPE)	PIPE	958
960	ACNE(IPIPE)=TX(1,JTOP,IPIPE)	PIPE	959
	BONE(IPIPE)=0.	PIPE	960
	CONE(IPIPE)=0.	PIPE	961
	ATWO(IPIPE)=TX(1,1,IPIPE)	PIPE	962
	BTWO(IPIPE)=0.	PIPE	963
965	CTWO(IPIPE)=J.	PIPE	964
	RETURN	PIPE	965
	END	PIPE	966

```

      SUBROUTINE UCDEF(TX,WX,I)
      C SUBROUTINE DETERMINES PHYSICAL PROPERTIES AND HEAT TRANSFER COEFFIC-
      C IENTS FOR TRANSIENT PART OF PIPE SUBROUTINE.
      C
      C REFER TO PIPE SUBROUTINE FOR DEFINITION OF SYMBOLS.
      C
      COMMON/PIPE1/ ID(53),KINSUL(53),LNTH(53),MAXSTP(53),OD(53),
      1 TCELL(53),TINSUL(53),TSURF(53),XGAP(53),XINSUL(53)
      COMMON/PIPE2/JEND(53),JTYP(53),NODES(53)
      10 COMMON/PIPE3/ A(2,53),C(2,53),DELTA(53),DOVRA(53),RESIS(3,53),
      1 RHO1(53),UA(2,53),UAPA(53),UXX(53),UY(53),VOLNA(53)
      2 WTC(2,53),WTPPIPE(53),XD1(53),XNODES(53)
      DIMENSION KM(2),TX(2,9,53),WX(53)
      REAL NUNO,KH,KINSUL,MAXSTP
      15 C
      C TBAR1 IS AVERAGE TEMPERATURE OF SODIUM IN THE PIPE LEG.
      C TBAR2 IS AVERAGE TEMPERATURE OF PIPE WALL IN THE PIPE LEG.
      C
      JTOP=JEND(I)
      20 TBAR1=.5*(TX(1,1,I)+TX(1,JTOP,I))
      TBAR2=.5*(TX(2,1,I)+TX(2,JTOP,I))
      JUN=JTOP-1
      DO 10 J=2,JUN
      TBAR1=TBAR1+TX(1,J,I)
      25 10 TBAR2=TBAR2+TX(2,J,I)
      TBAR1=TBAR1/XNODES(I)
      TBAR2=TBAR2/XNODES(I)
      C
      C CALCULATE PHYSICAL PROPERTIES AND PARAMETERS WHICH ARE A FUNCTION OF
      30 C TEMPERATURE.
      C
      RHO1(I)=59.566-7.950E-3*TBAR1-.2872E-6*TBAR1**2+.06035E-9*TBAR1**3
      VIS1=10.**((1.0203+397.17/(TBAR1+459.688))-4.925*ALOG10(TBAR1+
      1 459.688))
      35 KM(1)=54.306-1.878E-2*TBAR1+2.0914E-6*TBAR1**2
      C(1,I)=.34574-.79226E-4*TBAR1+.34086E-7*TBAR1**2
      KM(2)=8.087+.0043*TBAR2
      C(2,I)=.1175+.00001875*TBAR2
      WTC(1,I)=VOLNA(I)*RHO1(I)*C(1,I)
      40 WTC(2,I)=WTPPIPE(I)*C(2,I)
      C
      C CALCULATE SODIUM FILM COEFFICIENT.
      C
      RENO=DOVRA(I)*ABS(WX(I))/VIS1
      45 PRNO=C(1,I)*VIS1/KM(1)
      PHIS=PHIF(RENO,0.)
      IF(PHIS-PRNO) 40,41,41
      40 PSIS=1.-PHIS/PRNO
      GO TO 42
      50 41 PSIS=0.
      42 PENO=RENO*PRNO
      NUNO=5.0+.025*(PSIS*PENO)**.8
      HI=NUNO*KM(1)/XD1(I)
      C
      55 C CALCULATE UA PRODUCTS.
      C
      UA(1,I)=1./(1./HI+RESIS(1,I)/KM(2))*A(1,I)

```

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SUBROUTINE JOCEF

74/74 OPT=1

FTN 4.2+74351

04/03/75 13.35.55.

60

```
UA(2,I)=1./((RESIS(2,I)/KM(2)+RESIS(3,I)/KINSUL(I))*A(2,I)
UAPA(I)=UA(2,I)*UXX(I)/(UXX(I)+UYI(I)*UA(2,I))
RETURN
END
```

```
UCDEF 53
UCDEF 60
UCDEF 61
UCDEF 62
```

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